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DESIGN AUDIT REPORT OF COMCAST'S NETWORK PERFORMANCE MEASUREMENT SYSTEM

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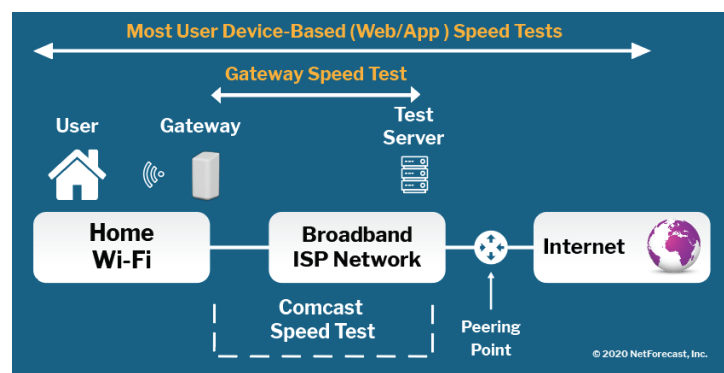
April 15, 2020

EXECUTIVE SUMMARY

Speed testing is complex, and it requires precision and knowledge for valid results. Users believe that speed test results tell them all they need to know about their Internet performance. Environmental factors within a user's home like Wi-Fi congestion and interference, home network loading, and underpowered/ overloaded devices can easily lead to slower than expected speed test results. Additionally, the Internet path outside an ISP's network to the test server or the test server itself may be congested. Finally, the results are biased by relying on users initiating tests when they perceive that the Internet is slow. It is not unusual for a speed test service to deliver vastly different values to the same subscriber home for several requests within the same minute. Summaries based on aggregating these test results (crowdsourcing) bring with them the built-in flaws described above, which can hide the actual source of speed degradation.

Comcast engaged NetForecast to audit the technical approach and implementation of one of the systems it uses to measure the network connectivity speeds it delivers to its subscribers. Comcast's network performance measurement system monitors the performance of Comcast's own network from in-home gateways to servers located within Comcast's network and near a peering point into the Internet. To enable the audit, Comcast provided NetForecast with design and implementation documentation and access to internal personnel to provide additional information.

Comcast's network performance measurement system comprises four major components: client software in its Xfinity gateways; test servers within its network; a test scheduler; and a data collection service. NetForecast validated the efficacy of the speed tests run from the Xfinity gateway to the Comcast servers. This system is used for analysis of Comcast's network performance only. Unlike publicly available tools, it does not reflect other factors that may impact a user's Internet experience, such as performance of the in-home network or the rest of the Internet.



Comcast's system avoids all of the above shortcomings by testing between a Xfinity gateway and a test server within Comcast's network, providing an accurate assessment of the speed delivered by the Comcast portion of the overall Internet path. In addition, the system checks for home network loading and test server processing capacity before running each test.

NetForecast concluded that Comcast's internal network speed measurement system and methodology are consistent with current best practices and industry standards, should deliver accurate speed measurement results, and include sufficient safeguards to support system and measurement reliability. This system is not currently available to the public.

Internet connection speed receives a great deal of media attention, and at first glance it is a useful and easy to understand metric. But there are inherent shortcomings in the way speed is commonly measured that can mislead subscribers as to the root cause of the lower speeds, so to interpret speed numbers it is important to know precisely what is measured and how it is measured. [1] A connection speed will always be dictated by its weakest link, even if the rest of the Internet is providing high throughput. Comcast has implemented a network speed measurement system that measures only the performance of the network elements it controls to deliver Internet service to its subscribers. Comcast engaged NetForecast to audit its testing methodology and expected system accuracy. To perform the audit, Comcast provided NetForecast with system documentation to validate the system architecture, methodology, and theoretical operational integrity.

The typical Internet user believes that an Internet speed test number, usually obtained from a source selected after a quick Internet search, tells them all they need to know about their Internet performance. But numbers produced from tests originating from users' devices show high variability. Environmental factors within a user's home more likely influence the test outcome than the Internet connection itself. Wi-Fi congestion and interference, home network loading, and underpowered/overloaded devices can easily lead to slower than expected speed test results. Furthermore, the Internet path to the test server may be congested at locations outside the broadband ISP's network. Finally, the test server may be overloaded with requests for a variety of other measurement requests unrelated to speed testing. Variability in routes along the complex test client-to-server path lead to highly variable speed results. It is not unusual for a speed test service to deliver vastly different values to the same subscriber home for several requests within the same minute. [2]

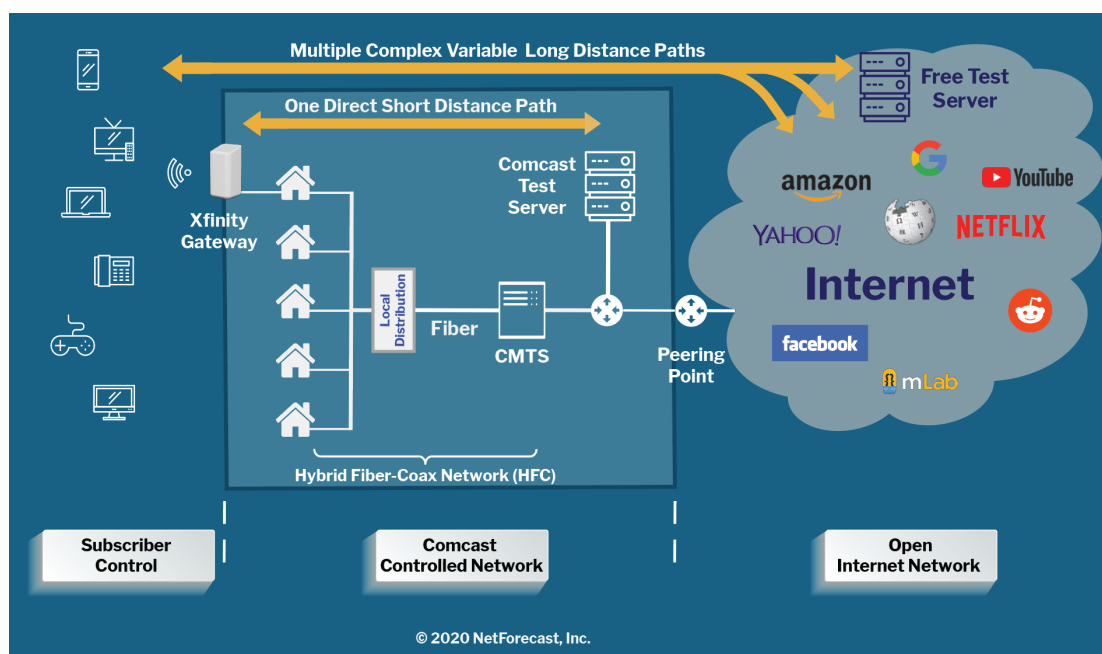
Web-based, ad-supported speed test providers direct users to their servers. Although these services continually improve their testing methods and increase their test server pools, issues like server loading, user equipment shortcomings, and many users testing concurrently during prime time rather than over time, continue to adversely influence the results. It is important to note that in most cases these services rely on crowdsourcing, with users initiating the tests themselves, usually when they believe their Internet connection is slower than it should be. Thus, user-initiated tests can introduce self-selection bias into measurements and can also be impacted by Wi-Fi issues and competing traffic in the household.

Comcast Purpose Statement

"The Xfinity gateway speed test was developed to measure our network's ability to deliver the Quality of Experience (QoE) that customers expect and that we know is a key part of providing a good overall customer experience. This system augments existing measurements of our DOCSIS delivery network at the Cable Modem Termination System (CMTS), regional and backbone network points, and points of interconnection with other networks. Thus, it provides another perspective and tool from which we can validate customer QoE in addition to the other longstanding methods, enabling a higher level of service assurance for our technical teams that work to deliver a reliable and high-performing Internet service."

Comcast's network performance measurement system measures the speed between Comcast-owned gateways at the subscriber premises and servers within Comcast's regional infrastructure. Testing in this way eliminates issues such as users' devices, and slow in-home Wi-Fi or Ethernet network conditions. It measures performance within Comcast's local and regional infrastructure only (i.e., Comcast's hybrid fiber coaxial access networks and regional networks). Secure end-to-end operation and data storage safeguards prevent malicious activity and ensure that testing does not interfere with normal network operations or degrade network performance.

The following diagram illustrates the testing methodology.



This system measures the portion of the Internet it delivers to its subscribers—between the in-home gateway and Comcast regional test server, as shown above. The Internet performance measurement system DOES NOT measure the subscriber's experience for traffic traversing peering points between Comcast's network and the public Internet (shown on the right in the diagram), nor does it measure the subscriber's experience on the home network (shown on the left in the diagram).

[According to Comcast, it has other tools such as NetFlow to test other aspects affecting user QoE and capacity, including those that measure performance to Internet-based content, at points of interconnection, in the DOCSIS network, and in the regional and backbone networks. Those tools were not analyzed and are beyond the scope of this report.]

COMCAST NETWORK PERFORMANCE MEASUREMENT SYSTEM ARCHITECTURE

The Comcast network performance measurement system includes the following architectural elements:

- Speed test client software
- Speed test servers
- Test controller
- Collection and reporting middleware

Speed test client software embedded in RDK-B [3] enabled Xfinity gateways in subscriber homes runs tests to speed test servers within each Comcast service region. The speed test client software is currently deployed on millions of Xfinity gateways. Tests are initiated through an API using HTTP protocols. The speed test client software is automatically updated when necessary.

Dedicated speed test servers provide resources to measure the speed between the Xfinity gateway and the nearest server. The server negotiates with the gateway to ensure that adequate resources (i.e., server utilization) are available to run the test without influencing the outcome.

The test controller governs test scheduling, test initiation, and security authorization. Ongoing speed tests are performed on random subsets of subscribers, generating approximately 700,000 measurements per day. Besides continuous testing to assess speeds and network health, the controller also handles on-demand test requests for customer support and other informational purposes.

The final architectural component is middleware that collects, stores, and reports on the speed test results. This includes distributing test data between databases to meet various storage and reporting needs.

COMCAST NETWORK PERFORMANCE MEASUREMENT SYSTEM METHODOLOGY

Comcast's network performance measurement system methodology is structured around well-defined client/server exchanges. These exchanges are accomplished using publicly vetted and proven tools: iPerf [4] and curl [5] to reduce actual or perceived measurement bias associated with proprietary tools. The iPerf and curl parameters selected by Comcast were reviewed and found to be appropriate as discussed in this document.

Each measurement involves three phases. An initial phase confirms connectivity and measures latency. Latency is measured using a curl "HEAD" command from the gateway to the measurement server. The connection time is measured by curl in milliseconds, and testing stops if the connection failed. The latency measurement detects and supports IPv4 and IPv6 addressing.

The initial latency test phase is followed by a second phase consisting of a TCP downstream test, and a third phase consisting of a TCP upstream test. Downstream tests are conducted using four parallel streams at 500 Mbps and above, and two parallel streams

below 500 Mbps. Upstream tests use two parallel streams. Both down and upstream tests are limited to eight seconds. Multiple streams ensure the measurements are unaffected by TCP protocol limitations, and the eight-second limit minimizes the effect of test traffic on the network.

By design, TCP transfers are subject to a “slow start” process (aka ramp-up time). After the three-second slow start, TCP generally operates at a higher steady throughput. Therefore, to accurately measure maximum-available bandwidth, Comcast uses the iPerf “omit” option to delete the first three seconds of test transfer time from the measurement results. The formal eight-second test time starts in the fourth second of the test traffic transfer. [6]

Measurements occur in all regions based on randomized client selection. Randomly selecting clients provides a more comprehensive view of network conditions. The system is programmed to perform enough tests to ensure statistically meaningful results. Measurements are run within a specified window rather than at an exact time to reduce test collisions. Scheduling methodology ensures that testing occurs around the clock.

Tests are assigned to each gateway within a time window and are randomized within each window to avoid many concurrent tests at the server. To prevent test traffic from adversely affecting the user experience, the client checks gateway CPU utilization to gauge subscriber traffic volume, and it does not test when utilization is above a pre-set threshold. Comcast sets the threshold for each gateway model and release based on lab testing.

Safeguards are built into the system at multiple points. Test server rate limiters, authentication checks, circuit breakers, and code instrumentation are designed to help ensure the system operates reliably, securely, and as designed.

Comcast’s speed testing is implemented only for residential subscribers with Comcast-owned Xfinity gateways that run RDK-B software. Currently this represents a large majority of residential customers. Comcast randomly tests a significant number of residential subscriber lines within the testable population every month.

NETFORECAST EVALUATION

NetForecast examined high-level Comcast speed test system design documentation to determine if the system is capable of measuring the speed between an Xfinity gateway and an in-region test server. This report section evaluates the suitability of the system components to meet its objective and evaluates how the system performs as a whole. The data that was shared by Comcast did not include any personal, sensitive, or customer-identifiable data.

EVALUATION OF INDIVIDUAL MEASUREMENTS

The downstream and upstream measurements between the client and the server are the foundational system output, and as such, NetForecast rigorously assessed how the system makes these measurements. In NetForecast’s assessment, Comcast’s selection of iPerf as its measurement tool should produce sound and defensible results. NetForecast investigated the details of how iPerf is invoked, the parameters used, and any limitations that may occur from the network environment at test execution time. Comcast chose TCP

for the testing over other protocols. Selecting a TCP-exclusive speed test method reports effective bandwidth after accounting for necessary TCP/IP overhead. This better reflects the user's actual experience compared to theoretical service speeds.

NetForecast closely examined TCP slow start [6] as an issue influencing speed test results. The effect of slow start on measurements is handled in the system by implementing a three-second "omit" window at the start of each iPerf session. We determined that the three-second window is conservative and adequate for avoiding the TCP slow-start mechanism which by design prevents maximum throughput (i.e., speed).

The initial phase of each test involves measuring the latency from the client to the server. Comcast chose the curl tool instead of the commonly used ICMP Ping tool to measure latency. NetForecast determined this was a reasonable design decision that provides a conservative value consistent with the transport mechanism of most network traffic. Curl provides a more conservative value because the curl head command requires multiple client/server exchanges compared to ICMP Ping's single exchange.

EVALUATION OF SERVER CONFIGURATION AND ROUTING

Adequate server resources are critical to obtaining valid maximum bandwidth measurements. Dedicated server hardware, server loading, and server locations within the regional data centers ensure that servers provide adequate resources for the testing. In addition, NetForecast received confirmation from Comcast that no routing mechanism is in place to influence or prioritize test traffic.

EVALUATION OF MIDDLEWARE FUNCTIONALITY

Comcast has significant system infrastructure to handle and store test results. NetForecast determined that the ETL pipeline that manages data transfer and storage is designed to current industry standards and should adequately support measurement data collection.

NetForecast reviewed a sample of raw data records and determined that all pertinent information is appropriately captured and recorded.

EVALUATION OF SYSTEM CONTROL FUNCTIONALITY

Comcast's test control and scheduling software comprises many functional parts, including multiple methods for scheduling test plans in the system. NetForecast determined that adequate safeguards are in place to ensure that tests do not negatively impact overall network performance. Schedule windows are created to avoid too many concurrent tests. Communication between the controller and the controlled parts of the system use industry-standard methods such as APIs and have low overhead. Meaningful checks are enforced within the control system to ensure testing integrity is not compromised and network operation is not affected.

EVALUATION OF COMMON DESIGN ELEMENTS

NetForecast identified overarching precepts in reviewing the system design and documentation. We identified security as a primary focus of all aspects of component communication, test initiation, and at-rest data storage. Beyond the testing itself, many of the Comcast network performance measurement system components rely on proven

services consistent with current best practices and industry standards. Safeguards are in place to ensure the system has enough resources to complete tests without resource limitation issues, and to ensure that system component failures do not propagate and cause system-wide issues or degrade network performance for subscribers.

NetForecast determined that the general design of Comcast's network performance measurement system appears adequate to initiate tests that should lead to accurate and timely results.

CONCLUSIONS

NetForecast's audit concludes that the design of Comcast's network performance measurement system should deliver accurate speed measurement results and meet their objective for testing within individual Comcast regions. Our investigation revealed no mechanisms by which test packets or data handling would introduce bias in the reported data. In NetForecast's assessment, Comcast's system design reflects extensive knowledge of the complexities of speed testing. Comcast's infrastructure design is based on best practices and industry standards and includes sufficient security and safeguards to support system and measurement reliability.

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3. [*RDK-B overview*](#)
4. [*iPerf homepage*](#)
5. [*curl homepage*](#)
6. Ajay Tirumala, Les Cottrell, and Tom Dunigan, [*Measuring end-to-end bandwidth with iPerf using Web100*](#), (Presented at Passive and Active Monitoring Workshop, November 2003).

Alan Jones is NetForecast's Director of Software Development. He has lead teams in developing products and internal infrastructure for some of the largest telecom companies in the world. After eight years in cellular handset design and testing, he spent over a decade working on test systems for mobile networks. He currently works with mobile and cloud-based product development.

Peter Sevcik is the founder and CTO of NetForecast and is a leading network performance expert. An Internet pioneer, Peter was among the first to measure and develop Internet performance improvement techniques. He helped design more than 100 corporate and commercial networks. In addition, Peter invented the Apex performance reporting methodology, and has co-patented application response-time prediction and network congestion management algorithms.

Andrew Lacy is NetForecast's director of analytics and has a 30-year track record delivering solutions to complex business and technical requirements. He has extensive experience as a development leader designing, building, and deploying products. He has a strong technical background in data communications, game software, server-based gaming, embedded systems, server software, web, and database design.

GLOSSARY OF TERMS USED IN THIS REPORT

API: Application Programming Interface. Functions and procedures allowing the creation of applications that access the features or data of an operating system, application, or other service

Bandwidth: The transfer rate of data bits over time represented as million(mega)-bits-per-second or Mbps.

Cross Traffic: Concurrent internet traffic in or out of a subscriber location that may affect a speed test.

Crowdsourcing: The practice of obtaining information or input into a task or project by enlisting the services of a large number of people, either paid or unpaid, typically via the Internet.

CMTS: Cable Modem Termination System. The device at the head end which controls and communicates with cable modems.

Effective Bandwidth: The data rate seen by a subscriber's application after accounting for protocols required to deliver information reliably.

ETL: Extract, Transform, and Load. A process that automates the collection, processing and storage of large amounts of data into a database or data warehouse.

Hybrid Fiber Coaxial Cable System: (HFC) is a telecommunications industry term for a broadband network that combines optical fiber and coaxial cable. It has been commonly employed globally by cable television operators since the early 1990s

ICMP: The Internet Control Message Protocol (ICMP) is a supporting protocol used in the determination of errors as part of the overall Internet protocol suite.

RDK-B: The Reference Design Kit for Broadband (RDK-B) is an open source initiative standardizing software functionalities for broadband devices.

Speed: For the purposes of this report, speed is equivalent to Effective Bandwidth.

TCP: Transmission Control Protocol. The primary data exchange protocol used on the internet.