ARTICLE

Measuring Library Broadband Networks to Address Knowledge Gaps and Data Caps

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ABSTRACT

In this paper, we present findings from a three-year research project funded by the US Institute of Museum and Library Services that examined how advanced broadband measurement capabilities can support the infrastructure and services needed to respond to the digital demands of public library users across the US. Previous studies have identified the ongoing broadband challenges of public libraries while also highlighting the increasing digital expectations of their patrons. However, few large-scale research efforts have collected automated, longitudinal measurement data on library broadband speeds and quality of service at a local, granular level inside public libraries over time, including when buildings are closed. This research seeks to address this gap in the literature through the following research question: How can public libraries utilize broadband measurement tools to develop a better understanding of the broadband speeds and quality of service that public libraries receive? In response, quantitative measurement data were gathered from an open-source broadband measurement system that was both developed for the research and deployed at 30 public libraries across the US. Findings from our analysis of the data revealed that Ookla measurements over time can confirm when the library's internet connection matches expected service levels and when they do not. When measurements are not consistent with expected service levels, libraries can observe the differences and correlate this with additional local information about the causes. Ongoing measurements conducted by the library enable local control and monitoring of this vital service and support critique and interrogation of the differences between internet measurement platforms. In addition, we learned that speed tests are useful for examining these trends but are only a small part of assessing an internet connection and how well it can be used for specific purposes. These findings have implications for state library agencies and federal policymakers interested in having access to data on observed versus advertised speeds and quality of service of public library broadband connections nationwide.

INTRODUCTION

The COVID-19 pandemic exposed the severity of the digital divide in the United States. During this time, lack of access to computers and the internet has been highlighted among individuals and families with limited monthly incomes in tribal, rural, and urban communities where broadband is neither available nor affordable. Decades of research has shown that this digital divide is further deepened along racial and ethnic lines. Wealthier, white, and more educated individuals consistently have higher rates of home computer and broadband ownership. Many without this societal privilege rely on their local public libraries and other community spaces to fill these gaps. The pandemic has also underscored just how significant public libraries have been in addressing people's need for computers and high-speed internet. Last year, for example, mainstream news

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organizations shared several stories about children, parents, and teachers all relying on wireless internet access while seated outside in school and public library parking lots, which happens both during and outside library hours.[1] Much less attention has been paid, however, to the broadband infrastructure and technical support that public schools and libraries need to meet the digital demands of their communities.

In 2018, our research team, composed of researchers and practitioners at the Simmons University School of Library and Information Science, Measurement Lab (M-Lab), and Internet2, received a grant (award #71-18-0110-18) from the US Institute of Museum and Library Services (IMLS). The purpose was to investigate how advanced broadband measurement capabilities can inform the capacity of the nation's public libraries to support the online software applications and social and technical infrastructure needed to promote the National Digital Platform.[2] In this paper, we present findings from this study, which seeks to address a gap in understanding, particularly among researchers, practitioners, and policymakers, about the speeds and quality of service of public library internet connections across the United States. Through our research we learned that there are significant gaps in knowledge about broadband speeds and quality of service measures that are impacting the ability of public libraries to support their communities' digital needs. In this context, we hope the quantitative data and analysis presented in this paper contributes to the scholarship on broadband measurement in libraries, as well as to expanding awareness and understanding of broadband data. More concretely, we hope this paper helps to raise awareness of the urgent need for shared knowledge about broadband data and infrastructure that supports digital services in public libraries.

We begin the paper with a brief review of key studies that have highlighted the important role of public libraries in promoting digital equity, as well as studies that have discussed the importance of measuring broadband connectivity in public libraries. We concentrate particularly on those studies that have sought to elucidate the opportunities and challenges of both connecting public libraries with high-speed internet connections and educating public librarians, other researchers, and policymakers about what is meant by broadband infrastructure and services. We then present our findings from the quantitative analysis of our broadband measurement data, which highlights the ways in which ongoing, locally collected measurements can enhance libraries' understanding of their internet service and help inform interactions with patrons and IT service providers. The paper concludes with a discussion of the contribution of our research to the scholarship, and we briefly discuss the implications for state and federal policymakers interested in better understanding the role that library broadband measurement data can play in promoting healthy digital equity ecosystems.

LITERATURE REVIEW

Digital Inclusion and Broadband Measurement in Public Libraries

Public libraries in the United States have been committed to bridging the digital gap by providing free public access to computers, internet, and digital literacy skills for decades.[3] For example, in their study of how public libraries respond to inquiries about the digital divide through participatory forms, Schenck-Hamlin, Han, and Schenck-Hamlin found that public libraries have been recognized as the "first and last" resort for internet access particularly "for those unable to afford high-speed connections at home."[4] Further, Bertot, Real, and Jaeger affirmed this idea with their Digital Inclusion Survey data, collected over several years, by stating, "America's public libraries are an important force for bridging this (digital) divide, with 62.1% of these outlets reporting that they are the only free providers of Internet access inclusive of computers in their communities."[5] In addition to providing public access to computers and the internet, US public libraries have placed an emphasis on promoting the general public's awareness and skills around broadband through delivering free digital literacy training sessions, as well as hosting civic discussions around the topic of broadband connections with their patrons.[6] To further illustrate how public libraries narrow the digital divide, DeGuzman, Jain, and Loureiro explained that telemedicine has become a new norm in today's medical visits, which quickly became a reality during the COVID-19 pandemic. In their article, the authors show how public libraries can play a critical role in bridging this "digital health divide" that exists in many communities.[7] As a bottom-up means to promote digital inclusion in the US, the role that public libraries have played to promote digital inclusion and equity cannot be overlooked. However, as Jaeger et al. explained in their study on how public libraries address the digital divide and digital inclusion, "one curious constant across policy approaches to digital divides in many, though not all, nations has been the failure to involve librarians in the formulation of definitions, policies, or other aspects of the policy-making process."[8] It is within this space that public librarians and the technological staff who support them can play an important role in co-designing the tools, skills, and knowledge needed to better understand broadband in public libraries.

Broadband Measurement in Public Libraries

Many public libraries, particularly small, rural, and tribal libraries, face ongoing challenges in gaining accurate information about their broadband speeds and quality of service. This lack of information can limit their capacity to provide a wide range of applications and services to the community. As Bertot, Real, and Jaeger concluded, one of the big challenges that public libraries have been dealing with is that the speed of public library internet connections "can vary significantly according to local population density."[9] In reaction to this situation, public librarians have shown great interest and need to acquire knowledge about their libraries' current broadband performance.[10] Digital inclusion scholars have proposed topics that future research on public libraries and broadband measurement should explore.[11] These topics include how to better inform public librarians in order to assist them in planning, as well as how to deliver sufficient and quality broadband connections to the community. Other topics include looking at how to help public libraries justify the need for more workstations and bandwidth using data coming from "empirical measures, especially longitudinal measures."[12] These and other questions remain largely unanswered in the academic literature.

THE MEASURING LIBRARY BROADBAND NETWORKS (MLBN) PROJECT AND RESEARCH DESIGN

Research Questions and Significance of Study

Our research sought to address this gap in the scholarship on broadband measurement in public libraries through the following research question: How can public libraries utilize broadband measurement tools and training materials to develop a better understanding of the broadband speeds and quality of service that public libraries receive? In response, our research team gathered quantitative data from an open-source broadband measurement system that was both developed for this study and deployed at 30 public libraries across the US. Our research is significant because answers to these questions can help strengthen public libraries as essential anchor institutions and partners in providing data to address the digital needs of their communities. The findings from our study can also assist public libraries in responding to the challenges of developing a more integrated, equitable, and dynamic set of infrastructures for delivering public computing access and digital library services.

Project Overview and Research Design

The Measuring Library Broadband Networks (MLBN) project (https://slis.simmons.edu/blogs/mlbn/) was originally conceptualized to be completed in four phases during the two-year grant period. During the first phase, we organized a "participatory design" workshop with our 10 first-year public libraries who agreed to serve as part of our research panel on the project.[13] Findings from our analysis of the qualitative data gathered during the workshop revealed that public libraries wanted access to broadband measurement data in order to: (1) better communicate with their patrons about their library's broadband connectivity, (2) respond to their communities' digital needs, and (3) justify the importance of robust internet connectivity to their funders.[14] Our analysis revealed early on in the project that knowledge gaps existed around the performance of public library broadband networks, patron and staff experiences using the library's internet connection, and the meaning and value of measurements such as speed tests.

During the second phase of the project, we applied what we learned from insights gained during the workshop to our site visits with the 10 participating first-year public libraries. During our fieldwork at the libraries, we sought to interview four different groups of people: (1) library staff, (2) library administrators, (3) IT staff, and (4) IT administrators. The purpose was to gain multiple perspectives on the same sets of questions, which would provide additional qualitative data to help answer our research questions. In a few of the libraries, the library administrator was also the primary IT professional on site. In other words, depending on the size of the organization, librarians often wore several hats, which is certainly not uncommon for small, rural, and tribal libraries.

In addition to conducting interviews with these four groups, we also held focus groups with patrons on site at each of the libraries. During this process, we were able to learn more about the context, character, and communities of our partner libraries and gain a better sense of what it is like to work at and/or be a patron of each library, as well as why public libraries might need an open-source broadband measurement system. The other main goal during this phase was to learn more about and document the process of installing our broadband measurement devices. Through this process, we gained additional insights into the nuances of the network configurations at each location and refined our device configurations and setup instructions in response. Ultimately, we sought to identify potential barriers to the measurement devices working properly in the networks of our second-year libraries, when we would not have the luxury of being there in person.

At the conclusion of the research program in March 2021, we asked participating library and/or IT staff to complete a final evaluation survey. Twenty libraries responded to a range of questions, two of which related to their understanding of the library's internet connectivity and network management practices: "Is there an overall download and/or upload cap on the connection to the entire library building?" and "Is there a cap on individual devices using the internet at the library?" Eight libraries responded to one or both of the above questions; their responses are in table A.2 in Appendix B.

Training Manual

During phases 2 and 3, we worked with Carson Block, a well-known library technology expert and consultant who helped us to develop our MLBN Training Manual (https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/8XXXZQ). The development of the manual was led by Chris Ritzo, Carson Block, and Colin Rhinesmith to assist our second-year participating public libraries in being able to install the measurement devices on their own. The manual provides a comprehensive overview of our MLBN project, including what we learned in the first year of the project about why public libraries would want to measure broadband at their libraries. Section 2 focuses on the setup instructions that public libraries would need to install the devices to measure both wired and wireless internet connections. We also provided details on the hardware used, device management, and data collection, as well as the data visualization platform developed for the project, which allows public libraries to access and use the broadband data gathered from the devices installed on their network. The manual includes complete information about how the measurement platform used in this study can be set up independently for future use by any library, institution, or individual. We knew this manual would be essential for scaling to the 60 total public libraries for our project and for any additional library after the end of our grant.

Final Cohort of Participating Libraries

Libraries participating in this research were recruited primarily through the suggestion of the project's advisory board, many of whom represented state library agencies, regional research and education networks, or other intermediary organizations working with or supporting public libraries. Though the COVID-19 pandemic limited our ability to scale up to our goal of 60 libraries, ultimately 30 libraries were recruited to participate in the research. Appendix A lists the final cohort of participating libraries, the specific branch where measurements were conducted, the city, state, and the library's IMLS Code.

Broadband Measurement Data Collection

Quantitative measurements of the network connections at participating libraries were collected using the Murakami software developed by M-Lab, running from a dedicated, on-premise measurement computer/device.[15] This software provides tests from two large platforms for crowdsourced speed tests: M-Lab's Network Diagnostic Tool versions 5 and 7 (NDT) and speedtest-cli, an open source client using the Ookla platform.[16] NDT is a network performance test of a connection's bulk transport, conforming to the Internet Engineering Task Force's (IEFT) RFC 3148.[17] M-Lab provides two NDT testing protocols (ndt5 and ndt7), each measuring different aspects of the Transmission Control Protocol (TCP).[18] All versions of NDT measure upload and download speeds and latency using a single TCP stream, between the computer running the test and the nearest M-Lab server. Ookla is a commercial company that created the network performance test speedtest.net.[19] Ookla's test also measures upload and download speeds, as well as latency, but provides the option to measure using a single TCP stream or using multiple streams. The primary differences between these two platforms' tests are the use of single or multiple TCP streams and the location of testing servers.[20]

At each location (with a few exceptions), two devices were configured using network details supplied by library or IT staff and shipped to the library with setup instructions (in some cases, depending on network complexity, only one device was installed). One device was connected to the switch or router where internet service connected the location (egress). The other device was connected to an available switch port on the same virtual local area network (VLAN) as WiFi access points. The intention was to measure the capacity of the entire location using the egress device, and the capacity of a single WiFi access point (AP) to serve multiple patrons using the WiFi AP device. Once connected, each device ran tests approximately six randomized times within each 24-hour period.

Each Murakami device ran four tests: NDT 5, NDT 7, Ookla single-stream, and Ookla multi-stream. Each test result was exported to an archive in Google Cloud. This data was imported into BigQuery and analyzed in DataStudio.[21] Data from the 2019 Public Libraries Survey (PLS) from IMLS was also included to describe each library's locale, service population, and number of public computers, annual computer use sessions, and annual WiFi sessions reported.[22] Public data provided by both Ookla and M-Lab for the counties in which each MLBN library was located were loaded to compare each platform's reported aggregate measurements for the surrounding area to the measurements conducted at the libraries.[23] Aggregate public data for the surrounding counties in our analyses excluded all measurements from the libraries themselves. Along with the data itself, specific details on our data import, cleaning, and analysis are provided in our publicly available MLBN Dataverse (https://dataverse.harvard.edu/dataverse/mlbn), hosted by Harvard University.

Limitations

The COVID-19 pandemic created challenges for the research team in scaling up to 60 libraries, as was planned at the beginning of the project. Therefore, we had to limit our outreach and engagement during 2020. When we asked the final 30 public libraries that were able to participate in the research whether they had closed their doors during the pandemic, all of them said yes. However, all the libraries reported that they continued to provide wireless internet access, even though their buildings were closed to the public during this time. Although we were unable to scale up to 60 public libraries, we were still absolutely thrilled with the response we received from the libraries that were able to participate.

The NDT 7 tests in our program uncovered a now-resolved bug where measurements were limited by the performance of our selected premise devices, which lack proper support for encryption.[24] This is observable in some of our data as a large jump in measured speeds from NDT 7 after November 1, 2020. The jump in measured throughput from NDT 7 tests after November 1, 2020 reflected when encrypted NDT 7 tests were disabled and began running unencrypted.[25]

FINDINGS

Individual Libraries' Data

Data collected at each library is provided in an interactive MLBN DataStudio report, along with summary information about the library from the 2019 Public Libraries Survey.[26] Aggregated download, upload, and latency metrics from measurements conducted at each library can be viewed on page 2, Individual Library Data (see figure 1 for an example).[27]

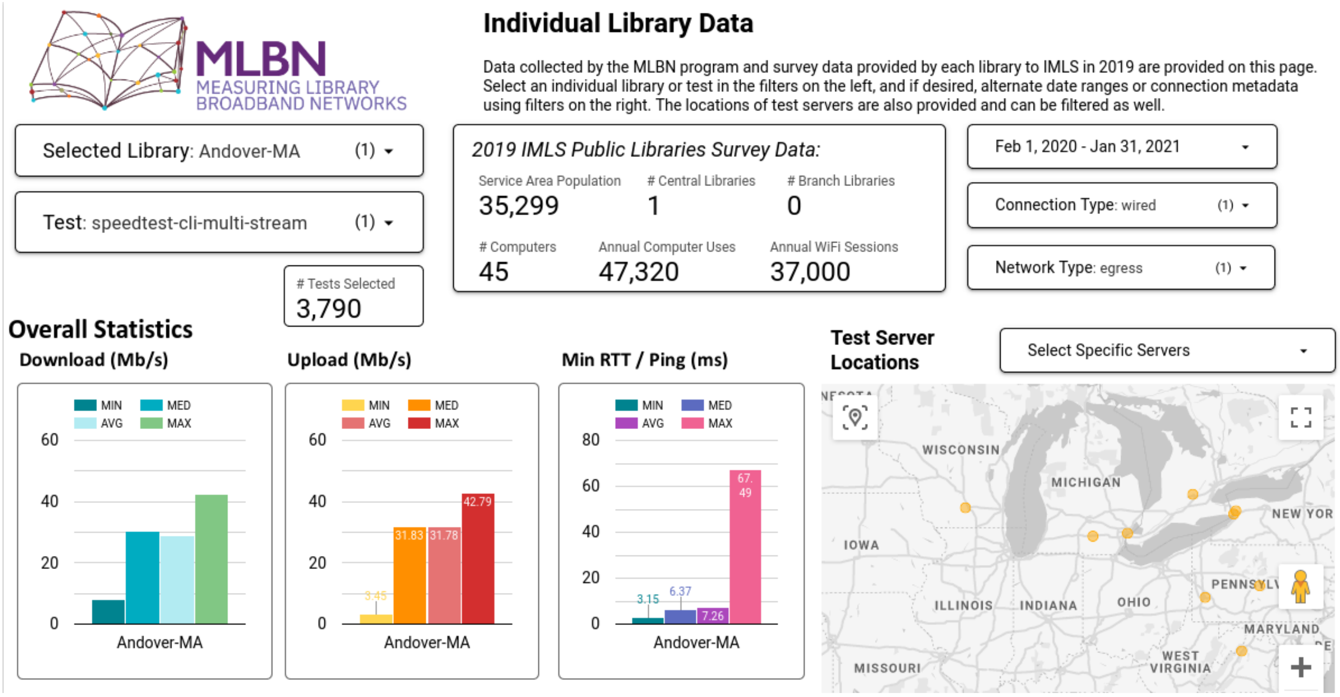


Figure 1. Individual Library Data page for Andover, Massachusetts.[28]

A unique feature of the report is a map of server locations to which tests were conducted. This feature demonstrates the different topologies of the Ookla and M-Lab platforms and enables analysis of measurements to specific servers. If a library's internet service provider (ISP) hosts an Ookla server, it can be selected to display only measurements of the ISP's network, as shown in figure 2. The Federal Communications Commission (FCC) distinguishes this topology as on-net, when the server and client are both within the same network, in contrast to off-net, where the server and client are in different networks.[29]

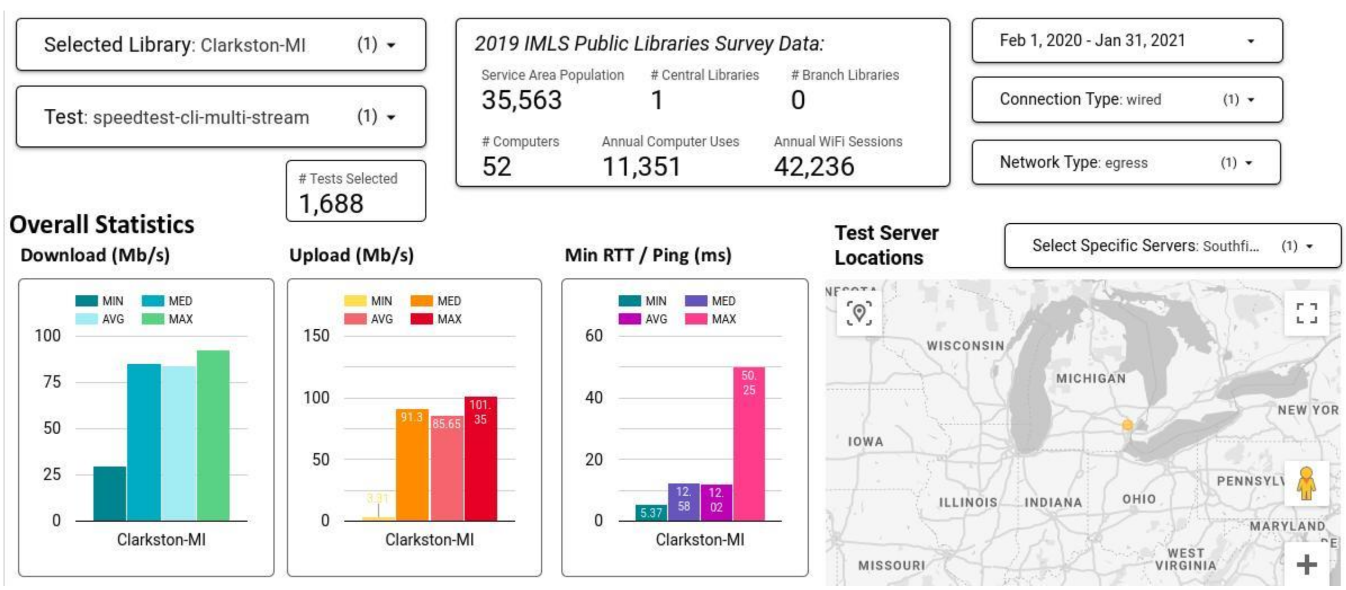
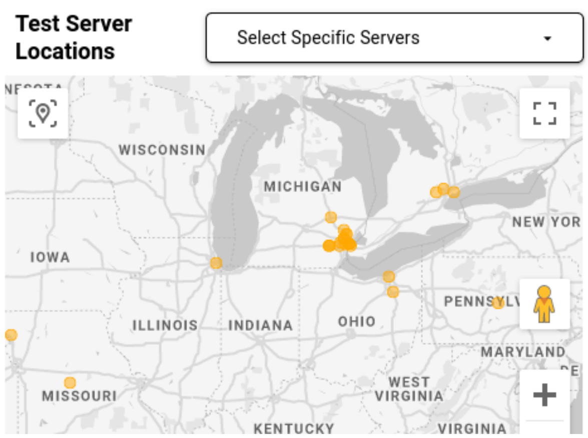
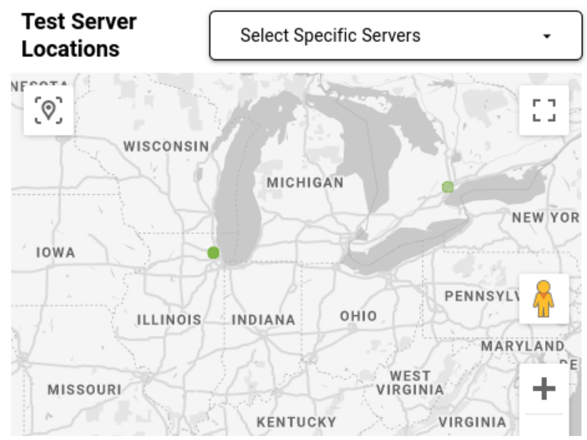


Figure 2. Individual Library Data page for Clarkston, Michigan, MERIT Networks' nearest Ookla server selected.[30]

By selecting all servers, we can observe the wide geographic range of Ookla servers used. Conversely, when we select one of the NDT tests, we can see that M-Lab servers are only hosted in large metropolitan areas, as seen in figure 3. This demonstrates key differences in the server locations of these two measurement platforms and how the data from each relates to the FCC's national broadband standard.[31]



Clarkston, Michigan—all Ookla servers selected[32]



Clarkston, Michigan—all M-Lab servers selected[33]

Figure 3. Test server locations for Clarkston, Michigan—all Ookla and M-Lab servers selected.

Additional aggregate speeds are provided on the Individual Library Data page to communicate general measurement trends over time: maximum upload and download speed by month, day, hour, and weekday (see figures 4–7). This allows a library to confirm advertised speeds, as seen in figure 4 where the connection at Clarkston, Michigan, was measured consistently at just under 100 Mbps symmetric download and upload. We also observe where measurements are not always consistent, as seen below in figures 5 and 7. In figure 5 we observe a dip in the upload median for Westchester County, New York, in late June 2020, and a drop in upload median in late October 2020. With additional information, a library could correlate these observations with network outages, service changes, or network management changes. For example, the change in October 2020 could have been a network management change or service change to 200 Mbps symmetric. In figure 7 we observe a trend that many librarians will recognize: a slight dip in median speeds over the peak hours of use.

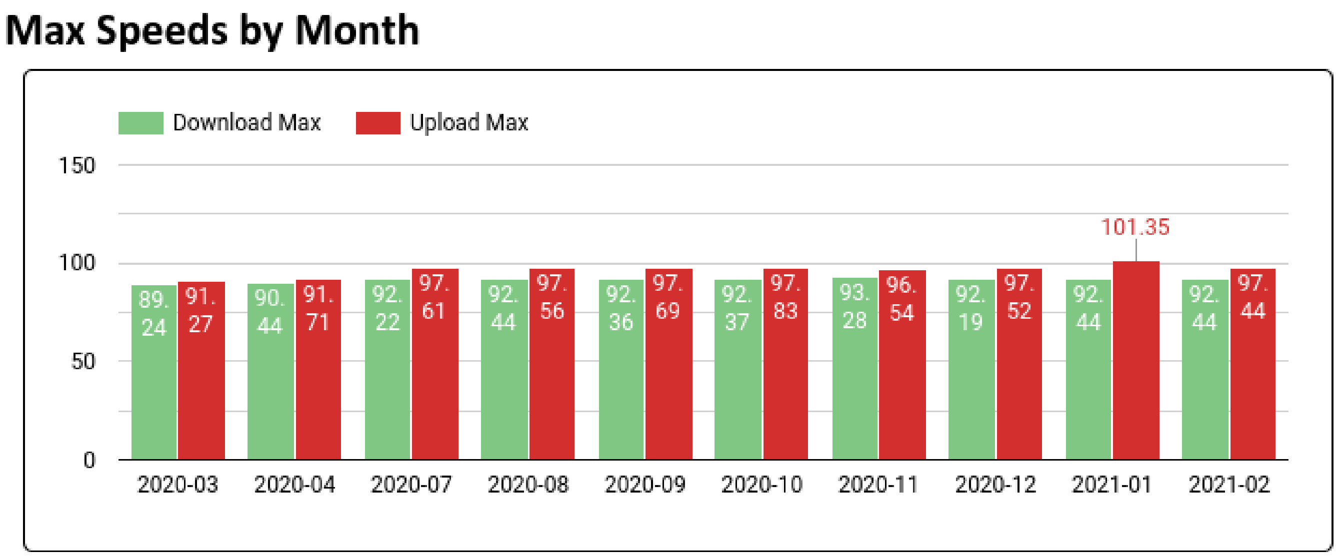


Figure 4. Max speeds by month—Clarkston, Michigan.[34]

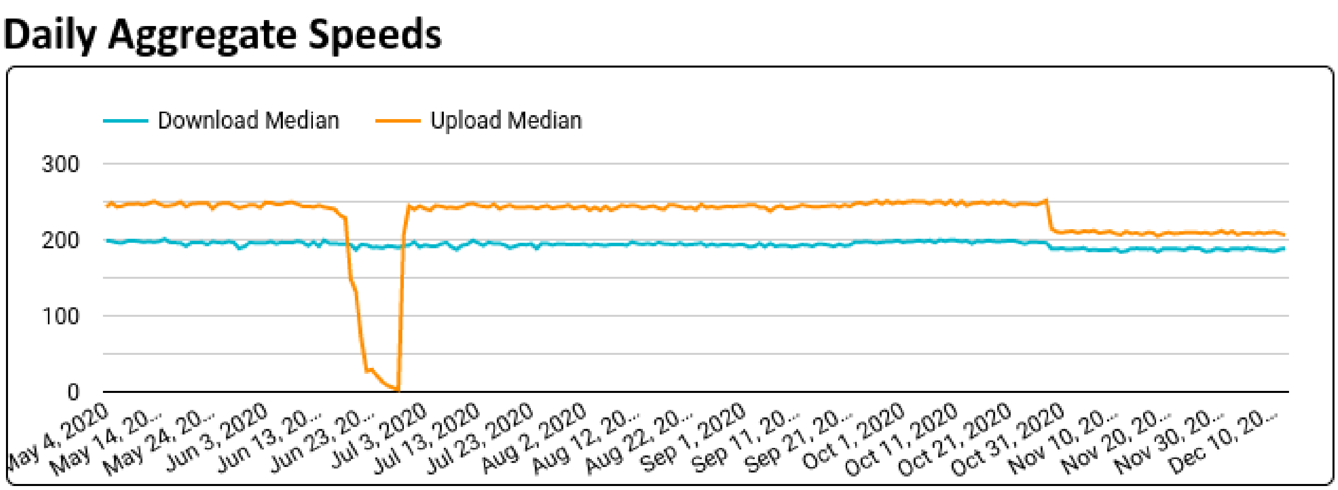


Figure 5. Daily aggregate speeds—Westchester County, New York.[35]

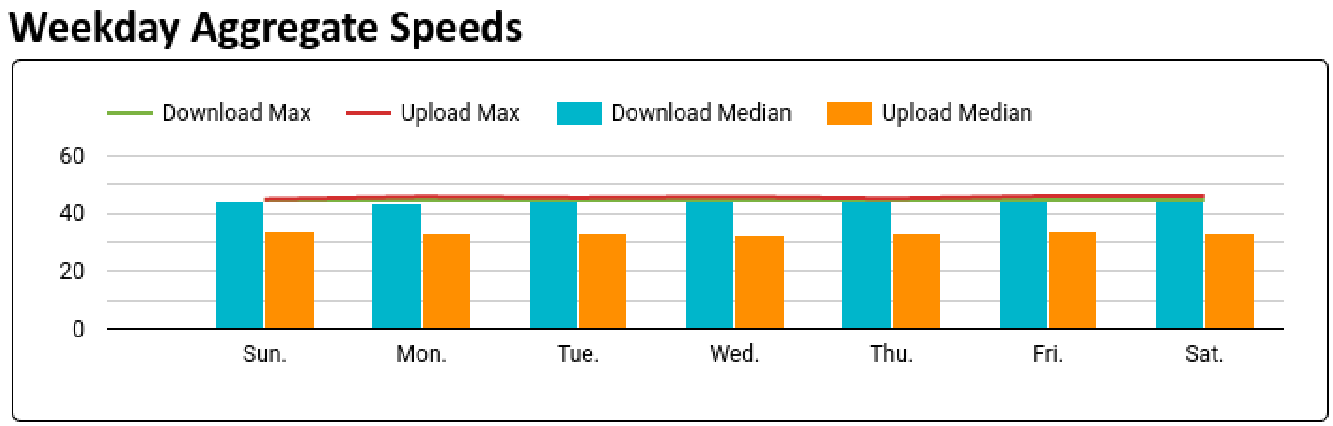


Figure 6. Weekday aggregate speeds—Pasco County, Florida.[36]

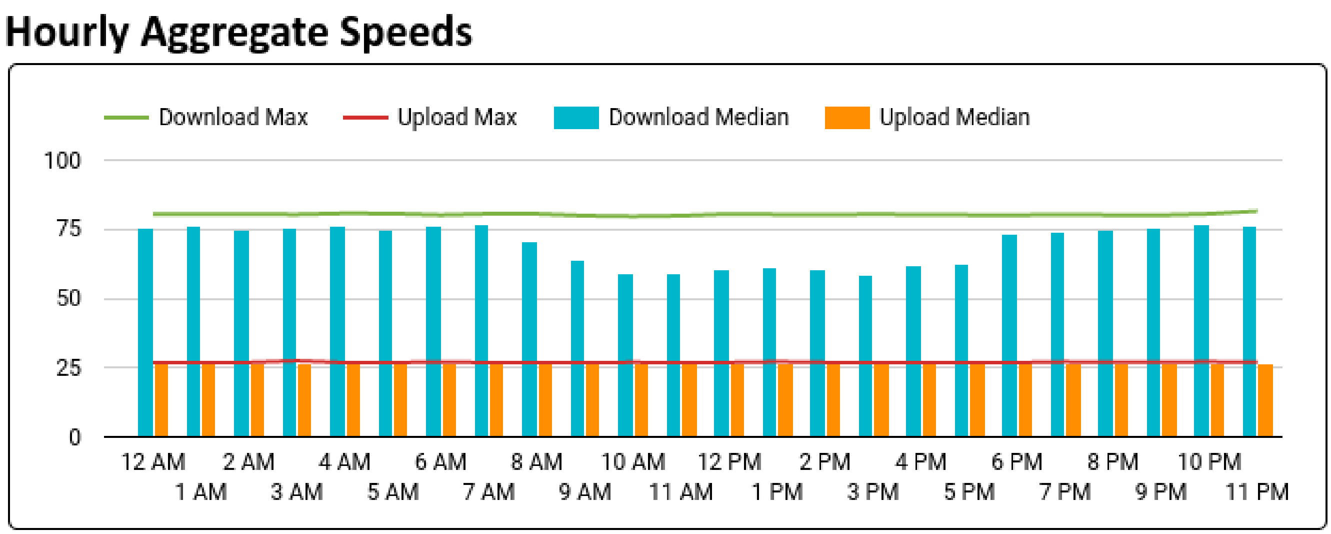


Figure 7. Hourly aggregate speeds—Estherville, Iowa.[37]

With additional local knowledge about network use, conditions, and events, library and IT staff can use ongoing measurements to confirm and explain service changes or uncover issues that are not previously known. Many MLBN libraries sought ongoing measurements of internet service to confirm service delivery levels, and some shared their expected service speeds in our final program evaluation survey. The list of libraries that shared their expected service levels are listed at the end of this paper. Using these reported speeds as an example, we can observe where the overall measured speeds were consistent with the service levels and where they were not, using the Ookla multi-stream measurements. Bennington (VT) Free Library reported a 100 Mbps symmetric connection as their expected service level, and the monthly maximum speeds range between 93 and 98 Mbps.[38] Similar results were seen in Live Oak, Georgia; Monroe County, Michigan; and Sheridan, Arkansas.[39]

In other cases, the reported service levels did not match the measurements. In Pasco County, Florida, measurements indicate a 50 Mbps symmetric connection where the reported service level was 100 Mbps download and 25 Mbps upload.[40] And in Ventura County, California, our measurements confirm an ~300 Mbps symmetric connection but the reported service level was 1 Gbps symmetric.

Finally, in several cases measurements may confirm anomalies or changes in the library's internet service. In these examples we do not have local knowledge of changes in service or events that might explain anomalies observed in the data, but we can nonetheless observe that a change happened and make an inference about the causes. Some examples include:

- Graham County, Arizona—possible service delivery change in May 2020 from ~100/10 (download/upload Mbps) to ~300/30[41]
- Traverse City, Michigan—possible service delivery change in January 2021 from ~80/5 to ~300/20[42]
- Waltham, Massachusetts—change to symmetric download and upload in November 2020 from ~50/25 to ~50/50[43]
- Truro, Massachusetts—observed changes in symmetry of upload and download measurements in June 2020 and March 2021 are perhaps indicators of testing changes in network management to adapt to changing needs[44]
- Westchester County, New York—observed dip in some upload measurements in late June 2020 at specific times of day for unknown reason[45]

Comparing Average Monthly Maximum Speeds

The final two pages (5 and 6) of our Data Studio report display the maximum overall speeds and the average monthly maximum speeds measured for each library, filterable by IMLS code, access media, and type of ISP.[46] Figure 8 shows a report for the average maximum speeds per test at libraries connected with fiber.

				ndt5		ndt7		speedtest-cli-multi-st...		speedtest-cli-single-s...	
Library	Locale Code	Access Me...	ISP Type	Down	Up	Down	Up	Down	Up	Down	Up
Andover-MA	21	Fiber	State/City	41.55	39.79	37.19	42.08	39.07	39.12	38.76	38.99
Bennington-VT	32	Fiber	Commercia...	93.61	92.83	63.42	73.2	93.64	96.25	73.98	66.57
Caruthersville-MO	33	Fiber	R&E Network	18.91	18.64	18.84	19.23	18.8	19.02	15.38	14.43
Cherokee-IA	33	Fiber	Cooperative	53.09	5.8	48.99	6.23	53.01	5.96	52.64	5.83
Clarkston-MI	21	Fiber	R&E Network	91.29	89.64	66.44	74.68	91.89	96.56	84.44	84.61
Ferguson-CT	12	Fiber	R&E Network	467.83	489.08	133.53	153.28	296.65	344.03	211.82	181.94
Live-Oak-GA	12	Fiber	Commercia...	290.06	299.17	132.79	148.63	284.92	289.24	144	135.07
MonroeCO-Bedford-MI	23	Fiber	Commercia...	-	-	42.83	21.72	52.76	21.44	30.93	21.15
Multnomah-County-OR	12	Fiber	Commercia...	584.73	259.83	24.43	25.16	203.81	222.75	196.2	153.8
Pasco-County-FL	21	Fiber	Commercia...	22.98	44.4	43.23	47.04	44.68	45.25	32.29	40.98
Pryor-OK	32	Fiber	R&E Network	89.31	88.23	65.71	73.95	89.38	94.41	86.51	81.16
Saline-County-AR	21	Fiber	Commercia...	140.07	140.38	108.33	116.06	137.26	141.69	101.17	106.79
St-Paul-MN	11	Fiber	State/City	212.06	214.29	24.39	25.1	196.18	257.19	180.22	161.79
Truro-MA	32	Fiber	Non-profit	119.91	22.81	77.26	23.39	106.65	23.29	70.45	22.98
Twin-Falls-ID	33	Fiber	Cooperative	94.35	19.46	64.86	23.53	95.52	21.82	80.76	17.61
Ventura-County-CA	21	Fiber	R&E Network	562.99	429.05	189.48	218.28	300.29	348.96	177.56	148.94
Westchester-County-NY	21	Fiber	Commercia...	689.18	460.45	116.65	118.25	201.87	249.13	217.21	186.69

Figure 8. Average maximum speeds per test measured at MLBN Libraries connected with fiber.

Comparison of Measurements and Related Data

To support increased understanding of network measurement within the public library community, we also compared measurements from the public libraries that participated in our study to the public data of crowdsourced measurements from the two large scale internet measurement platforms used in our research measurements, Ookla and M-Lab. We can observe the differences or similarities in measurements between the tests conducted from the libraries' premise devices and the publicly released data in aggregate for the surrounding county. The weighted average speeds and latency are provided by quarter, since Ookla's public data limits more granularity.

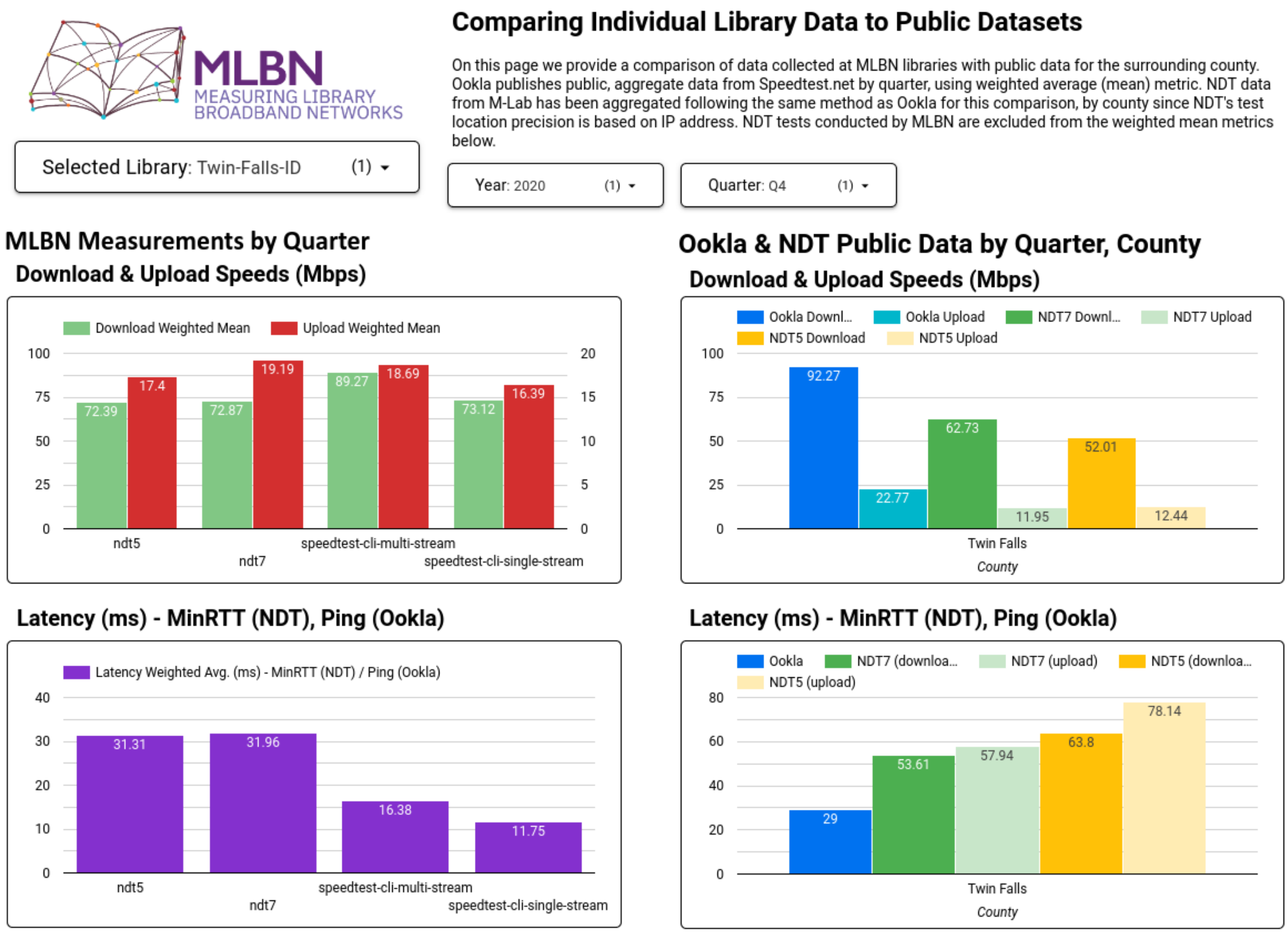


Figure 9. Comparing individual library data to public datasets—Twin Falls, Idaho, 2020 Q4.[47]

On page 4 of the Data Studio report we can observe whether the measured speeds in MLBN libraries were lower or higher than measurements from the surrounding county (see figure 9), along with the percentage difference between the two sources (see figure 10).[48] While these differences are interesting to observe, and in some cases seem quite pronounced, this is not a finding that explains whether libraries are getting better or worse speeds than their communities. This is a coarse comparison that we might think of as a kind of litmus test for further inquiry, rather than findings that tell a definitive story. Ookla public data aggregates all measurements from all ISPs together, while measurements from MLBN libraries are from one. A subscription to Ookla Speedtest Intelligence might enable more direct comparisons on a per ISP basis.

Library/County	Quarter	Locale C...	MLBN - Downl...	MLBN - Upload	County Downl...	County Upload	% Dif. Downlo...	% Dif. Upload
Andover-MA / Essex	1	21	28.91	29.93	165.37	48.27	140.48	46.9
	2	21	26.2	29.45	154.19	48.19	141.9	48.28
	3	21	29.38	34.07	154.19	48.19	135.98	34.32
	4	21	31.08	32.79	154.19	48.19	132.9	38.04
Bennington-VT / Bennington	1	32	89.58	92.66	113.83	24.28	23.84	116.95
	2	32	92.72	93.63	82.17	12.05	12.06	154.38
	3	32	92.43	92.83	82.17	12.05	11.74	154.03
	4	32	90.56	92.76	82.17	12.05	9.71	154
Caruthersville-MO / Pemiscot	3	33	17.48	18.24	114.36	70.02	146.97	117.32
	4	33	17.66	18.14	114.36	70.02	146.5	117.68
Cherokee-IA / Cherokee	2	33	49.06	5.63	96.85	18.53	65.51	106.84
	3	33	49.84	5.61	96.85	18.53	64.09	107.03
	4	33	50.88	5.61	96.85	18.53	62.23	107.06

Figure 10. MLBN Data Studio Report, page 4—Was public data or library data higher or lower?

DISCUSSION

Our research builds on the Digital Inclusion Survey that used a version of the Ookla test in a supplemental speed test study in which, "libraries were asked to run the speed test when the library was closed, during regular hours of operation, and when usage was light, normal, or heavy, by the librarians' estimation."[49] The software created by MLBN to collect ongoing, randomized measurements extends the idea of the Digital Inclusion Survey's supplemental speed test, making it a source of monitoring data that can be correlated with each location's connection plans, service tiers, costs, and other metadata. This approach aligns with the methods used by the FCC by using a dedicated, on-premise device.[50] The MLBN system also goes further, providing a framework for any open-source measurement to be added as an available test. Since the conclusion of our research, several new tests have either been added or are being considered.[51] As new measurement tools and analyses are developed by the research community, the MLBN system can incorporate them and bridge network science researchers' understandings to anchor institutions and the general public.

While speed tests have been used in this research and its predecessors, we find there is a gap in public understanding about what these tests can tell us. One important outcome of our study is that understanding the experience of using the internet, measuring it, and regulating it all need additional measurements and approaches that go beyond speed tests alone. Speed tests and the platforms that support them are very different. Internet service plans may focus on upload and download speeds, as does telecommunications regulation at the FCC, but these tests offer only simple and incomplete assessments. The Ookla and M-Lab platforms provide two different controlled experiments designed to measure internet protocols and performance for different segments of the internet's topology. They both use data generated specifically for the measurement itself. But these tests do not measure our experiences using the internet in general. For that we need network science researchers to develop new measurement methods and analyses. We advocate for even more nuance and additional metrics in the measurement and understanding of internet service beyond speed. This perspective aligns with the researcher and network science community who are designing new measurements to account for user experience, content delivery, and latency issues, all of which are often incorrectly assumed to be measured by speed tests.[52]

We took the approach of using multiple tests and platforms to provide complementary measurements of different aspects of delivered internet service. If we need to confirm advertised service levels, we can look at the Ookla test data. In this analysis, we used the average monthly maximum speeds as measured by the Ookla multi-stream test since it was used in the Digital Inclusion Survey and most closely aligns with ISPs' terms of service.[53] M-Lab's NDT, on the other hand, provides a diagnostic measurement for how well the underlying TCP protocol is performing over the measured path. That measurement path for M-Lab tests always traverses the boundaries between networks. If we want to assess our ISP's connectivity to the internet beyond the last mile network it maintains, we can examine the NDT data.

However different the methodologies and measurements of Ookla's speed test and M-Lab's NDT test are, we agree with the internet measurement community that measurements of throughput or speed should not be the only focus of assessing a connection's quality, and a broader public understanding that includes other measurements and nuances needs to be cultivated.[54] Researchers' understanding of the usefulness of both Ookla and NDT measurements is not static, as recent analyses of their public datasets have shown.[55] The research community is also exploring new metrics derived from various data sources that may eventually provide analyses that speak to user experience of using the internet, as well as other technical factors that can influence performance such as latency, bufferbloat, and responsiveness.[56]

What Does This All Mean for Public Libraries?

Building on the speed test used in the Digital Inclusion Survey, the MLBN measurement system enables communities to collect ongoing measurements using a dedicated premise device, leveraging available open-source measurement tools, instead of running periodic or occasional tests. Using this longitudinal data, libraries can confirm expected service levels using Ookla test results, uncover where there is a mismatch in understanding of service levels or network management practice, or compare a library's measured service to the surrounding community using public data sources. Additional measurements like M-Lab's NDT can assess a library's connectivity beyond the ISP's network. The resulting measurements are useful for interrogating the differences in platforms, their tests, and regulatory or funding benchmarks. But while speed tests can provide useful metrics for understanding general trends and anomalies, an appropriate understanding of what they do and do not measure is also needed. Speed tests demonstrating advertised levels do not necessarily mean that users of that network will not experience slowness as content is delivered to their computers over the same connection. As the federal government prepares to outlay infrastructure dollars to states to improve internet access and service quality, libraries and other public institutions in their states will need specific data and understanding of its nuances and differences.

CONCLUSION

In this paper, we sought to promote greater understanding about the speeds and quality of service of public library internet connections, an understudied area within library and information science, as well as among broadband policymakers. Library staff and administrators need information to understand and communicate about a library's network capacities, management practices, and diagnostic or monitoring information. The availability of measurements from different sources can help build shared understanding about a library's internet connectivity between library staff and IT or network administration personnel. And while speed tests are admittedly limited in what they can tell us about internet capacity, library staff who have access to these types of measurements, as well as other information provided by a library's IT staff, would be better equipped to engage with patrons around questions of internet stability and capacity in support of the library's mission.

From our observations of the data collected, the MLBN measurement system can be used to enhance understanding of the library's internet service and network management. For the subscribed service levels identified at MLBN libraries, Ookla measurements confirm whether the library's measured connection speeds matched the expected service levels and when they did not. When measurements are not consistent with expected service levels, libraries can observe the differences and correlate this with additional local information. Ongoing measurements conducted by the library enable local control and monitoring of this vital service and support critique and interrogation of the differences between internet measurement platforms, their topologies, tests, and data, from the perspective of the library doing the measurement. Speed tests are useful for examining these trends but may not always be indicative of a user's experience accessing and using internet content and services. New research and leadership from the internet measurement community are needed to provide more nuanced and authentic assessments of both network performance and user experience. Emerging research and analyses published openly can be added to the MLBN system to support increased public understanding of internet connection quality and user experience.

We hope this paper and our research will help support public libraries interested in ongoing measurement and assessment of their internet service, as well as contribute to discussion of the implications for state and federal policymakers interested in better understanding that public libraries play a key role in their local digital equity ecosystems.

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Data Accessibility
The datasets supporting this article have been uploaded to the Harvard Dataverse, located here: https://dataverse.harvard.edu/dataverse/mlbn

APPENDIX A: ALL PARTICIPATING LIBRARIES

Table A.1. The final cohort of participating libraries, the specific branch where measurements were conducted, the city, state, and the library's IMLS Code

Library	Branch (if applicable)	City	State	IMLS region code
Andover Memorial Hall Library	—	Andover	MA	21 - Suburb, Large
Arkansas River Valley Regional Library	Arkansas River Valley	Dardanelle	AR	33 - Town, Remote
Avery Mitchell Yancy (AMY) Regional Library	Avery Morrison Library	Newland	NC	42 - Rural, Distant
Bennington Free Library	—	Bennington	VT	32 - Town, Distant
Caruthersville Public Library	—	Caruthersville	MO	33 - Town, Remote
Cherokee Public Library	—	Cherokee	IA	33 - Town, Remote
Clarkston Independence District Library	Main Branch	Clarkston	MI	21 - Suburb, Large
Cochise County Library District	Elfrida	Elfrida	AZ	32 - Town, Distant
Denver Public Library	Central Library	Denver	CO	11 - City, Large
Estherville Public Library	—	Estherville	IA	33 - Town, Remote
Mid Arkansas Regional Library System	Grant County Library	Sheridan	AR	33 - Town, Remote
Casewell County Library	Gunn Memorial Public Library	Yanceyville	NC	42 - Rural, Distant
Hall County Library System	Gainesville	Gainesville	GA	13 - City, Small
Hollis Public Library	—	Hollis	AK	43 - Rural, Remote
Live Oak Public Libraries	Bull Street Library	Savannah	GA	13 - City, Small
Monroe County Library System	Bedford Branch Library	Temperance	MI	21 - Suburb, Large

Library	**Branch (if applicable)**	**City**	**State**	**IMLS region code**
Multnomah County Library	St. Johns Branch	Portland	OR	12 - City, Midsize
Pasco County Library	Regency Park Library	New Port Richey	FL	21 - Suburb, Large
Pryor Public Library	—	Pryor	OK	32 - Town, Distant
Union County Library System	The Public Library for Union County	Lewisburg	PA	32 - Town, Distant
Safford City-Graham County Library	—	Safford	AZ	32 - Town, Distant
Saline County Library	—	Benton	AR	33 - Town, Remote
Saint Paul Public Library	Rondo Branch, Central Branch	Saint Paul	MN	11 - City, Large
The Ferguson Library	—	Stamford	CT	12 - City, Midsize
Traverse Area District Library	Kingsley Branch Library	Kingsley	MI	21 - Suburb, Large
Truro Public Library	—	Truro	MA	21 - Suburb, Large
Twin Falls Public Library	—	Twin Falls	ID	33 - Town, Remote
Ventura County Public Library	EP Foster Branch, Admin Branch	Ventura	CA	21 - Suburb, Large
Waltham Public Library	Main library	Waltham	MA	21 - Suburb, Large
Westchester County Public Library	Hendrick Hudson Free Library, Library system datacenter	Montrose	NY	21 - Suburb, Large

APPENDIX B: FINAL PROGRAM EVALUATION SURVEY

Table A.2. Final evaluation responses on internet connectivity and network management

Library	Survey respondent role(s)	Service tier from survey (download/upload)	Per device limit imposed
Bennington Free Library	Library staff, IT staff	100/100	-
Live Oak Public Libraries	IT staff	300/300	-
Monroe County Library System	Network administrator	50/20	-
Pasco County Library	Network administrator	100/25	-
Grant County Library	Library administrator	15/15	-
Public Library for Union County	IT staff	-	10 Mb/s
Ventura County Public Library	IT staff	1000/1000	-
Waltham Public Library	Library staff, IT staff	100/100	50 Mb/s

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