Internet Access Index

Measuring the Availability and Household Adoption of High-speed Internet

National Preparedness Analytics Center
Decision and Infrastructure Sciences Division

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What is the Internet Access Index (IAI)?

The internet is a central driver in how households access information and services, learn, connect with family and friends, shop, and work. However, almost 14 percent of households in the United States[1] do not have the ability to access high-speed internet. Access to broadband or high-speed internet has taken on increased importance during the COVID-19 pandemic as many workplaces and schools shifted to a virtual environment. Argonne National Laboratory (Argonne) developed the IAI to better understand the challenges many households face in connecting to high-speed internet, whether due to lack of broadband availability from internet service providers or difficulties in subscribing to a broadband service.

What Does the IAI Measure?

The IAI is calculated as the product of 3 factors using publicly available data from the Federal Communications Commission and the U.S. Census Bureau. The first two factors gauge the quality and availability of high-speed internet and the third factor represents the public's ability to subscribe to high-speed internet services. The IAI scores United States' census tracts on a [0,1] scale, where values near 0 represent areas with less internet access and values approaching 1 represent more internet access. The maximum score (1.0) of the IAI would mean that all census blocks within a census tract have high speed internet available at the highest national speed (currently 1000 mbps), and that all households within the tract have a fixed broadband subscription of some type. To better visualize the results, Argonne binned the data into 5 relative bins (darker colored bins means better internet access) and created maps available at www.anl.gov.

Why is the IAI Important?

The COVID-19 pandemic surfaced deep digital divides across America. A lack of access to high-speed internet has made it more difficult for households to work from home or access basic services, including education and healthcare. Understanding where high-speed internet is accessible and accessed (where households subscribe to broadband services) will continue to play a critical role in the well-being of individuals, the economy, and communities well into the future. The IAI index and accompanying map identifies areas that could be considered broadband deserts where communities do not have quality access to the internet and therefore will find it more difficult to participate in an increasingly digital world. For example, it highlights locations where it is harder for students to participate in virtual learning, where individuals cannot access telemedicine services, or work remotely.

[1] American Community Survey Table S2801, 2019 1-Year Estimates.

How to Use the IAI?

The goal of the IAI is to provide an easy-to-understand metric that can be flexibly applied to a wide variety of research and decision-making purposes that relate to internet access. Researchers and policymakers can use this index to better understand the current high-speed internet accessibility landscape and to assess potential impacts of variable internet accessibility on education, healthcare, economic development, and other critical services through the lens of high-speed internet access. For example, governments, industry, and non-for-profit organizations could consider how to take advantage of areas with high levels of internet access as well as make accommodations for those without internet access. In these communities, individuals may not have an email address or the ability to easily complete digital forms.

Go to the IAI story map located here to view the results and interact with IAI data. You can also download the IAI data here.

Introduction

The internet is a central driver in how households access information and services, learn, connect with family and friends, shop, and work. However, almost 14 percent of households in the United States[2] do not have the ability to access high-speed internet for a variety of reasons including:

- The availability of internet service or broadband infrastructure in their community,
- The willingness or financial ability to subscribe to an internet service provider,
- The capacity of the individual to buy the equipment (i.e. computer, tablet, cell phone)

The Internet Access Index (IAI) described in this paper focuses on the first two factors, as these are frequently the product of large collective investments.

Access to broadband or high-speed internet has taken on increased importance during the COVID-19 pandemic. In the first quarter of 2020, broadband usage increased by 47% over the first quarter of 2019[3]. The pandemic caused the spike in demand as:

- Many workplaces have shifted to a virtual environment. According to the Federal Reserve Bank of Dallas, 35.2 percent of workers who participated in the Real Time Population Survey (RPS) reported working from home in May 2020, as compared to 8.2 percent in February 2020.[4]
- Primary and secondary schools and institutions of higher learning across the United States have deployed distance-learning programs to protect the wellbeing of students and teachers.
- Non-emergency healthcare services significantly shifted to telemedicine visits as compared to in office visits.[5]

> The Federal Communication Commission (FCC) indicates that the term 'broadband' commonly refers to high-speed internet access that is always on and faster than dial-up access. The current definition of high-speed internet is 25 mbps down/3 mbps up. This is the minimum download speed recommended for activities such as education and telecommuting.
>
> Federal Communications Commission. *Broadband Speed Guide.* https://www.fcc.gov/consumers/guides/broadband-speed-guide

COVID-19 surfaced deep digital divides across America. A lack of access to high-speed internet has made it more difficult for households to access basic services, including education and healthcare. Prior to the pandemic, Common Sense Media estimated that six-in-ten students (58%) said they used the internet at their home to do homework every day or almost every day. The same study also found that approximately 15-16 million K-12 public school students lived in homes without either an Internet connection or a device adequate

[2] American Community Survey Table S2801, 2019 1-Year Estimates.

[3] Weinschenk, C. (2020). Open Vault: Pandemic Drives Almost a Year's Worth of Broadband Traffic Growth in the Span of a Couple of Weeks. https://www.telecompetitor.com/openvault-pandemic-drives-almost-a-years-worth-of-broadband-traffic-growth-in-the-span-of-a-couple-of-weeks/

[4] Bick, A., Blandin, A. and Mertens, K. (2020) Work From Home After the COVID-19 Outbreak. Federal Reserve Bank of Dallas. https://www.dallasfed.org/-/media/documents/research/papers/2020/wp2017r1.pdf

[5] Koonin LM, Hoots B, Tsang CA, et al. Trends in the Use of Telehealth During the Emergence of the COVID-19 Pandemic — United States, January–March 2020. Morbidity and Mortality Weekly Report 2020; 69:1595–1599. DOI: http://dx.doi.org/10.15585/mmwr.mm6943a3

for distance learning at home resulting in a homework gap.[6] This "homework gap" has now become a "learning gap" as the pandemic has led to an increased reliance on virtual learning in K-12 schools and institutions of higher education across America.

Goals

As the pandemic has served to highlight, understanding where high-speed internet is accessible *and* accessed (where households subscribe to broadband services) will continue to play a critical role in the well-being of individuals, the economy, and communities. Recognizing this need, Argonne National Laboratory (Argonne) developed the IAI to focus on the connectivity challenge: broadband availability and broadband adoption or subscription. Later iterations or enhancements may look at challenges related to device availability, digital skills, and applications, such as for health screenings, workforce training, and education.

The goal of the IAI is to provide an easy-to-understand metric that can be flexibly applied to a wide variety of research and decision-making purposes. The IAI uses nationwide, publicly available data from the FCC and the U.S. Census Bureau American Community Survey (ACS) to measure both availability (internet infrastructure and speed) and household adoption by combining advertised internet availability and speed data as reported by internet service providers (ISPs) with household subscription data.

Researchers and policymakers can use this index to better understand the potential impacts of variable internet accessibility or as one factor in more complex models looking at broader impacts of disparity and inequality nationwide. For example, policymakers can assess the implications of COVID-19's impact on education, healthcare, economic development, and other critical services through the lens of high-speed internet access.

This publicly available resource will assist government and non-government stakeholders with analysis related to infrastructure deployment in current broadband deserts, as well as programs to increase the number of lower income individuals that can afford internet subscription services. Additionally, this index can identify locations where government and not-for-profit programs and services should not rely on a household's internet access to provide services, for example individuals in households that do not have internet access may not have email addresses or be able to complete on-line forms.

During the IAI development process, Argonne consulted with staff from the National Telecommunications and Information Administration (NTIA), Federal Communications Commission (FCC), Department of Education, and the Federal Emergency Management Agency (FEMA) to solicit technical input.

[6] Chandra, S., Chang, A., Day, L., Fazlullah, A., Liu, J., McBride, L., Mudalige, T., Weiss, D., (2020). Closing the K–12 Digital Divide in the Age of Distance Learning. San Francisco, CA: Common Sense Media. Boston, Massachusetts, Boston Consulting Group.

Data Sources

Table 1: Data sources used to compute the ANL Internet Accessibility Index.

Index Data	Data Source	Reference Period
Median Download Speed within a tract; Maximum Download speed within a block	Federal Communication Commission (FCC) Fixed Broadband Deployment Data Form 477	Dec 31, 2019 data
Percent of blocks within a tract with download speeds ≥ 25 mbps	FCC Form Fixed Broadband Deployment Data Form 477	Dec 31, 2019 data
Percent of households with a broadband subscription (excluding cellular-only subs)	Census Bureau American Community Survey (ACS) Table S2801 5-year estimates	2015 – 2019

To compose the IAI, Argonne relied upon two nation-wide datasets, which are discussed below.

FCC Fixed Broadband Deployment Data (Form 477)

The most extensive publicly available data set detailing available service and internet speeds is collected by the FCC in their Fixed Broadband Deployment Data Form 477 (FCC Broadband; Table 1)[7]. These data are self-reported by the ISPs and list information for both business and consumer/residential services such as maximum advertised upload and download speeds (megabits • second^{-1}; mbps) and the technology deployed to achieve those speeds. Because these data are self-reported there is the potential for broadband coverage to be overstated.

For the IAI, Argonne used all the available FCC speed information for the consumer/mass market/residential data regardless of technology[8]. Argonne derived two variables from the maximum advertised download speeds reported in the FCC Broadband data.

- *The median of the maximum advertised download speed.* These data are reported at the census block-level. Argonne scaled the data up to the census tract-level to match the spatial scale of other data products used in the analysis. Using the median allows for the retention of some of the census block-level characteristics in the data when scaled up to census tract. The FCC's Broadband Speed Guide indicates that the minimum download speed recommended for activities such as education and telecommuting is between 5 and 25mbps[9].

[7] Federal Communications Commission. Fixed Broadband Deployment Data from FCC Form 477 https://www.fcc.gov/general/broadband-deployment-data-fcc-form-477

[8] Federal Communications Commission. *Technology Codes used in Fixed Broadband Deployment Data*. https://www.fcc.gov/general/technology-codes-used-fixed-broadband-deployment-data

[9] Federal Communications Commission. *Broadband Speed Guide*. https://www.fcc.gov/consumers/guides/broadband-speed-guide

- *Percentage of census blocks within a census tract where ISPs advertise speeds greater than 25mbps.* The FCC Broadband Speed Guide also defines the minimum threshold for "Advanced" broadband service as 25mbps. As such, Argonne also calculates the percentage of blocks within each tract that report maximum advertised download speeds ≥ 25mbps.

ACS 5-yr-estimate broadband subscription data (Table S2801)

To capture on-the-ground household accessibility to broadband infrastructure, Argonne used the American Community Survey (ACS) Table S2801 5-year estimate (2015-2019) internet subscription data (ACS Subscription; Table 1)[10]. The primary advantage of using multiyear estimates is the increased statistical reliability of the data compared with that of single-year estimates, particularly for small geographic areas and small population subgroups. The inclusion of these survey data with detailed household adoption metrics helps to reduce potential overstating of maximum download speeds reported by the ISPs to the FCC. The ACS details broadband internet subscriptions based on households who said 'yes' to at least one of the following types of internet subscription: broadband such as cable, fiber optic, or DSL; a cellular data plan; satellite; or a fixed wireless subscription. As the FCC Broadband data refers to in-home broadband speeds only, the cellular-only respondents were removed from this broadband subscription metric. A map of cellular-only subscription levels can be found in Appendix A.

Method

The IAI is calculated as the product of 3 factors. The first two factors gauge the quality and availability of high-speed internet; 1) the ratio of median census tract download speeds to the maximum national download speed (the Download Speed Ratio) and 2) the percent of census blocks within a census tract with available Advanced Broadband Speeds (≥ 25 mbps) (Percent Advanced Broadband Speed). The third factor represents the public's ability to access the available high-speed internet by calculating the percent of households with broadband subscriptions per census tract (Percent Broadband Subscriptions).

Download Speed Ratio

To match the spatial scale among data sources, Argonne scaled the FCC data from the Census block-level to the tract level by calculating the median of the maximum advertised download speeds for all services in all blocks within a census tract. To create a scale between zero and one that can then be combined with the percent values of the other two factors, Argonne divided this census tract median value with the greatest maximum advertised download speed for blocks at the national level (currently 1000 mbps or 1 gigabit). Scaling download speeds by the national maximum also provides the ability to easily compare individual census tracts regardless of location (i.e. it is possible to compare a census tract from California to one in Puerto Rico.

The median download speed data has a distinct right tail to the distribution, because there are many more instances of middling to poor internet speeds across the country compared to the very few (< 4%

10 ACS Table S2801 5-year averages (2015-2019) https://data.census.gov/cedsci/table?q=Computer&t=Telephone,%20Computer,%20and%20Internet%20Access&tid=ACSST5Y2018.S2801

of blocks; FCC Data) instances of census tracts with median speeds close to the maximum advertised speed of 1000 mbps (Figure 1).

To reduce the influence of this long right tail, we applied a Box-Cox transformation[11] on both the median download speeds and the national maximum download speeds. This transformation makes it easier to integrate the ratio with the ACS data, and serves to make the data near-normally distributed, which allows the index to be used with a wider array of analytical methods such as regression analysis which assumes a normal distribution to the data. For a full description of the Box-Cox transformation method, please see Appendix B.

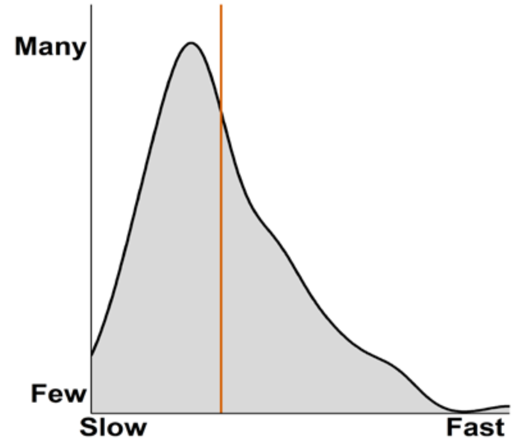


Figure 1: Example of a distribution with a distinct right tail. Notice how the mean (orange vertical line) is pulled to the right of the apex of the distribution curve. This occurs because a few 'Fast' values skew the mean towards the upper end.

Index Calculation

All three census-tract scale factors are combined to create the IAI equation; 1) the Download Speed Ratio, 2) Percent Advanced Speed), and 3) Percent Broadband Subscriptions). Argonne transformed the Percent Advanced Speed and Percent Broadband Subscriptions into proportions (0.0-1.0) to match that of the Download Speed Ratio.

$$IAI = Download\ Speed\ Ratio\ \times Percent\ Advanced\ Speed\ \times Percent\ Broadband\ Subscription \quad [eq1]$$

The calculated index value scores a census tract on a [0,1] scale, where values near 0 represent areas with less internet access and values approaching 1 represent more internet access. A tract that scores closer to 1.0 on this index indicates: 1) that most of the blocks within the tract are listed as having maximum advertised download speeds that are similar to the overall maximum download speed available nationally, 2) most of the blocks within the tract have advertised download speeds that are at or above the broadband threshold of 25 mbps, and 3) most households within the tract have a broadband internet subscription of some type. An example of how the index is calculated is detailed in eq2, below.

Download Speed Ratio: ratio of median census-tract download speeds to the maximum national download speed of 1000 mbps.

Percent Advanced Speed: Percent of census blocks within a census tract with available Advanced Broadband Speeds (≥ 25 mbps).

Percent Broadband Subscriptions: percent of households with broadband subscriptions per census tract.

Example:

- Median download speed for the tract: 25 mbps
- Maximum download speed, Nationally: 1000 mbps
- Percent of blocks within the census tract with broadband speeds: 75% (0.75)
- Percent of households in the census tract with a broadband subscription: 65% (0.65)

[11] Box, G.E.P. and D.R. Cox. 1964. An Analysis of Transformations. Journal of the Royal Society. Series B (Methodological). 26(2) pp. 211-252.

$$(\text{BoxCox}\ (25)/(\text{BoxCox}\ (1000)) \times 0.75\ \ \times 0.65\ = 0.317 \qquad [\text{eq2}]$$

To better analyze the results and to map the three individual factors and the IAI, Argonne sorted each of the data sets into five bins. Argonne mapped the median of the ISP reported download speed data rather the Download Speed Ratio to make the actual reported download speeds more accessible for users (Figure 2). To identify the best binning methodology for the data sets the research team used the Python Spatial Analysis Library, PySAL, and its Exploratory Spatial Data Analysis sub-package. Python is an open-source, high-level programming language that is used in social science research. The package includes nine potential binning methods.[12,13,14] Argonne found the best fit for the data sets was the Jenks-Caspall classification method, which reduces the potential for outliers within each data class and maximizes variation between data classes.

After binning the datasets into five bins, the research team created choropleth maps using color to illustrate each of the five bins.

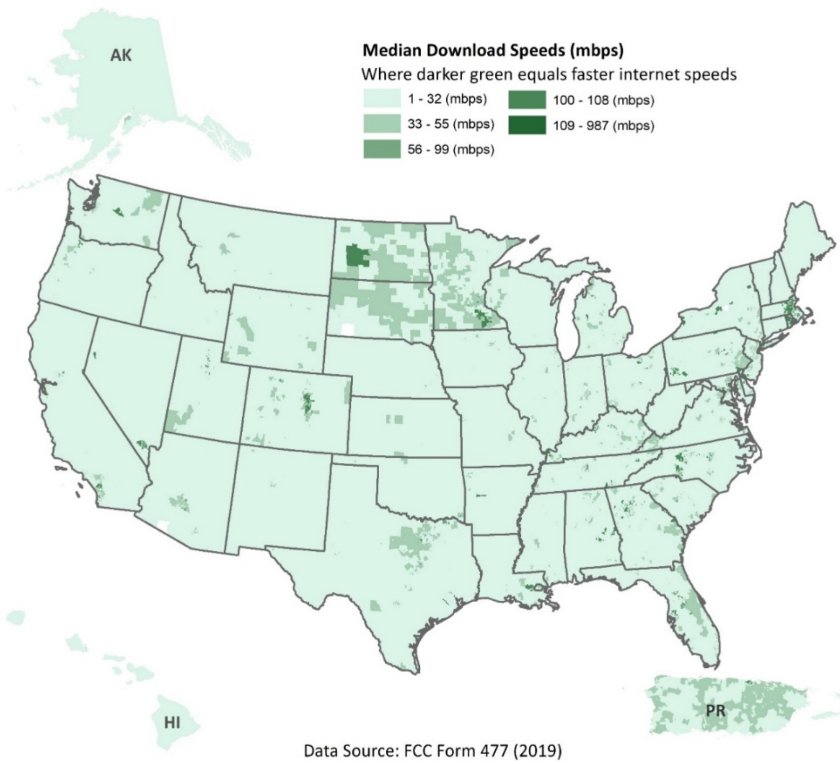


Figure 2: Census tract median download speeds. Median download speed is used in the calculation of the Download Speed Ratio described in the methods section. Darker green regions indicate faster median download speeds (mbps). Data from FCC Form 477.

12 The Python Exploratory Spatial Data Analysis Package includes the following nine binning methods: Equal Interval, Fisher Jenks, Head Tail Breaks, Jenks Caspall, Maximum Breaks, Natural Breaks (kmeans, stochastic), Quantiles, Percentiles, and Standard Mean.

13 Sergio Rey, Wei Kang, Levi John Wolf, mhwang4, jlaura, Philip Stephens, James Gaboardi, Charles Schmidt, Martin Fleischmann, and David C. Folch. "Pysal/Mapclassify: Mapclassify 2.3.0." Zenodo, 2020. https://pypi.org/project/mapclassify/

14 Mapclassify source code for classification schemes: https://pysal.org/mapclassify/

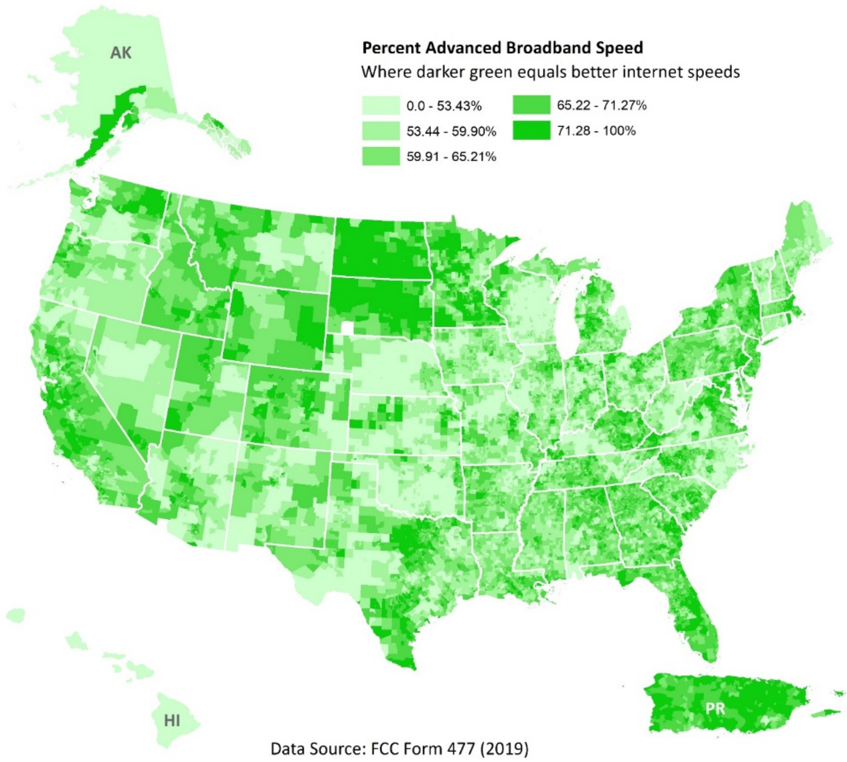


Figure 3: Advanced Broadband Speed for census tracts across the U.S. Darker green regions indicate more blocks within the tract have access to advertised download speeds greater than or equal to 25 mbps. Data from FCC Form 477 Data.

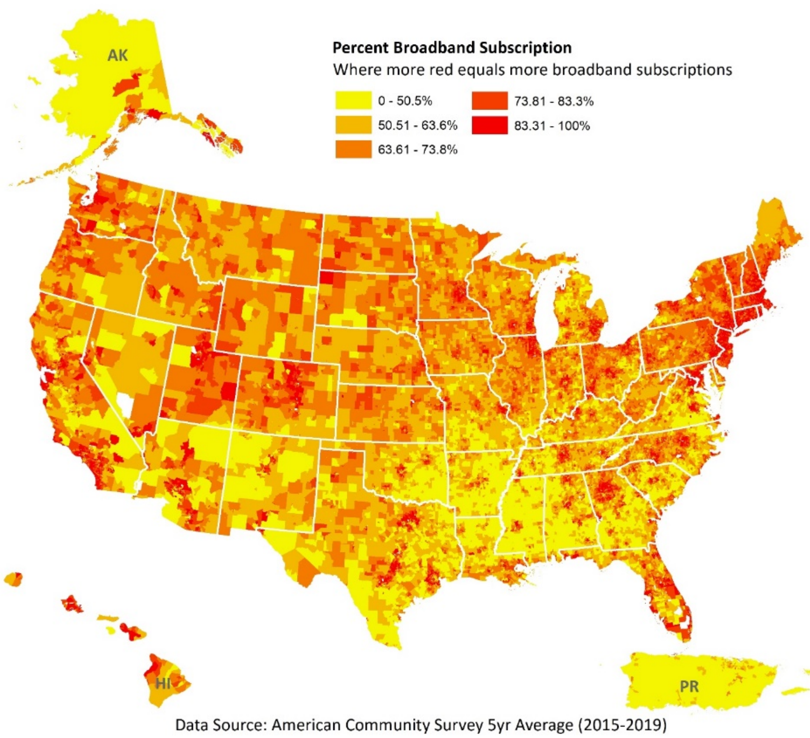


Figure 4: Percent Broadband Subscription for census tracts across the U.S. Note: cell-only subscriptions are not included.

Internet Access Index

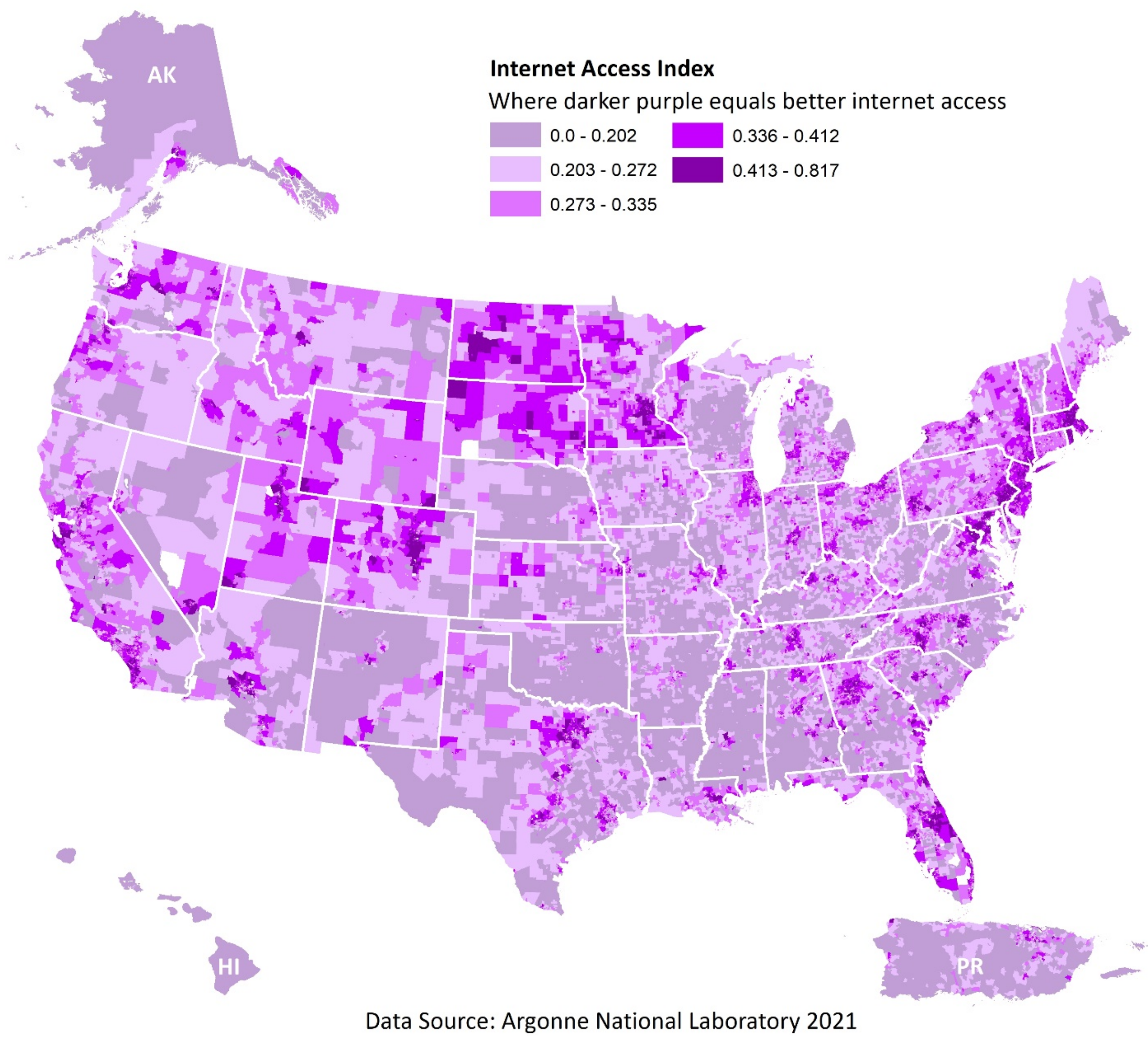


Figure 2: Resulting Internet Access Index (IAI) scores for the US. The IAI is the product of the Download Speed Ratio, Percent Advanced Speed, and Percent Broadband Subscriptions. The index is scaled between 0 (poor access) and 1 (more access). Darker purple regions indicate higher IAI scores and therefore more internet access.

Limitations

Following are discussions of limitations of this index:

Data quality. As with any index, the quality of the index is determined in large part by the quality and completeness of the inputs. Data collected by the FCC are self-reported by the ISPs, leading to the potential for broadband coverage to be overstated. There has been bipartisan agreement in Congress to improve data collection on broadband service availability, however funding has yet to follow. Most recently, the FCC opened a Notice of Proposed Rule Making *In the Matter of Establishing the Digital Opportunity Data Collection Modernizing the FCC Form 477 Data Program*. This Order recognizes the need for more granularity and more accuracy in the data collection and requests additional public comment on the data collection process.[15] As more granular and accurate nationwide data becomes available in the future, Argonne will update the IAI accordingly.

Missing Data. There are some instances of missing values in the data sets used. Because the ACS data are based on household survey data, there is always a chance of having tracts that are not sufficiently populated to be represented (ex. National Parks), or are reported by other means such as Tribal land. Calculations are available for 98.8% of the census tracts analyzed.

Lack of validation. There is no current dataset available to check the accuracy of the IAI. Argonne did compare the IAI to an index that has been used to better understand the potential digital divide that exists in the U.S. The Digital Divide Index (DDI) measures physical access/adoption of internet in technology across the country at the county level. The DDI uses similar data from the ACS and FCC, but layers in additional social measures such as: percent of homes without a computing device, percent of the population over 65, and the individual poverty rate among others[16]. To facilitate the comparison of IAI with the DDI, Argonne aggregated the IAI from the Census tract level to the county level. Overall, there exists a strong relationship (Pearson's $r = -0.34$; $p < 0.05$) between the IAI and the DDI for systematically selected states. Higher DDI values indicate greater distress (greater digital divide) and is inversely scaled to the IAI with the negative relationship expected.

[15] FCC, "Establishing the Digital Opportunity Data Collection Establishing the Digital Opportunity Data Collection," FCC-20-94, July 17, 2020, https://www.fcc.gov/document/fcc-improves-broadband-data-and-maps-bridge-digital-divide-0.

[16] Gallardo, R. (2020). Digital Divide Index. Purdue Center for Regional Development. Retrieved from Digital Divide Index (DDI): http://pcrd.purdue.edu/ddi

Key Results

The IAI serves as a general measure of internet accessibility across the United States. At the national scale, the mean IAI score is 0.302 (median = 0.300) with a minimum of 0 and a maximum of 0.817. This means that the average census tract within the U.S. scores just over 30% of the maximum possible score. The maximum score (1.0) of the IAI would mean that all blocks within the tract have access to the Advanced Broadband Speed at the best speed available, nationally (currently 1000 mbps), and that all households within the tract have a fixed broadband subscription of some type. The IAI's tract-level results are summarized at the state level and represent a 'typical' tract within each state (Table 2).

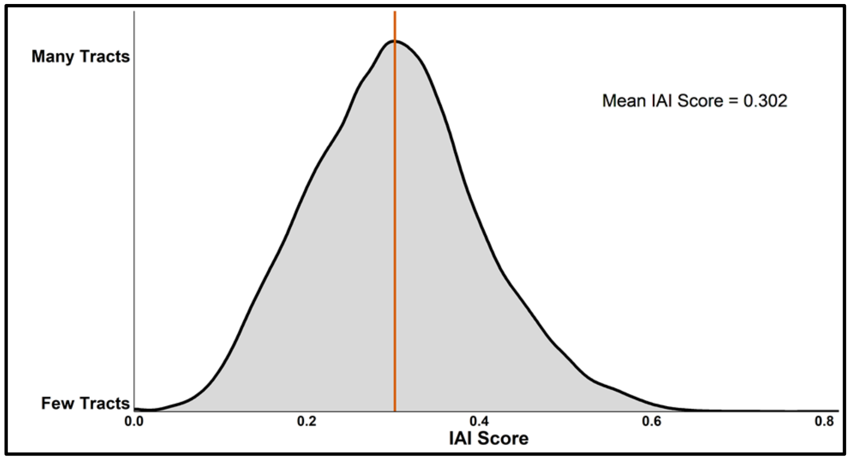


Figure 3. Density distribution curve for the resulting IAI scores.

It is important to note that state-level summary does not show the variability of the census tract data. Argonne recommends using the IAI at the tract-level for the most accurate representation of the results as is shown in this example of Cook County, Illinois.

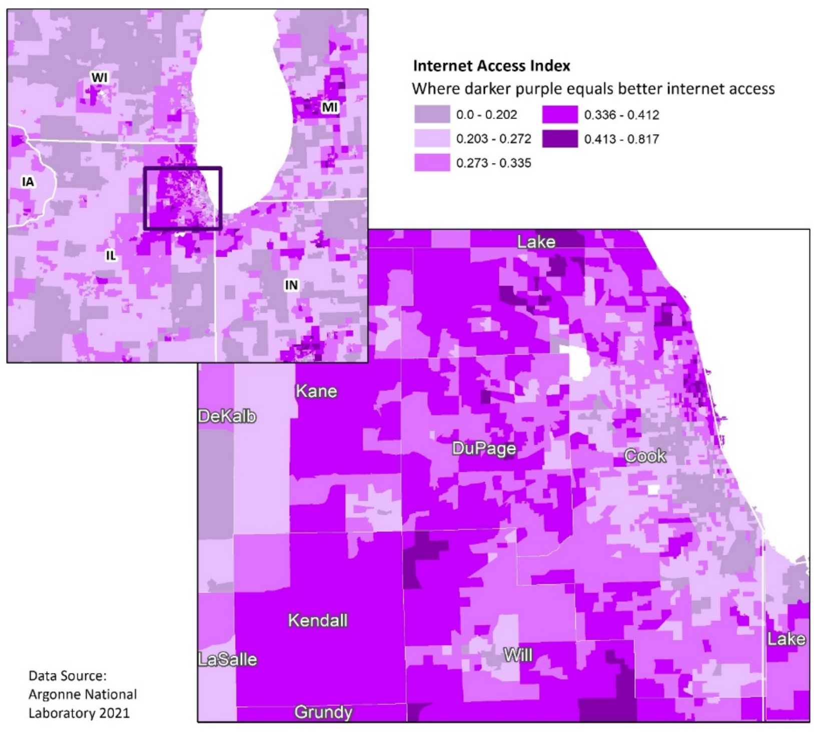


Figure 7: This view of the seven county region surrounding Chicago illustrates the variability of internet access at the census tract level.

Additional findings include:

- The District of Columbia showed the greatest average state-level score (0.5) and Hawaii the lowest (0.13) using the IAI.
- New York showed the greatest difference (0.71) between the minimum (0) and maximum (0.71) state IAI Scores, whereas Hawaii showed the smallest range (0.21) with a minimum IAI score of 0.04 and a maximum score of 0.25.
- The highest scoring Census tract can be found in Suffolk County Massachusetts (0.817)
- 64% of the top 25 tracts are located in the District of Columbia.

- The lowest scoring tracts using this index are generally located in more rural areas. Almost 60% of the 25 lowest scoring tracts are located in Alaska.

Table 2. National-scale summary statistics for the Internet Index and variables used in its calculation.

Statistic	Median Download Speeds	Perc. Adv. Speeds	Perc. Broadband Sub.	Internet Index Score
Min	1.0	0.00	0.0	0.000
Q1	25.0	57.8	60.7	0.232
Median	25.0	63.8	72.7	0.300
Mean	32.0	63.4	70.4	0.302
Q3	30.0	69.3	82.5	0.365
Max	987.0	100.0	100.0	0.817
NA's	33	33	888	913

Median Download Speeds

- Nationally, Median Download Speed is about 32mbps for an average tract and ranges from 1 mbps to 987 mbps (Table 2). The lowest median speeds coming from two tracts in rural Alaska and the fastest two tracts being located in Huntsville Alabama.
- The District of Columbia had, on average, the highest (147.74 mbps Median Download Speed) median tract level internet speeds, whereas Hawaii had on average the lowest speeds (6.92 mbps Median Download Speed).
- Alabama showed the greatest difference in Median Download speeds (difference = 969 mbps) from a high of 987mbps to a low of 18 mbps.

Percent Broadband Subscriptions

- Nationally, a typical tract sees about 70% of households subscribe to some form of fixed broadband services (Table 2). Percent Broadband Subscriptions ranged from census tracts with 0% (zero) to 100%. There are 26 census tracts that have zero Percent Broadband Subscriptions, with eight of those being located in New York and 3 each in Texas and Puerto Rico.
- A total of 109 census tracts have estimates of 100 Percent Broadband Subscriptions, with New York and California accounting for 23 and 13 of those, respectively.
- New Hampshire had the highest mean broadband subscription rate (80.62), and Puerto Rico recorded the lowest mean subscription rate (36.57%; Table 3).
- Variability in broadband subscriptions was greatest in New York, Oklahoma, Tennessee, Michigan, North Carolina, Texas, California, Florida, South Carolina, and Connecticut, where the range of Precent Broadband Subscriptions were 100. This means that there are tracts where all households have a broadband subscription of some type and tracts were zero households have a fixed broadband subscription of some type.
- Vermont saw the smallest difference (41.1%) between minimum (53.6%) and maximum (94.7%) Percent Broadband Subscriptions across tracts (Table 3).

Percent Advanced Speed

Having access to advanced broadband speeds will be necessary in an ever increasing remote-access society.

- Nationally, the average Percent Advanced Speed value ranged from 0% (zero) to 100% within a tract. Approximately 63% of the blocks within a 'typical' tract met or exceeded the threshold for advanced broadband speeds.
  - Nationally, 14 census tracts do not have access to advanced broadband speeds, with 10 tracts in Alaska and 4 tracts in Hawaii.
  - In 241 tracts every block has access to advanced internet speeds, with Florida, Puerto Rico, and Michigan composing 46, 39and 33 of those tracts, respectively.
- The District of Columbia, Puerto Rico, and Colorado show the greatest access to Advanced Broadband Speed with averages of 84.45%, 74.04% and 73.18%, respectively (Table 3).
- Hawaii, Oklahoma, and West Virginia showed the lowest levels of access to advanced broadband speeds (38.13%, 51.40%, 51.95%, respectively).
- Alaska showed the greatest range between minimum and maximum Percent Advanced Speed (0% and 98.7%, respectively) and Rhode Island showed the smallest range (58.7% and 77.2%, respectively) with a difference of 69.29% (Table 3).

Conclusion and Future Methodological Enhancements

The IAI index and accompanying map identify regions of the country that score very well where households have adequate access to broadband infrastructure. However, there are also many areas of that could be called broadband deserts where communities do not have quality access and therefore may find it difficult to participate in an increasingly virtual environment. These areas of inequity are not only realized at broad spatial scales, but can exist within the same city, or even from census tract to census tract as seen in the Northeastern Illinois (Figure 7). Presenting the IAI with census-tract granularity provides the means to target needed interventions at these specific areas. The straight-forward nature of the index also allows for a rapid diagnosis of whether the challenges for an area are the result of a lack of infrastructure (low Download Speed Ratio/ Percent Advanced Speed) or are a lack of access (low Percent Broadband Subscriptions).

This initial IAI is intended to serve as a foundational resource that can help to analyze broadband access related to critical services, such as education and healthcare. Argonne will continue to update and refine the IAI as new data becomes available and new analytic use cases are identified. Specific next steps could include:

- Additional analytic opportunities:
  - Exploration of household access to distance learning, and the identification with locations with a potential 'homework gap' where students required to attend school remotely do not have adequate access to the requisite infrastructure.
  - Analysis of areas where telework may be inhibited due to lack of adequate broadband access.
  - Identification of areas where improved internet access may facilitate greater access to expansive healthcare services.
  - Identification of areas where programs that rely on email addresses or digital forms need to provide accommodations for those without easy internet access.

- Methodology enhancements:
    - Scaling the index to multiple geographic extents (i.e. Census block, school district, county) to allow for further analytic flexibility.
    - Further analysis of regions that do not meet the 25mbps threshold of broadband internet.
    - Implementation of machine learning approaches to identifying additional characteristics that either support or result in higher index values.
    - Analysis of equitability of internet access by demographic and economic characteristics.
    - Qualitative analysis of missing data from US territories beyond Puerto Rico.

Table 3. State-level summaries showing mean values [minimum value, maximum value] calculated from tract-level data. Mean values can be interpreted as a typical or average tract within each state or territory.

FIPS	State/Territory Name	State/Territory Abb	Perc. Broadband Sub.	Median Download Speed (mbps)	Perc. Adv. Speeds	IAI Value
01	Alabama	AL	58.39 [20.2, 96.6]	30.85 [18, 987]	61.52 [30.05, 83.98]	0.24 [0.04, 0.53]
02	Alaska	AK	68.81 [0, 92.8]	19.19 [1, 35]	52.75 [0, 98.71]	0.24 [0, 0.5]
04	Arizona	AZ	71.65 [6.4, 100]	33.87 [10, 100]	65.62 [33.71, 86.06]	0.33 [0.02, 0.67]
05	Arkansas	AR	54.83 [0, 91.9]	24.67 [5, 100]	59.93 [36.35, 76.33]	0.21 [0, 0.4]
06	California	CA	76.19 [0, 100]	29.83 [9, 100]	62.06 [39.53, 84.75]	0.32 [0, 0.62]
08	Colorado	CO	78.02 [6.4, 100]	56.69 [15, 100]	73.18 [35.29, 86.16]	0.42 [0.03, 0.68]
09	Connecticut	CT	77.47 [0, 100]	25.1 [18, 35]	57.29 [46.49, 72.97]	0.29 [0, 0.41]
10	Delaware	DE	75.86 [35.4, 99.1]	51.18 [25, 100]	67.31 [51.08, 78.46]	0.37 [0.14, 0.6]
11	District of Columbia	DC	73.42 [37.3, 100]	147.74 [25, 330]	84.45 [69.47, 94.36]	0.5 [0.22, 0.81]
12	Florida	FL	72.29 [0, 100]	30.89 [10, 100]	65.6 [41.47, 87.04]	0.32 [0, 0.63]
13	Georgia	GA	67.52 [9.5, 98.9]	36.66 [10, 100]	65.72 [40.05, 83.23]	0.31 [0.03, 0.59]
15	Hawaii	HI	76.68 [34.1, 100]	6.92 [2, 21]	38.13 [28.77, 49.52]	0.13 [0.04, 0.25]
16	Idaho	ID	70.07 [15, 91.9]	25.12 [12, 35]	68.64 [43.26, 84.9]	0.31 [0.06, 0.48]
17	Illinois	IL	70.16 [17.6, 100]	25.57 [4, 100]	59.63 [36.54, 84.03]	0.27 [0.06, 0.53]
18	Indiana	IN	66.12 [15.7, 100]	27.23 [8, 100]	58.2 [32.52, 84.19]	0.25 [0.03, 0.51]
19	Iowa	IA	67.54 [21, 100]	24.35 [5, 80]	57.76 [33.82, 77.56]	0.25 [0.08, 0.42]
20	Kansas	KS	68.89 [24.1, 97.2]	24.18 [5, 87.5]	57.07 [30.81, 78.74]	0.26 [0.08, 0.52]
21	Kentucky	KY	65.34 [23, 100]	29.85 [10, 100]	63.12 [37.49, 82.12]	0.28 [0.08, 0.56]
22	Louisiana	LA	60.35 [7, 100]	26.2 [10, 100]	55.2 [30.19, 76.57]	0.22 [0.02, 0.53]
23	Maine	ME	73.65 [41.1, 93.1]	24.47 [5, 25]	58 [44.04, 69.47]	0.28 [0.11, 0.38]
24	Maryland	MD	76.24 [17.1, 98.6]	40.14 [10, 100]	67.64 [42.04, 81.69]	0.36 [0.08, 0.62]
25	Massachusetts	MA	78.68 [33, 100]	51.91 [20, 200]	67.61 [49.28, 100]	0.39 [0.13, 0.82]
26	Michigan	MI	68.53 [0, 100]	28.81 [6, 100]	60.17 [34.52, 85.09]	0.28 [0, 0.56]
27	Minnesota	MN	73.76 [31.2, 97.4]	44.29 [18, 300]	72.7 [44.31, 86.41]	0.39 [0.13, 0.66]
28	Mississippi	MS	51.87 [17.5, 95.6]	26.33 [12, 100]	61.7 [43.13, 76.63]	0.21 [0.06, 0.48]
29	Missouri	MO	66.18 [22.8, 100]	24.73 [2, 100]	57.9 [29.61, 79.29]	0.25 [0.04, 0.51]

30	Montana	MT	68.86 [24.4, 94.9]	26.23 [5, 80]	64.15 [37.68, 82.78]	0.29 [0.09, 0.56]
31	Nebraska	NE	71.75 [37.1, 95.6]	24.14 [5, 100]	57.67 [28.61, 73.86]	0.27 [0.07, 0.5]
32	Nevada	NV	72.07 [19.8, 97.9]	54.61 [10, 100]	68.38 [42.51, 86.67]	0.36 [0.1, 0.64]
33	New Hampshire	NH	80.62 [46.5, 96.2]	24.93 [7, 40]	61.36 [48.11, 80.9]	0.32 [0.19, 0.48]
34	New Jersey	NJ	77.58 [18.8, 100]	29.6 [25, 100]	67.33 [53.85, 79.12]	0.35 [0.08, 0.51]
35	New Mexico	NM	60.75 [2, 100]	28.42 [9, 80]	64.09 [30.96, 87.69]	0.26 [0.01, 0.51]
36	New York	NY	73.62 [0, 100]	36.56 [18, 500]	67.82 [43.74, 86.44]	0.34 [0, 0.71]
37	North Carolina	NC	69.78 [0, 100]	32.2 [6, 100]	61.66 [40.56, 82.56]	0.29 [0, 0.6]
38	North Dakota	ND	70.08 [39.8, 95.2]	33.74 [25, 100]	71.55 [51.48, 82.66]	0.34 [0.15, 0.53]
39	Ohio	OH	69.94 [8.9, 100]	26.12 [10, 100]	60.49 [36.5, 82.3]	0.28 [0.03, 0.5]
40	Oklahoma	OK	61.38 [0, 100]	19.65 [3, 100]	51.4 [29.97, 78.61]	0.19 [0, 0.44]
41	Oregon	OR	76.01 [39.1, 97.4]	34.01 [2, 100]	61.69 [30.95, 83.17]	0.32 [0.06, 0.58]
42	Pennsylvania	PA	72.16 [25.1, 100]	36.75 [3, 500]	66.71 [40.94, 83.25]	0.33 [0.1, 0.7]
44	Rhode Island	RI	75.27 [29.9, 93.1]	67.31 [25, 100]	69.29 [58.77, 77.2]	0.39 [0.13, 0.56]
45	South Carolina	SC	64.6 [0, 100]	27.5 [10, 100]	64.65 [37.04, 81.46]	0.28 [0, 0.56]
46	South Dakota	SD	69.35 [22.4, 93.5]	29.12 [25, 40]	70.71 [50.85, 85.48]	0.33 [0.09, 0.5]
47	Tennessee	TN	64.11 [0, 100]	29.12 [3, 100]	62.31 [39.2, 82.08]	0.27 [0, 0.59]
48	Texas	TX	65.58 [0, 100]	30.81 [6, 100]	62.98 [25.43, 87.5]	0.28 [0, 0.62]
49	Utah	UT	78.12 [9.6, 97.4]	42.18 [2, 100]	72.98 [37.31, 87.76]	0.4 [0.03, 0.64]
50	Vermont	VT	74.53 [53.6, 94.7]	21.05 [2, 25]	55.21 [42.88, 74.39]	0.25 [0.04, 0.41]
51	Virginia	VA	73.13 [24.5, 100]	30.35 [5, 100]	66.57 [45.41, 81.78]	0.33 [0.08, 0.58]
53	Washington	WA	79.23 [21.2, 100]	28.54 [10, 100]	63.72 [31.66, 85.66]	0.34 [0.05, 0.55]
54	West Virginia	WV	66.25 [34.8, 89.2]	22.08 [6, 25]	51.95 [36.17, 70.32]	0.22 [0.09, 0.34]
55	Wisconsin	WI	70.5 [22, 95.6]	21.9 [2, 45]	52.21 [31.26, 77.7]	0.23 [0.04, 0.43]
56	Wyoming	WY	72.08 [40.9, 89.4]	28.81 [18, 50]	65.26 [46.36, 79.91]	0.32 [0.17, 0.48]
72	Puerto Rico	PR	36.57 [0, 77.9]	41 [25, 100]	74.04 [52.09, 90]	0.19 [0, 0.46]

Appendix A: Select Index Tables and Figures

Table 4: List of the 25 highest scoring tracts on the Internet Index.

Rank	Census Tract	County	State	IAI Value	Median Download Speed (mbps)	Max. Download Speed (mbps)	Perc. Adv. Speeds	Max Download Speed (State)	Perc. Broadband Sub.
1	Census Tract 9901.01	Suffolk County	Massachusetts	0.817	100	100	100.00	1000	100.00
2	Census Tract 15	District of Columbia	District of Columbia	0.814	330	1000	94.36	1000	93.40
3	Census Tract 14.01	District of Columbia	District of Columbia	0.786	330	1000	92.20	1000	92.30
4	Census Tract 12	District of Columbia	District of Columbia	0.779	330	1000	92.52	1000	91.20
5	Census Tract 10.01	District of Columbia	District of Columbia	0.745	330	1000	90.49	1000	89.20
6	Census Tract 5.02	District of Columbia	District of Columbia	0.732	200	1000	88.54	1000	93.70
7	Census Tract 8.01	District of Columbia	District of Columbia	0.725	200	1000	89.72	1000	91.60
8	Census Tract 7.01	District of Columbia	District of Columbia	0.720	200	1000	88.27	1000	92.50

9	Census Tract 68.04	District of Columbia	District of Columbia	0.718	100	987	87.93	1000	100.00
10	Census Tract 16	District of Columbia	District of Columbia	0.716	330	1000	90.39	1000	85.80
11	Census Tract 112.02	New York County	New York	0.706	200	1000	80.00	1000	100.00
12	Census Tract 3	District of Columbia	District of Columbia	0.705	200	1000	86.69	1000	92.20
13	Census Tract 8.02	District of Columbia	District of Columbia	0.705	200	1000	88.37	1000	90.40
14	Census Tract 4011.01	Delaware County	Pennsylvania	0.703	500	1000	81.13	1000	90.80
15	Census Tract 95	New York County	New York	0.696	200	1000	81.32	1000	97.00
16	Census Tract 6	District of Columbia	District of Columbia	0.691	200	1000	90.73	1000	86.40
17	Census Tract 44	District of Columbia	District of Columbia	0.691	200	1000	85.36	1000	91.80
18	Census Tract 24	District of Columbia	District of Columbia	0.684	330	1000	86.84	1000	85.30

19	Census Tract 140.08	Douglas County	Colorado	0.683	100	987	86.16	1000	97.10
20	Census Tract 147	New York County	New York	0.677	200	1000	81.82	1000	93.80
21	Census Tract 139.10	Douglas County	Colorado	0.675	100	987	85.89	1000	96.30
22	Census Tract 8141	Maricop a County	Arizona	0.673	100	1000	85.74	1000	96.20
23	Census Tract 93.01	District of Columbia	District of Columbia	0.671	330	1000	87.17	1000	83.40
24	Census Tract 4	District of Columbia	District of Columbia	0.671	200	1000	87.29	1000	87.10
25	Census Tract 112.01	New York County	New York	0.665	200	1000	80.95	1000	93.20

Table 5: List of the 25 lowest, non-zero, scoring tracts on the internet index. Index values of 0.000 in this table are the result of rounding. Results are presented in ascending order.

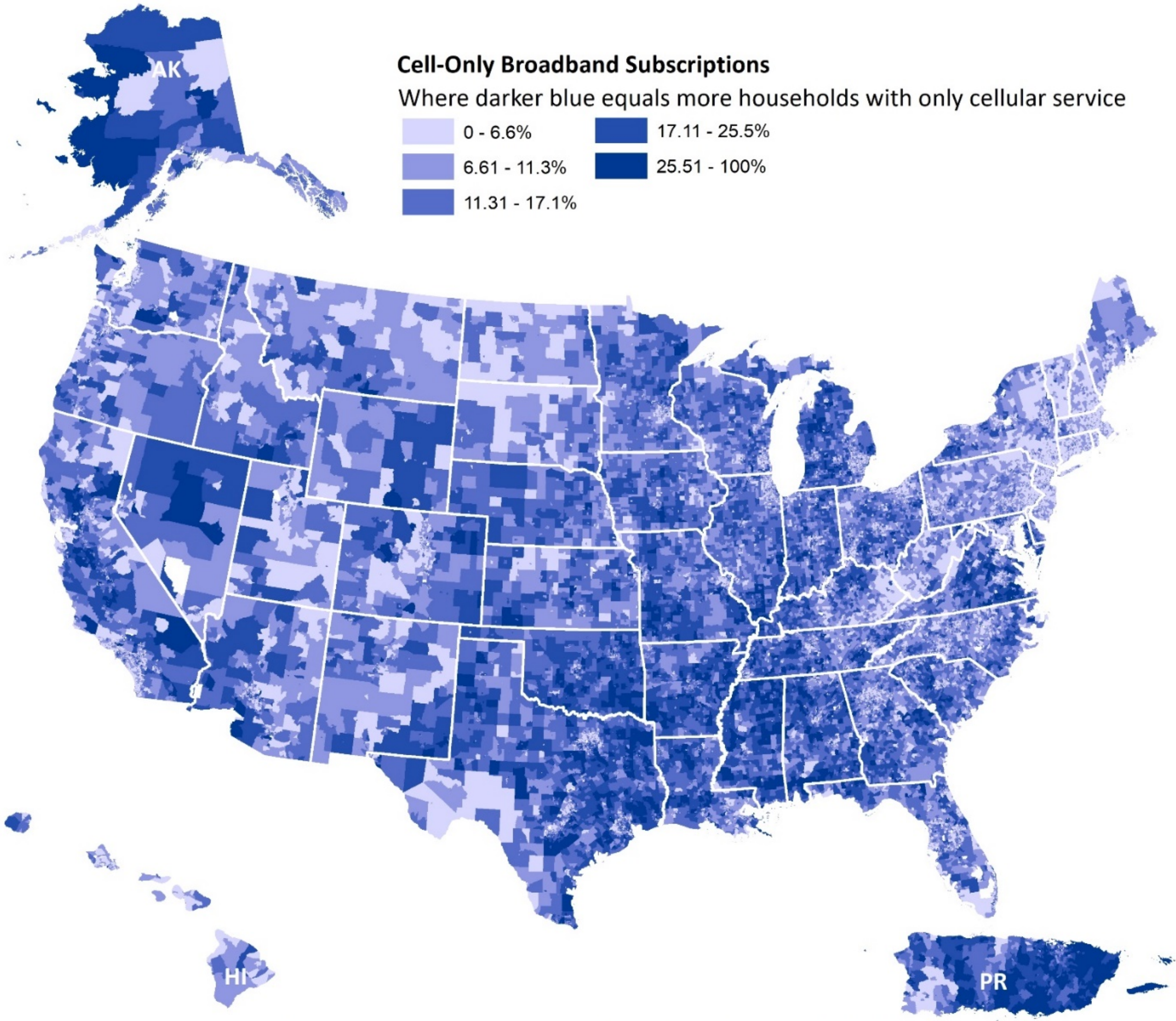
Rank	Census Tract	County	State	IAI Value	Median Download Speed (mbps)	Max. Download Speed (mbps)	Perc. Adv. Speed	Max Download Speed (State)	Perc. Broadband Sub.
1	Census Tract 2	Yukon-Koyukuk Census Area	Alaska	0.000	2	40	0.30	1000	32.50
2	Census Tract 1	Southeast Fairbanks Census Area	Alaska	0.000	2	200	0.25	1000	55.40
3	Census Tract 1	Kodiak Island Borough	Alaska	0.000	2	50	0.24	1000	65.70
4	Census Tract 3	Bethel Census Area	Alaska	0.001	2	35	1.25	1000	28.70
5	Census Tract 17	Fairbanks North Star Borough	Alaska	0.001	2	50	1.01	1000	35.60
6	Census Tract 1	Nome Census Area	Alaska	0.002	2	35	2.68	1000	32.00
7	Census Tract 4	Southeast Fairbanks Census Area	Alaska	0.005	2	1000	6.19	1000	42.80
8	Census Tract 9400	Socorro County	New Mexico	0.008	25	35	63.97	1000	2.00
9	Census Tract 19	Fairbanks North Star Borough	Alaska	0.012	4	1000	6.49	1000	53.30
10	Census Tract 1057	Oklahoma County	Oklaho ma	0.013	3	1000	46.36	1000	9.90
11	Census Tract 48	Orleans Parish	Louisia na	0.017	20	1000	39.16	1000	7.00

12	Census Tract 1	Denali Borough	Alaska	0.017	2	1000	12.05	1000	77.80
13	Census Tract 2	Nome Census Area	Alaska	0.018	2	25	16.75	1000	60.30
14	Census Tract 18	El Paso County	Texas	0.019	25	940	56.18	1000	5.10
15	Census Tract 4	Yukon-Koyukuk Census Area	Alaska	0.019	2	35	29.32	1000	35.10
16	Census Tract 9450	Coconino County	Arizon a	0.023	25	115	54.12	1000	6.40
17	Census Tract 1	Northwest Arctic Borough	Alaska	0.023	2	35	28.81	1000	43.30
18	Census Tract 9584	Lares Municipio	Puerto Rico	0.023	25	100	62.77	1000	5.60
19	Census Tract 9443	Apache County	Arizon a	0.024	25	115	50.91	1000	7.30
20	Census Tract 252	Caddo Parish	Louisia na	0.025	25	987	53.62	1000	7.10
21	Census Tract 9401	Prince of Wales-Hyder Census Area	Alaska	0.026	2	35	25.66	1000	55.20
22	Census Tract 9.03	Pueblo County	Colora do	0.027	25	987	64.41	1000	6.40
23	Census Tract 2	Matanuska-Susitna Borough	Alaska	0.027	2	1000	21.65	1000	69.20
24	Census Tract 3	Yukon-Koyukuk Census Area	Alaska	0.027	2	35	36.28	1000	41.50

25	Census Tract 9409	Sandoval County	New Mexico	0.029	25	100	54.45	1000	8.20

Data Source: American Community Survey 5yr Average (2015-2019)

Figure 4: National map of households with cellular-only broadband subscriptions presented at the Census tract level (ACS 5-yr average 2015-2019). Darker blue hues represent areas where more households have cell-only subscriptions.



Data Source: American Community Survey 5yr Average (2015-2019)

Data Source: American Community Survey 5yr Average (2015-2019)

Appendix B

To match the spatial scale among data sources, Argonne scaled the FCC Form 477 data up from the Census block level to the tract level. To do this, the median of the maximum advertised download speeds for all services in all blocks within a tract is recorded. Additionally, the greatest maximum advertised download speed for blocks at the national level is used in the ratio calculation.

A Box-Cox transformation[17] (λ= -0.22) was performed on the entire distribution of median download speeds (n = 74,001). After optimizing for λ, the maximum national download speed (1000mbps) was transformed using the same equation prior to the calculation of the ratio (eq2). The transformed numbers are then used to calculate the Download Speed Ratio that is then used in the greater IAI calculation.

A Box-Cox transformation was performed on these data as the original data have a distinct long right tail. Without the transformation this tail would persist through the index calculation, leading to less actionable results for end users. Performing the transformation on these data prior to the ratio calculation results in a final index distribution scaled between 0 and 1 that approximates a normal distribution and allows for quantitative differences to be more easily described at lower index values.

[17] Box, G.E.P. and D.R. Cox. 1964. An Analysis of Transformations. Journal of the Royal Society. Series B (Methodological). 26(2) pp. 211-252.

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