5G Deployment in Underserved Areas of California

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INTRODUCTION

5G service (fifth-generation cellular wireless) is the newest form of wireless broadband internet and it offers significantly faster upload and download speeds than other traditional forms of internet service. This is done by accessing more frequency channels to communicate on: existing cellular networks use frequencies from 0.7 to 2.1 GHz, while 5G will be deployed not only on these frequencies, but also microwave frequencies as high as 300 GHz. In theory, 5G will allow download speeds up to 10Gbps, compared to the 2,000 mbps that the current fastest cable internet service provides. Additionally, 5G offers much faster latency speeds (the time it takes to send information from one place to another) than other services, with speeds as low as 1 ms. According to the FCC data, the service with the best performance is fiber, with speeds averaging around 17 ms.

The main conversation about 5G is centered on mobile phones and other connected devices, but this project focused on its potential to replace or compete with traditional home internet providers. These could be cable, fiber optic, or DSL connections. Up until now, wireless home Internet service has been prohibitively expensive for most families when compared to existing wireline service. However, 5G has the potential to make fixed wireless service more competitive and economical than previous wireless technologies.

5G is not without its flaws though. One of the largest drawbacks and barriers to 5G implementation is that it only has a range of around 1 kilometer when using higher microwave frequencies. This can be partially alleviated by the use of higher-sensitivity directional antennas mounted outside homes, but distance remains a significant factor. This makes it much more viable for areas with a high population density, leading to an optimization problem that spatial analysis is equipped to handle.

This project focused on areas of California that would benefit most from 5G installation. These would be areas that have insufficient internet speeds or lack access to affordable broadband internet entirely. Existing cellular and satellite fixed broadband services are not included, as the prices for these services are typically much higher than the prices for wireline cable and fiber optic providers.

BACKGROUND

As previously mentioned, there are multiple types of internet a person can have access to. Today, the technological boom and numerous private telecommunications companies are largely due to the Telecommunications Act of 1996. The act was largely initiated by the Federal Communications Commissions (FCC), and it loosened the regulation the government had on electronic media. These looser regulations gave way to media companies being able to have the ownership of different types of media like TV, cable, satellite, radio, and internet station. This in turn yielded for more companies and multiple types of internet to appear. From that electronic media become a competitive industry, which is why companies provide different types of internet service and various price ranges.

Wireline providers

Historically, wireline (wired) Internet service has been the only feasible option for high-speed, low-latency access to the Internet. This market has been served using increasingly advanced protocols and equipment, with the lowest-cost option being Digital Subscriber Line (DSL).

DSL is deployed over existing phone lines and offers speeds far higher than legacy dial-up connections: dial-up has a maximum throughput of about 56 kbps, while early symmetric DSL could reach speeds of 1.5 to 3 mbps (1500 to 3000 kbps). Symmetric DSL has been largely overtaken by Asymmetric DSL, which, depending on the implementation, can provide download speeds of around 15 mbps. DSL has significant downsides, however. First of all, the real-world performance varies greatly depending on the quality of phone lines. Second, the uplink speeds are limited compared to other technologies, generally being only a fraction of the downlink speeds. And finally, the speed of the connection is inversely related to the distance between the home and the DSL provider, meaning that rural implementations have far lower speeds than suburban and urban networks. For these reasons, among others, DSL has fallen out of favor in recent years.

Cable Internet access emerged as a superior technology to DSL in the early 2000's. Rather than use electrical signals on copper telephone lines, this technology used radio-frequency signals on coaxial lines originally built for cable television systems. Cable Internet access offered higher speeds and capacity, while also not suffering from dramatic reductions of throughput over long distances. However, deployment of this technology was limited to areas that had existing cable TV systems, so again, rural areas were often left out.

Fiber-to-the-home (FTTH) became commercially available in the United States starting in the late 2000's and early 2010's, with Verizon FiOS and AT&T U-Verse. FTTH uses similar protocols as cable Internet access, but does so using fiber-optic lines rather than coaxial lines. As a result, FTTH offers further bandwidth and capacity advantages. However, new equipment and communications lines had to be installed in order for homes to be connected via fiber, which again meant that rural areas were generally left out of fiber-to-the-home deployments.

Wireless Internet service

Wireless networks have historically had several disadvantages compared to wireline networks. Unlike wireline networks, which can use increasingly large sets of frequency bands to increase total bandwidth, wireless networks must operate on limited sets of frequencies. This is due to two major factors: the fact that wireless spectrum is shared by other commercial, government, and military entities; and the fact that, although higher frequencies also support higher capacity, range is reduced as frequency increases.

Cellular phone service in the United States has traditionally used wireless spectrum ranging from 800 MHz to 1900 MHz, which offers sufficient bandwidth for phone calls and basic web browsing, while also being able to penetrate buildings and trees. However, these frequencies have become increasingly crowded as the number of mobile devices has increased, resulting in higher prices and/or lower speeds than wireline Internet service providers. For instance, Verizon Wireless Connected Home ranges in price from $60 a month for 10 GB of data to $150 a month for 40 GB of data. While these plans use 4G LTE and can provide speeds meeting the FCC targets, they are prohibitively expensive for most people. AT&T offers a more affordable fixed wireless plan in rural areas for $50 a month with 250 GB of data, but at speeds of only 10 mbps download, not meeting the FCC target of 25 mbps.

The other nationally available wireless technology is satellite-based Internet access. Although this option is available nationwide, spectrum constraints in different divisions of the country mean that actual speed and availability varies. Two major satellite ISPs operate in the United States: HughesNet and ViaSat. HughesNet offers the FCC target of 25 mbps download and 3 mbps upload, but at prices similar to Verizon Wireless's Connected Home Plans. ViaSat offers larger amounts of data, but does not meet the

FCC targets for download speed. These satellite providers also suffer from high latency, making online activities such as video conferencing and gaming problematic.

The Potential of Millimeter-Wave 5G

Unlike existing third generation (3G) and fourth generation (4G LTE) networks, 5G networks offer enhanced capacity and the ability to use a wide range of frequencies. One of the main advantages to 5G, in addition to more efficient data transfer and reduced latency, is the fact that it is not limited to the existing frequency range of 800 MHz to 1900 MHz. 5G can also use millimeter-wave frequencies.

Millimeter-wave frequencies, also known as Extremely High Frequency (EHF) spectrum, offer far greater bandwidth than existing cellular bands because they currently have far less traffic, and because higher frequencies can handle more bandwidth per MHz of spectrum. The primary downside to millimeter-wave bandwidth is greatly reduced range compared to lower frequencies, and an inability to penetrate buildings.

These downsides mean that millimeter-wave technology is unlikely to be used for mobile phones outside of densely populated cities and special cases such as sports stadiums. However, fixed wireless setups differ significantly from mobile wireless setups. According to an IEEE report, millimeter-wave 5G can reliably connect homes up to 1.5 kilometers away from the nearest base stations when used with directional antennas mounted on top of homes.

Verizon Wireless has formalized plans in the United States to sell fixed 5G Internet access in some markets, calling their service Verizon 5G Home. This service will cost $70 per month, and offer speeds of up to 1,000 mbps, far faster than the existing 4G services offered by Verizon and AT&T, and without data caps.

MOTIVATION

Access to affordable internet is crucial in today's world. This has become even more apparent due to the COVID-19 situation, as social distancing and citywide shutdowns have been implemented across the country. According to Pew Research Center, "roughly half of U.S. adults (53%) say the internet has been essential for them personally during the pandemic and another 34% describe it as 'important, but not essential'." For many, internet access is essential for work, school, and healthcare.

Many companies have switched to working from home and are making use of many online tools to stay connected. It is expected that many of these strategies will continue through the workforce, post-pandemic. For those who have lost their jobs due to the current recession, the internet is extremely important for finding and applying to jobs and filing for unemployment.

Schools of all grade levels have closed and switched to virtual learning almost overnight. Students who cannot access the internet will be left behind, as their peers continue to receive their online education. In California, around 1.2 million students do not have reliable internet or access to the appropriate technology to participate in online school (Johnson). This only serves to further education inequity statewide.

Many healthcare providers are now offering telehealth services exclusively to minimize risk for workers and patients alike. However, if people do not have access to the internet, they are now cut off from any sort of medical treatment that they might require.

The FCC's target for modern broadband speeds is 25 mbps download and 3 mbps upload. However, even this might not be enough to use many of the services that online healthcare, school, or work use. Many schools and businesses are using video-conferencing services such as Zoom to deliver lectures and proctor exams. A single uplink to Zoom would use nearly 3 mbps, meaning that the FCC minimum is barely enough to support this, and insufficient if other users or applications need bandwidth.

Those who do not have access to reliable or affordable internet access will be at a great disadvantage to those who do. This gap in accessibility and proximity to technology and the internet has been coined the "digital divide". This divide will continue to grow and deepen as society becomes more reliant on the internet to work, learn, and stay connected. Access to the internet is no longer a luxury, but rather an integral part of many aspects of life.

METHODOLOGY AND DATA SOURCES

The two main data sources for this project were the FCC National Broadband Map and economic and demographic information provided by the U.S. census.

FCC National Broadband Map

The FCC National Broadband Map provides a list of broadband providers for every census block in the United States. This data is downloadable via a CSV file, and organized geographically by the FIPS code for every census block. All broadband providers in the United States offering speeds of 0.2 mbps or more are required to provide a list to the FCC containing all census blocks where they offer service. Additionally, the data also specifies the name of the Internet service provider (e.g. “Xfinity”); the holding company operating the provider (e.g. Comcast); the type of technology being used identified by a two-digit code (including satellite, fixed cellular, cable, fiber, etc.); the maximum download and upload speeds offered in megabits per second; and if the company provides service to consumers, businesses, or both.

For this project, the data was filtered down to California only, and only including providers that offer service to consumers. Satellite providers such as HughesNet and ViaSat and cellular broadband offered by wireless providers like AT&T and Verizon Wireless were not considered in the project, as these services are generally unaffordable. In order to do this, the original FCC Fixed Broadband data was narrowed down using the open source application CSVKIT. CSVKIT was used to select the relevant columns, filter out data that applied to other states, and remove satellite and cellular listings. Next, GNU Awk was used to truncate the FIPS codes in order to coarsen the data points from the census block level to the census tract level. GNU Sort was then used to remove any duplicate listings from the remaining data, for example, if a cable company offered identical speeds in several different blocks within a census tract. Once these tools were used to transform the CSV file into a manageable size, it was imported into Microsoft Excel, where the Filter and Sort tool was used to list the highest available speeds in each census tract.

US Census Data

From the census, a shapefile of the tracts in California was used, along with data tables of economic and demographic information. Information from the census is coded by

FIPS codes, like the FCC data, which was used to cross-reference census data and FCC data within the same geographic system. Every FIPS code is composed of a 2-digit state number (06 for California), a 3-digit county number, a 6-digit census tract number, and a 4-digit census block number. These codes were used to join the shapefile to the data tables. Prior to doing this, the codes needed to be modified to match the different files to create a join key. This was done by writing a code that ran in the Python window of ArcGIS.

The census shapefile was also joined with the FCC Broadband Map. Two color coded maps were made from this, showing upload and download speeds in each tract. From these maps, tracts that did not meet FCC standards for broadband speeds or did not have any wireline service were selected. The speeds in question are lower than 3 Mbps for uploading and 25 Mbps for downloading data.

These tracts were then analyzed according to their demographic and economic information to find places that would either be most suited for 5G networks, or more in need. The three main categories used to designate these tracts were age, income, and population.

In this project, it was assumed that younger people are more likely to use the internet and more likely to own multiple devices that connect to the internet. For this reason, the analysis focused on tracts with the largest percentage of people between the ages of 15-19 and 20-24, which are the typical age ranges of students in high school and college.

CHALLENGES AND DRAWBACKS

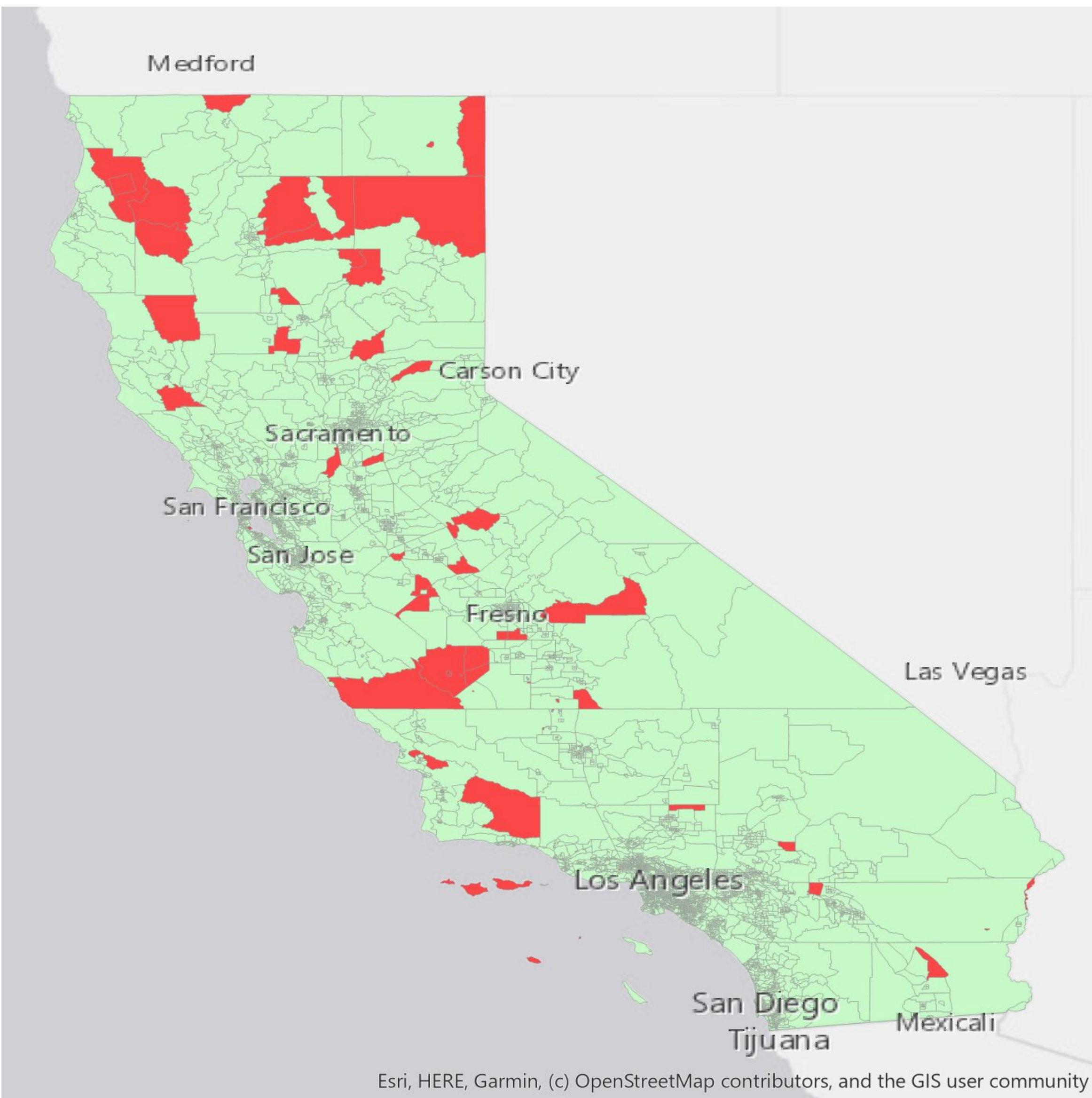
Many challenges arose in the process of completing this project. Most of the issues stemmed from data collection and formatting. The U.S. census provides lots of information to the public, but most of it is formatted for user viewing. It took a bit more digging to find usable raw data for analysis.

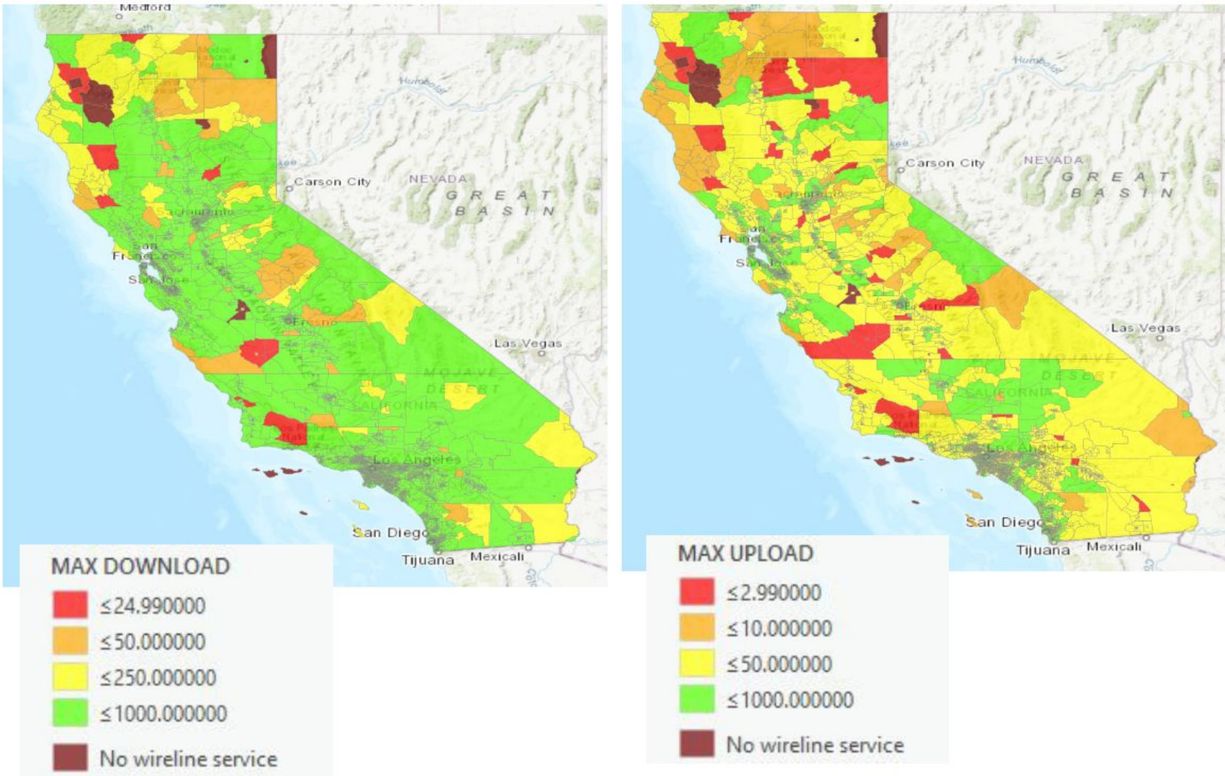
The census data tables all came as unreadable tables for ArcGIS and had to be converted to Excel files before they could be used. Joining the tables after this was not as easy as expected, in particular, because all of the FIPS codes used began with the number zero, which ArcGIS truncated when treating the code as an integer. Finding and formatting the appropriate join key took quite a bit of trial and error, and was not successful on all the tables and files at first.

Because the FCC data is encoded by census block, and there are over 700,000 census blocks in California alone (as small as one square city block), we needed to coarsen the data in order to analyze it. We did this by stripping the last four digits from the FIPS codes, which was valid because every census block is a part of exactly one census tract. The downside of this technique was that it is possible for a speed to only be offered in one block within a tract, so generalizing the data in this way meant that the number of underserved areas was underestimated.

RESULTS

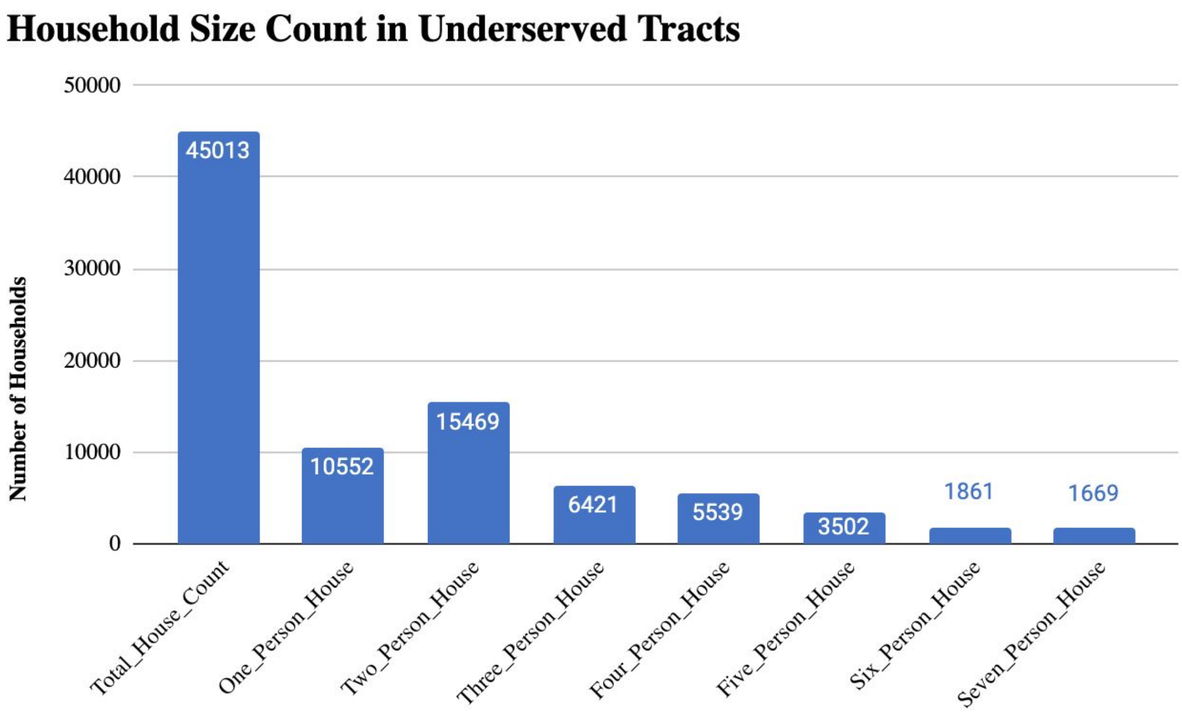
According to the FCC data, 67 tracts in California did not meet the requirements for broadband access, displayed below.These tracts were analyzed based on demographic factors; age, population size, and economical status. These factors were examined based on the census data that we retrieved for each tract. Through statistical analysis of the tracts that did not meet the FCC requirements for broadband there was evidence that these tracts did not have adequate access to internet broadband. From the several factors that were analyzed only the tracts' population size and economic status of the resident showed a reportable statistical correlation.



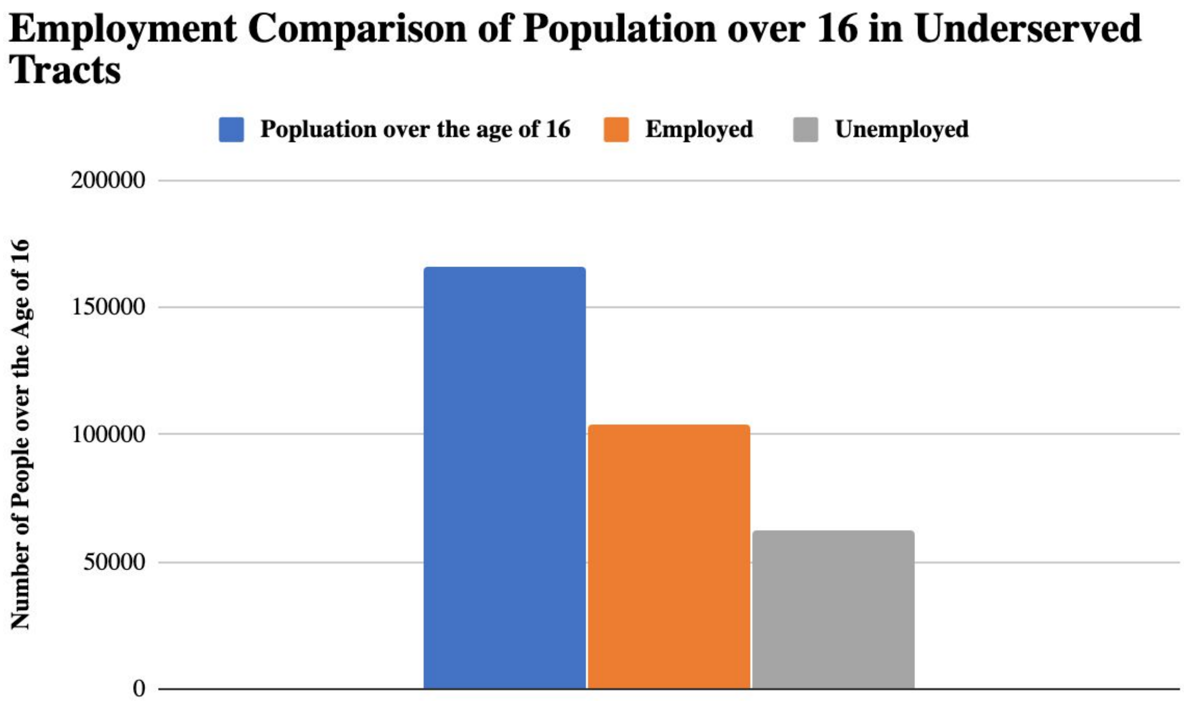


This figure shows the highest available download and upload speeds in every census tract in California. Areas in dark red have no wireline service, and are generally very remote. Areas in red have wired broadband access, but do not meet the FCC's minimum targets.

Urban areas are difficult to see on the state-level map, but generally speaking have competitive and high-quality Internet access.



The graph above shows the average household size of the 67 underserved tracts based on the California 2010 census data. From the graph the plurality of the households in these tracts are two-person households, however the amount of households with three or more people still made up a larger percentage of households of these tracts. The amount of households with three or more people makes up 42 percent of the total amount of households in that area. Even though the one and two person household makes a larger percentage of household, it does not cover the larger amounts or residents. Whereas the one and two-person household has about 41,500 people, the three or more person households has about 82,000 residents. Population size matters, and based on the data from our project we learn that areas with larger populations overall would benefit more from 5G.



We also focus on the overall employment status of the population from tracts that did not meet the FCC criteria from modern broadband in order to see if there was an economical relationship for why they did not have quality internet access. The graphs show how much of the population who is over the age of 16 is employed or not. The data showed that only about 37 percent of the population is unemployed from the labor force. The employment rate is high for these areas since it affects about 62,000 people, but overall it does not affect a larger number of residents of these tracts. We assume that since the percentage of unemployed people is relatively high it lowers the income status of the population as a whole, so even if the amount of people who are employed is high the tract itself still has a low economic status.

From this we concluded that areas that have low economic status will benefit from 5G because the type of internet will be low quality since the overall depiction of the tract's economic status is lower.

We looked closer at the 67 tract to find similarities and differences to help us get more precise answers for our research question. From the 67 tract, 10 tracts were selected with the highest percentage of people aged 15-19 or 20-24. 6 tracts were identified as having over 40% of the population living under the poverty level. 5 tracts with the highest population among the underserved tracts were found. Each tract contains over 6000 residents.

Of these tracts, overlap in all three categories existed in only one, tract 06045010100. This tract met the criteria for both population and age. Taking this into account, 20 tracts have been found that would be good places to install 5G networks.

Tracts with > 10% of Population ages 15-19 or 20-24	**Tracts with > 40% of residents under poverty line**	**Tracts with largest population (>6000)**
06063000501	06025010101	06045010100
06079011504	06063000502	06089012702
06053010900	06063000501	06019008100
06063000502	06053011400	06019006403
06065044521	06079011400	06079011504
06107004800		0605981000
06019007801		
06045010100		
06019007802		

CONCLUSION

There is a socioeconomic impact that is due to privatization of electronic media because there is no fixed price or type. This allows for more technological advancements, for example internet service progressed from DSL to cable, to fiber-to-the-home. However, this also created a gap between the quality service provided and the type of people who could afford it. Before the Telecommunication Act of 1996, there wasn't as much of a socioeconomic divide on access to telecommunication technology as there is now.

Our project is able to look at the gap between the amount of access a person can get. We identified areas that were considered underserved based on the FCC standards and our own previous stated criteria. We found evidence that supported the existence of the digital divide, and we want to use 5G to solve the problem in California.

The digital divide and lack of broadband access is a serious issue in California. The 67 tracts identified as underserved contain 60,760 households and 210,953 residents, all of whom deserve access to the internet. Given that COVID-19 has forced many aspects of day to day life online, there is an even greater need for internet access than ever before.

As a developed country, the United States still falls short when it comes to citizens' access to affordable and reliable internet service. Implementation of 5G could potentially solve these issues, in California and beyond. This is not a process that can happen overnight, as there are many considerations that need to be made as for where and how these networks can be set up. Hopefully, the work done in this project can help answer some of the where questions for this issue.

ACKNOWLEDGEMENTS

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