BEFORE THE
FEDERAL COMMUNICATIONS COMMISSION
WASHINGTON, D.C. 20554

In the Matter of	
Establishing the Digital Opportunity Data Collection	WC Docket No. 19-195
Modernizing the FCC Form 477 Data Program	WC Docket No. 11-10

COMMENTS OF THE CALIFORNIA PUBLIC UTILITIES COMMISSION

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I. INTRODUCTION

The California Public Utilities Commission (CPUC) submits these comments in response to the Federal Communications Commission's (Commission or FCC) July 16, 2020 *Second Report and Order and Third Further Notice of Proposed Rulemaking* (*Third FNPRM*) proposing rules to further develop the Digital Opportunity Data Collection.[1]

These comments focus on the proposed challenge process by which State, local, and Tribal entities (collectively "government entities") can submit data to the FCC to contest mobile provider coverage data.[2] Specifically, the *Third FNPRM's* proposed requirements on challenge data do not meet the requirements of the Broadband DATA Act.[3] It requires the FCC to establish a user-friendly challenge process through which consumers and government entities may submit coverage data to the FCC to challenge the accuracy of provider-submitted coverage data. The FCC should not move forward with the proposed challenge process requirements; instead, it should adopt requirements that are more manageable for governmental entities while yielding statistically reliable information.

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[1] In the Matter of Establishing the Digital Opportunity Data Collection; Modernizing the FCC Form 477 Data Program, *Second Report and Order and Third Further Notice of Proposed Rulemaking*, WC Docket Nos. 19-195, 11-10 (FCC 20-94) (rel. July 16, 2020) (*Third FNPRM*).

[2] Although these Comments refer mainly to data submissions in the context of the challenge process, the Comments (e.g., regarding requirements for transparency, throughput testing and test server location, and concerns regarding reliance on Radiofrequency (RF) signal strength tests) also apply to providers' data submissions in other contexts, such as the verification process addressed in the *Third FNPRM,* Section IV.D.1 "Verifying Mobile Data."

[3] Broadband Deployment Accuracy and Technology Availability Act, Pub. L. No. 116-130, 134 Stat. 228 (2020) (codified at 47 U.S.C. §§ 641-646) (Broadband DATA Act).

II. DISCUSSION

A. The FCC Should Adopt a More Flexible Approach by Which Government Entities May Challenge Providers' Claims of Mobile Speed, Coverage, and Quality.

The *Third FNPRM* proposes and seeks comments on requirements regarding State, local, and Tribal governments' challenges to mobile provider coverage data.[4] The proposal presumes a one-square kilometer overlay of the area to be challenged, and focuses on the number of speed tests necessary in each grid, the maximum distance between tests (e.g., no more than one-half kilometer), and the percentage of grids to test that conflict with a provider's data to effectively constitute a successful challenge.[5]

These presumptions and details regarding challenge testing represent an approach that is overly complicated and unnecessarily expensive and burdensome – likely impossible for a State the size of California. This testing approach is not necessary and inconsistent with the Broadband DATA Act's requirement that the challenge process be user-friendly.[6] Instead, the CPUC urges the FCC to adopt a challenge approach that is flexible enough to work for both large and small States, cities, and Tribes and for large and small challenge areas. Rather than a rigid formula by which challenges must be made, challenges should be judged by their data's ability to predict actual service that users experience. Overlaying square kilometer grids over areas to be challenged and requiring multiple locations to be tested in each grid would

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[4] *Third FNPRM* para 152.

[5] *Third FNPRM* para. 153.

[6] 47 U.S.C. §§ 642(a)(1)(B)(iii), (b)(5)(A).

not work for California, as explained below. For the same reasons, we suspect it will likely not work for any but the smallest States, local governments, or Tribes wishing to challenge small areas of claimed mobile coverage.

The facts in California easily illustrate the problem. For example, Verizon, AT&T, T-Mobile, and Sprint submitted data to the CPUC asserting LTE coverage of approximately 352,850 square kilometers in California as of December 31, 2019.[7] If the FCC were to require three speed tests at different locations in each square kilometer grid, California would have to conduct tests at 1,058,550 locations for the challenge process – a patently impossible task. Much of that area is not accessible by roads, and such a testing requirement, even if possible, would be inordinately costly. Clearly, this would be an unreasonable burden for California, let alone on smaller entities, as the FCC notes in the *Third FNPRM* citations.[8]

In addition, the FCC proposes to require that the government entities' challenges be comprised of both stationary and mobile speed tests.[9] We disagree with this proposal. There is no need for challenge data to incorporate both stationary and mobile testing. States should have the freedom to choose between stationary or mobile tests or be able to employ a combination of both. Requiring both types of testing increases the cost of the challenge process, without improving the reliability of the challenge data.

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[7] Although the FCC has not yet published providers' December 31, 2019 Form 477 submissions, California has availability data because it requires providers to submit their availability and connection data directly to the CPUC.

[8] *Third FNPRM* fns. 363 - 364.

[9] *Third FNPRM* para. 153.

Stationary service speeds and quality are likely better than those that users would experience while in motion. If the results of stationary tests yield slower and lower-quality service or coverage asserted by providers, those results should be accepted as effective challenges to the providers' coverage claims. Accordingly, government entities should be free to submit challenges based on stationary tests only.

The CPUC has taken a different and highly reliable approach, called CalSPEED,[10] to evaluate statewide mobile speed, quality, and coverage data for each of the national Commercial Mobile Radio Service (CMRS) providers. Statewide testing of each carrier's service is necessary to identify areas that, contrary to a provider's claims, lack service entirely or where service speeds and quality are below what is reported, and thus need to be challenged.

CalSPEED uses mobile testing software we have developed called Surveyor. CalSPEED relies only on outdoor, stationary testing, using commercially available mobile devices at the time of testing that incorporate radio and antenna technology capable of achieving CMRS networks' maximum performance. The CPUC's previously completed CalSPEED drive test in 2017[11] consisted of measuring each provider's service at just under 2,000 locations.

As explained in Attachment A, CalSPEED uses a statistical method called Kriging to predict the throughput and service quality metrics of providers' broadband

[10] This approach is highly accurate, as described in Attachment A. The CPUC has apprised the FCC about its CalSPEED program in previous sets of comments and has provided CalSPEED data to the FCC.

[11] Prior to 2020, California conducted its last statewide drive test in Fall 2017.

service at areas between the locations at which we perform measurements. These interpolation models predicted up to 85 percent of the variation in Internet throughput performance by location. In 2020, the CPUC reinstated CalSPEED drive testing and has expanded the program to test at 4,000 locations, rather than 2,000.[12] By doubling the number of locations, we expect the predictive ability of our interpolations to increase. These 2,000 new locations represent a denser mix of rural and urban locations, extend into additional areas of greater "rurality," and retain locations at each area on or near recognized Tribal lands. The CPUC also added locations at each of the state's county fairgrounds,[13] locations in State and national parks and forests, locations in areas from which mobile 9-1-1 calls have originated and locations requested by the California Office of Emergency Services (CalOES) for public safety/first responder purposes.

The 4,000 locations where we will measure service are mapped in Figure 1 below. As can be seen, our location selection is robust and well distributed throughout the State in all areas with accessible roads. This expanded approach would yield reliable results and is more manageable than the 1,058,550 California locations that would require testing in the *Third FNPRM's* proposed approach.

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[12] We actually perform 160 individual one-second download and upload throughput tests for each network at each of the 4,000 locations (totaling 640,000 individual tests) and calculate the mean of all such individual tests for the results that are used to arrive at an interpolated map layer.

[13] Information on coverage at fairgrounds is important as they are frequently used as evacuation sites in the event of disasters such as earthquakes and wildfires.

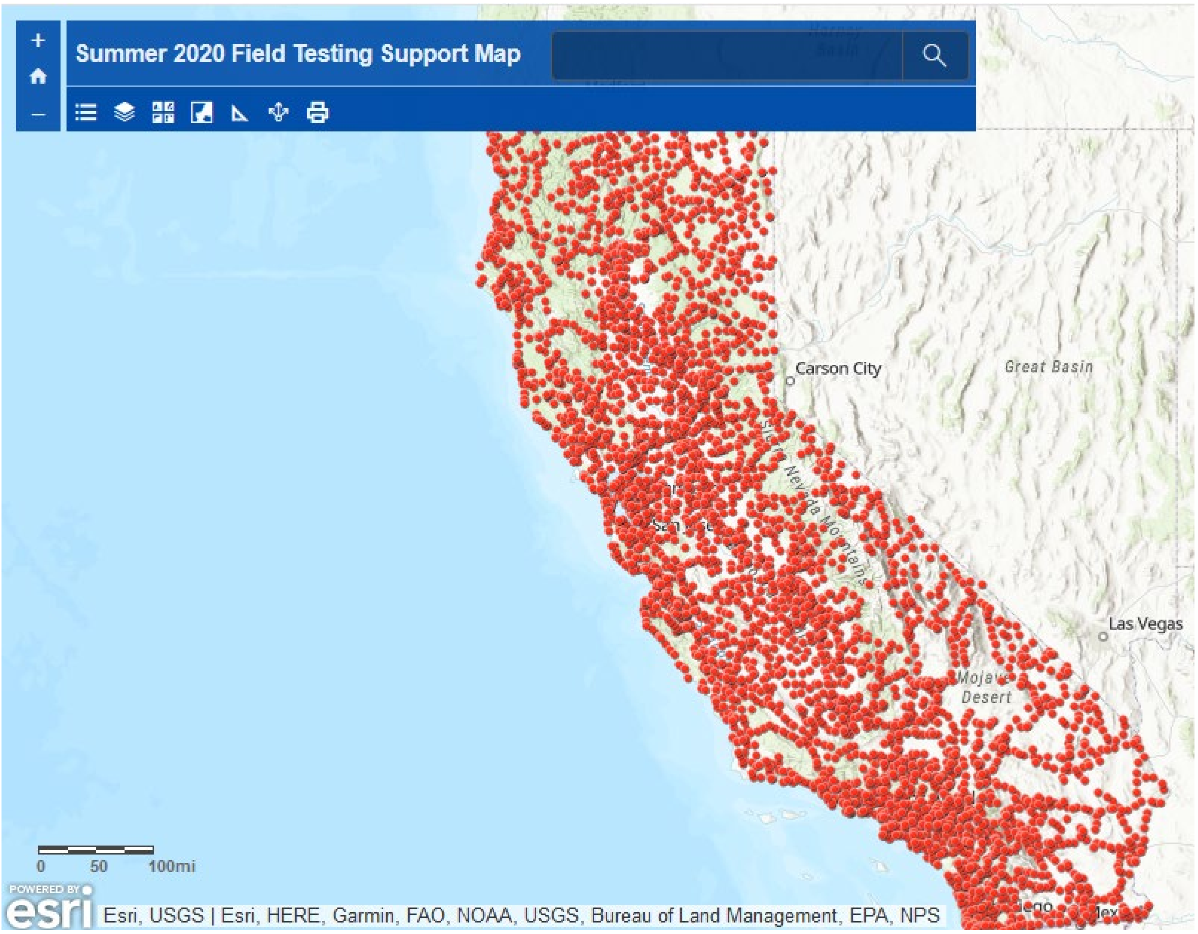

Figure 1- CalSPEED Field Testing Locations Selected for Summer 2020.[14]

Beginning in Spring 2021, the CPUC will perform two statewide drive tests per year, with tests performed on the following nine networks: the LTE networks of Verizon, AT&T, T-Mobile, and the legacy Sprint network now operated by T-Mobile; the 5G networks of Verizon, AT&T, T-Mobile, and DISH; and FirstNet's public safety network.[15]

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[14] These locations will continually be used in biannual drive testing planned for subsequent years.

[15] To provide safe conditions for our drivers, all testing is done during daylight hours.

As we prepare these Comments, the CPUC is conducting a drive test of the four LTE networks named above, plus FirstNet. Testing began on August 3, 2020 and we have completed testing of approximately 85 percent of the 4,000 designated test locations to date.[16]

The CPUC will use CalSPEED results of upload and download speeds, latency, and other results relative to the quality of the user experience to create spatial interpolation models on a one square kilometer grid. These models are then used to create maps illustrating interpolated statewide results. In creating the models, the CPUC uses statistical Kriging techniques described in prior CPUC Comments filed in this docket and in Attachment A of these Comments. We suggest the FCC accept geospatial files of interpolated speed, quality and coverage measurements from approaches like CalSPEED as legitimate challenges to providers' coverage and speed data.[17]

Allowing government entities flexibility in using an approach to challenge providers' coverage data, whether it be a grid method, California's CalSPEED method, or other methods which government entities can demonstrate have a high predictive value, would be appropriate. This would strike the right balance of accuracy and cost

[16] The current wildfires ravaging California may interfere with or delay the completion of the current test drive.

[17] With regard to how providers may rebut challenges, the *Third FNPRM* proposes in Paragraph 157 to allow providers to "submit comprehensive on-the-ground data, <u>or a statistically valid and sufficient sample of such data</u> to verify its coverage maps in the challenged area…." in response to a challenge by a government entity (Underlining added). The CPUC's CalSPEED mobile analysis consists of a sufficient sample of testing data and a statistically valid method to rebut providers' initial assertions of coverage and quality. To hold government entities to a higher standard than the FCC proposes to apply to providers would be a patent violation of due process and equal protection.

the FCC seeks and the Broadband DATA Act requires. For California, the cost of performing each biannual round of testing of nine networks, including interpolation, analysis, and mapping is expected to be less than $450,000. While not an insignificant cost, it is one California is willing to bear given the importance of "getting the broadband map right." Billions of public dollars will be expended to subsidize mobile broadband service in the coming years, and it is crucial to the people of California and the nation that the national broadband maps be as accurate as possible.

B. Challenge Responses Should Require On-the-Ground Testing of Throughput and Quality Metrics, Not Radiofrequency (RF) Signal Strength.

The *Third FNPRM* proposes and seeks comments on a process by which mobile providers can respond to challenges of their coverage data.[18] Mobile providers initially submit data to the FCC on their networks' coverage and speeds based on propagation models.[19] Signal strength assumptions are a key input to those propagation models. When a government entity submits challenge data that contradicts the coverage and speed output of providers' propagation models, providers should not be able to provide a response to such challenge that merely consists of RF test results that are then used as

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[18] *Third FNPRM* paras. 156 – 162.

[19] In its Comments to the *Report and Order and Second Further Notice of Proposed Rulemaking* in this docket, the CPUC opposed the use of propagation modeling to determine providers' coverage and quality. In its *Second Report and Order and Third Further Notice of Proposed Rulemaking,* the FCC acknowledged the CPUC's concerns and responded that, "[w]e expect that the coverage probability, cell loading, and clutter parameters we adopt today will help ensure reliability of the data we collect." (*See* fn. 89.) Yet, these expectations have not been validated and cannot be validated by providers merely measuring RF signal strength and using those measurements as inputs to a propagation model that uses the same parameters from the initial propagation. Measurements of throughput and quality should be used to validate the expectations that a propagation model produces accurate coverage and quality predictions.

inputs to propagation models. As explained in Attachment A, RF signal strength is an extremely poor predictor of Internet throughput, with an R squared value averaged across all providers in California of only 12 percent.

We are not alone in our view that RF signal strength is a poor predictor of the service that consumers are likely to experience. In a recent *ex parte* filing to the Commission in this proceeding, T-Mobile stated, "…the Commission should not set a minimum value for signal strength (e.g., for RSRP or RSSI).[footnote omitted]… signal strength is not a reliable proxy for coverage or service quality."[20] [Emphasis added.]

Rather, to rebut challenge data, the FCC should require providers to perform on-the-ground tests of actual throughput achieved with commercially available mobile devices. Providers should have the same flexibility as government entities discussed above (or other requirements imposed by the FCC for challenge data), but should be required to show that the predictive value of their data is higher than the challenge data.

Testing software and methods used by providers to respond to challenges must be completely transparent. The location of servers used for such testing must be located outside the providers' network, and should, as with our Surveyor app, be located in a location such as the Amazon Web Services (AWS) cloud platform, so that results mimic those that can be expected by actual users of the providers' service.

[20] Letter from Steve B. Sharkey, Vice President, Government Affairs, Engineering and Technology Policy, T-Mobile to Ms. Marlene H. Dortch, Establishing the Digital Opportunity Data Collection , WC Docket No. 19-195; Modernizing the FCC Form 477 Data Program, WC Docket No. 11-10, August 17, 2020.

C. Government Entities Should Not Have to Substantiate Their Data Through Certification When Using Widely Accepted Open Source Test Methods and Statistically Sound Approaches.

The FCC proposes to require that speed test data submitted by government entities be substantiated by the certification of a qualified engineer or official, although it appears to limit this requirement when third-party applications are used.[21] Such substantiation should not be required when government entities submit data gathered with applications such as Surveyor (which is based on the open source, industry standard iPerf measurement tool) and statistical interpolation models, such as the Kriging method used by CalSPEED (itself a third-party feature incorporated in ESRI ArcGIS products). Certification will merely add to the cost of the challenge process, further increasing the burden on government entities, which is not consistent with the Broadband DATA Act's provisions.

D. Transparency of Testing Software, Test Methods, and Test Results is Essential.

For all data submitted to the FCC for use on the broadband map in the DODC process, complete transparency of testing methods and test results is essential. Both our Surveyor code and our test results are completely transparent. The Surveyor app is open

[21] *Third FNPRM* para. 153.

source.[22] Both Surveyor code and our test results are published on GitHub.[23] However, there is little transparency with providers' propagation models, providers' commercial testing software used to measure attributes of their service, and the method by which RF propagation models are somehow converted into Internet throughput and latency models. Transparency is necessary to understand and trust the broadband mapping process, and the FCC should require transparency of the testing methods and results in the DODC.

III. CONCLUSION

The CPUC urges the FCC to revise its proposal regarding challenge data requirements. The FCC should allow governmental entities more flexibility in their approach for submitting challenge data; should require on-the-ground testing of actual throughput for mobile providers responding to challenges; and should make transparent

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[22] And, the test routine used by Surveyor is iPerf, itself open source. As explained in Wikipedia at https://en.wikipedia.org/wiki/Iperf:

iPerf is a widely used tool for network performance measurement and tuning. It is significant as a cross-platform tool that can produce standardized performance measurements for any network. iPerf has client and server functionality, and can create data streams to measure the throughput between the two ends in one or both directions. Typical iPerf output contains a time-stamped report of the amount of data transferred and the throughput measured.

The data streams can be either Transmission Control Protocol (TCP) or User Datagram Protocol (UDP):

- UDP: When used for testing UDP capacity, iPerf allows the user to specify the datagram size and provides results for the datagram throughput and the packet loss.
- TCP: When used for testing TCP capacity, iPerf measures the throughput of the payload. iPerf uses 1024 × 1024 for mebibytes and 1000 × 1000 for megabytes.

iPerf is open-source software written in C, and it runs on various platforms including Linux, Unix and Windows (either natively or inside Cygwin). The availability of the source code enables the user to scrutinize the measurement methodology. (emphasis added)

[23] Surveyor can be used by other entities on a royalty-free basis. Others may modify Surveyor to substitute their own local (or distant) test servers as appropriate.

the mobile provider testing methods and test results. The FCC should not require government entities to substantiate their challenge data through certification when widely accepted open source test methods and statistically sound approaches are used. Such a requirement would only increase the burden and cost for government entities. Overall, these recommendations will strengthen the accuracy and integrity of the mobile broadband coverage data. The CPUC appreciates this opportunity to provide this input to the FCC.

Respectfully submitted,

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September 8, 2020

ATTACHMENT A –

Accurately Measuring Mobile Internet

Accurately Measuring Mobile Internet

Ken Biba[1]
Novarum, Inc.
August 2020

We believe in evaluating mobile Internet service in a way that closely matches the direct user experience - TCP/IP[2] quality. The California Public Utilities Commission (CPUC) has been measuring the quality of Internet service in California since 2010 in its CalSPEED project. Our open source CalSPEED Surveyor system, based on Android smartphones and the industry standard iPerf Internet performance measurement tool, collects many metrics of Internet performance and quality as the user would experience them.

We find these four key conclusions from our survey of the mobile Internet experience based on this multi-year series of measurements in a large-scale environment.

- TCP/IP performance is the benchmark of the mobile Internet user experience.
- Transparent measurement of TCP/IP performance is key to credibility. Open source is preferable to proprietary methods.
- Signal strength is a very poor predictor of wireless TCP/IP performance. TCP/IP performance is poorly correlated with mobile signal strength (LTE RSRP) with only **12%** of TCP/IP variance explained by this indicator.
- TCP/IP performance of mobile broadband networks is highly correlated with spatial interpolation (using Kriging) models created from direct TCP/IP measurements across the state. These interpolation models predict up to **85%** of the variation in TCP performance by location and provide critical information related to public health and safety, such as mobile

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[1] Ken Biba is the CTO and co-founder of Novarum, who designed the CPUC's CalSPEED measurement program and the Surveyor app. His design was implemented by the CPUC's contractors at California State University, Monterey Bay and the Geographic Information Center at California State University, Chico. In addition, significant contribution to this paper's discussion and statistical evaluation of Kriging was made by Dr. Corey Garza. Dr. Garza is an associate professor of Marine Science in the School of Natural Sciences at California State University, Monterey Bay. Dr. Garza's work involves using GIS modeling and spatial statistics to examine multi-scale survey data across complex geographic landscapes.

[2] From Britannica online, https://www.britannica.com/technology/TCP-IP:

> TCP/IP, in full Transmission Control Protocol/Internet Protocol, standard Internet communications protocols that allow digital computers to communicate over long distances. The Internet is a packet-switched network, in which information is broken down into small packets, sent individually over many different routes at the same time, and then reassembled at the receiving end. TCP is the component that collects and reassembles the packets of data, while IP is responsible for making sure the packets are sent to the right destination. TCP/IP was developed in the 1970s and adopted as the protocol standard for ARPANET (the predecessor to the Internet) in 1983.

broadband availability in high fire risk areas or areas requiring mass evacuations in and during disasters.

CalSPEED and Surveyor

CalSPEED is the CPUC program to measure, predict and map Internet service quality in California.

Surveyor is the CalSPEED measurement application. Surveyor is hosted on various platforms and has a core measurement engine based on the open source and industry standard network performance tool iPerf. It works in combination with embedded CalSPEED high performance server instances in the Amazon Web Services infrastructure (where many major Internet service are based) to measure the end-to-end user visible quality of Internet TCP/IP packet service.

Surveyor collects over 300 metrics for mobile wireless Internet, fixed landline, WISP or WiFi connections including the following: date and time, location, smartphone model, carrier, type of network service, multiple performance metrics to different Internet servers in different parts of the Internet, multiple TCP connections to measure throughput, TCP reliability, ping latency, UDP (User Datagram Protocol) packet loss/latency/jitter, DNS (Domain Name System) latency and RF signal strength, frequency, modulation rate and SSID for WiFi. Surveyor uses dynamically adjusted TCP flows and window size to ensure highest performance assessment consistent with reliable service.[3]

Typically, when used for measuring mobile broadband performance, Surveyor is run on a standard smartphone, one for each carrier. To avoid the systemic noise of the capabilities of different Internet measurement devices, we do our surveys with a common baseline of the same Internet device - using the most capable client devices then available. Generally, measurements of each network are run sequentially to eliminate the possibility of interference between measurements on different carriers.

In our most recent mobile quality survey in the Fall of 2017, we used the CalSPEED Surveyor app to measure mobile Internet in about 2000 urban and rural locations, as well as on or near all designated Tribal lands in California. In 2019, Surveyor measured mobile and fixed Internet service for the four national providers as well as FirstNet in almost 1000 locations in and on 74 California county fairgrounds in anticipation of public safety emergencies in which fairgrounds are used for emergency first responders as well as civilian evacuation.[4]

In future mobile surveys beginning with our Summer 2020 LTE survey, CalSPEED will augment its measurement density to 4000 locations, with increased emphasis on locations relevant to public safety usage of mobile networks and to the State's COVID-19 response. In both cases, knowledge of TCP/IP throughput is critical. In our Summer 2020 survey, CalSPEED Surveyor is measuring the FirstNet public safety network in addition to the LTE networks of the three national carriers (including the legacy Sprint network).

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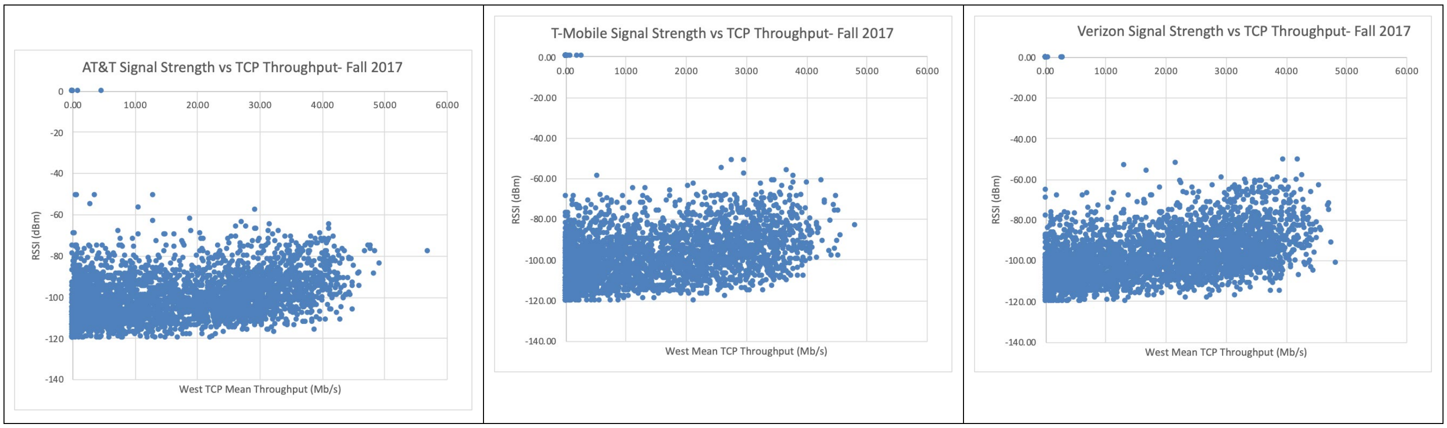
[3] While the CPUC uses Surveyor to measure both mobile and fixed networks, this paper focus on the use of Surveyor in its CalSPEED program evaluating mobile broadband networks.

[4] This work was performed by CSU Chico's Geographic Information Center (GIC) under contract with the Governor's Office of Emergency Services (CalOES).

	Signal Strength	
	R-value	R^2
AT&T	0.31	10%
T-Mobile	0.35	12%
Verizon	0.39	15%
Average		12%

LTE Signal Strength Correlation with TCP/IP Quality

In our most recent mobile quality survey in the Fall of 2017, we measured signal strength (specifically Received Signal Strength Indicator (RSSI)) as reported by the Android communications API at the same time and place we measured digital Internet service quality including TCP/IP throughput and packet latency.



Looking at the LTE connections for the major mobile carriers, we found poor correlation between signal strength and TCP/IP throughput. The above scatter diagrams plot each measurement of signal strength and the corresponding throughput for each carrier and illustrate poor correlation and predictability. It is effectively impossible to predict TCP/IP throughput from a given signal strength for any of the mobile carriers in California.

Computing the correlation between signal strength and TCP downstream throughput (R-value) and then the R^2 for each carrier we can see that signal strength explains (on average) only 12% of the variance in TCP throughput.

Signal strength, alone, is a poor predictor of Internet service quality and coverage.

It might be possible (in theory) to construct a bottom-up composite estimate of throughput using a chain of measurements and assumptions including: signal strength, noise, interference, channel bandwidth, version of LTE/5G, degree of MIMO (if available), degree of channel aggregation, RAN channel Internet loading, RAN channel Internet bandwidth sharing algorithm and performance, aggregate tower load and sharing; and tower backhaul load and capability.

However, most of these metrics are carrier internal and unlikely to be available to sophisticated third parties, much less users, limiting any utility in third party challenges. Further, this bottom-up approach gets impossibly complex when we wish to extend our measurement beyond the very edge of the radio access network to include the effects of Internet peering choices to assess the end-to-end performance needed to get to user services hosted in the Internet.

We conclude that --

- models built solely on RF signal propagation alone may predict signal strength, but signal strength in isolation does not accurately predict actual user experience of Internet performance;

- models that require additional, internal carrier information, to propagate engineering models of Internet performance are unlikely to be available to third parties and may not provide an accurate picture of actual user experience; and
- propagation models are not the best way to depict Internet coverage and quality when accurate models using spatial interpolation of easily measured metrics such as TCP throughput can be constructed using transparent tools at modest cost.

CalSPEED Modeling Internet Service Quality

CalSPEED uses Kriging, an advanced statistical spatial interpolation technique to develop predictive models of various metrics of mobile Internet quality including throughput and latency. We can predict mobile TCP/IP throughput vs location with high accuracy - explaining approximately 85% of the variation in TCP/IP throughput vs location to a resolution of 1 km^2 throughout much of the state of California. We create spatial interpolation models of California for a number of Internet performance metrics (i.e. TCP/IP throughput, latency, VoIP MOS, etc.).

Kriging is a class of local interpolation techniques that are quite commonly used to address spatial prediction problems in the context of mining, hydrogeology, natural resources and environmental science. The basic of idea of Kriging is to estimate data at a point based on regression of observed surrounding values of that point weighted according to the spatial correlation of adjacent points. We found that CalSPEED demonstrated the high-quality predictive capability of Kriging models to predict Internet metrics.

All sample points are entered into a Geographic Information Systems (GIS) database and GIS models depicting the spatial variation in an Internet performance metric were created. We select the subset of the sample points within the publicly asserted coverage area of the carrier. These sample points were separated into training and evaluation data sets in the development of our models. Seventy percent of the points were randomly selected for use in the training of the models while the remaining 30% were set aside as the 'observed' data set for evaluating the accuracy of model predictions. We then used the General Linear Model (GLM) tool in the R statistical software package to create prediction rasters that display the selected Internet metric for unsampled locations using a binomial logistic regression model.[5] GLMs are believed to be good tools for analyzing spatial relationships because they do not force the data into unnatural scales. GLMs do not require the data to be linear or have constant variance and they are capable of using data from a number of different probability distributions (Guisan et al. 2002). A stepwise Akaike's information criterion (AIC) analysis selects variable to determine the best fit model.[6]

To test model accuracy, Cohen's Kappa values were calculated for each of the models to determine the agreement between the predicted and observed throughput. Cohen's Kappa is a statistical test that measures the agreement between categorical terms. It is similar to percent agreement but is more robust in that it takes into account agreement occurring by chance.[7] A predicted raster of each Internet metric was derived from the probability of detecting a given throughput by setting a threshold probability of 0.6. This value was chosen because it is within the range of 0.5 to 0.7, which is commonly used in published GLM

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[5] Guisan A, Edwards TC, Hastie T (2002) Generalized linear and generalized additive models in studies of species distributions: setting the scene. Ecol Model 157:89–100.

[6] Posada D, Buckley TR (2004) Model selection and model averaging in phylogenetics: advantages of Akaike Information Criterion and Bayesian approaches over Likelihood Ratio Tests. Syst Biol 53:793–808.

[7] Cohen J (1960) A coefficient of agreement for nominal scales. Educ Psychol Meas 20:37–46.

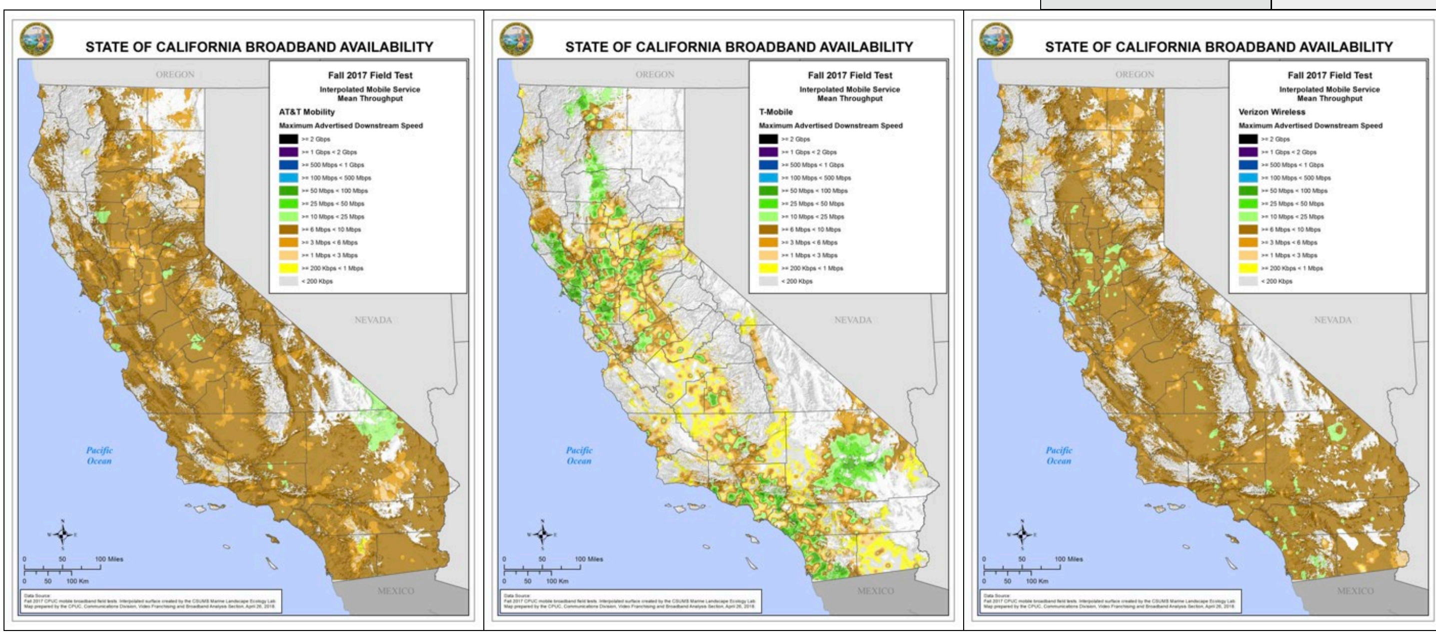
studies[8] (Hirzel & Guisan 2002). The observed Internet metric for each sample that was reserved and not used in model fitting were compared with the respective predicted presence/absence raster cell values, and the agreement between the two was quantified using Cohen's Kappa analysis.

While the prediction varies from metric to metric and between carriers, this accuracy analysis gives predictions that explain (on average) 85% of the variation in TCP/IP throughput. Very high quality indeed, far higher than predictions based on signal strength (certainly alone) and with far fewer measurements in the field decreasing the cost of data collection. These are measurements that correlate highly with the experience of users with their own smartphones.

Carrier	R^2
AT&T	78%
T-Mobile	88%
Verizon	90%
Average	85%

We can easily convert these high-resolution models into maps that visually demonstrate mobile Internet performance.

Our downstream throughput maps illustrating these models for each carrier to the West server[9] are shown below. In each case we have masked the coverage area to the asserted coverage area of each carrier.[10]



We can compute similar models and subsequent maps for other Internet quality metrics such as latency and packet loss. Further, these models of Internet service quality can be analyzed with other geographic data to inform other important safety and public policy issues. A few examples could be:

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8 Hirzel A, Guisan A (2002) Which is the optimal sampling strategy for habitat suitability modelling. Ecol Model 157: 331–341.

9 The West server is hosted in a high performance instance in San Jose location of Amazon Web Services.

10 We do this in our Kriging process to eliminate the negative impact on performance averages when we find no network connection or poor network performance in areas where carriers do not claim coverage.

- Responsible local public safety agencies evaluating whether reliable mobile service is available to notify residents to evacuate in the event of disasters, and from whom.
- School districts can evaluate what providers' devices they should use to distribute hot spots to convert mobile service to Wi-Fi to students so they can participate in distance learning.
- The CPUC and public safety agencies can have a baseline of pre-disaster mobile service to understand whether a disaster has degraded the service, and if so, post-disaster testing can determine whether it has been restored.

More information about CalSPEED's mobile methodology and our analysis is contained in the CalSPEED Final Report.[11]

[11] Available at https://www.dropbox.com/s/m7n6fafswq2ant2/CalSPEED%20Mobile%20-%20Final%20Report.pdf?dl=0.