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

In the Matter of: Inquiry Concerning the Deployment of Advanced Telecommunications Capability to All Americans in a Reasonable and Timely Fashion, Pursuant to Section 706 of the Telecommunications Act of 1996, as Amended by the Broadband Data Improvement Act.	GN Docket No. 17-199

COMMENTS OF THE CALIFORNIA PUBLIC UTILITIES COMMISSION

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Dated: October 5, 2017

I. INTRODUCTION

The California Public Utilities Commission (California or CPUC) submits these comments in response to the Federal Communications Commission's (FCC or Commission) *Thirteenth Broadband Progress Notice of Inquiry* (*NOI*) Concerning Deployment of Advanced Telecommunications Capability Pursuant to Section 706 of the Telecommunications Act of 1996.[1]

The FCC is seeking comments regarding, among other issues, whether the FCC should evaluate broadband deployment based on the presence of *some form* of advanced telecommunications capability, be it fixed or mobile, or alternatively whether advanced telecommunications capability should include access to mobile broadband service as well as fixed broadband services, whether the FCC should maintain its 25 megabits per second (Mbps) download / 3 Mbps upload (25 Mbps / 3 Mbps) speed benchmark for fixed broadband, whether the FCC should have specific speed benchmarks for mobile broadband, whether the FCC should incorporate measures of latency or consistency of service into their benchmarks for both fixed and mobile broadband, and what benchmarks/metrics should be used to evaluate mobile broadband deployment.

The CPUC comments here on some, but not all, of the issues raised in the *NOI*, and provides our most recent data and analysis from our Spring 2017 mobile testing, as well as our analysis of fixed broadband deployment in the state, in order to inform the FCC's decisions regarding both mobile and fixed broadband as they relate to advanced telecommunications capabilities, including the extent to which they are being deployed to all Californians in a

[1] *Inquiry Concerning the Deployment of Advanced Telecommunications Capability to All Americans in a Reasonable and Timely Fashion*, GN Docket No. 17-199, *Thirteenth Broadband Progress Notice of Inquiry*, DA 17-843 rel. Aug. 8, 2017 (*NOI*).

reasonable and timely manner.[2] Silence on other questions posed by the FCC's *NOI* signifies neither agreement nor disagreement by the CPUC.

The CPUC has been studying broadband measurement techniques, particularly with regard to mobile broadband service, since 2012. The CPUC has: 1) created and implemented CalSPEED, a project that gathers data regarding mobile broadband throughput, quality and reliability for the four national carriers; 2) published a mobile crowd-sourcing application; and 3) performed semi-annual field testing of mobile broadband service quality in urban, rural and tribal areas throughout the state of California from the user's perspective.

Every six months since 2012, the CPUC has collected approximately 2,000,000 test results at the same 1,986 field locations throughout California.[3] Our testing protocol was enhanced in 2014 to capture backhaul and middle mile information in order to compare urban, rural and tribal service characteristics and impacts. We have now collected nearly 25,000,000 measurements of the performance of the networks deployed by the four major mobile broadband carriers across California: AT&T Mobility, Sprint, T-Mobile, and Verizon Wireless. We also just completed analysis of the latest Spring 2017 data collection.[4] Because of our testing and

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[2] For other material regarding the CPUC's CalSPEED program and analysis of results, see also Comments of California Public Utilities Commission *Inquiry Concerning the Deployment of Advanced Telecommunications Capability to All Americans in a Reasonable and Timely Fashion, and Possible Steps to Accelerate Such Deployment Pursuant to Section 706 of the Telecommunications Act of 1996, as Amended by the Broadband Data Improvement Act*, GN Docket No. 14-126, *Tenth Broadband Progress Notice of Inquiry*, filed September 4, 2014; Comments of the California Public Utilities Commission, *Inquiry Concerning Proposed Methodology for Connect American High-Cost Universal Service Support Recipients to Measure Speed and Latency Performance to Fixed Locations*, WC Docket No. 10-90, (DA 14-1499), filed Dec. 22, 2014.

[3] Test locations increased from 1,200 to 1,896 as of Fall 2013.

[4] In addition, the CalSPEED raw testing data is posted on Github at https://github.com/CalSPEED/Field_Test_Data, which we incorporate herein by reference. Availability maps and GIS summary shapefile data for wireline, filed wireless and mobile services are available at http://www.cpuc.ca.gov/General.aspx?id=1197.

analysis, the CPUC is in a unique position to provide recommendations to the FCC based on data collected in California.

The CPUC is also in the process of expanding its CalSPEED program to include fixed broadband testing in addition to mobile. We will initially construct and distribute 500 devices throughout the state, with both rural and urban areas represented proportionately, to perform the same test protocols that we use for our mobile testing. Our fixed testing will be similar in many ways to the FCC's SamKnows testing, and our testing incorporates relevant best practices developed in the FCC's Measuring Broadband America project. However, our methodology for fixed testing also incorporates the unique aspects of our mobile testing program, such as testing to both local and distant servers in order to better evaluate the actual user experience.

The comments below rely on the analysis of CalSPEED data performed by the CPUC, as well as by CPUC consultant Ken Biba at Novarum, Inc., and CPUC consultants at California State University (CSU) at Monterey Bay and the Geographic Information Center at CSU Chico.[5] Mr. Biba's complete analysis of the Spring 2017 results is appended to this filing as Attachment 1 (Biba Report).[6] Excerpts of our analysis of the Spring 2017 field test results are also included in these comments below. We also incorporate by reference two CPUC reports, the California

[5] CalSPEED is an open source, non-proprietary, network performance measurement tool and methodology created for the CPUC, funded originally via a grant from the National Telecommunications and Information Administration (NTIA). CalSPEED is now funded through the California Advanced Services Fund (CASF). CalSPEED uses a methodology pioneered by Novarum. The software measurement system was created and is maintained by a team at California State University Monterey Bay, led by Professors Sathya Narayanan and YoungJun Byun. CalSPEED mapping and measurement field operations are managed by the Geographic Information Center at California State University at Chico. Statisticians at CSU Monterey Bay assist the team with detailed geographic and statistical analysis of the data set.

[6] CalSPEED: California Mobile Broadband – An Assessment - Fall 2014, Ken Biba, Managing Director and CTO Novarum, Inc. The Biba Report can also be accessed at http://www.cpuc.ca.gov/General.aspx?id=1778.

Advanced Services Fund, Annual Report (CASF Report),[7] and the Digital Infrastructure Video Competition Act Annual Report for Year Ending December 31, 2015 (DIVCA Report).[8]

II. DISCUSSION

A. Evaluating Fixed and Mobile Broadband Deployment

In this *NOI*, the FCC asks whether to focus its *Inquiry* on whether *some form* of advanced telecommunications capability, be it fixed *or* mobile, is being deployed to all Americans in a reasonable and timely fashion.[9] Alternatively, the FCC asks whether it should evaluate deployment based on the presence of both fixed *and* mobile services.[10] While the CPUC does not take a position here on whether *both* fixed and mobile services should be included in the definition of "advanced telecommunications service,"[11] our experience and data do not support substituting mobile broadband for fixed broadband services. The CPUC accordingly urges the FCC not to base advanced telecommunications capability on the presence of mobile broadband alone, where there is no advanced capable fixed service available.

The CPUC recently concluded an investigation into the state of California's telecommunications market and an analysis of the state of competition in its various sub-markets. In the resulting decision, Decision (D.) 16-12-025, the CPUC found that mobile and residential

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[7] CASF Annual Report, published April 2017, available at http://www.cpuc.ca.gov/General.aspx?id=9226.

[8] DIVCA Video, Broadband and Video Employment Report, June 2017. Available at http://www.cpuc.ca.gov/uploadedFiles/CPUCWebsite/Content/About_Us/Organization/Divisions/Office_of_Governmental_Affairs/Legislation/2017/Final_DIVCA_Video_Broadband_and_VideoEmployment_Report_6-6-17a.pdf.

[9] *NOI* at ¶ 6.

[10] *Id*. at ¶ 7.

[11] As discussed below, however, the CPUC does have recommendations on including mobile performance benchmarks and metrics.

broadband services are "generally not substitutes."[12] Several factors went into this determination. As noted in that decision, residential broadband service is typically delivered over coaxial cable or existing phone lines using DSL technology. Wireless data services access the Internet using a mobile phone (or tablet), and, in wireless' current leading technology, the 4G LTE protocol, which can provide download speeds faster than DSL but is often slow and unreliable compared with Internet provided over cable or fiber.

In addition, the CPUC found that data caps even for "unlimited" data plans and higher data usage charges for smart phone-based Internet access limit the ability of Californians to cost-effectively use their mobile data subscription to meet all of their data needs. Also, many websites offer limited functionality when accessing them via a smart phone through mobile broadband connections. Consequently, mobile broadband offers inferior functionality compared to accessing some websites via computers and fixed wireline broadband connections.

Ultimately, the CPUC found that while residential and mobile broadband data services are in many respects functional substitutes—both services allow users to access email, browse the web, stream audio and video content, etc.— factors such as lower data caps and much higher data use charges for mobile broadband suggest that they are not reasonable economic substitutes at present.[13]

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[12] CPUC Decision (D.) 16-12-025, slip op. at p. 44, available at http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M171/K031/171031953.pdf; CPUC D.17-07-011, Order Denying Rehearing of D.16-12-025, available athttp://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M192/K128/192128830.PDF. The object of the CPUC's investigation was to take a snapshot of the telecommunications marketplace in California, with an "as of" date of December 31, 2015. The CPUC's findings were made within that timeframe, and the CPUC may revisit this analysis as it continues to measure wireless performance.

[13] *Id*. at slip op. pp. 44-45, Finding of Fact No. 7(g).

B. Metrics and Benchmarks for Defining Advanced Telecommunications Services

The FCC seeks comment on how to evaluate both fixed and mobile services, what benchmarks and metrics it should use to evaluate "advanced telecommunications capability," and whether factors other than speed should be considered.

As discussed further below, the CPUC urges the FCC to obtain reliable mobile data and set mobile performance benchmarks. The CPUC further urges the FCC to use latency and consistency as part of the criteria defining "advanced telecommunications capability," both for fixed broadband services as well as mobile broadband services. The CPUC has been using industry-accepted algorithms, which utilize speed along with quality and reliability metrics we track, to evaluate whether consumers can employ their broadband service to originate and receive high-quality voice, data, graphics, and video telecommunications services. This is precisely the functionality required for service to be considered as supporting "advanced telecommunications capabilities." We recommend the FCC do the same.

1. The Commission Should, at Minimum, Maintain the 25Mbps/3 Mbps Speed Benchmark for Fixed Advanced Telecommunications Capability.

The *NOI* seeks comment on whether and how to incorporate various benchmarks into the definition of advanced telecommunications capability, including speed.[14] The *NOI* further proposes to maintain the current speed benchmark of 25 Mbps download and 3 Mbps upload (25 Mbps/3 Mbps) for fixed broadband.[15]

[14] *NOI*, at ¶¶ 22-30.

[15] *NOI*, at ¶ 14.

As noted in the *NOI*, Section 706 of the Federal Communications Act defines advanced telecommunications capability as "*high-speed*, switched, broadband telecommunications capability that enables users to originate and receive high-quality voice, data, graphics, and video telecommunications."[16] In its investigation into the state of competition in California, the CPUC found the FCC's speed benchmark for "Advanced Services," set at 25 Mbps download and 3 Mbps upload, to be a "useful, reasonable, and forward-looking division to separate the broadband market into 'low-speed' and 'high-speed' tiers."[17] The CPUC stated in its decision:

> We note that higher speeds improve the performance of video streaming services from companies like Netflix and Amazon, as well as live-video feeds from companies like Facebook and Twitter. While Netflix recommends a five Mbps connection for high definition video streaming, households that include multiple end-users using multiple devices to access multiple services at the same time may find that download speed inadequate.[18]

A significant justification cited by the FCC in its 2015 Broadband Progress Report, in creating the new 25/3 benchmark, was that households may comprise multiple individuals using multiple devices. The CPUC further notes that fixed providers (especially cable providers) are already routinely offering speeds substantially in excess of the 25/3 benchmark. The CPUC anticipates that this speed benchmark will not be static in the next decade, and urges the FCC to maintain, *at a minimum*, the 25 Mbps/3 Mbps speed benchmark.

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[16] *NOI*, at ¶ 13, citing 47 U.S.C. § 1302(d)(1) (emphasis added).

[17] CPUC D.16-12-025, slip op. p. 48, Finding of Fact No. 12.

[18] *Id*. at slip op. pp. 48-49 (citations omitted).

2. The Commission Must use Metrics for Quality and Reliability in Addition to Speed to Define Advanced Telecommunications Capabilities.

The CPUC's CalSPEED mobile testing program has enabled California to collect and analyze a vast array of data not only about mobile broadband speeds, but other aspects of service we measure, such as latency, jitter, packet loss, failed connections, and packet routing. We have concluded that, while throughput is relevant, the actual user's experience depends on the combination of these other measures as well. As our current data and analysis shows, it is crucial to consider quality and reliability in determining the capabilities of the networks that have been deployed.

It is clear from our CalSPEED mobile testing program that mobile service is subject to extreme variability. A consumer may receive 10/3 Mbps throughput one moment, but 3/1 Mbps the next, and 20/10 Mbps the moment after that at the same location. In light of this variability, the question becomes, what is the typical consumer experience? Even with high throughput speeds, given reliability and quality concerns, the service actually received at any given point may not be good enough to support advanced communications capabilities.

The most useful way we have found to "grade" the throughput, quality and reliability of mobile broadband service is to determine how well the service will support the most popular broadband uses. We utilize industry-accepted algorithms to relate performance measurements to suitability for various uses. We use a well-established formula to calculate a Mean Opinion Score (MOS) to determine whether service tested at a particular location will support mobile VoIP service known as Voice over LTE (VoLTE). The MOS takes quality measures such as latency and jitter in addition to throughput into account to determine whether the data service is stable enough to allow acceptable ("toll quality") voice service.[19] Similarly, we use a formula published by youTube[20] to determine whether the broadband service will support video streaming, and at standard or high-definition quality. We calculate video and voice quality using results from both upload and download tests to "grade" whether the service will support 2-way video conferencing.

Another important variable in judging the quality of broadband service is the location of the server at the far end of the connection. A user's experience depends on the connection all the way from his or her device to the far destination, not just the quality of the connection between the device and the cellular transmitter. We see significant differences in service capability depending on whether our connection is to a local server (e.g., located in the Amazon cloud on the west coast) or to a distant server (e.g., located in the Amazon cloud in Virginia). For video streaming from popular movie services like Netflix, Hulu or Amazon Prime, content will likely be cached locally. When judging video streaming capability, it may be appropriate to use test results from a nearby server.[21] However, when judging VoLTE or 2-way video conferencing capability, it may be appropriate for the FCC to seek test results involving a distant server, as the party on the "other end of the phone" can be anywhere in the world.

[19] MOS is a subjective measure of whether voice quality is considered acceptable by consumers that is derived objectively using an industry-standard algorithm. An MOS score 4 is considered to indicate good quality service.

[20] Available at https://www.google.com/get/videoqualityreport/#methodology.

[21] Some broadband speed tests always test to a nearby server.

3. The FCC Should Develop a Mobile Broadband Field Test Program and Expand Its Use of Fixed Testing Devices for Data on Broadband Deployment Rather than Rely on Provider-Submitted Data.

Through the CPUC's CalSPEED mobile testing, it has become clear that the data mobile providers submitted to the FCC on Form 477 showing their lowest advertised speeds do not help determine whether mobile broadband service at any given location is of high enough quality or reliability to support advanced communications services. In comments the CPUC filed in the FCC's Inquiry into Form 477, the CPUC recommended that the FCC augment mobile broadband availability reporting with "speed testing, similar to the manner in which the CPUC measures mobile broadband service."[22]

The FCC seeks comment on the geographic level of data needed to evaluate broadband availability under Section 706.[23] For our CalSPEED mobile drive test, we have designated sufficient test points so that our interpolations of test data (that predict service characteristics in between those points) are reliable within one kilometer. We recommend that the FCC conduct similar mobile drive tests. If the FCC desires to achieve more granular interpolations, it can create a denser selection of test points.

The FCC further asks if it would be "practical to use deployment of various air interface technologies (e.g., LTE) as a proxy for speed benchmarks."[24] The CPUC urges the FCC not to use interface technologies as a proxy for speed benchmarks. While LTE (or newer generations of mobile technology about to be deployed) is required for mobile service to support advanced

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[22] Comments of the California Public Utilities Commission, Modernizing the FCC Form 477 Data Program, WC Docket No. 11-10, at p. 7 (filed Sept. 25, 2017).

[23] *NOI*, at ¶ 21.

[24] *NOI*, at ¶19.

capabilities, it is clearly not sufficient. As our mobile data and analysis show, even LTE often has quality and reliability problems that cause throughput to be highly variable. The number of failed connections experienced in the field, especially in rural areas, rules out using the air interface technology as a proxy for speed, quality or reliability.[25]

Just as we recommend the FCC expand the use of mobile speed testing to acquire more accurate information on mobile broadband deployment, we also recommend that the FCC expand its Measuring Broadband America (MBA) program to provide a more robust picture of fixed broadband deployment. In addition, the FCC should use data from its MBA program as a resource with which to validate broadband availability data submitted by providers on FCC Form 477. When used in this fashion, the FCC can adjust its view of what is available in a particular area from the highest advertised speed that was reported to it on Form 477 to the speed testing reveals is actually received by consumers. Finally, the CPUC recommends that the FCC engage the state commissions to design and execute similar fixed broadband test programs in their own states, as the states are better positioned to determine the number of fixed test devices and their geographic placement in order to capture urban, rural and tribal availability information.

4. The CPUC's Data and Analysis Can Help Inform the FCC's Determination on Whether Advanced Telecommunications Capability Has Been Deployed to All Americans in a Reasonable and Timely Fashion.

In the *NOI*, the FCC asks how it should treat the disparity between the availability of advanced telecommunications capability in and within urban, rural and tribal lands.[26] Additionally, the FCC proposes to analyze fixed and mobile broadband separately.[27] The

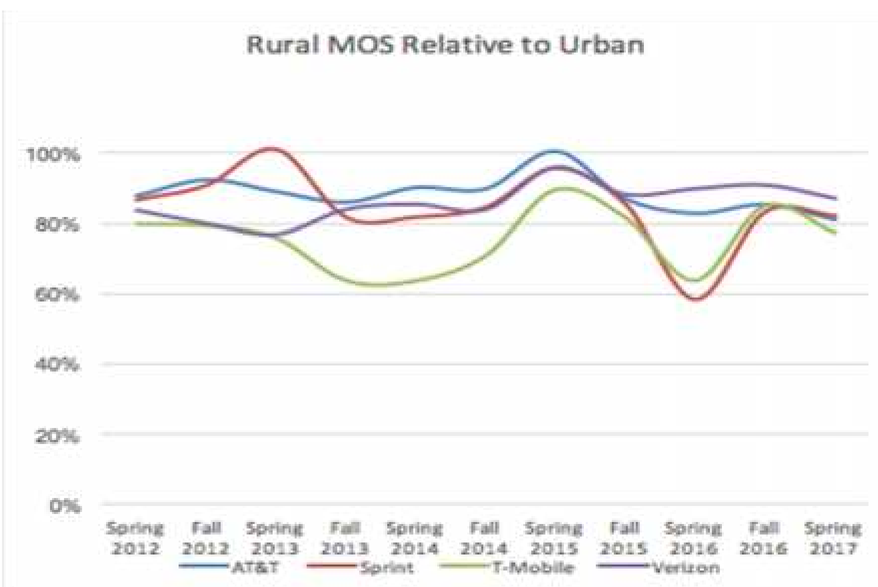
[25] *NOI*, at ¶ 21 inquires about the impact of failed connections on benchmarks.

[26] *NOI*, at ¶ 30.

[27] *NOI*, at ¶ 30.

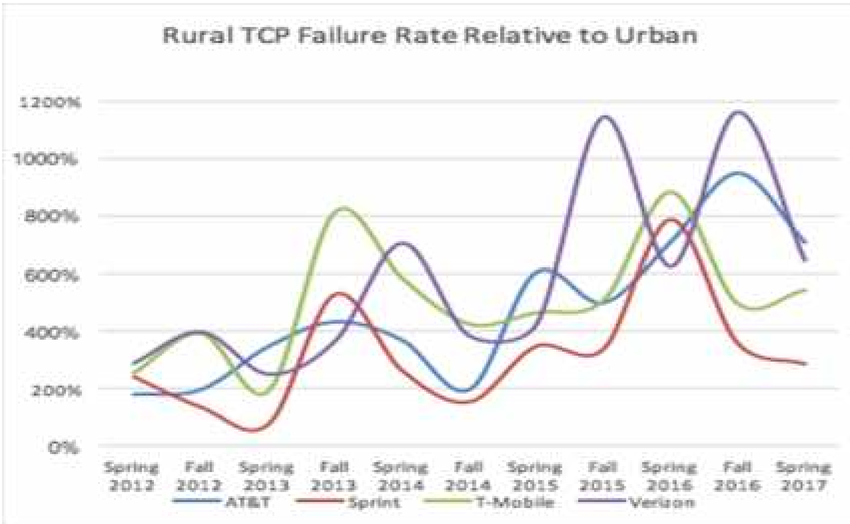
analyses in attached Biba Report, the CPUC CASF Report, and the DIVCA Report, provide information regarding the disparity in fixed and mobile broadband availability between urban, rural and tribal lands in California. The reports collectively show a disparity in the deployment of advanced telecommunications service in California in urban versus rural areas and tribal lands. These facts about California can help inform the FCC in its determination on whether advanced telecommunications services have been deployed to all Americans.

The Biba Report illustrates the gap in mobile broadband quality and reliability between urban, and rural areas and tribal lands. The line graph below, which is but one such example from the Report, shows that VoLTE service is of acceptable quality in rural areas approximately 85% as often as in urban areas of California, as measured by MOS. In fact, this urban/rural disparity is generally greater in the Spring 2017 tests compared to results from testing done the prior Fall.



The line graph below shows that consumers in California rural and tribal areas have experienced an increasing trend in the number of dropped connections compared to consumers in urban areas. Measurements of AT&T’s and Verizon’s mobile broadband networks in 2017 in

California show Transmission Control Protocol[28] (TCP) failure rates approximately seven times worse than their urban networks.



Similarly, the graph below, from the CASF Report, demonstrates the disparity in the availability of 25/3 Mbps service between urban and rural areas.[29]

Households* Served by Wireline Broadband at 25/3 Mbps**
(as of December 31, 2015)

2015	All California	Rural	Urban
Households	12,941,948	680,877	12,261,071
Households Served	12,196,361	254,438	11,941,923
Percentage	94%	37%	97%

* CA Department of Finance, January 2016 estimate.
** Served estimates based on the broadband data collected by CPUC as of December 31, 2015.

[28] TCP is the protocol by which a two-way communication between a user and a server on the Internet is established. A TCP failure happens when a user is unable to access a web site from a browser. The user experiences this as seeing the progress bar stop, and needing to push the enter button again to connect to the site.

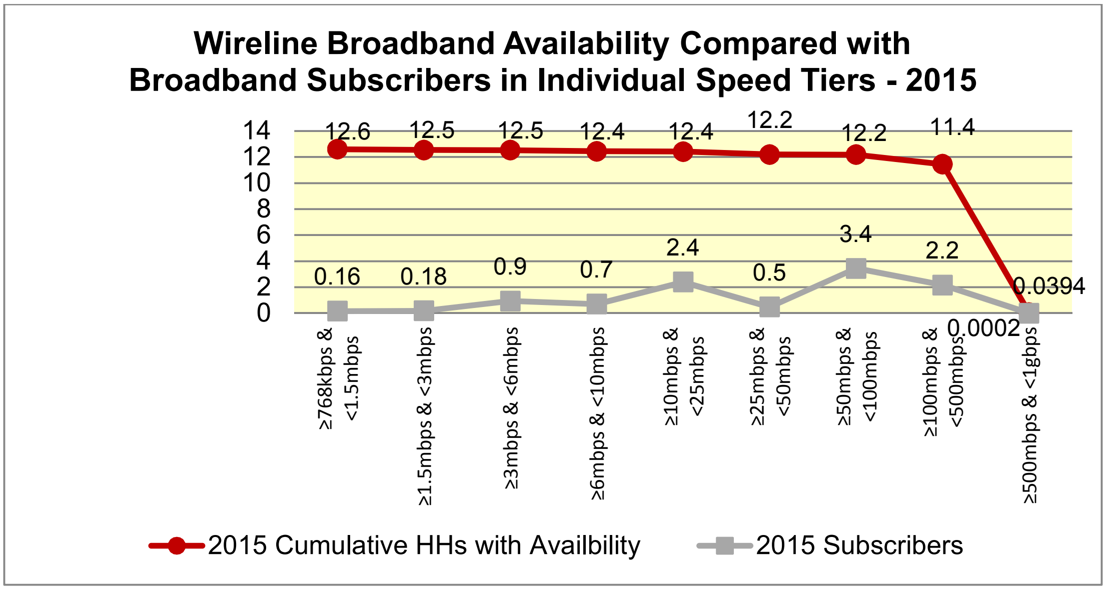
[29] CASF Report, page 43. The report contains additional information of the urban/rural disparity at different speeds. See pages 4-5 and 77-78.

With regard to the issue of whether advanced telecommunications capabilities have been deployed in a reasonable and timely fashion, California's analysis may also inform the FCC's thinking. In seeking comment on this issue, the FCC notes in the *NOI*, "[p]rior inquiries have examined various aspects of the deployment of and market for advanced services, such as: high-speed service availability and subscription…; the number of providers offering service through a particular technology; and the different technological options that consumers have for obtaining advanced services."[30]

The DIVCA Report includes several analyses relating to the aspects identified above. The two charts below show wireline subscriptions and availability by speed tier and the wireline technologies to which consumers subscribe. The first chart below compares the numbers of households that have broadband available in individual download speed tiers with the number of subscribers to the same speed tiers.[31] For example, the red line in the graphic below shows that 12.2 million California households (94.1%) had an advertised 50 Mbps to 100 Mbps wireline broadband download service available at the end of 2015, and the blue line shows that 3,448,935 of those households subscribed (28.3%). The red line also shows that 11.4 million of California households (88.4%) had an advertised 100 Mbps to 500 Mbps wireline broadband download service available at the end of 2015. The blue line shows that 2,164,055 of those subscribed to that speed tier (18.9%). This chart shows that most consumers have access to higher broadband speeds than they choose to purchase, although such choices are not necessarily available to all consumers in rural areas as discussed above.

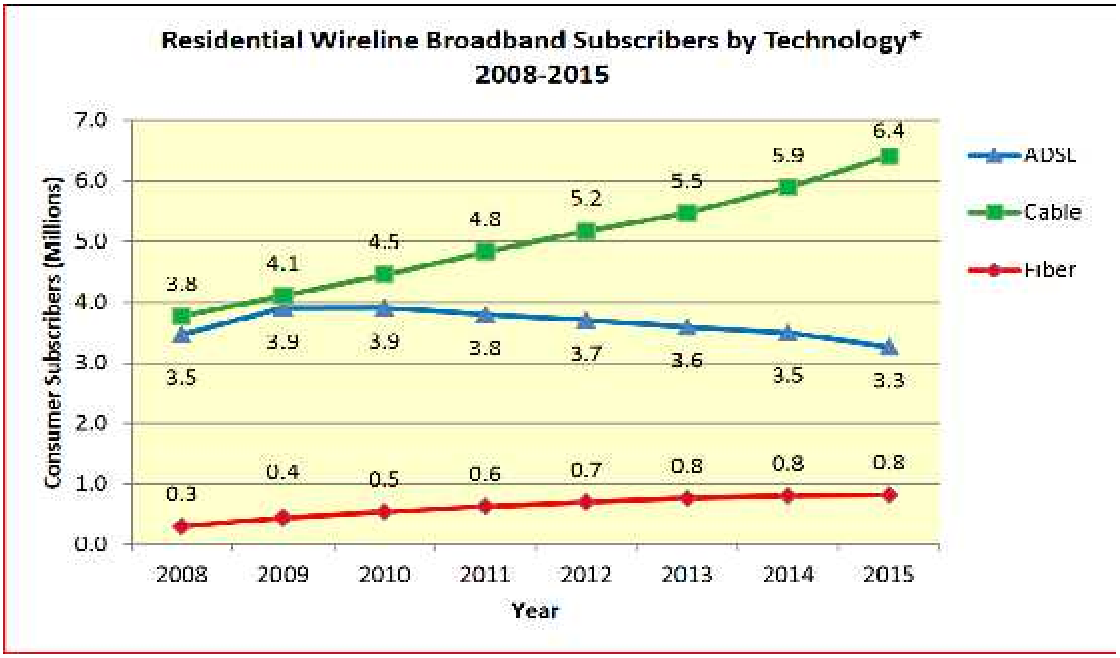
[30] *NOI*, at ¶ 34.

[31] DIVCA Report at p. 35.



With regard to the FCC's interest the different technological options that consumers have for obtaining advanced services, the following graph shows the technological choices of wireline broadband actually made by California consumers.[32] Since 2008, broadband subscriptions for cable services have grown while ADSL subscriptions have declined. The choice of fiber subscriptions is limited by the limited deployment of fiber to the home. In contrast, the disparate trends in cable and ADSL subscriptions reflect affirmative choices of consumers between the two competing technologies. Of note is that the most popular speed tier in the table above is the 50 to 100 Mbps offering, which is generally not available using ADSL technology, as depicted below.

[32] DIVCA Report at p. 34.



III. CONCLUSION

The CPUC appreciates this opportunity to share our mobile broadband testing methodologies, broadband data and analyses with the FCC to inform its policymaking in this *NOI*. We urge the FCC to consider the metrics and testing methodologies we have cited here in developing criteria and benchmarks for assessing consumer broadband and other technologies that deliver advanced telecommunications capability.

California urges the FCC to maintain the 25 Mbps/3 Mbps speed benchmark for fixed wireline broadband. To determine availability of advanced broadband capability, speed should not be the only criteria. The FCC should also consider how reliability criteria can be used to evaluate advanced telecommunications capability in relation to its established advanced services benchmark. In addition, California recommends that, at present, the FCC not deem mobile broadband service to be a substitute for fixed broadband service.

Respectfully submitted,

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Dated: October 5, 2017

ATTACHMENT 1

CalSPEED: California Mobile Broadband - An Assessment - Spring 2017

Persistent Urban/Rural Digital Divide Persists, Overall Mobile Broadband Returns to Year Ago Quality and Performance and Carrier Performance Throttling Continues

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Novarum, Inc.

This is an analysis of the measurement Round 11, spring 2017 dataset for CalSPEED. The key results for California mobile broadband include the following:

Persistent mobile digital divide	The rural/urban mobile digital divide appears to be persistent with rural users having material (about 1/3) poorer mobile broadband service over a period of years with little indication of improvement. This is true for throughput, latency, packet loss, MOS, jitter, broadband coverage and deployed technology. Spring 2017 shows additional incremental degradation.
Mean throughput worsens	Mean throughput worsens for all carriers (small increase for Sprint downstream and for Verizon upstream), and returns to levels last seen at least a year ago.
Carrier throughput throttling continues	Throughput throttling for all carriers continues from fall 2016 into spring 2017. The downstream throttling threshold continues from fall 2016 at ~42 Mb/s. The upstream throttling threshold continues from fall 2016 at ~20 Mb/s (15 Mb/s for Sprint).
Mobile broadband coverage decreases	Broadband coverage at the 25 Mb/s down, 3 Mb/s benchmark continues below year ago levels at ~13%. Using the for mobile broadband benchmark of 10 Mb/s down and 1 Mb/s up, improves “coverage” to ~50% for all carriers.
Underlying service quality mixed	Mean rural latency worsens, jitter worsens, packet error rate improves, and TCP connection reliability worsens for all carriers.
Rural and Tribal TCP connection failure rates 3-7x urban	TCP connection attempts fail much more often for rural users than for urban users for all carriers. An urban AT&T or Verizon user can expect 2% of TCP connection attempts to fail (often invisibly retried by the using applications) while ~20% or rural users can expect TCP connection failures.

Over the Top VoIP quality modestly improved, continued relative impairment for rural and tribal	VoIP quality continued improved after substantial degradation in spring 2016. Rural and tribal VoIP quality remains degraded.
LTE deployment coverage has peaked	Penetration of LTE in both urban and rural geographic categories appears to have peaked with a floor on 1/2G legacy replacement and on a cap on LTE deployment. Notably, there was no legacy 1/2G service detected for AT&T in California.
Internet latency stabilizes	The latency difference between east and west servers has stabilized at ~80 msec.
Internet video and conferencing results mixed	Internet OTT streaming video and conferencing availability modestly improved from fall 2016. A “Valley of Video Death” appears as a consistent area of No Service for OTT video in rural Southern California for all carriers.
East/West throughput differences continue at all time high	Ratio of east/west throughput continues pattern of last year with an all-time high of 60% for all carriers but Sprint at 40%.
Little difference between devices	There continues to be no material throughput or latency difference between current smartphones and tablets.
Weak relationship between signal strength and throughput	There is a modest correlation between Signal to Noise Ratio (SNR) and west throughput, but not for Received Signal Strength Indicator (RSSI). Moreover, the wide range in throughput values for any particular SNR or RSSI means both are poor predictors of throughput.

1. Calibrating the Mobile Internet Experience

Each of us relies on the Internet to research school papers, find a job, find and buy new products, read the news and increasingly to entertain ourselves. The Internet is not only becoming our newspaper, but also our phone, radio and television. How we do our jobs, raise our families, educate ourselves and our children, interact as responsible citizens, and entertain ourselves are all influenced by the quality of the Internet service we obtain. And ever increasingly, that service is not on our desk, but in our hand wherever we go.

Knowing the quality of this service is a vital piece of our modern ecosystem much in the same way as we research the brand of car we drive or the type of house we own. With multiple mobile Internet providers, an independent third party assessment of this quality allows consumers and policy makers to make informed choices.

CalSPEED is an open source, non-proprietary, network performance measurement tool and methodology created for the California Public Utilities Commission, funded originally via a grant from the National Telecommunications and Information Administration. CalSPEED is now funded through the California Advanced Services Fund. CalSPEED uses a methodology pioneered by Novarum. The software measurement system is created and maintained by a team at California State University Monterey Bay, led by Professors Sathya Narayanan and YoungJoon Byun. CalSPEED mapping and measurement field operations are managed by the Geographic Information Center at California State University at Chico. Statisticians at CSU Monterey Bay assist the team with detailed geographic and statistical analysis of the dataset.

Unlike many speed tests that offer just a horse race between carriers, CalSPEED tries to understand the quality of the mobile user broadband experience.

CalSPEED has now been in use in California for five years with eleven rounds of measurement over the entire state collecting over 30,000,000 measurements, at the same locations, across California of the four major mobile broadband carriers: AT&T Mobility, Sprint, T-Mobile and Verizon Wireless. This paper does a deep analysis of the first eleven rounds of measurement[1]. Previous papers have analyzed the prior rounds of measurement. The methodology has been rigorously analyzed with respect to other available mobile measurement tools[2]. This paper examines the incremental changes from the previous report extending thru the spring of 2017.

[1] Refer to Ken Biba's analysis in the Novarum mobile test reports on the CPUC web site, http://cpuc.ca.gov/General.aspx?id=1778
[2] Ken Biba, "Comparison of CalSPEED, FCC and Ookla", Novarum, Inc., September 2014

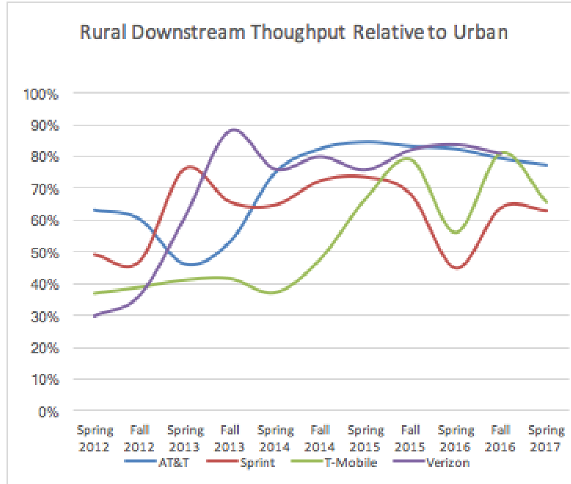
2. Persistent Mobile Digital Divide

A substantial collection of network metrics demonstrates that rural mobile broadband networks consistently (by approximately 1/3) underperform urban networks - both in performance and quality, for all carriers.[3] The data strongly suggests that this underperformance has continued for years, and trend lines suggest little improvement.

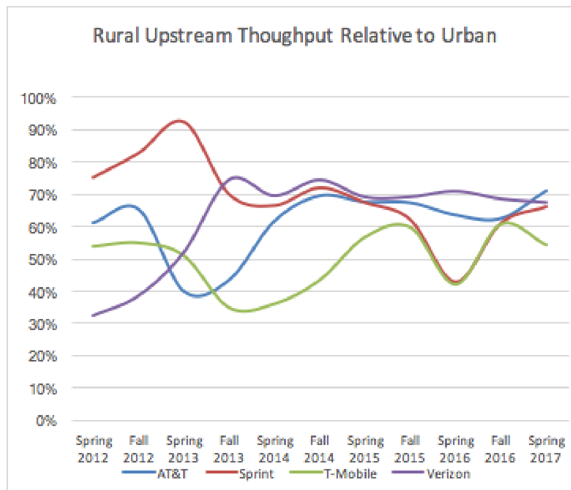
CalSPEED metrics help document this persistent digital divide.

[3] This analysis uses the urban vs. rural delineation as assigned in the 2010 Census Blocks geography. The classifications are defined here: https://www.census.gov/geo/reference/ua/urban-rural-2010.html. For the 2010 Census, an urban area will comprise a densely settled core of census tracts and/or census blocks that meet minimum population density requirements, along with adjacent territory containing non-residential urban land uses as well as territory with low population density included to link outlying densely settled territory with the densely settled core. To qualify as an urban area, the territory identified according to criteria must encompass at least 2,500 people, at least 1,500 of which reside outside institutional group quarters. The Census Bureau identifies two types of urban areas: a) Urbanized Areas (UAs) of 50,000 or more people; b) Urban Clusters (UCs) of at least 2,500 and less than 50,000 people. "Rural" encompasses all population, housing, and territory not included within an urban area.

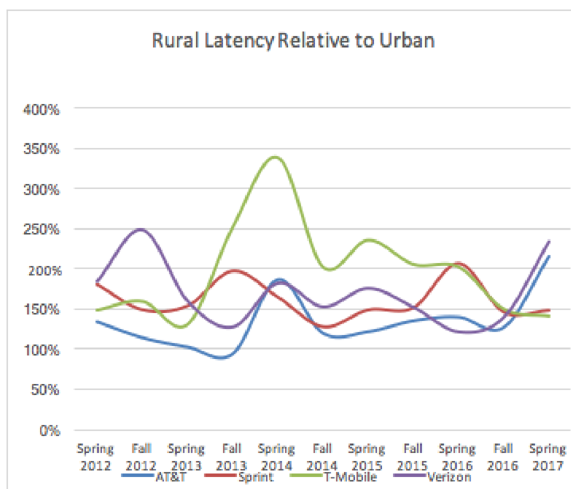
Rural mean downstream TCP throughput is consistently only 80% (and for Sprint and T-Mobile sometimes as little as 50%) of urban.



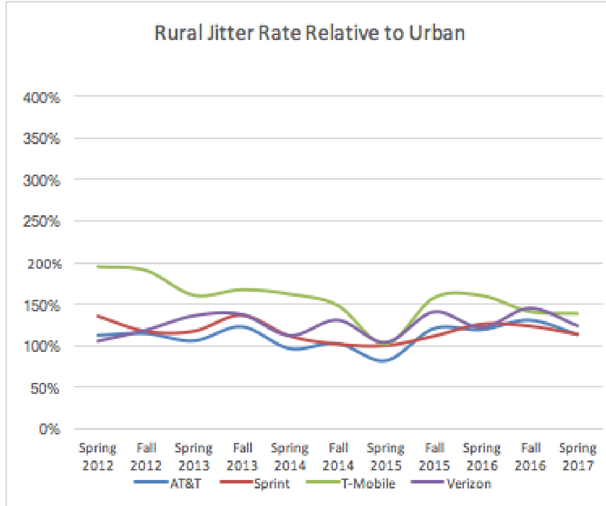
Rural mean upstream TCP throughput is consistently only 60-70% of urban.



Rural mean latency is consistently at least 50% (T-Mobile and Sprint) to 100% (AT&T and Verizon) worse than urban.

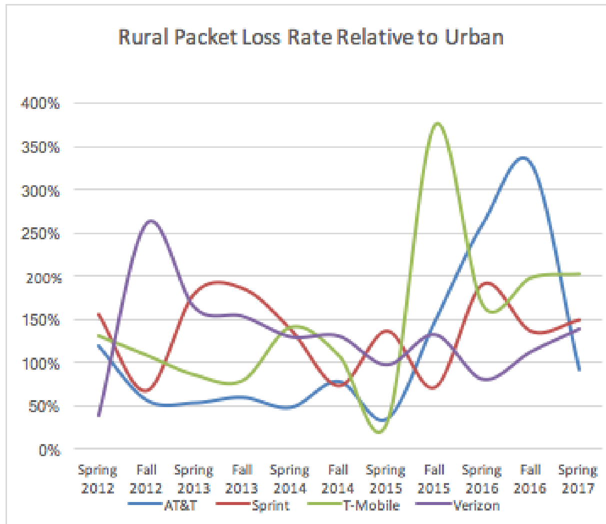


Rural mean jitter is consistently at least 20% worse than urban.

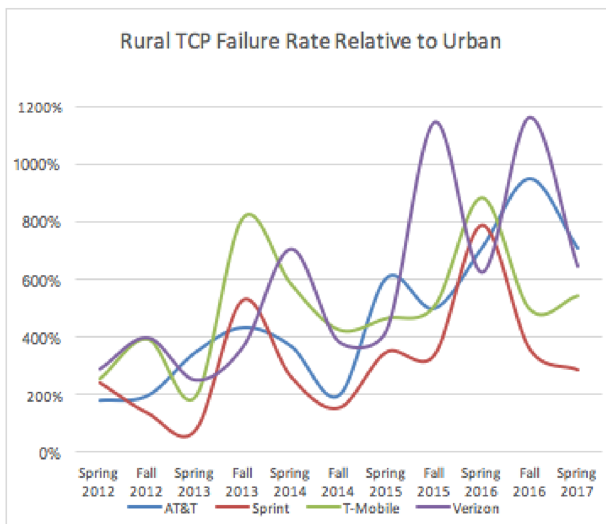


Rural packet loss is consistently 100-200% worse than urban. The poor performance of rural latency, jitter and packet loss strongly implies that real-time streaming voice and video services will perform materially worse in rural than urban areas.

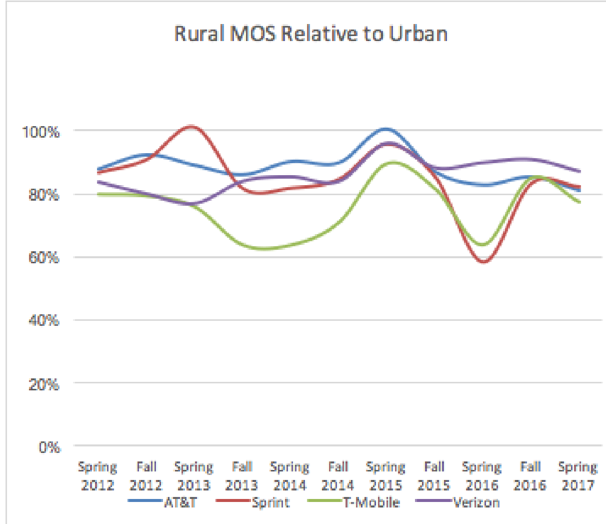
.



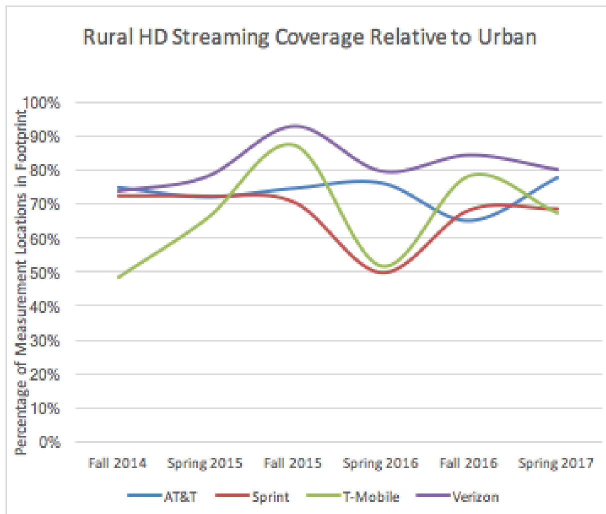
Rural TCP connection failure rate is consistently ~5x worse than urban with indications that this disparity is getting worse. For rural and tribal users of all carriers, about 1 in 5 TCP connection attempts fail.



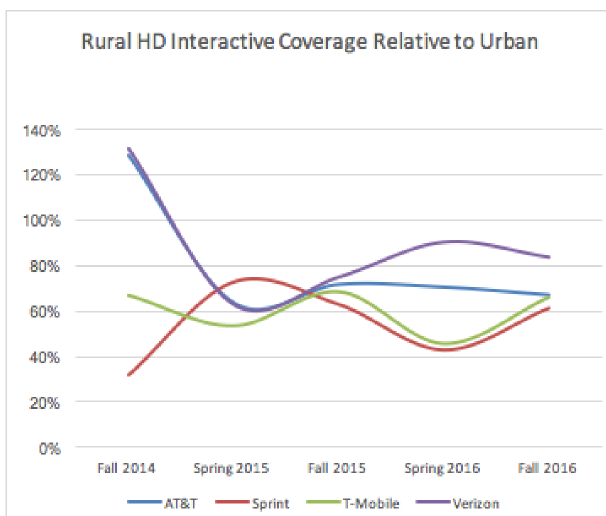
Rural OTT digital voice coverage is consistently only 85% of urban.



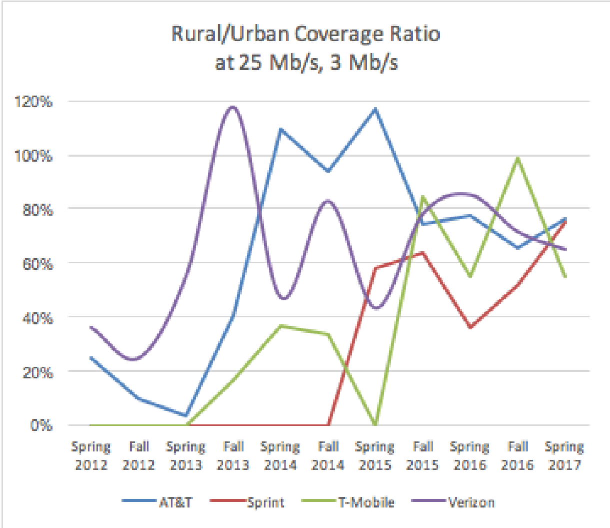
Rural streaming video coverage from the west server is consistently 60-80% of urban. Rural users will encounter no streaming availability 3x more frequently than urban users.



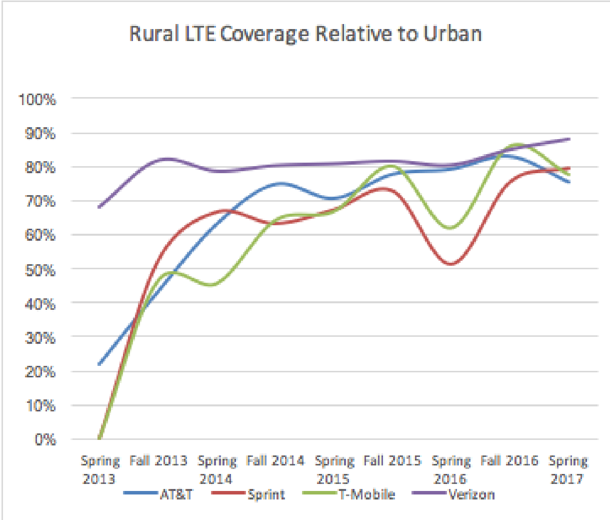
Rural conference video coverage is consistently 60-80% of urban. Rural users will encounter no conference availability 2x more frequently than urban users.



Rural mobile broadband coverage at the 25 Mb/s down and 3 Mb/s up benchmark is consistently 60-80% of urban.

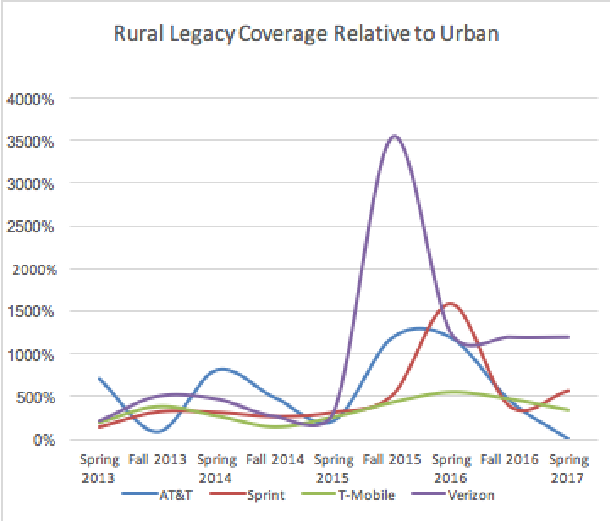


Rural LTE coverage is consistently 80% of urban. The trend suggests rural LTE availability will cap out below 85% of urban. This has substantial implications for the use of mobile broadband as a replacement for wired broadband in rural areas and for the capability of public safety services.



Rural mobile broadband consistently has more than 500% use of legacy 1G and 2G mobile broadband technology than urban. It is much more likely for a rural user to encounter very poor legacy mobile broadband service than an urban user.

A notable change in spring 2017 is the effective elimination of legacy rural coverage for AT&T.

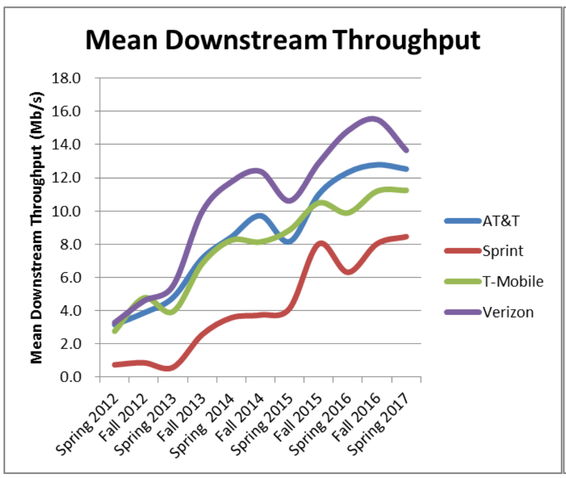


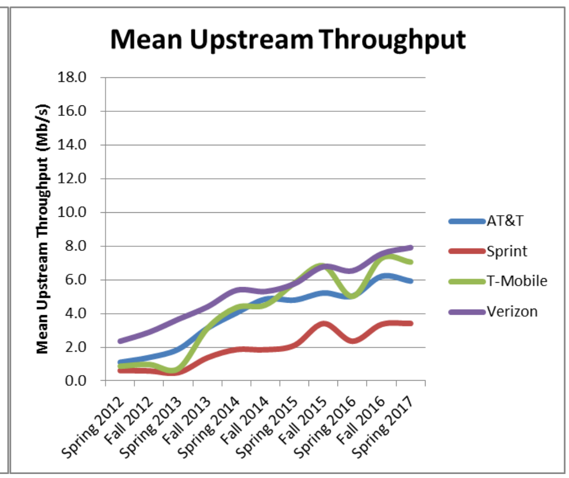
3. Mean Throughput Goes Back in Time

All mobile carriers show variation over time of mean downstream and upstream throughput, and it is expected that there will be variation from measurement period to measurement period. The general trend has been towards higher performance as carriers deploy newer, higher performance infrastructure technology and more cell towers. Variations in performance can be interpreted as correlated to changes (and mismatches) in network capacity and user demand.

For ease of analysis and consistency across all rounds of testing, we examine data from only smartphones[4]. As shown in the graphs below, mean downstream throughput decreased in spring 2017 for (almost) all carriers. Mean downstream throughput levels for AT&T, Sprint and Verizon returned to levels from a year ago- and T-Mobile showed no improvement from fall 2016 and only small improvement since fall 2015. There is a suggestion that historic throughput increases have leveled off. Further measurement rounds will help decide.

Mean carrier upstream throughput also regressed to levels from at least a year ago for AT&T, Sprint and T-Mobile.

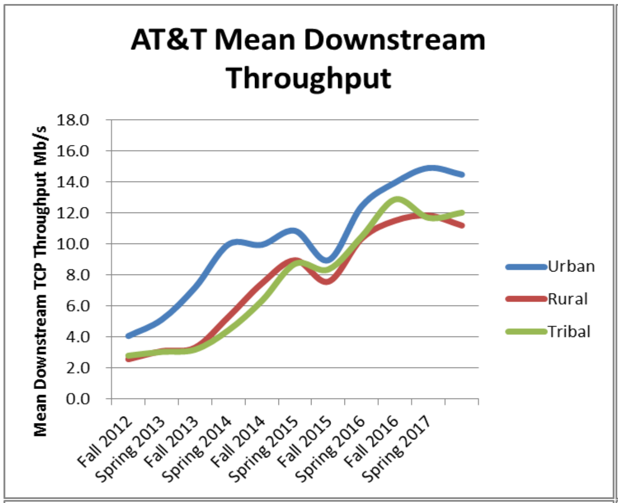


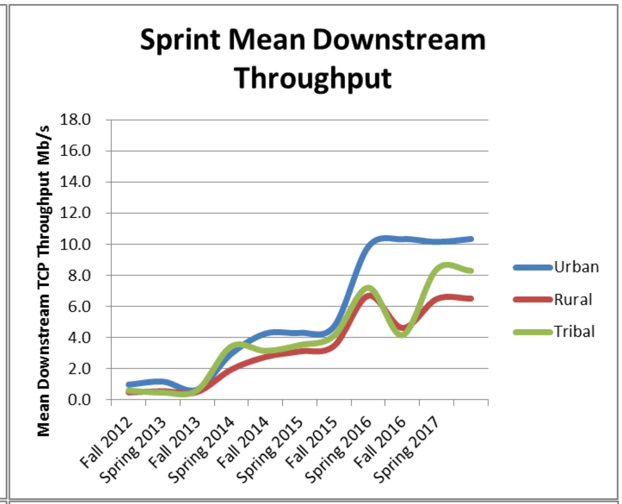


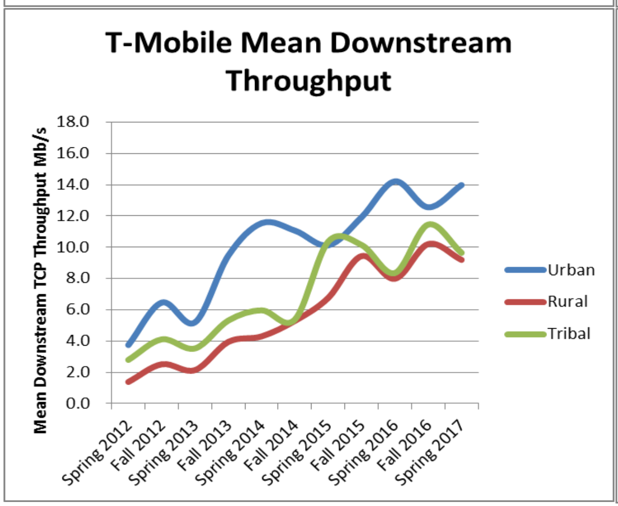
This regression of mean throughput was not limited to one demographic - we can see that all demographics, for most (AT&T, Sprint and T-Mobile) carriers show weakness in mean downstream AND upstream.

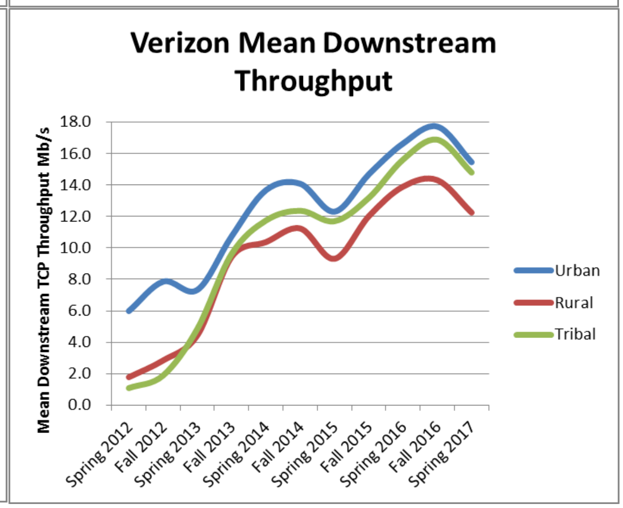
[4] For some of the earlier rounds of mobile field testing, we tested smartphones and USB modems side by side. Beginning with spring 2015 testing we replaced the USB modems with tablet devices. We see very little difference in performance between the tablets and the smartphones.

Downstream Throughput by Testing Round in Megabits-per-Second (Mb/s)

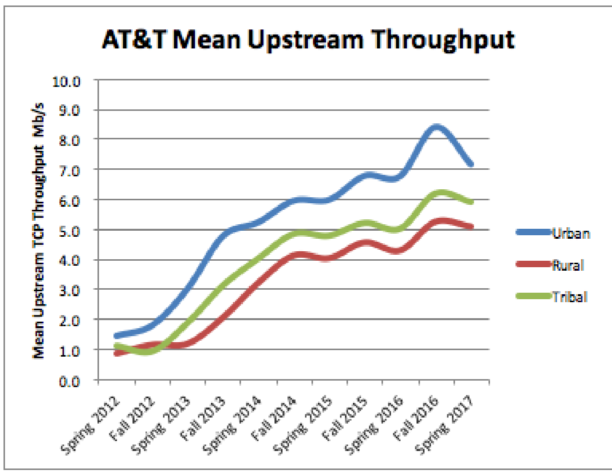


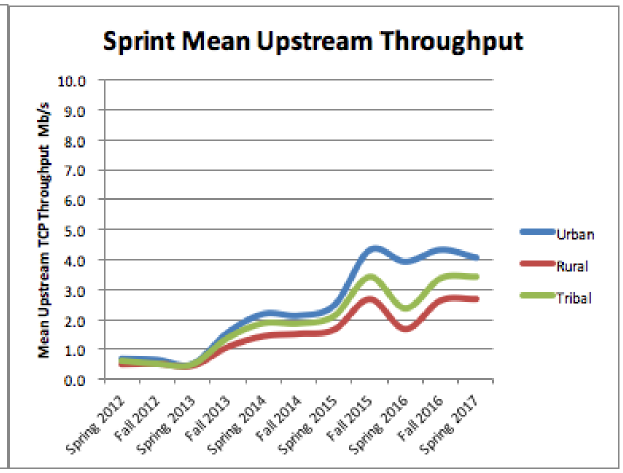


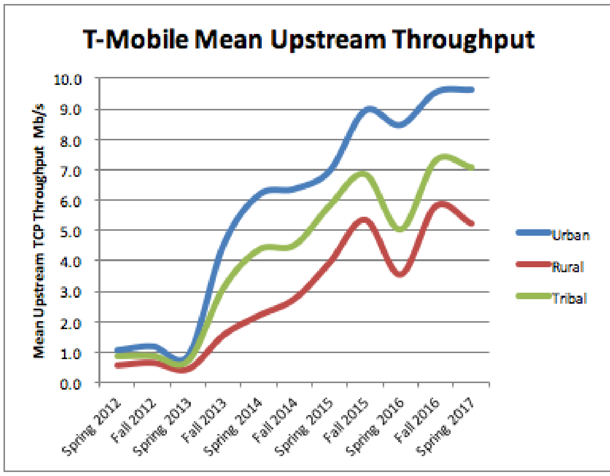


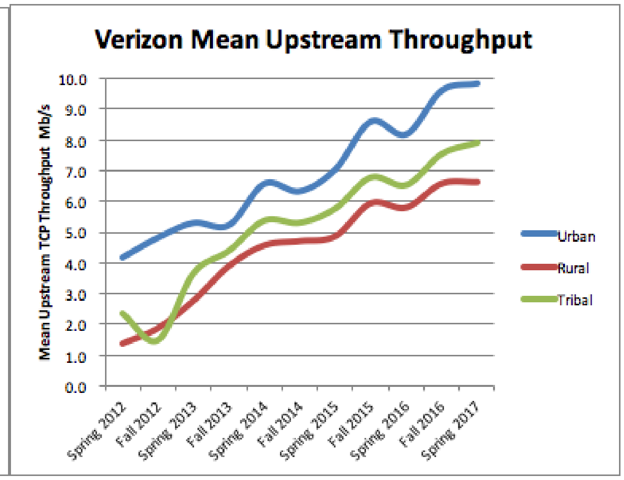


Upstream Throughput by Testing Round in Megabits-per-Second (Mb/s)





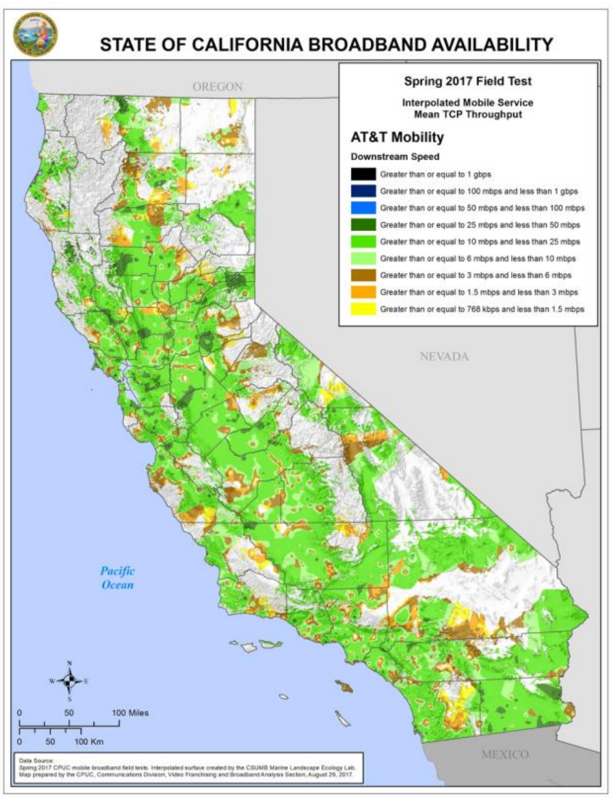




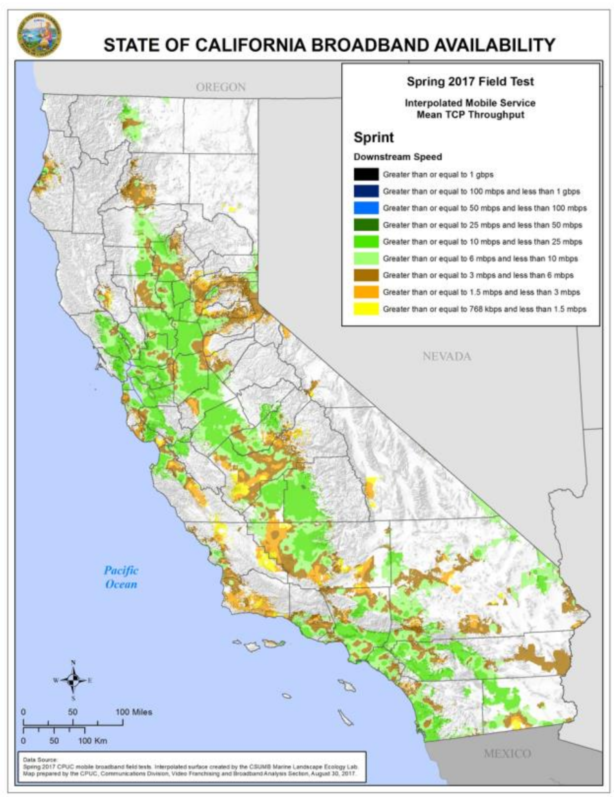
CalSPEED maps of the estimated mean downstream and upstream throughput across the state are clipped to the carrier-supplied coverage footprint.

First, estimated mean downstream throughput. AT&T and Verizon clearly have both a greater coverage footprint in California. Sprint and T-Mobile have a much smaller geographic footprint, particularly in rural California. Their rural coverage is largely confined to major road transportation corridors.

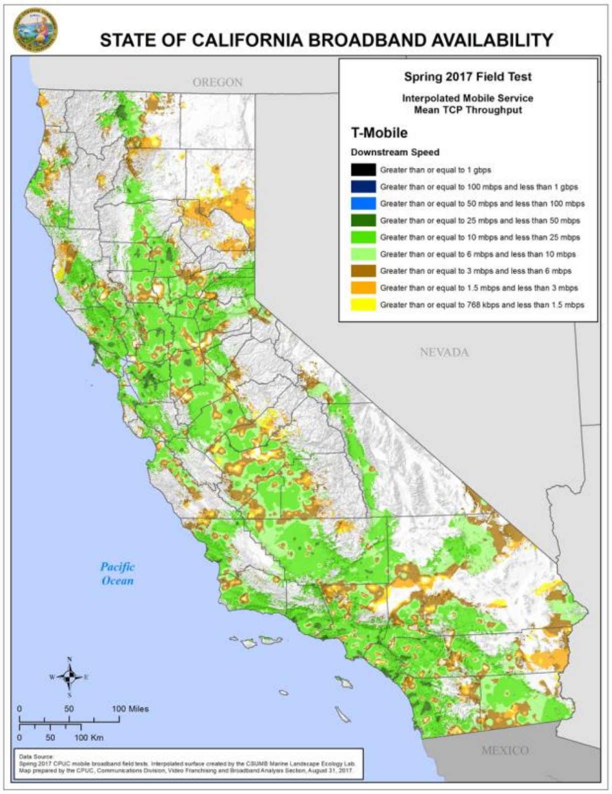
AT&T Downstream Coverage and Speed



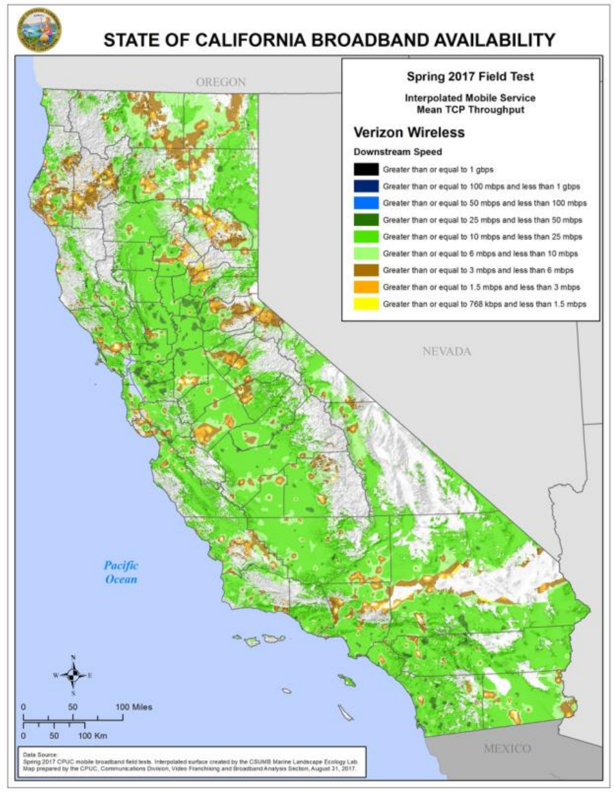
Sprint Downstream Coverage and Speed



T-Mobile Downstream Coverage and Speed

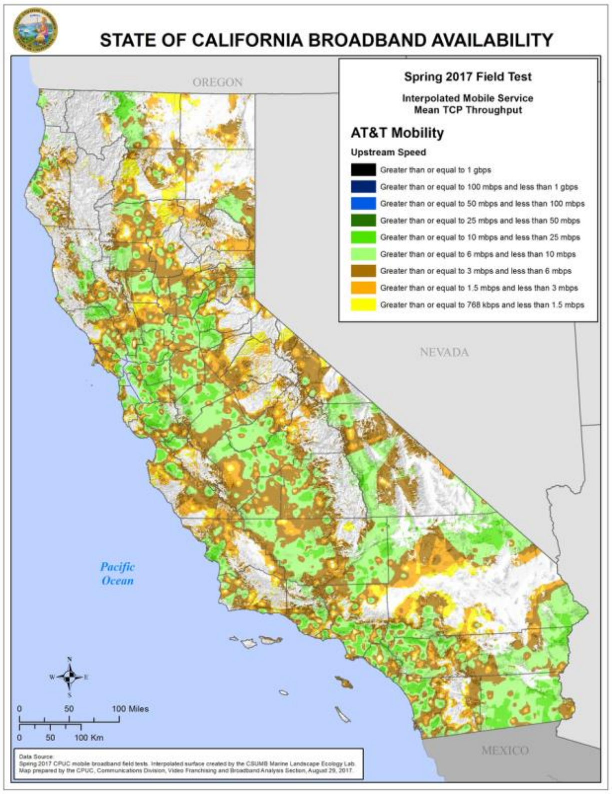


Verizon Downstream Coverage and Speed

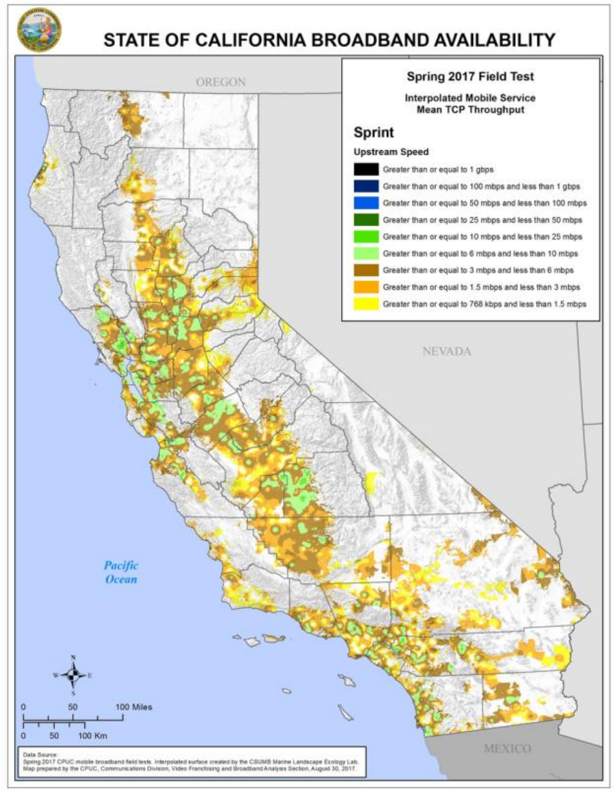


And then the estimated mean upstream throughput.

AT&T Upstream Coverage and Speed

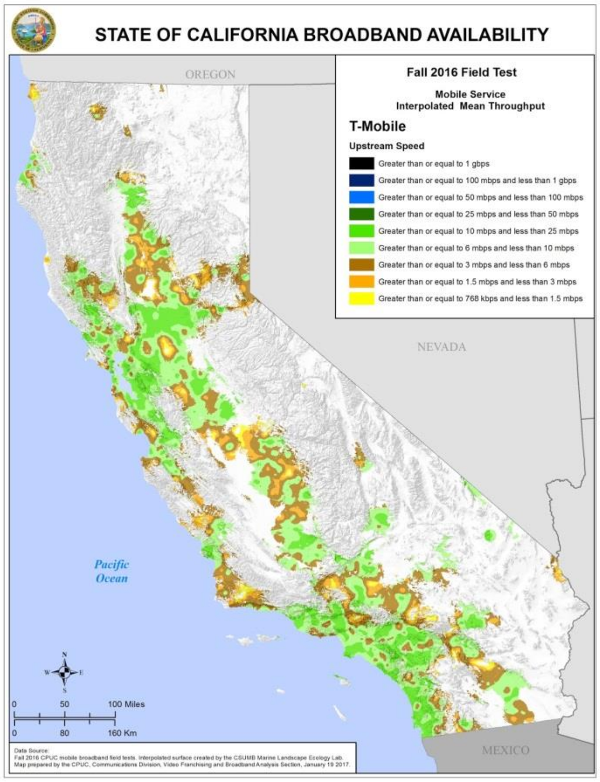


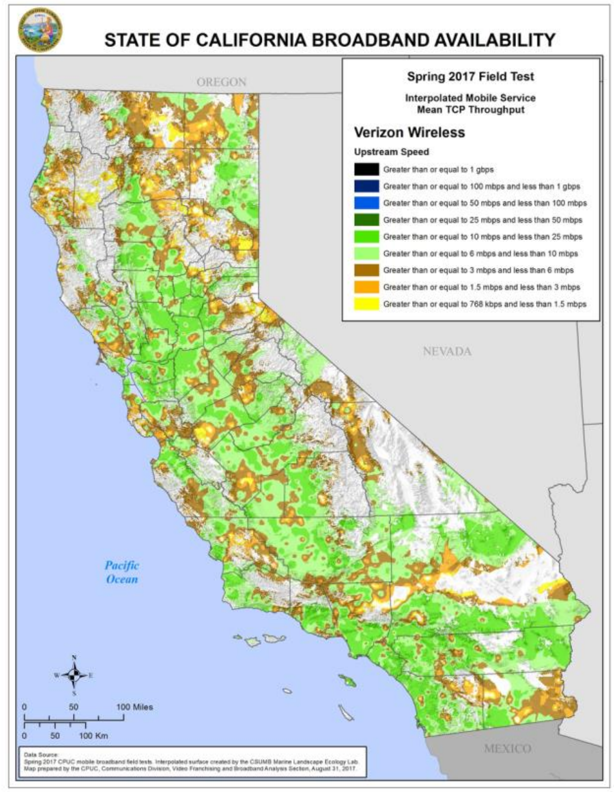
Sprint Upstream Coverage and Speed



T-Mobile Upstream Coverage and Speed

Verizon Upstream Coverage and Speed

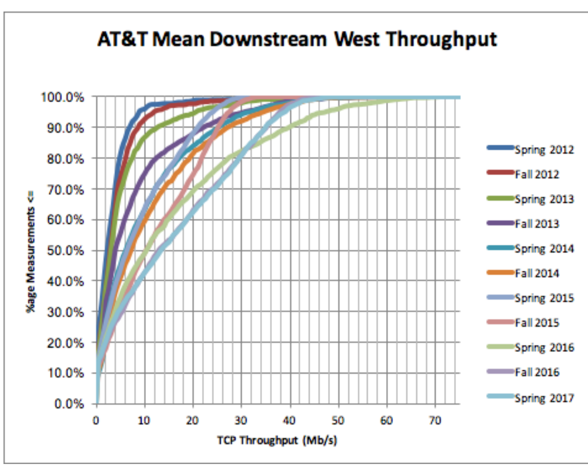


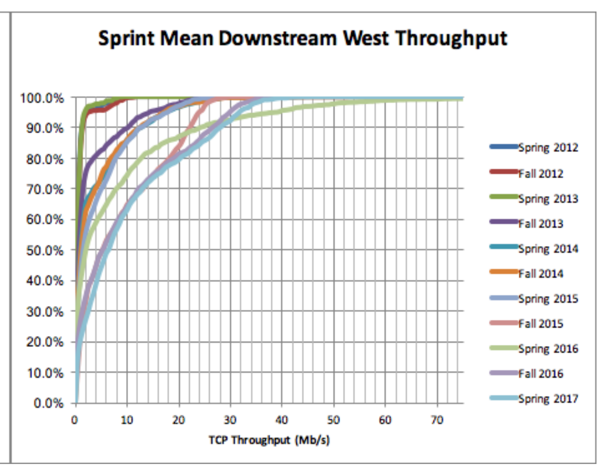


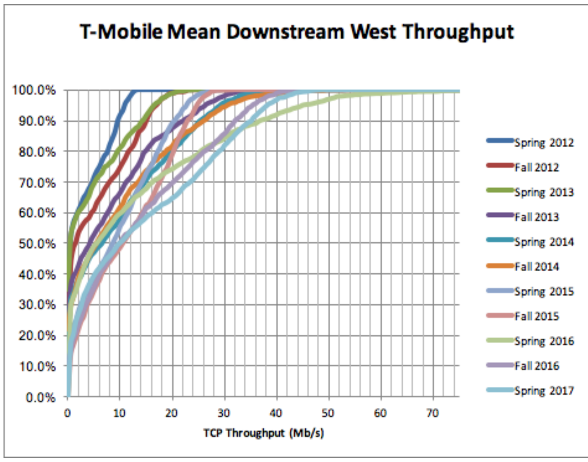
4. Performance Throttling Continues, Again

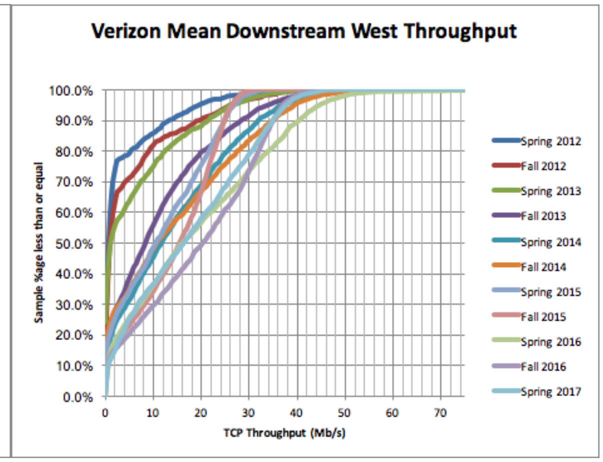
A pattern is appearing in possible high-end throughput throttling. The throttling observed in spring and fall 2015, which was not observed in spring 2016, now appears in fall 2016 and spring 2016.

This behavior can be seen in histogram plots of all the throughput measurements for each carrier.





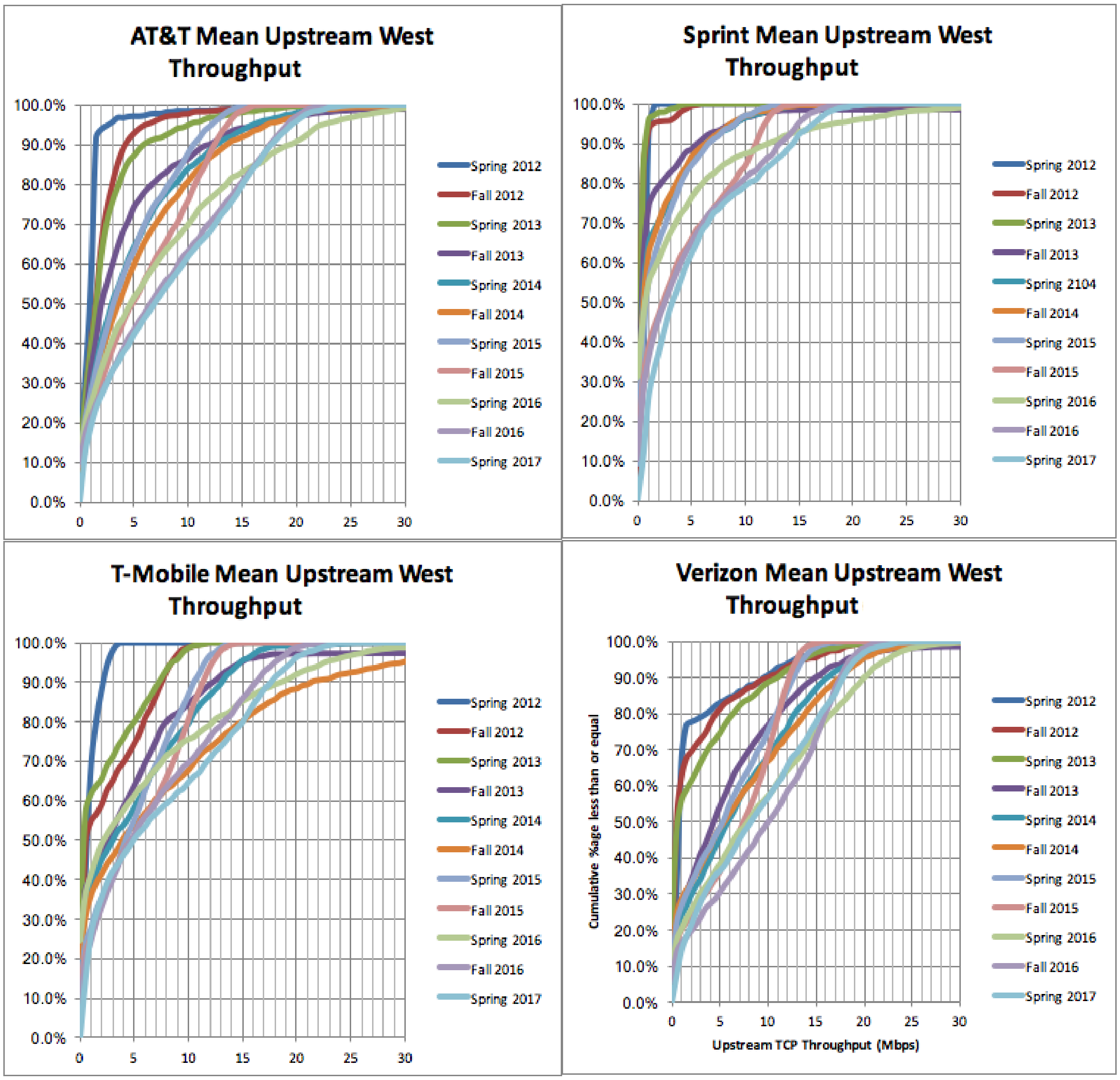




Spring and fall 2015 measurements showed clear downstream (and upstream) throughout throttling for all carriers, as demonstrated in the above cumulative histograms of downstream throughput for phones. We can see a clear change in the distribution for spring 2015. In prior measurement rounds we can see the distribution, for every carrier, move further to the right with time – indicating more measurement locations with higher performance. For spring 2015 we can see a clear difference – across all carriers – of the distribution curve moving to the left (both downstream and upstream), documenting a change in the performance distribution towards lower speeds with a clear common boundary of about 30 Mb/s. This strongly suggests intentional throttling of high performance throughput results.

This apparent throughput throttling no longer appeared in the spring 2016 measurements with strong tails to the high end of the throughput distribution with some very high performance results for all carriers. The throttling, for all carriers, had returned in the fall 2016 and continued in the spring of 2017. The downstream throttling threshold seems to have increased from the fall 2015 level of 30 Mb/s to 40 Mb/s in fall 2016.

The same pattern, at the same times, is also seen in the upstream throughput. The upstream throttling threshold seems have increased to 20 Mb/s (15 Mb/s for Sprint) in fall 2016/spring 2017 from 15 Mb/s (12.5 Mb/s for Sprint) in fall 2015.



5. Broadband Coverage Decreases

Let’s first look at broadband coverage at the 25 Mb/s down/3 Mb/s up[5] broadband benchmark, then at the 10/1 benchmark[6].

In the spring of 2015, there was a dramatic (~50%) decrease for AT&T, T-Mobile and Verizon in the number of measurement locations meeting the 25/3 benchmark. For the spring 2016 measurement round a similar dramatic increase in the number of locations meeting that benchmark is seen. The fall 2016 measurement saw a material decrease in the number of locations meeting 25/3 throughput.

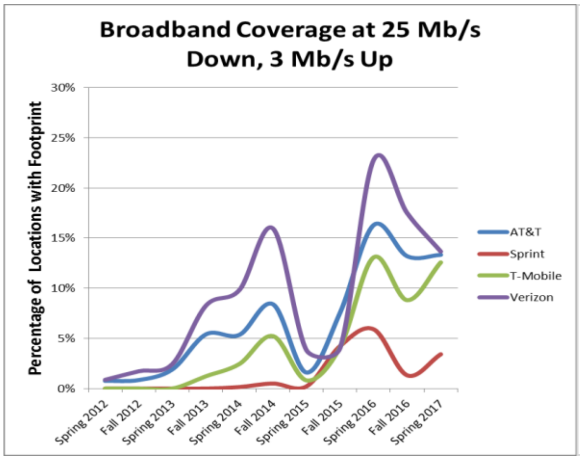
[5] The FCC established the 25/3 speed benchmark in their 2015 Broadband Progress Report to measure progress in the deployment of fixed broadband. See FCC GN Docket No. 14-126.

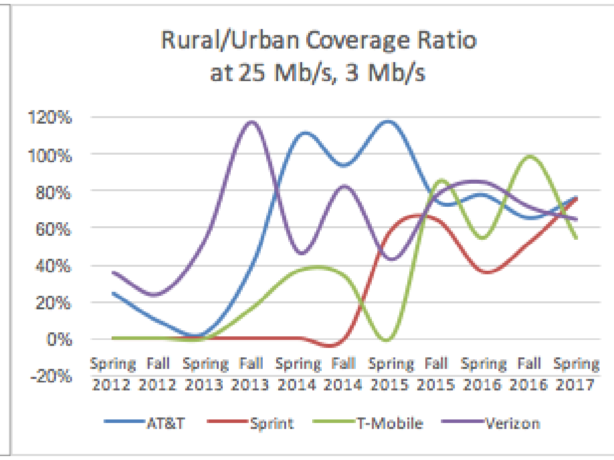
[6] Under the FCC’s Connect America Fund Phase II rules, service providers must offer broadband at speeds of at least 10 megabits per second (Mbps) downstream and 1 Mbps upstream with latency at or below 100 milliseconds round trip. See https://www.fcc.gov/consumers/guides/connect-america-fund-phase-ii-faqs.

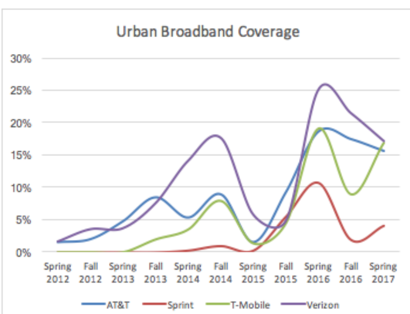
Spring 2016 measurements illustrate a convergence for AT&T, T-Mobile and Verizon at ~13% coverage.

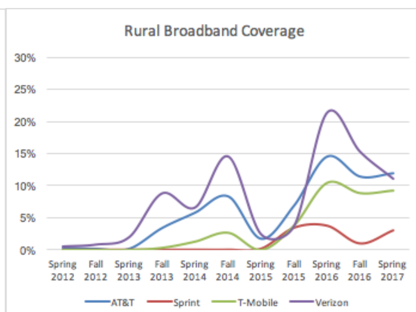
What is also interesting in the relative rural/urban coverage is the apparent stabilization at the ratio of ~70% for all carriers.

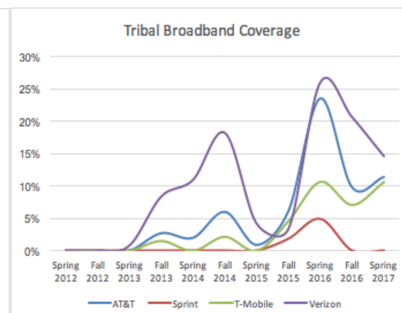
This same coverage pattern is observed for all carriers and for all demographics. Sprint uniquely has lower coverage in all demographics than the other three carriers.





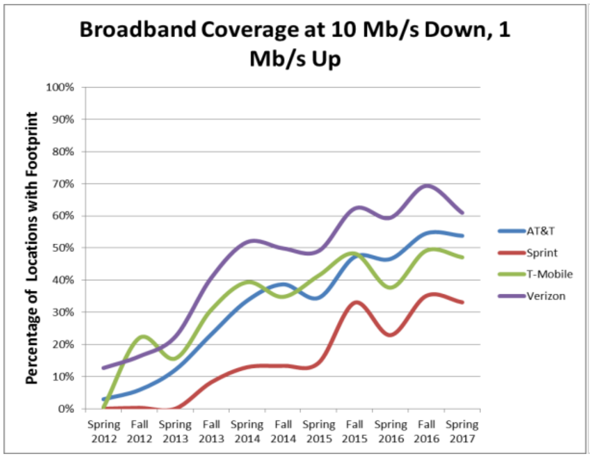


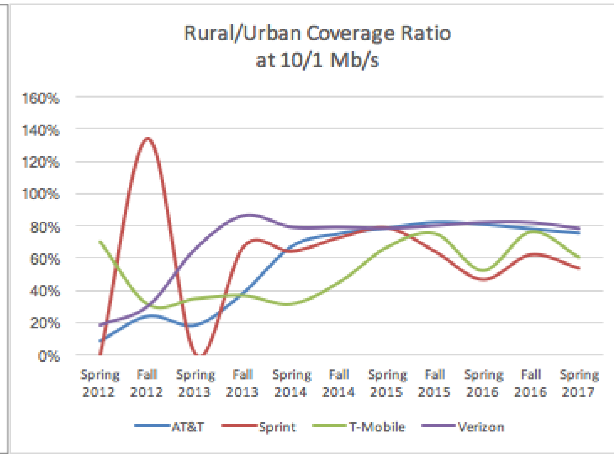


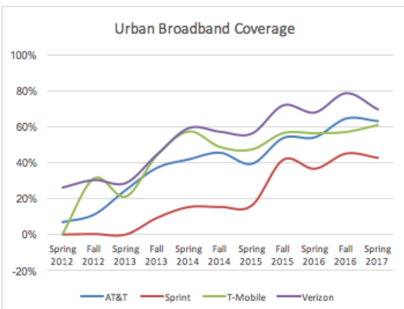


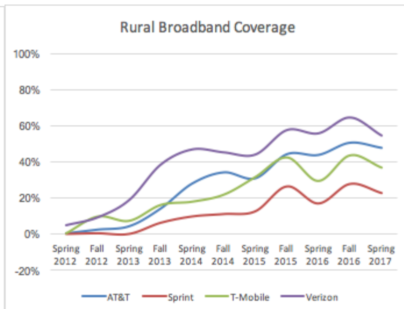
When looking at the 10/1 benchmark, we see substantive differences from the 25/3 benchmark.

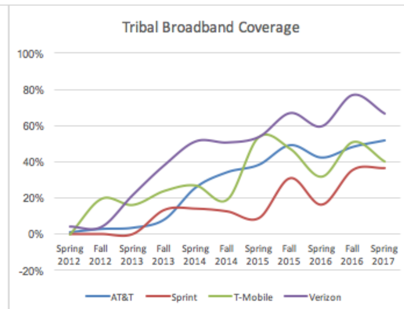
First, the average broadband coverage at 10/1 is substantially higher that at 25/3, at ~50% rather than the ~13% for 25/3. Second, the coverage at 10/1 has grown over the last 5 years at a steady rate rather than the dramatic swings at 25/3. Third, the rural/urban ratio is surprisingly similar at 10/1 (~70%) to 25/3 (70%).







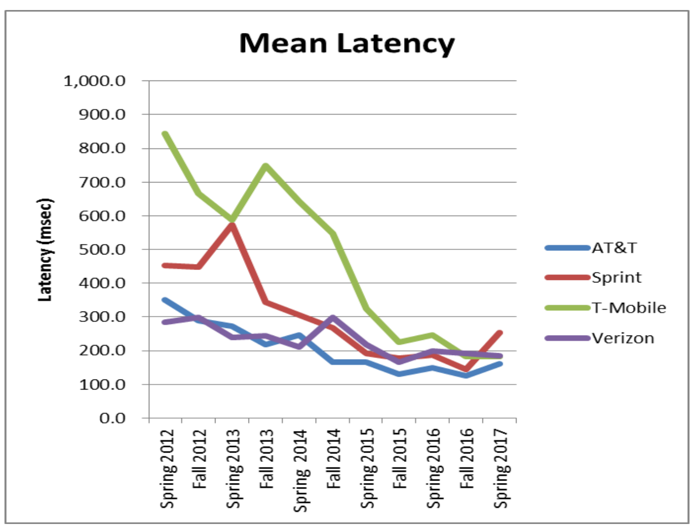


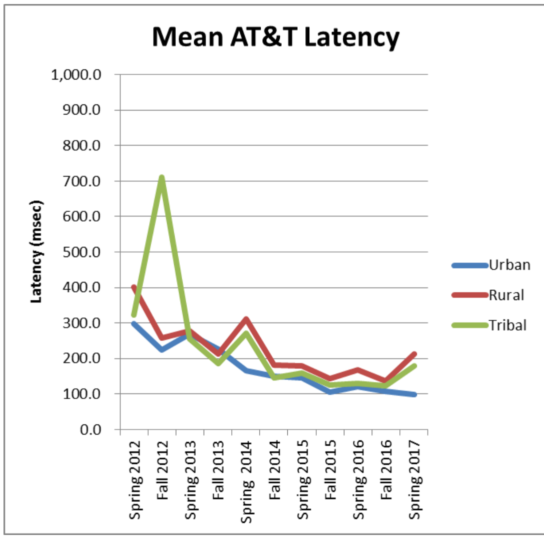


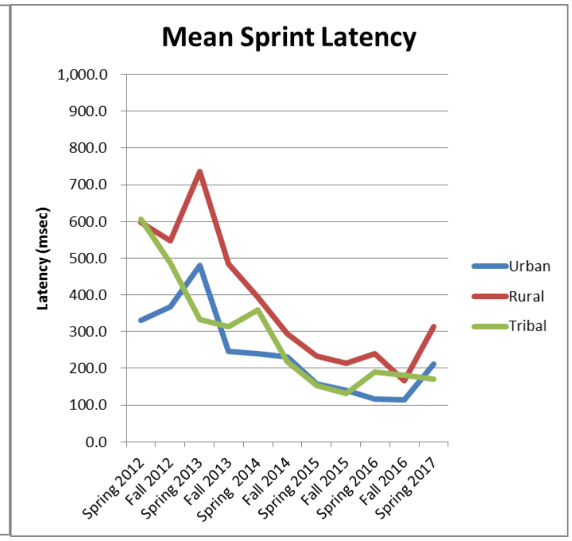
6. Measures of Service Quality Show Mixed Change

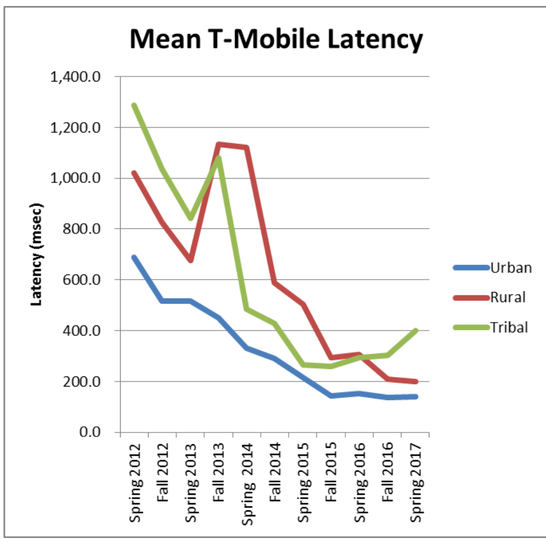
There is a mixed story in spring 2017 measurements of network quality.

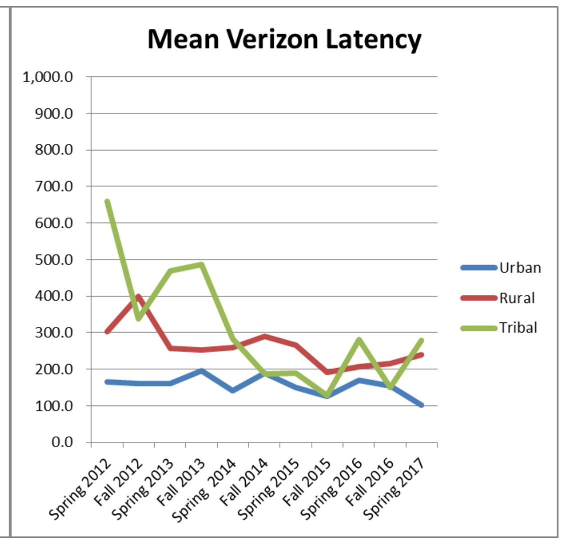
Mean latency (measured in milliseconds) worsened for both AT&T and Sprint and remained about the same for T-Mobile and Verizon. Demographic variation was somewhat unique for each carrier. For AT&T and Verizon, urban latency improved with rural and tribal worsened. For T-Mobile, there was modest improvement in urban and rural latency while tribal latency materially worsened. Sprint exhibited dramatic degradation in rural and urban latency, while tribal remained essentially unchanged.



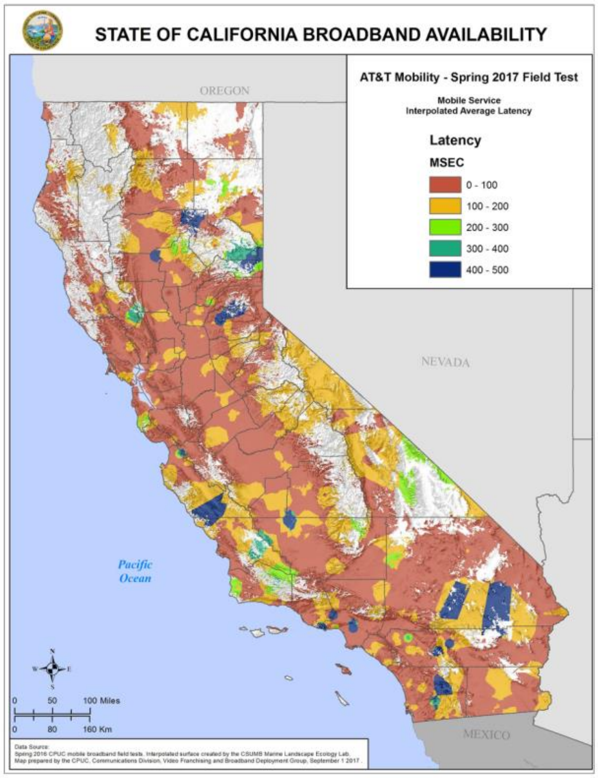


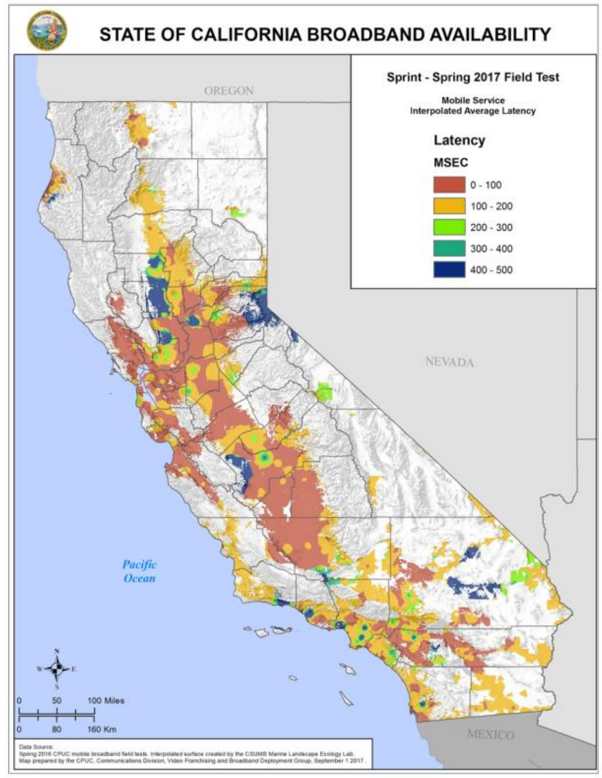


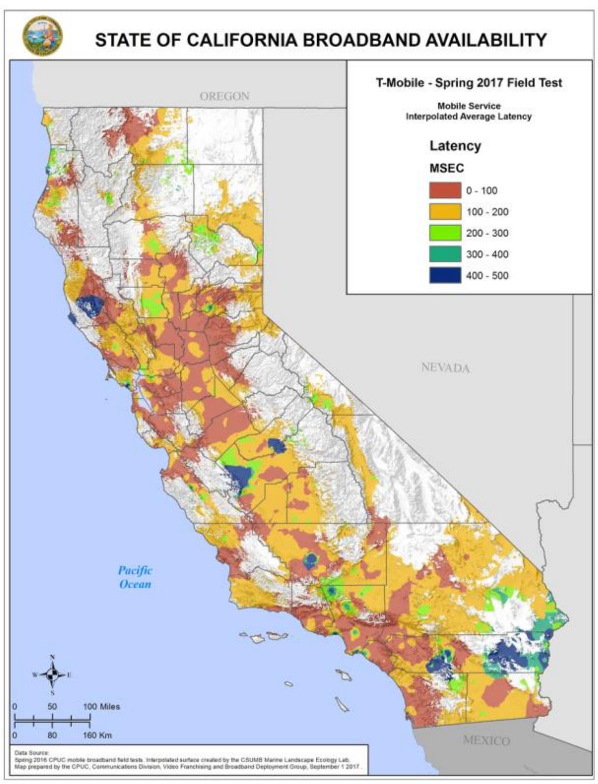


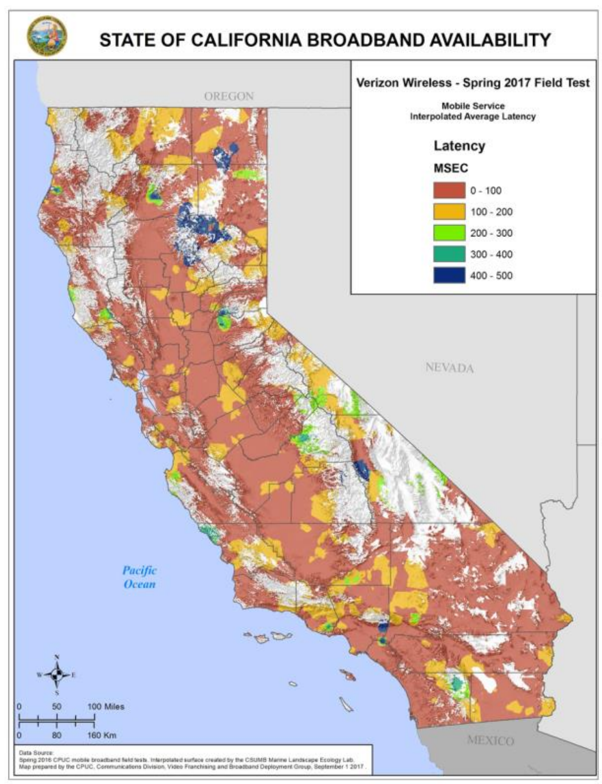


Latency varies across the state for all carriers. CalSPEED's latency maps are particularly useful for identifying specific areas of poor latency. In the following images, the warmer the color, the lower the latency

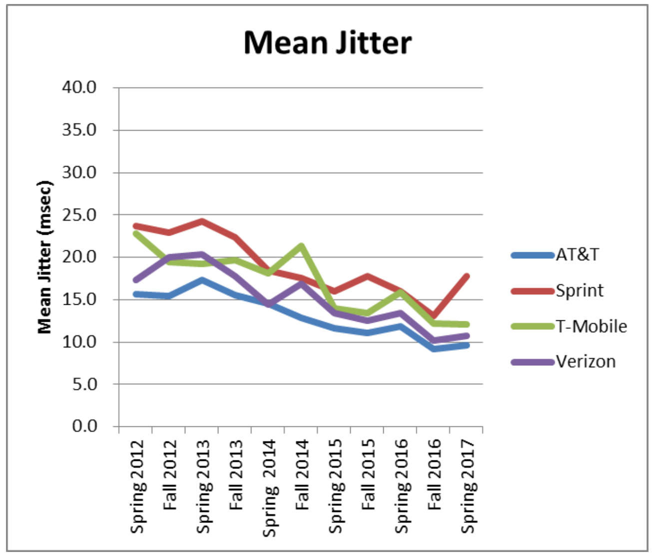

STATE OF CALIFORNIA BROADBAND AVAILABILITY
AT&T Mobility - Spring 2017 Field Test
Mobile Service
Interpolated Average Latency
Latency
MSEC
0 - 100
100 - 200
200 - 300
300 - 400
400 - 500
OREGON
NEVADA
Pacific Ocean
MEXICO
0 50 100 Miles
0 80 160 Km

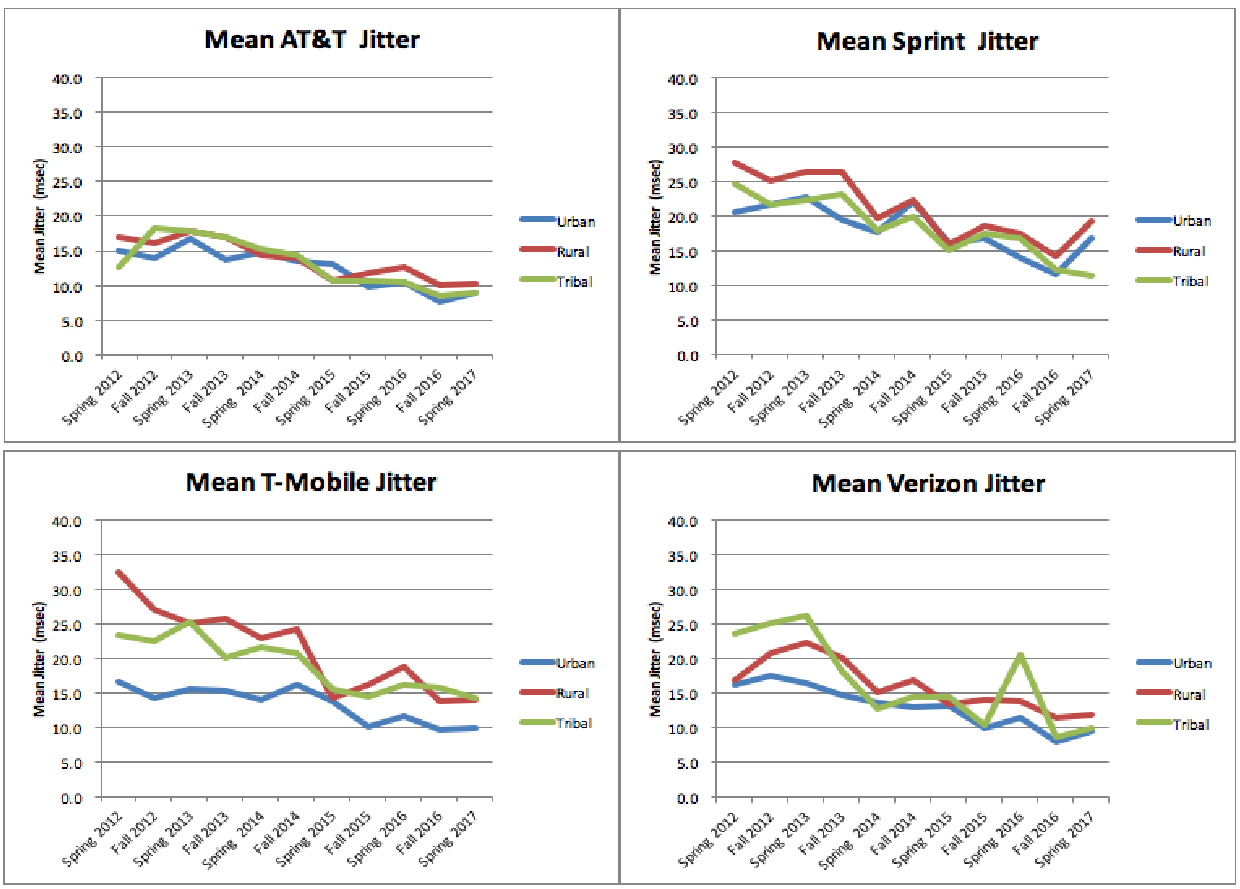

STATE OF CALIFORNIA BROADBAND AVAILABILITY
Sprint - Spring 2017 Field Test
Mobile Service
Interpolated Average Latency
Latency
MSEC
0 - 100
100 - 200
200 - 300
300 - 400
400 - 500
OREGON
NEVADA
Pacific Ocean
MEXICO
0 50 100 Miles
0 80 160 Km


STATE OF CALIFORNIA BROADBAND AVAILABILITY
T-Mobile - Spring 2017 Field Test
Mobile Service
Interpolated Average Latency
Latency
MSEC
0 - 100
100 - 200
200 - 300
300 - 400
400 - 500
OREGON
NEVADA
Pacific Ocean
MEXICO
0 50 100 Miles
0 80 160 Km


STATE OF CALIFORNIA BROADBAND AVAILABILITY
Verizon Wireless - Spring 2017 Field Test
Mobile Service
Interpolated Average Latency
Latency
MSEC
0 - 100
100 - 200
200 - 300
300 - 400
400 - 500
OREGON
NEVADA
Pacific Ocean
MEXICO
0 50 100 Miles
0 80 160 Km

Mean jitter[7] worsened for AT&T and Verizon for all demographics. Sprint demonstrated material degradation in urban and rural while showing improvement in tribal. T-Mobile showed degradation in tribal latency while staying constant in urban and rural areas.





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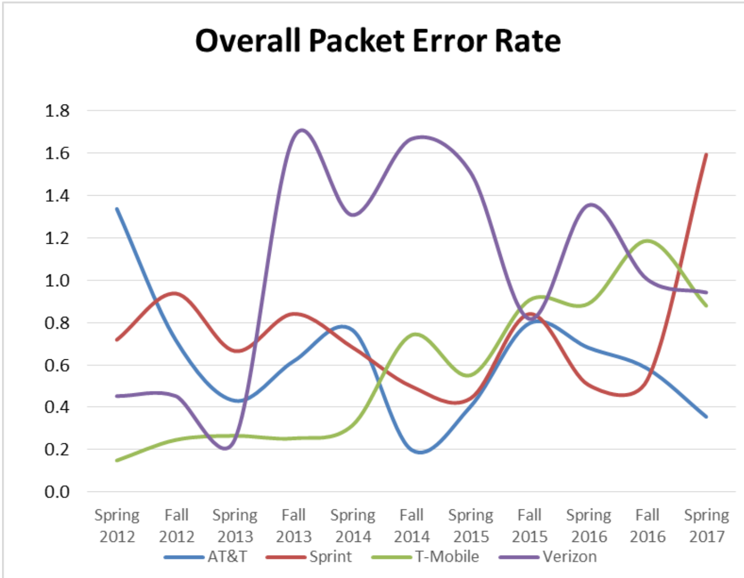
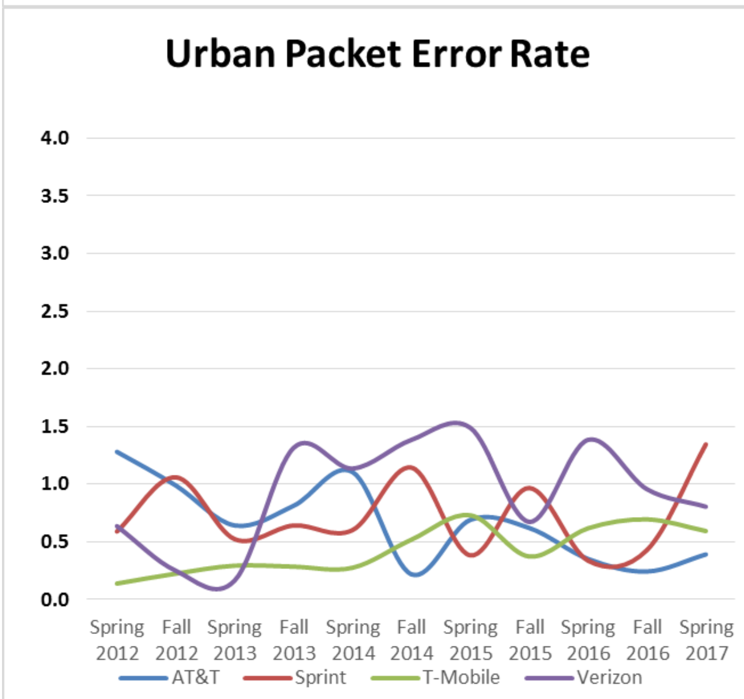
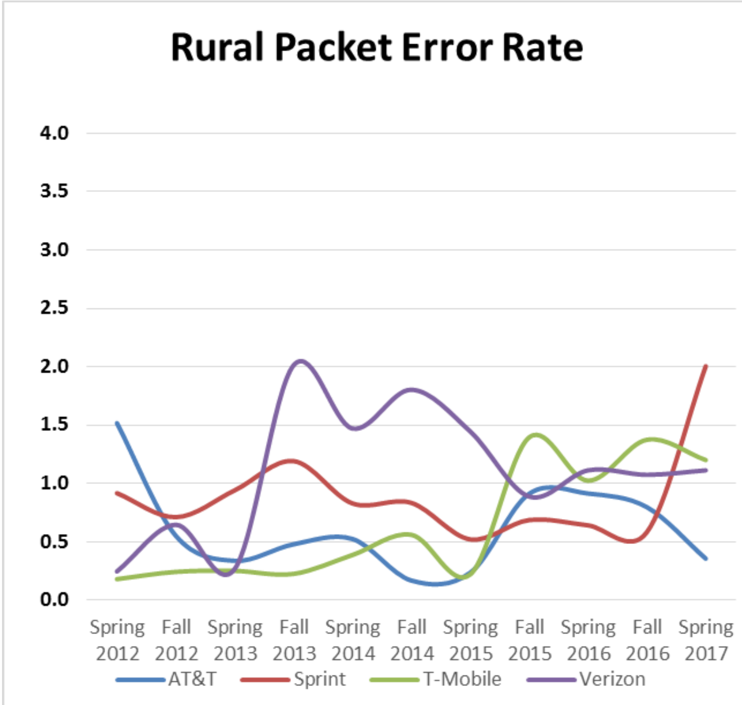
[7] Jitter is the measure of variation in latency. It is an important component of performance for real time streaming of audio and video.

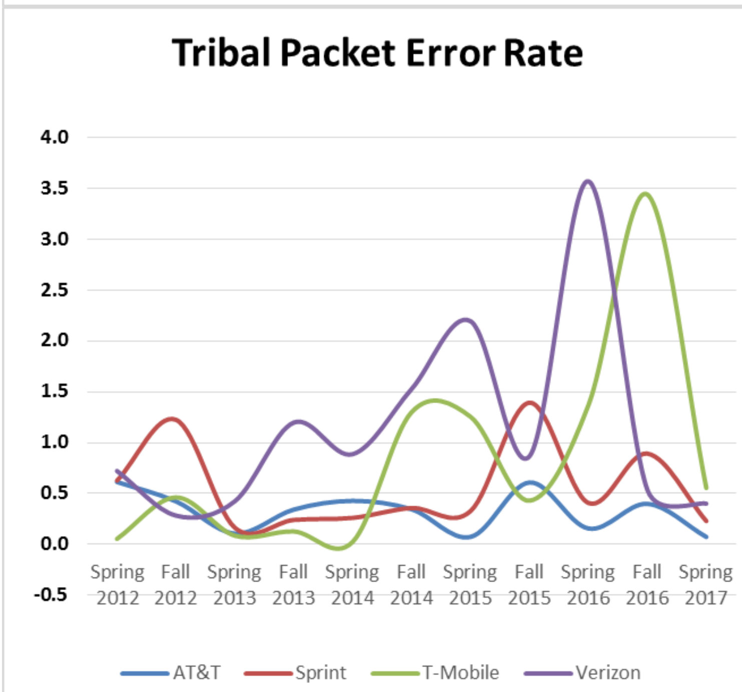
Mean packet loss[8] rates improved for AT&T, T-Mobile and Verizon and substantially worsened for Sprint. Urban packet loss degraded for AT&T and Sprint. Rural packet loss materially worsened for Sprint. Tribal packet loss improved for all carriers. On average rural has 50% more packet loss than urban for all carriers.

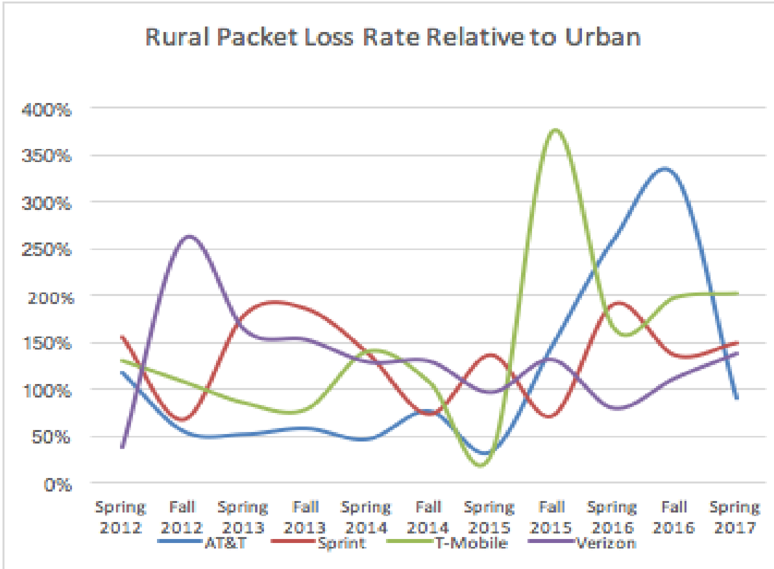




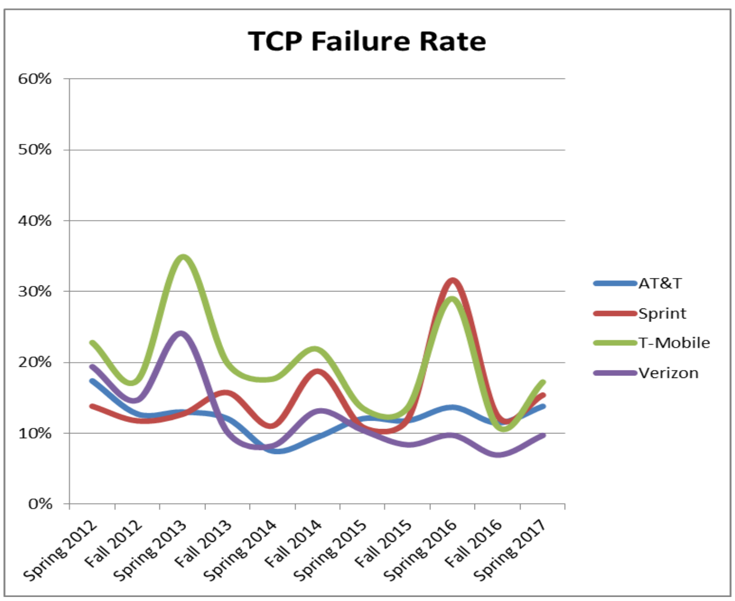
8 Mean packet loss is the average percentage of packets that are lost during transmission. Small increases in packet loss are particularly degrading for streaming media services.


Rural Packet Error Rate
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Spring 2012
Fall 2012
Spring 2013
Fall 2013
Spring 2014
Fall 2014
Spring 2015
Fall 2015
Spring 2016
Fall 2016
Spring 2017
AT&T
Sprint
T-Mobile
Verizon


Tribal Packet Error Rate
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
Spring 2012
Fall 2012
Spring 2013
Fall 2013
Spring 2014
Fall 2014
Spring 2015
Fall 2015
Spring 2016
Fall 2016
Spring 2017
AT&T
Sprint
T-Mobile
Verizon

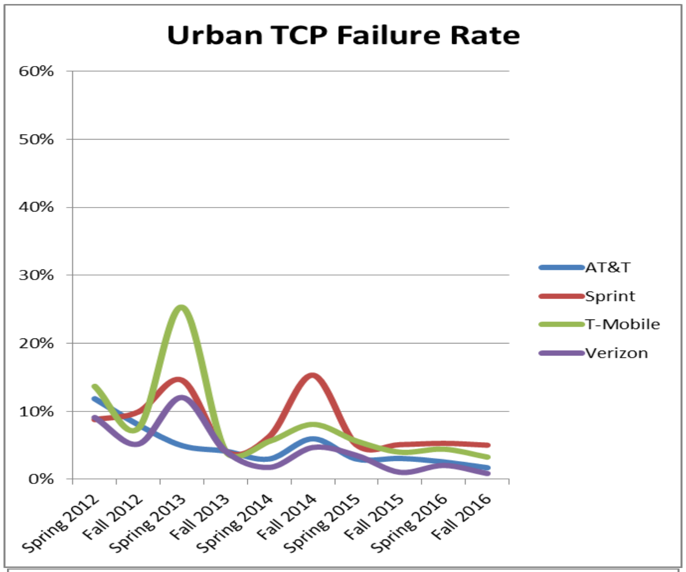


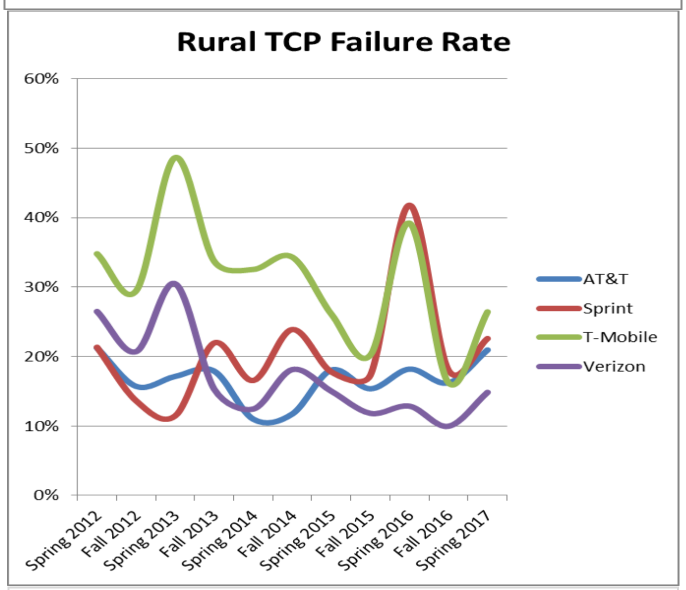
TCP connection quality[9], as measured by failed TCP connection attempts[10], worsened for all carriers. This degradation is almost entirely in rural and tribal TCP connection quality with modest improvements in urban quality. There remain profound differences between urban and rural areas with rural users having an almost 300-700% higher TCP connection failure rate over urban users even for AT&T and Verizon.

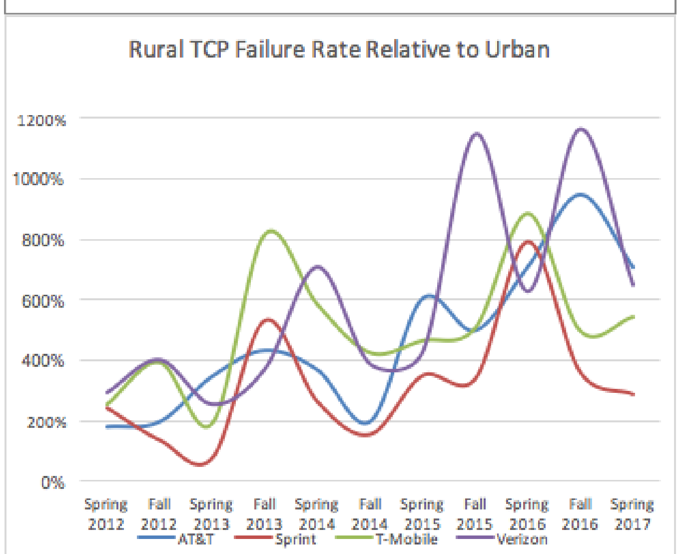


[9] The fundamental reliable connection service for the Internet is TCP - Transmission Control Protocol. It provides reliable delivery of an ordered stream of bytes and is the foundation service for web browsing, most streaming media services, email, IM and most other user Internet services. CalSPEED measures TCP quality in several ways: the failure rate of making a connection, and the consistency of the throughput during the connection - throughput variation.

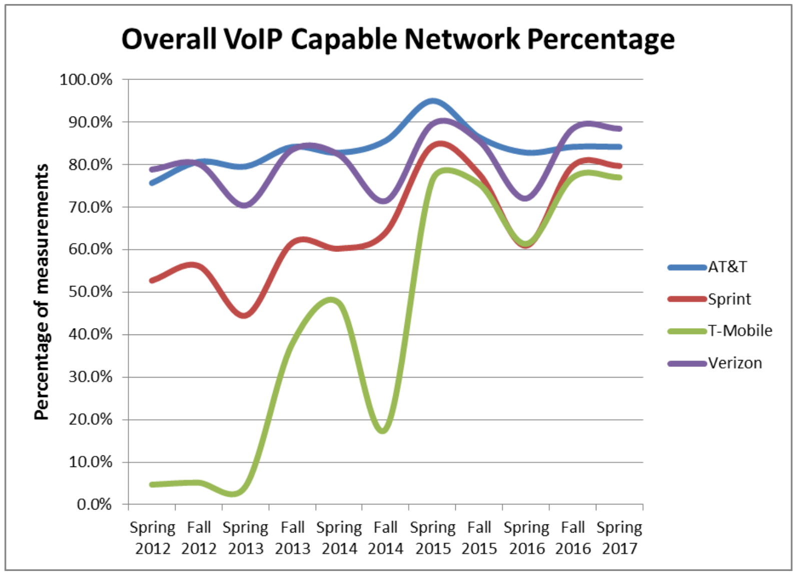
[10] TCP connection failure is a measure of how often TCP attempts to make a connection between source and destination and succeeds or fails to make the connection. It is the Internet equivalent to how often, in making a phone call that the call fails to connect to the destination.


Urban TCP Failure Rate
60%
50%
40%
30%
20%
10%
0%
Spring 2012
Fall 2012
Spring 2013
Fall 2013
Spring 2014
Fall 2014
Spring 2015
Fall 2015
Spring 2016
Fall 2016
AT&T
Sprint
T-Mobile
Verizon


Rural TCP Failure Rate
60%
50%
40%
30%
20%
10%
0%
Spring 2012
Fall 2012
Spring 2013
Fall 2013
Spring 2014
Fall 2014
Spring 2015
Fall 2015
Spring 2016
Fall 2016
Spring 2017
AT&T
Sprint
T-Mobile
Verizon

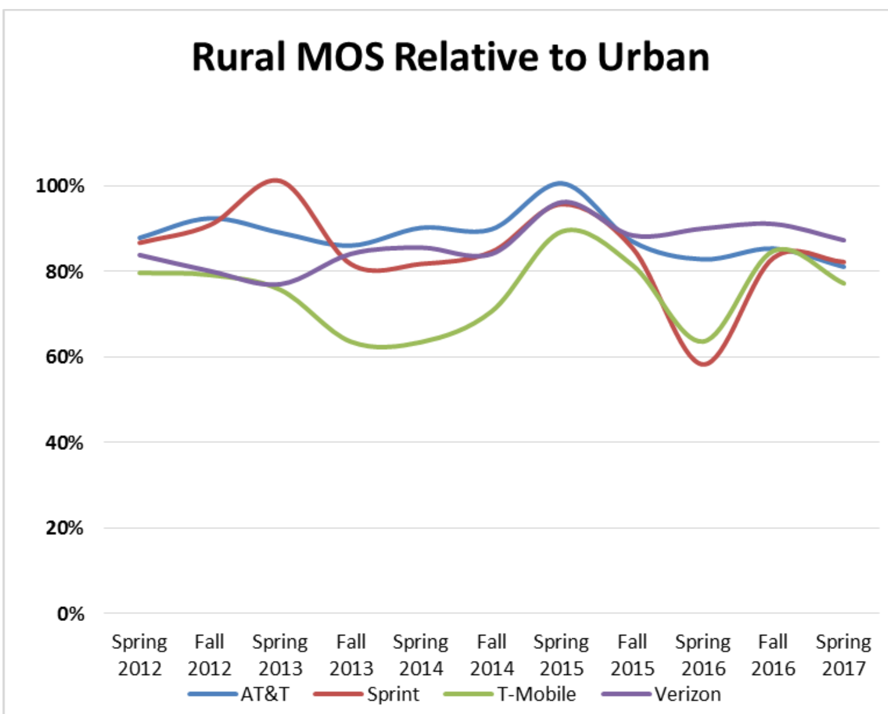

Rural TCP Failure Rate Relative to Urban
1200%
1000%
800%
600%
400%
200%
0%
Spring 2012
Fall 2012
Spring 2013
Fall 2013
Spring 2014
Fall 2014
Spring 2015
Fall 2015
Spring 2016
Fall 2016
Spring 2017
AT&T
Sprint
T-Mobile
Verizon

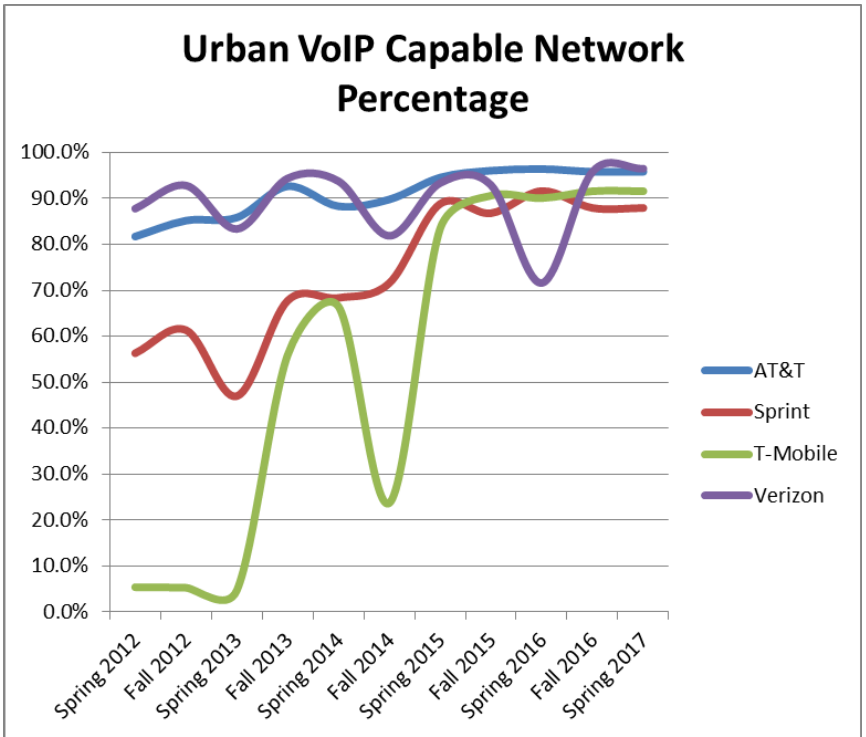
7. Over-The-Top Voice MOS Service Quality Stable



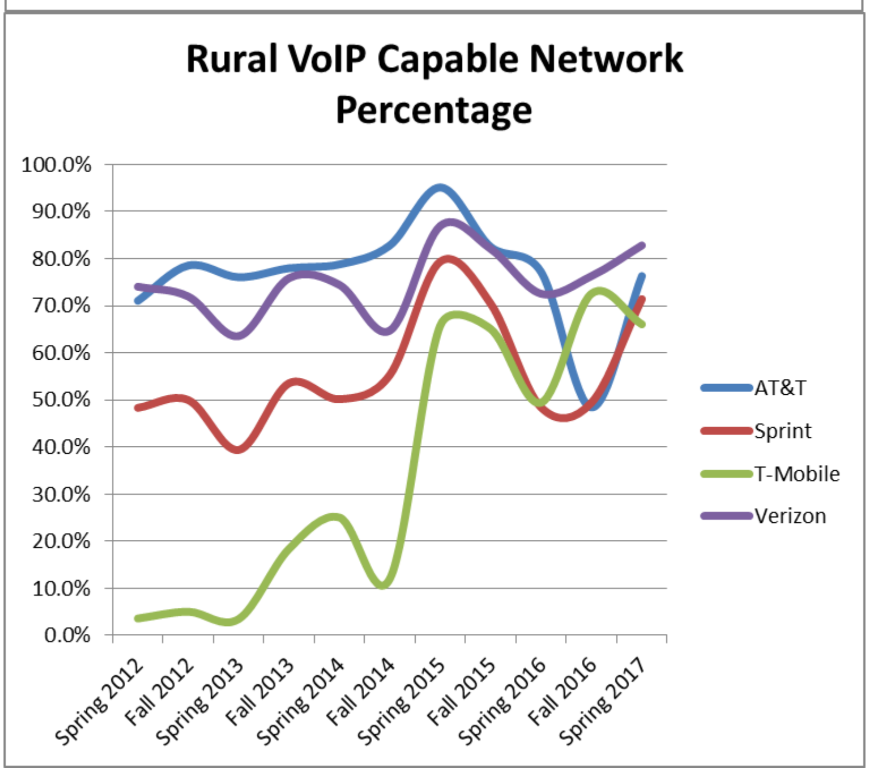
The following graphs track the number of test locations where the imputed Mean Opinion Score (MOS), which is an estimate of voice call quality, equals or exceeds 4.0 for over-the-top (OTT) voice services like Skype. The mixed results of quality metrics -- particularly in latency, jitter and packet loss -- translated into a flattening of the curve between spring 2015 and spring 2016, we noticed a drop in MOS 4.0 locations, but this degradation reversed in fall 2016. The reversal reflects improvement in the underlying latency, jitter and packet loss metrics. However, it appears that OTT VoIP coverage has still not returned to the peak of spring 2015.

While urban MOS remained stable for all carriers, all carriers still show material degradation for rural and tribal users. In particular, AT&T and Sprint showed dramatic improvements in rural and tribal OTT MOS quality. Sprint, T-Mobile and Verizon rural and tribal users show some (partial) recovery but AT&T rural and tribal users show materially increased degradation.

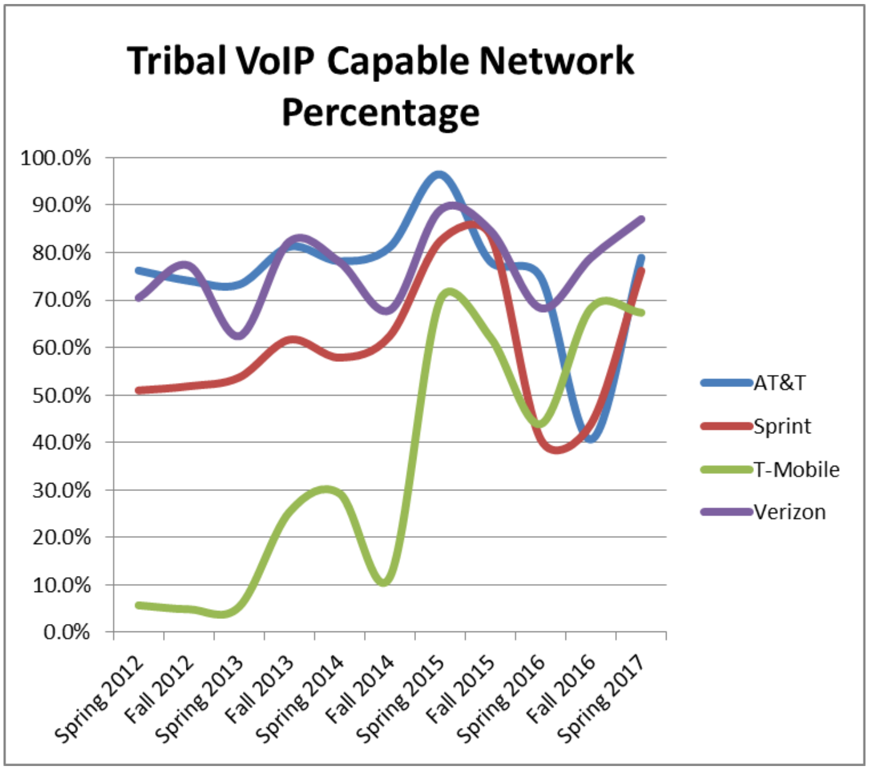




Urban VoIP Capable Network Percentage
100.0%
90.0%
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
Spring 2012
Fall 2012
Spring 2013
Fall 2013
Spring 2014
Fall 2014
Spring 2015
Fall 2015
Spring 2016
Fall 2016
Spring 2017
AT&T
Sprint
T-Mobile
Verizon



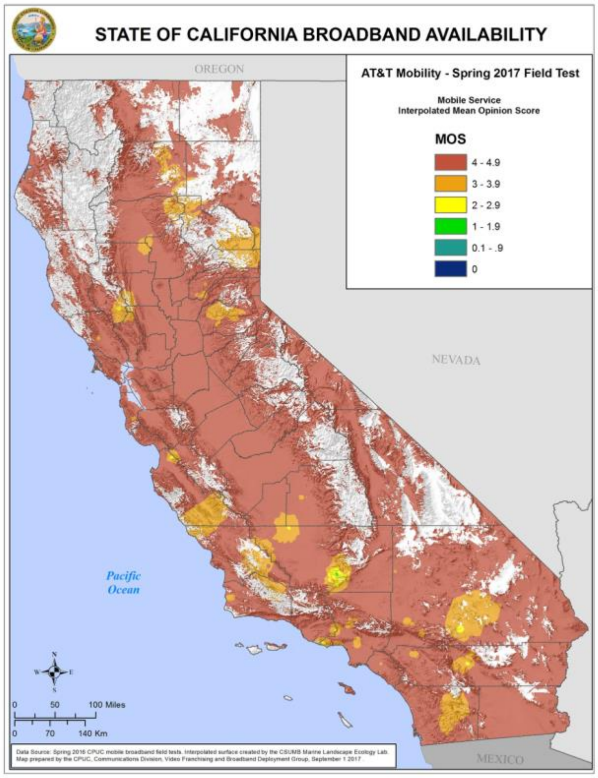
Rural VoIP Capable Network Percentage
100.0%
90.0%
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
Spring 2012
Fall 2012
Spring 2013
Fall 2013
Spring 2014
Fall 2014
Spring 2015
Fall 2015
Spring 2016
Fall 2016
Spring 2017
AT&T
Sprint
T-Mobile
Verizon

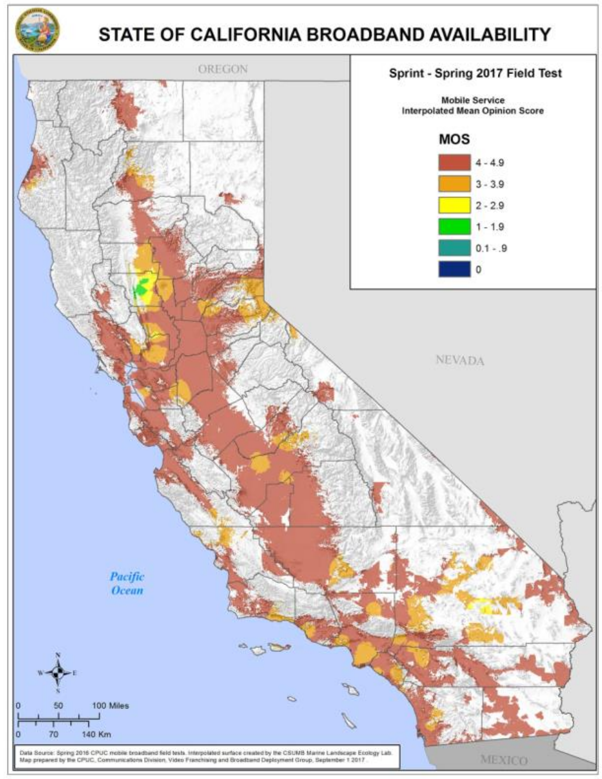


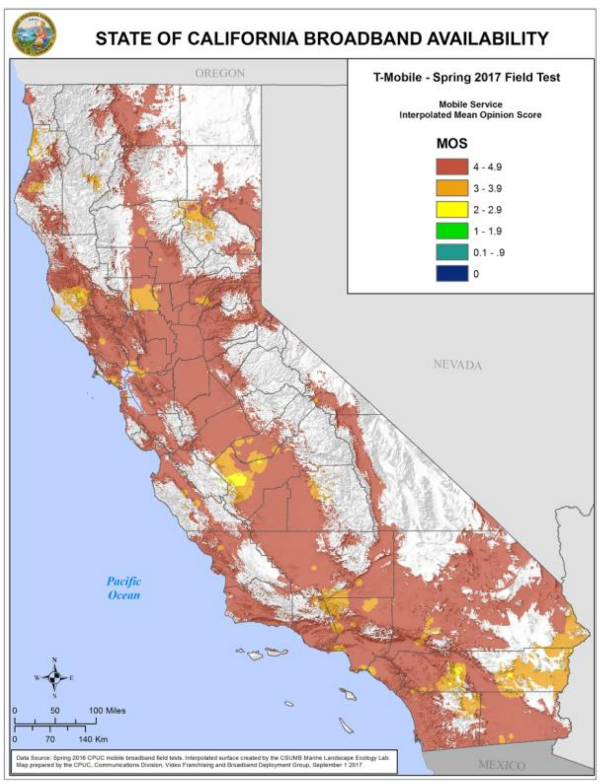
The ratio of average rural OTT MOS quality to urban has been stable during the entire time CalSPEED has been measuring OTT MOS - at ~85%.

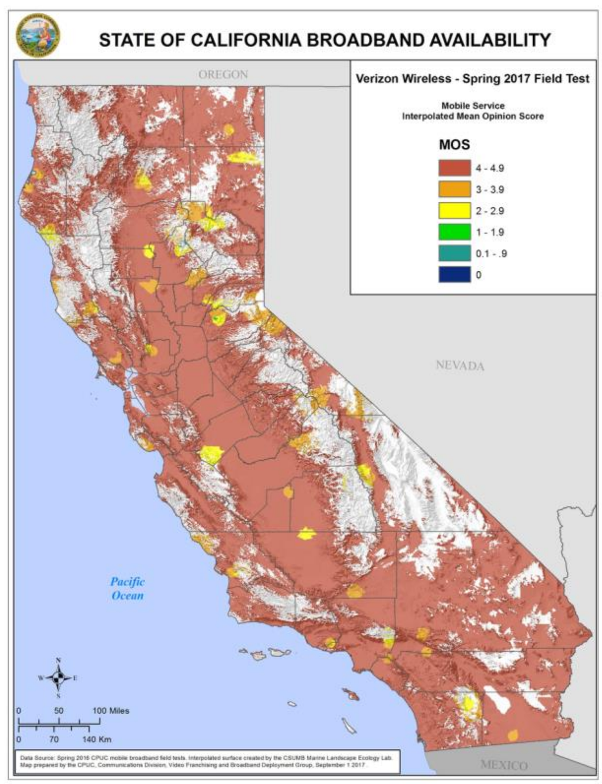
CalSPEED maps OTT voice MOS across the state for each carrier. AT&T and Verizon both have extensive OTT voice service across the state, with Sprint and T-Mobile limited to dense urban areas and major transportation routes.

Note that every carrier has spots of poor service in which OTT voice (and likely video) will likely not be possible due to quality. OTT voice is likely not reliable in any location not colored red. As with the latency maps, the warmer the color, the better the performance, with red being voice-grade quality.


STATE OF CALIFORNIA BROADBAND AVAILABILITY
AT&T Mobility - Spring 2017 Field Test
Mobile Service
Interpolated Mean Opinion Score
MOS
4 - 4.9
3 - 3.9
2 - 2.9
1 - 1.9
0.1 - .9
0
OREGON
NEVADA
Pacific Ocean
MEXICO
0 50 100 Miles
0 70 140 Km
Data Source: Spring 2016 CPUC mobile broadband field tests. Interpolated surface created by the CSUMB Marine Landscape Ecology Lab.
Map prepared by the CPUC, Communications Division, Video Franchising and Broadband Deployment Group, September 1 2017


STATE OF CALIFORNIA BROADBAND AVAILABILITY
Sprint - Spring 2017 Field Test
Mobile Service
Interpolated Mean Opinion Score
MOS
4 - 4.9
3 - 3.9
2 - 2.9
1 - 1.9
0.1 - .9
0
OREGON
NEVADA
Pacific Ocean
MEXICO
0 50 100 Miles
0 70 140 Km
Data Source: Spring 2016 CPUC mobile broadband field tests. Interpolated surface created by the CSUMB Marine Landscape Ecology Lab.
Map prepared by the CPUC, Communications Division, Video Franchising and Broadband Deployment Group, September 1 2017


STATE OF CALIFORNIA BROADBAND AVAILABILITY
T-Mobile - Spring 2017 Field Test
Mobile Service
Interpolated Mean Opinion Score
MOS
4 - 4.9
3 - 3.9
2 - 2.9
1 - 1.9
0.1 - .9
0
OREGON
NEVADA
Pacific Ocean
MEXICO
0 50 100 Miles
0 70 140 Km
Data Source: Spring 2016 CPUC mobile broadband field tests. Interpolated surface created by the CSUMB Marine Landscape Ecology Lab.
Map prepared by the CPUC, Communications Division, Video Franchising and Broadband Deployment Group, September 1 2017


STATE OF CALIFORNIA BROADBAND AVAILABILITY
Verizon Wireless - Spring 2017 Field Test
Mobile Service
Interpolated Mean Opinion Score
MOS
4 - 4.9
3 - 3.9
2 - 2.9
1 - 1.9
0.1 - .9
0
OREGON
NEVADA
Pacific Ocean
MEXICO
0 50 100 Miles
0 70 140 Km
Data Source: Spring 2016 CPUC mobile broadband field tests. Interpolated surface created by the CSUMB Marine Landscape Ecology Lab.
Map prepared by the CPUC, Communications Division, Video Franchising and Broadband Deployment Group, September 1 2017

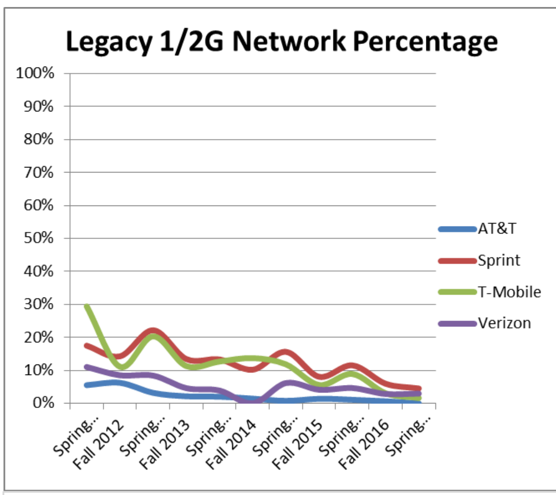
8. Technology Deployment Appears Stable

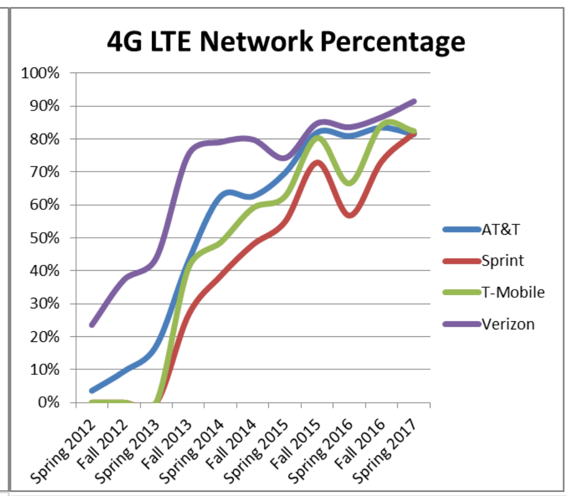
The deployment of LTE as well as the replacement of legacy 1G and 2G wireless access networks appears unchanged from the last four measurement rounds. The data suggests that as of the spring 2017 measurement, deployment of urban LTE is capped at between 90-95% of the measurement locations. Rural LTE deployment is at 70-85% of measured locations. Urban LTE deployment has remained stable since fall 2015.

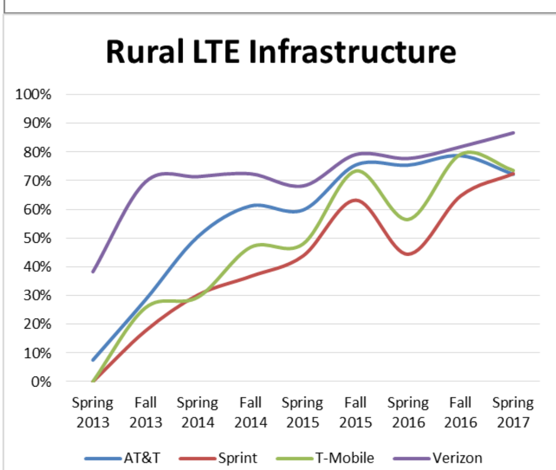
Legacy 1 and 2G networks appear to have hit a floor of removal at between 1-3% of measurement locations while legacy rural deployments are still between 2 and 9% (Sprint being the hindmost). Notably, for spring 2017, AT&T has registered no legacy 1/2G networks in any demographic.

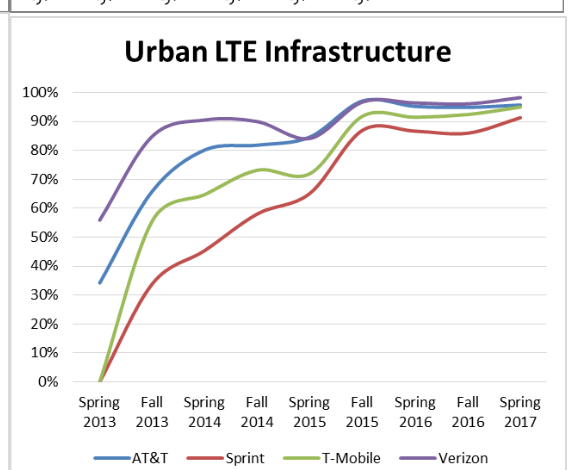
Rural users will encounter legacy service between 5 and 10 times more often than urban users for Sprint and T-Mobile, while for AT&T the likelihood is near zero. Rural users will experience LTE service only about 80% as often as urban users.

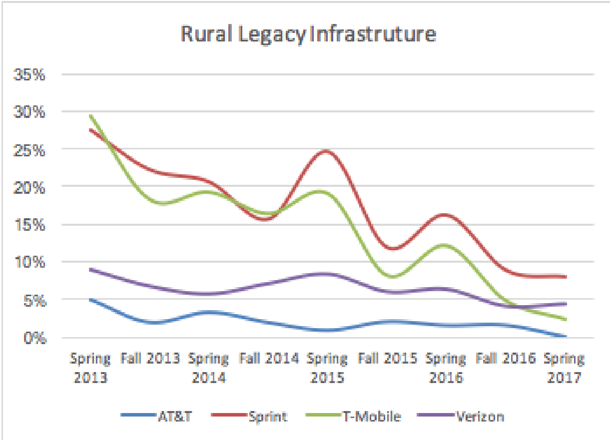
Advanced network services (such as VoIP and streaming video) are really only practical on LTE, and the extent to which LTE is not available, or legacy services are experienced instead, will dramatically degrade mobile broadband for rural and tribal users.

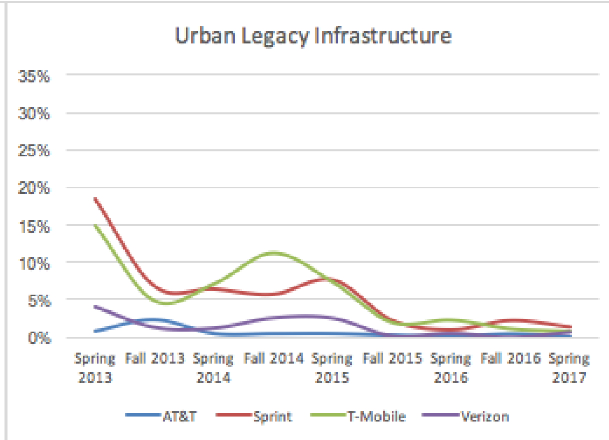


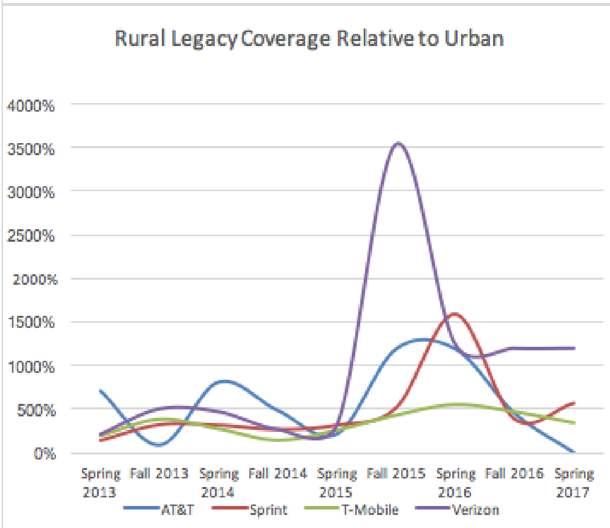


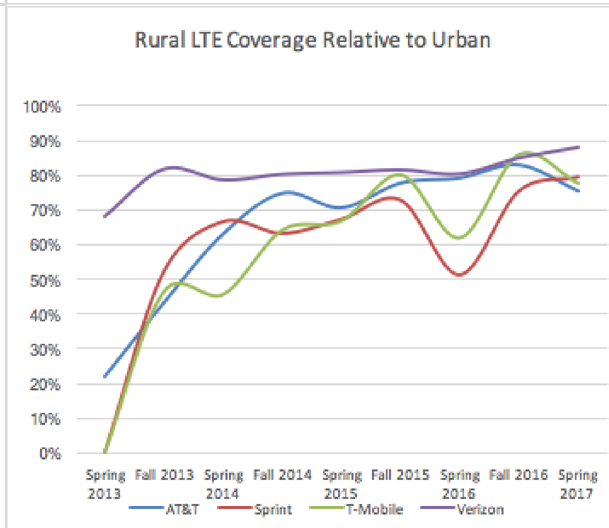












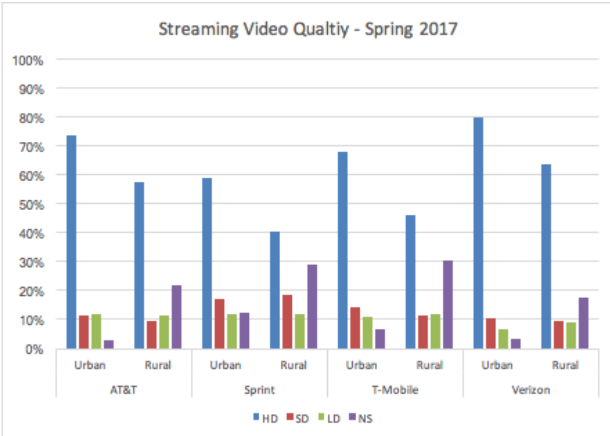
9. Video Quality Worsens

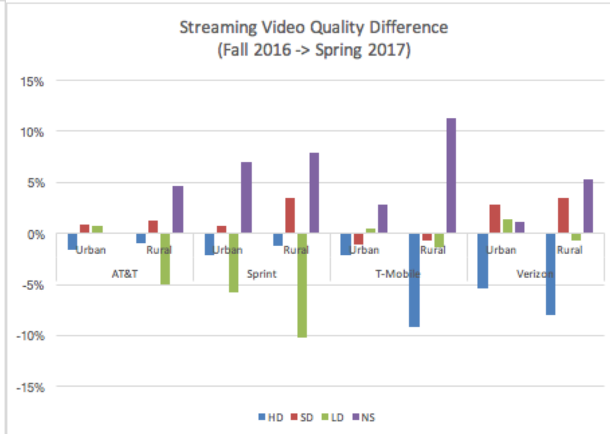
CalSPEED estimates over-the-top Internet video performance - both streaming (e.g. YouTube and Netflix) and interactive (e.g. Skype and FaceTime).

9.1 Video Streaming

Video streaming is the service of viewing a video, in real-time, stored on an Internet server. In order to reduce Internet traffic and improve video performance, most video content providers cache video content as close to the viewing user as possible to minimize latency and increase throughput. CalSPEED approximates this caching by estimating video streaming performance as downstream TCP throughput from the west server. The first analysis of CalSPEED video was for the spring 2015 measurement[11] and the analysis in this paper is the fifth update measurement from those conclusions.

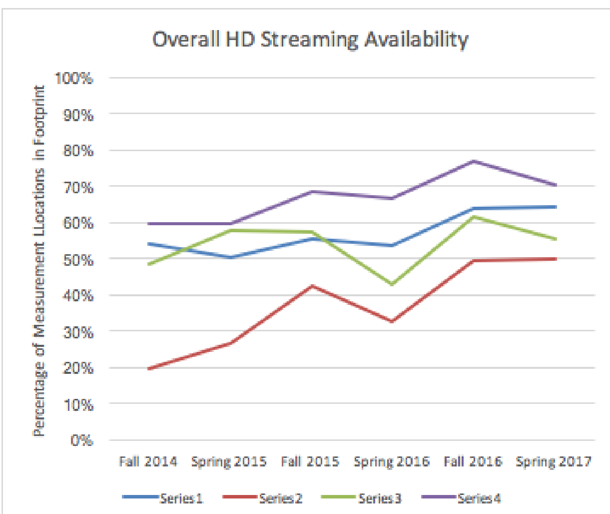
[11] Biba, Ken, "Wireless Video in California - Spring 2015", Novarum, Inc. January 2016

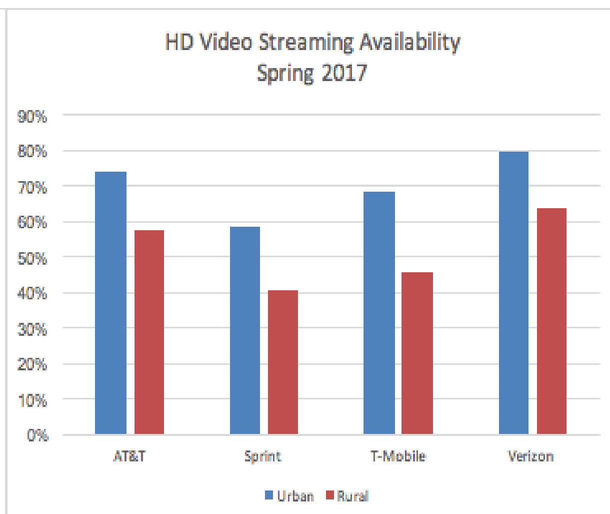




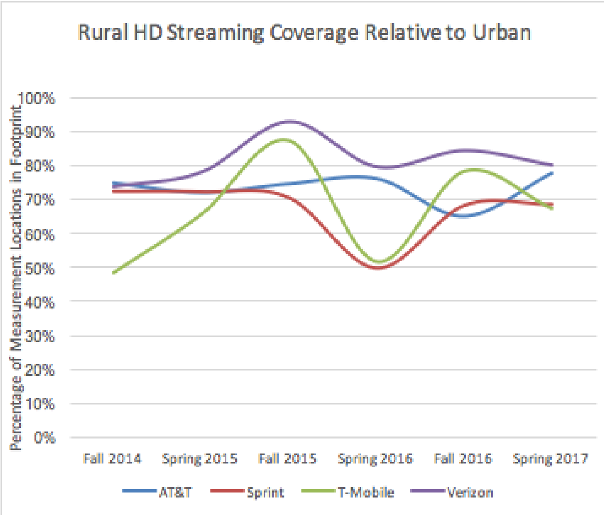
Spring 2017 streaming video quality has overall worsened for all carriers, with fewer measurement locations reporting high definition (HD) quality and more reporting no service (NS), standard definition (SD), or low definition (LD) quality. HD streaming video coverage for tribal users has decreased for all carriers, but most dramatically for Sprint and T-Mobile.

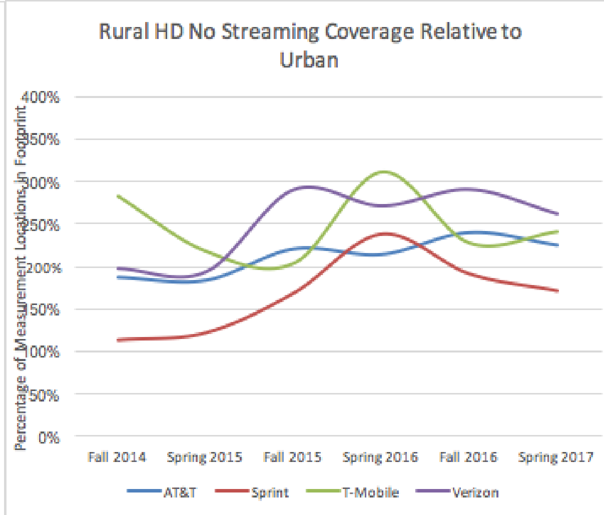
Rural users appear most impacted with 5-10% increases in “No Service” locations for all carriers.





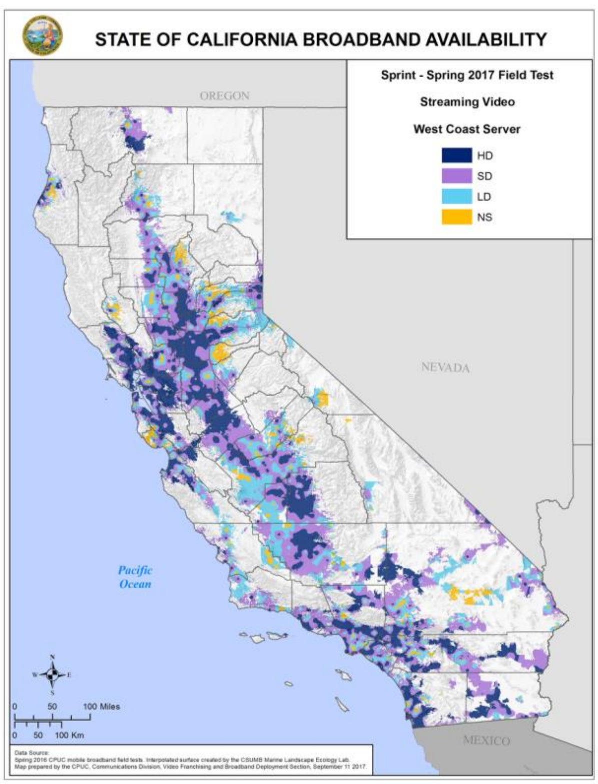
All four carriers continue to offer HD quality video streaming in over 50% of the urban measurement locations but all carriers show material drops in HD video streaming availability for rural and tribal users. Over the last five measurement rounds rural users, for all carriers, have about 70-80% of the HD streaming availability of urban users.

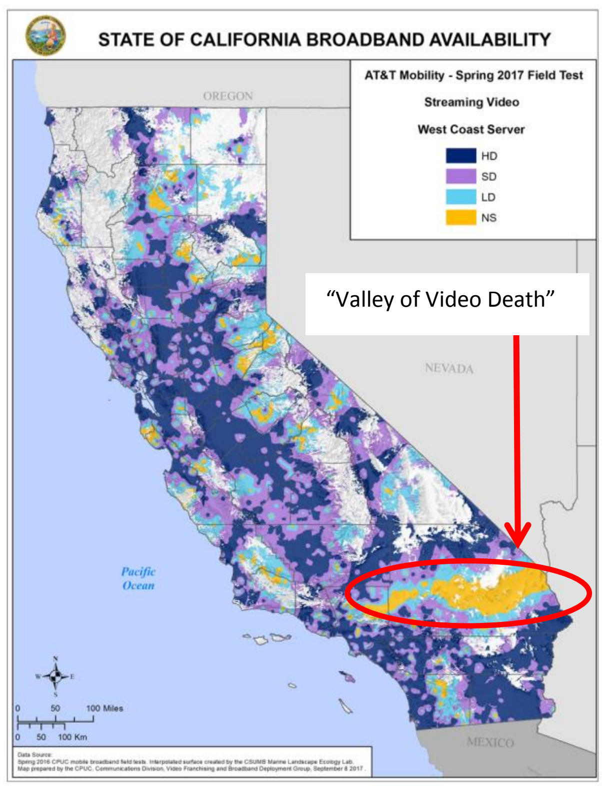


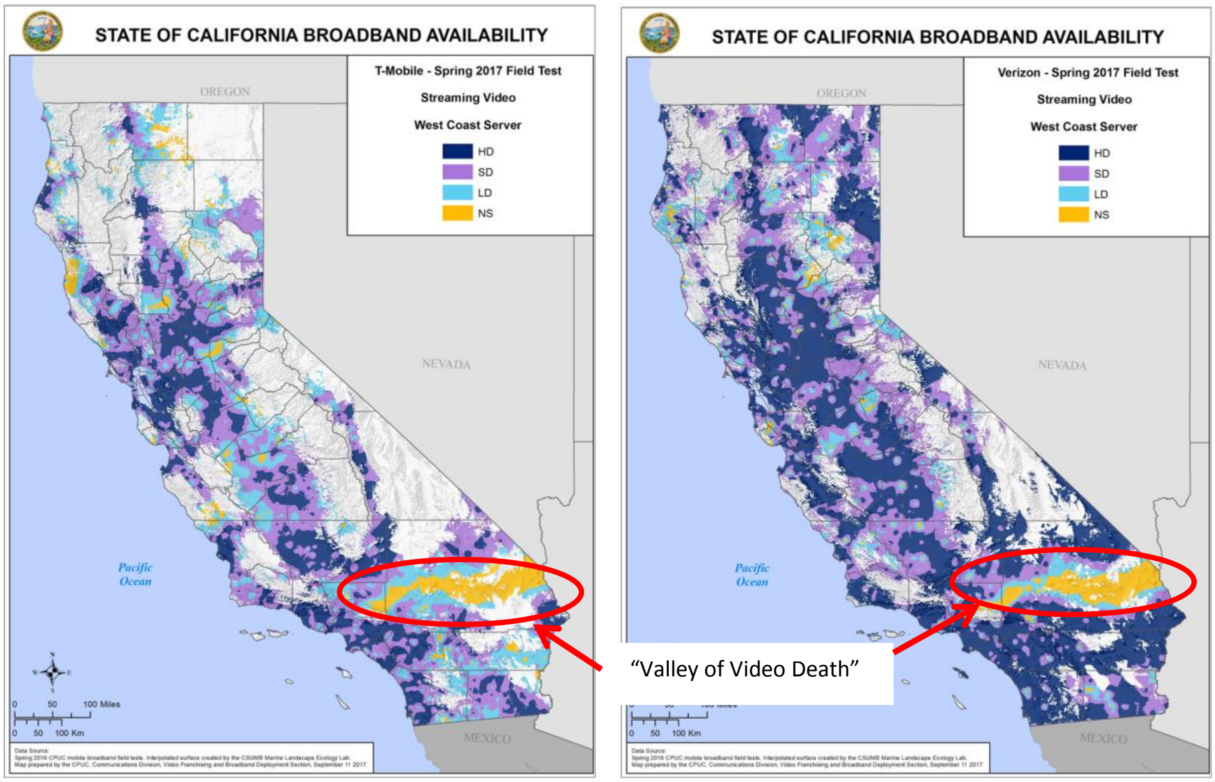


Rural users suffer from no HD streaming coverage ~2-3x more than urban users. Both HD availability and lack of coverage appear to be persistent over all six measurement rounds.

Mobile video streaming coverage is dramatically illustrated in the following coverage maps illustrating estimated mobile video service across the state for the four carriers. HD streaming coverage for all carriers is localized with Verizon giving the best overall state-wide coverage. A major difference is a dramatic band of poor (including No Service) across Southern California - the “Valley of Video Death” (in yellow) - for all four carriers.



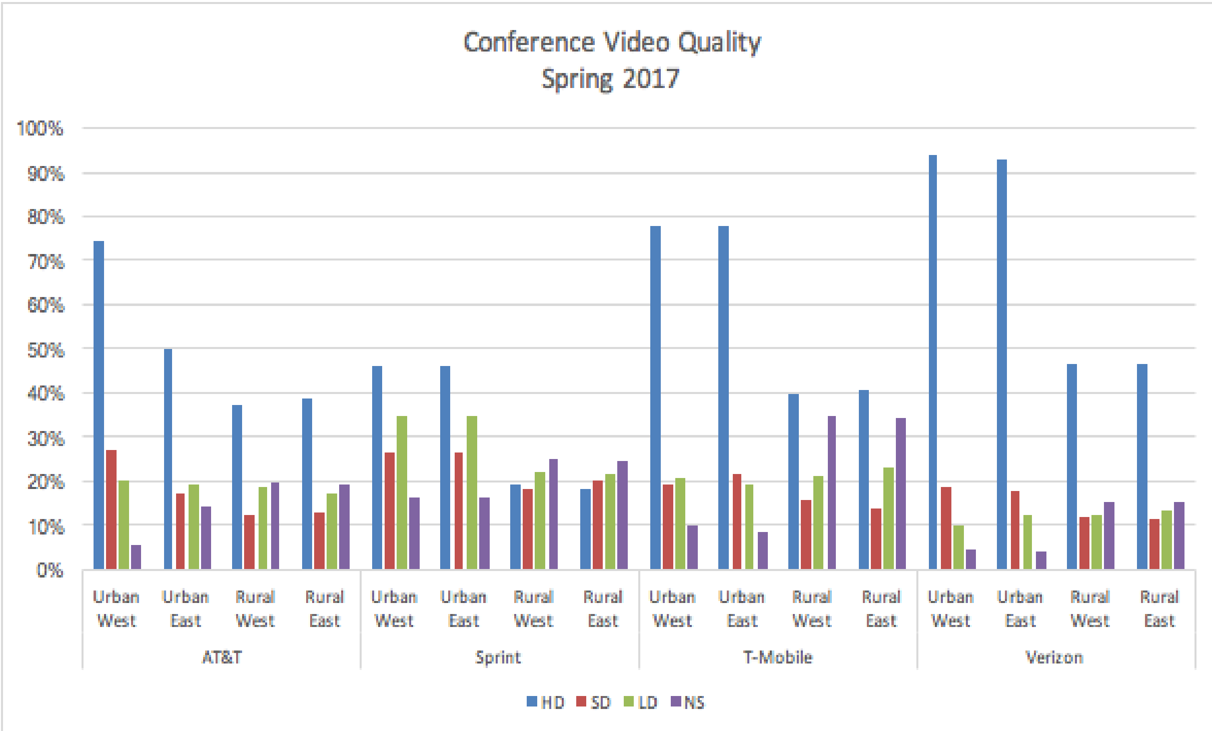


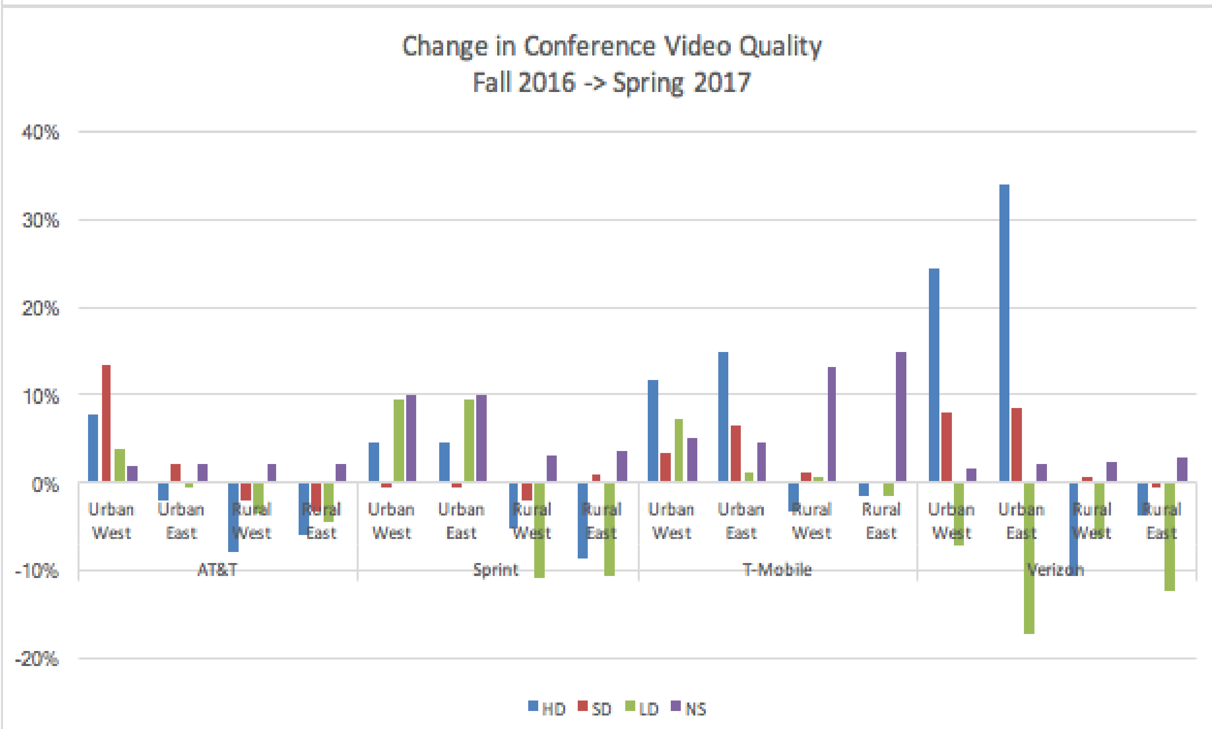


9.2 Video Conferencing

Conference video is a two way audio/video stream between two users. CalSPEED uses two-way MOS and streaming video streaming quality to construct a metric for interactive video. Two estimates are made to evaluate interactive conversations throughout the US: a “west” estimate using the west server to emulate one side of the interactive conversation and an “east” estimate using the east server.

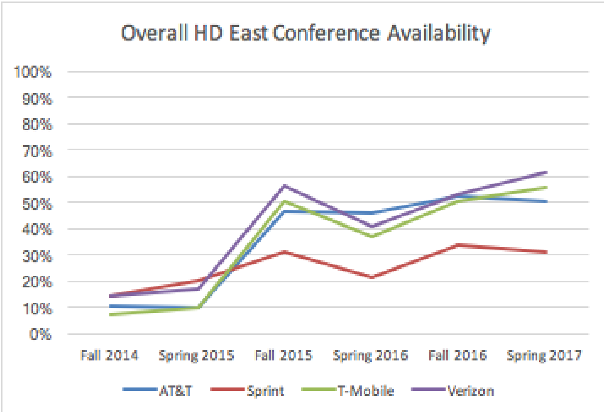
The video quality chart on the right illustrates that for all carriers and all geographies, conference video has modestly improved to the east server since spring 2016. Particular improvements have been for Sprint and T-Mobile for rural users.

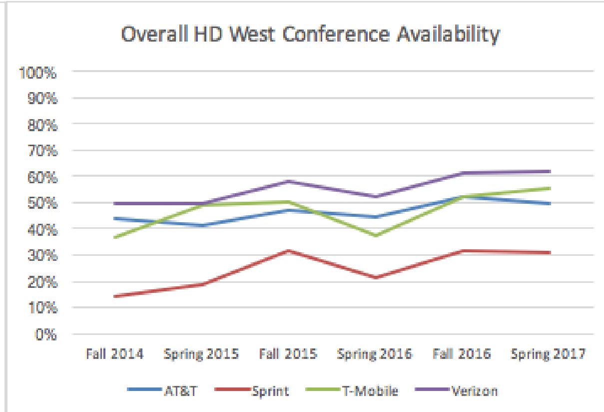


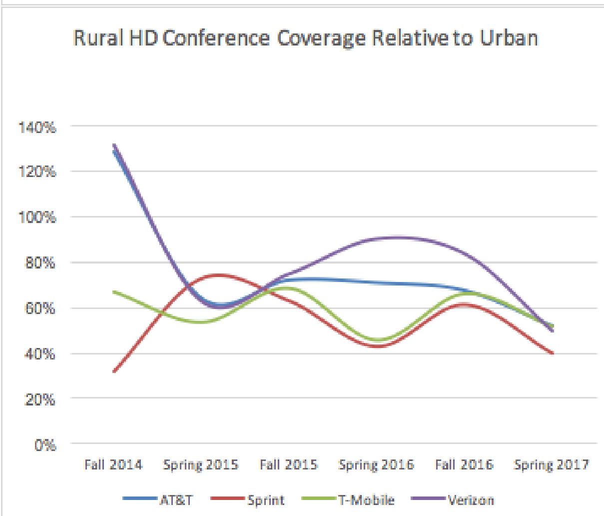


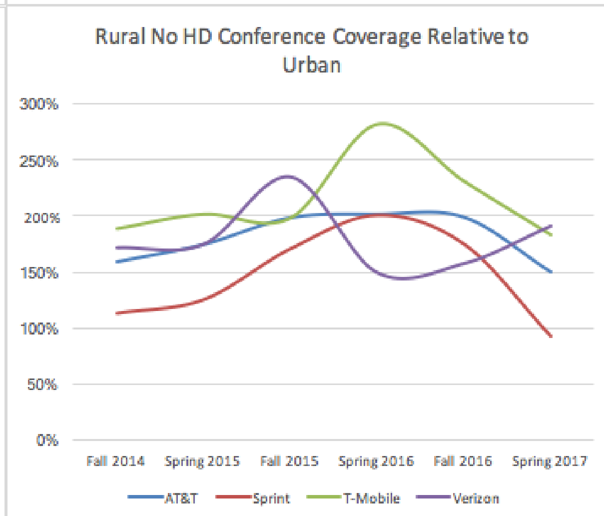
The chart on the left above, illustrates that conference video degrades in availability when moving from urban to rural users and from west to east conversations (the performance of the Internet backbone degrades the interactive video). All carriers showed improvement in urban interactive video quality (particularly Verizon) at the same time as showing degradation in rural interactive video coverage.

The Internet backbone, thru increased latency, can decrease the availability of HD quality conference video for all carriers. In measurements since fall 2015, HD conference availability is about equal between conference destinations - west or east.





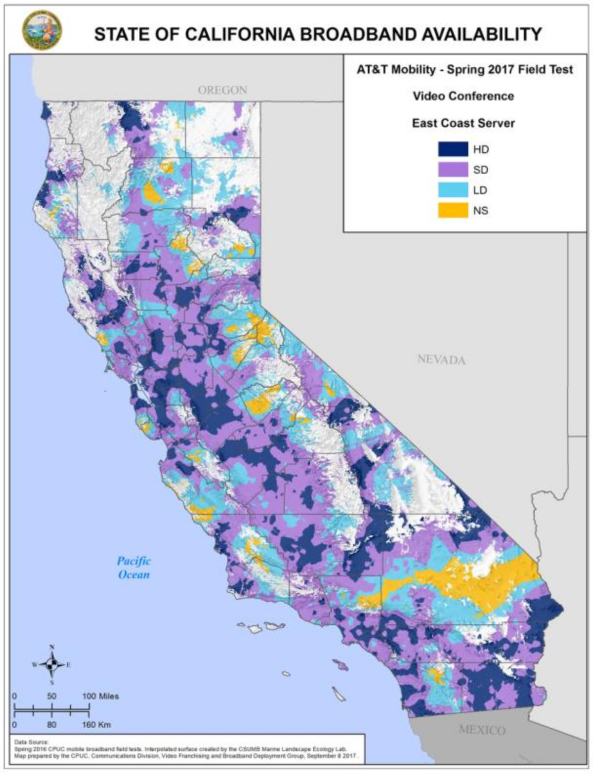




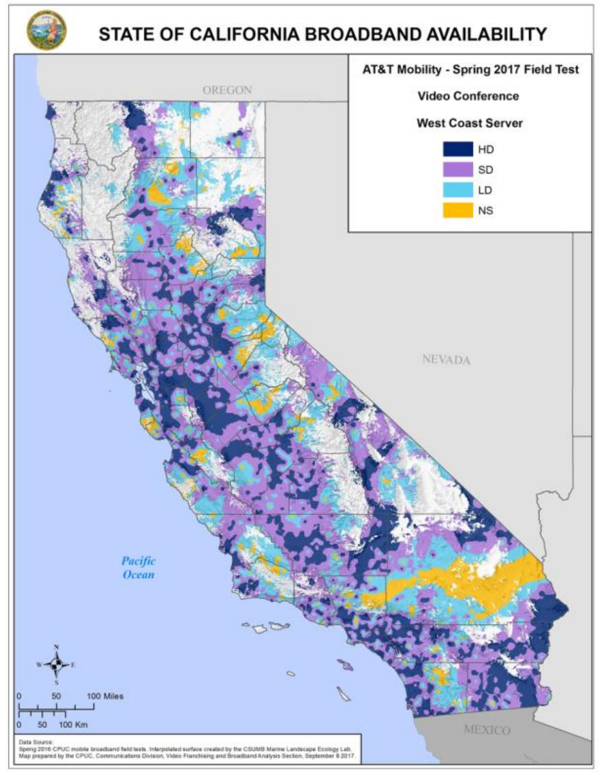
HD west and east conference availability are similar - ~50% of the measured locations (with Sprint around 30%). However (west illustrated above), rural users are materially less likely to have conference service availability. Only about 50-60% of rural users (compared to urban users) have access to HD conferencing and about 2x more rural users than urban users will have no conference ability at all (with the exception of Sprint, in which the lack of HD interactive video service is equally shared between urban and rural)

Interactive video service quality is mapped across the state for all four carriers in the following charts. With the increased east availability beginning in fall 2015, service quality east vs. west for all carriers is similar.

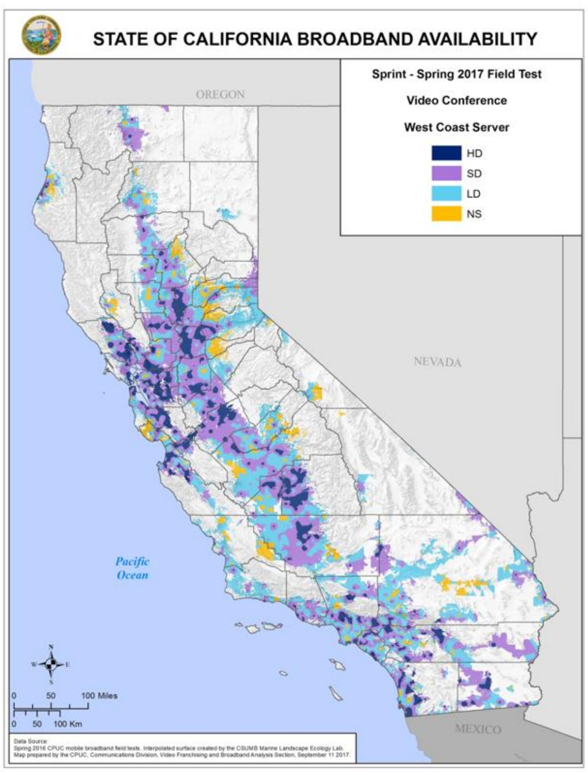
With spring 2017 we see a loss of interactive video service in Southern California - “Valley of Video Death” (the area marked in yellow).



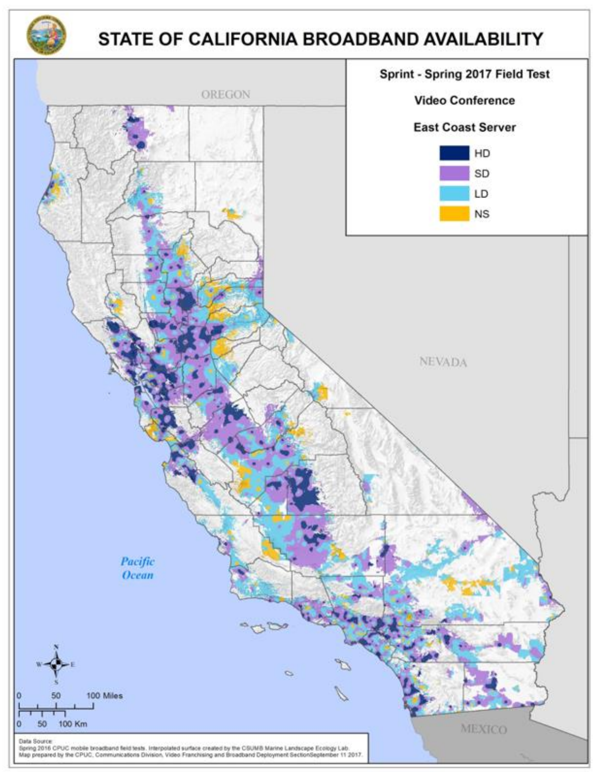
STATE OF CALIFORNIA BROADBAND AVAILABILITY
AT&T Mobility - Spring 2017 Field Test
Video Conference
East Coast Server
HD
SD
LD
NS
OREGON
NEVADA
Pacific Ocean
MEXICO
N
W
E
S
0 50 100 Miles
0 80 160 Km
Data Source:
Spring 2016 CPUC mobile broadband field tests. Interpolated surface created by the CSUMB Marine Landscape Ecology Lab.
Map prepared by the CPUC, Communications Division, Video Franchising and Broadband Deployment Group, September 8 2017.



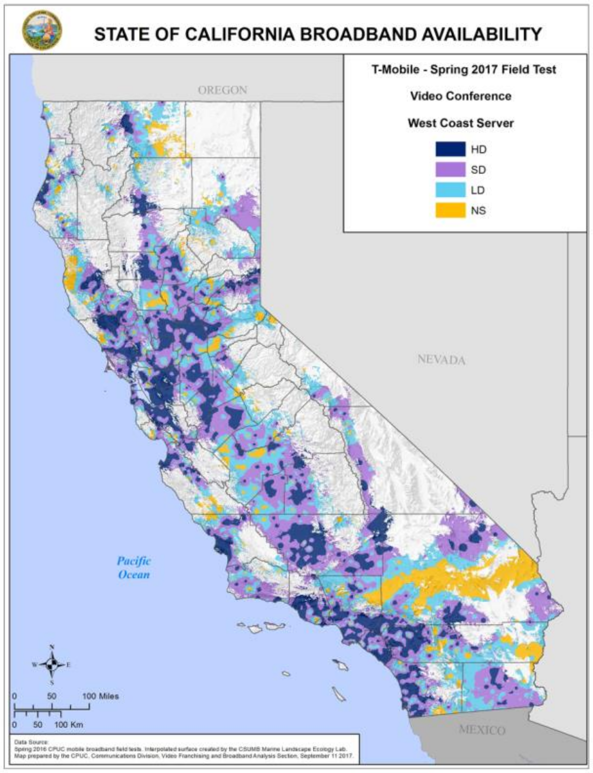
STATE OF CALIFORNIA BROADBAND AVAILABILITY
AT&T Mobility - Spring 2017 Field Test
Video Conference
West Coast Server
HD
SD
LD
NS
OREGON
NEVADA
Pacific Ocean
MEXICO
N
W
E
S
0 50 100 Miles
0 50 100 Km
Data Source:
Spring 2016 CPUC mobile broadband field tests. Interpolated surface created by the CSUMB Marine Landscape Ecology Lab.
Map prepared by the CPUC, Communications Division, Video Franchising and Broadband Analysis Section, September 8 2017.

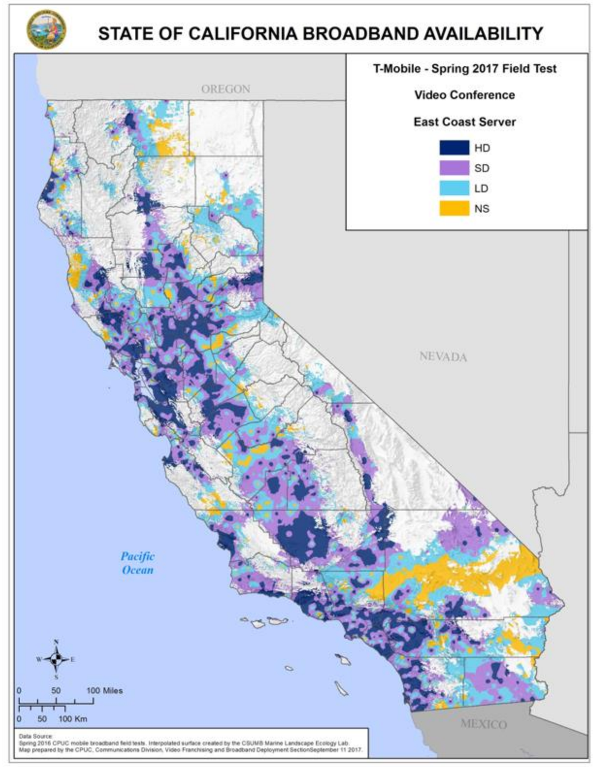


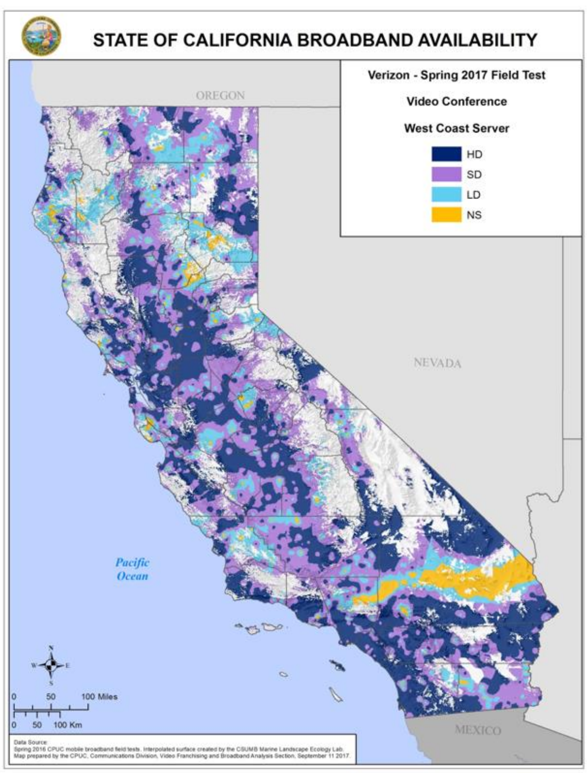
STATE OF CALIFORNIA BROADBAND AVAILABILITY
Sprint - Spring 2017 Field Test
Video Conference
West Coast Server
HD
SD
LD
NS
OREGON
NEVADA
Pacific Ocean
MEXICO
N
W
E
S
0 50 100 Miles
0 50 100 Km
Data Source:
Spring 2016 CPUC mobile broadband field tests. Interpolated surface created by the CSUMB Marine Landscape Ecology Lab.
Map prepared by the CPUC, Communications Division, Video Franchising and Broadband Analysis Section, September 11 2017.

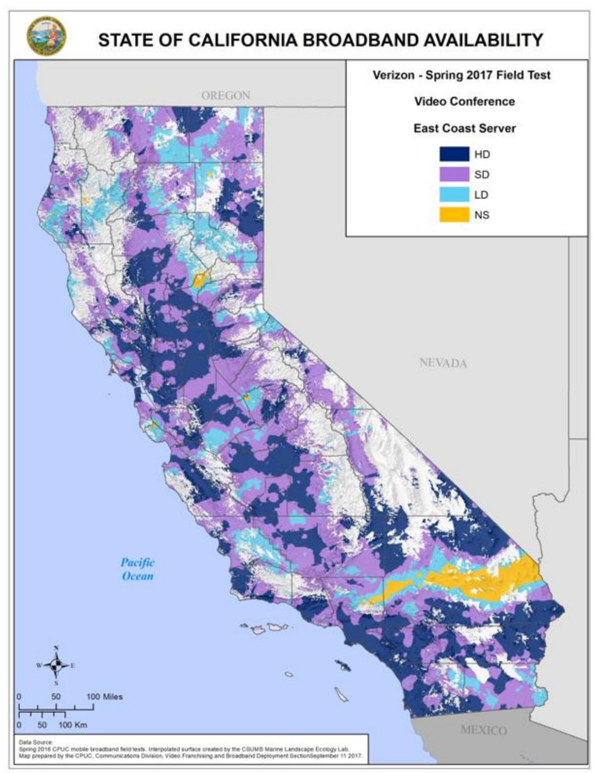


STATE OF CALIFORNIA BROADBAND AVAILABILITY
Sprint - Spring 2017 Field Test
Video Conference
East Coast Server
HD
SD
LD
NS
OREGON
NEVADA
Pacific Ocean
MEXICO
N
W
E
S
0 50 100 Miles
0 50 100 Km
Data Source:
Spring 2016 CPUC mobile broadband field tests. Interpolated surface created by the CSUMB Marine Landscape Ecology Lab.
Map prepared by the CPUC, Communications Division, Video Franchising and Broadband Deployment SectionSeptember 11 2017.


STATE OF CALIFORNIA BROADBAND AVAILABILITY
T-Mobile - Spring 2017 Field Test
Video Conference
West Coast Server
HD
SD
LD
NS
OREGON
NEVADA
Pacific Ocean
MEXICO
N
S
E
W
0 50 100 Miles
0 50 100 Km
Data Source:
Spring 2016 CPUC mobile broadband field tests. Interpolated surface created by the CSUMB Marine Landscape Ecology Lab.
Map prepared by the CPUC, Communications Division, Video Franchising and Broadband Analysis Section, September 11 2017.

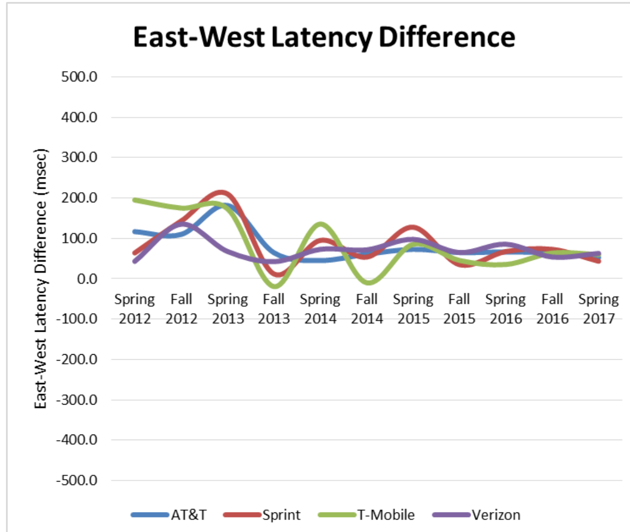

STATE OF CALIFORNIA BROADBAND AVAILABILITY
T-Mobile - Spring 2017 Field Test
Video Conference
East Coast Server
HD
SD
LD
NS
OREGON
NEVADA
Pacific Ocean
MEXICO
N
S
E
W
0 50 100 Miles
0 50 100 Km
Data Source:
Spring 2016 CPUC mobile broadband field tests. Interpolated surface created by the CSUMB Marine Landscape Ecology Lab.
Map prepared by the CPUC, Communications Division, Video Franchising and Broadband Deployment SectionSeptember 11 2017.


STATE OF CALIFORNIA BROADBAND AVAILABILITY
Verizon - Spring 2017 Field Test
Video Conference
West Coast Server
HD
SD
LD
NS
OREGON
NEVADA
Pacific Ocean
MEXICO
N
S
E
W
0 50 100 Miles
0 50 100 Km
Data Source:
Spring 2016 CPUC mobile broadband field tests. Interpolated surface created by the CSUMB Marine Landscape Ecology Lab.
Map prepared by the CPUC, Communications Division, Video Franchising and Broadband Analysis Section, September 11 2017.

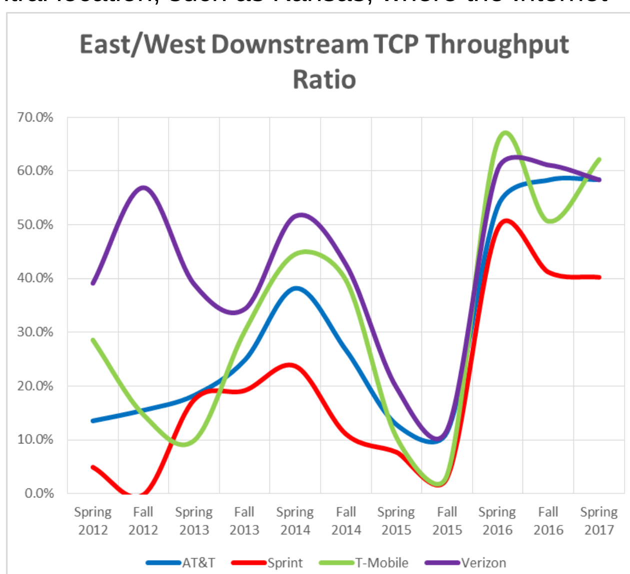

STATE OF CALIFORNIA BROADBAND AVAILABILITY
Verizon - Spring 2017 Field Test
Video Conference
East Coast Server
HD
SD
LD
NS
OREGON
NEVADA
Pacific Ocean
MEXICO
N
S
E
W
0 50 100 Miles
0 50 100 Km
Data Source:
Spring 2016 CPUC mobile broadband field tests. Interpolated surface created by the CSUMB Marine Landscape Ecology Lab.
Map prepared by the CPUC, Communications Division, Video Franchising and Broadband Deployment SectionSeptember 11 2017.

10. Latency Difference Stabilizes, Throughput Difference Continues

CalSPEED measures performance to two geographically distinct servers to estimate the full range of Internet service - both to "local" servers and "distant" servers. Since users will be accessing Internet resources located not just geographically local, but distributed around the U.S. and the world, how each carrier chooses to integrate into the full Internet as well as local access is a key component of the wireless broadband experience. For these measurements - we have two test servers, one in the San Francisco Bay Area ("west") and one in northern Virginia ("east").



In the best case, the physics of data transmission[12] adds about 80 milliseconds of latency to get from one coast to another - in addition to any local wireless access latency. Latency differences over 80 milliseconds suggest suboptimal carrier Internet routing choices for traffic between east and west. In the case where the latency difference between servers is zero, we speculate that traffic for both servers is peered through a geographically central location, such as Kansas, where the Internet distance to either the east coast server or the west coast server is essentially the same. In the past 18 months, all carriers are converging on a close to optimum geographic mean latency penalty of ~80 msec.



TCP throughput is related to latency - the longer the latency, the lower the throughput[13]. Historically, we have seen that downstream throughput from the east server to California clients is 10-50% less than throughput from the west server. The chart to the right demonstrates this fact.

In recent years (fall 2014 thru spring 2015), we noticed a substantial decrease in the TCP throughput difference, and in the spring 2016 a dramatic increase in the TCP difference for all carriers. This dramatic decrease in TCP throughput to the east server has continued into spring 2017.

[12] The 80 millisecond calculation takes into account the speed of light
[13] This is a consequence of TCP's data reliability and congestion control mechanisms.

11. Relationships between Signal Strength, Signal/Noise and Throughput

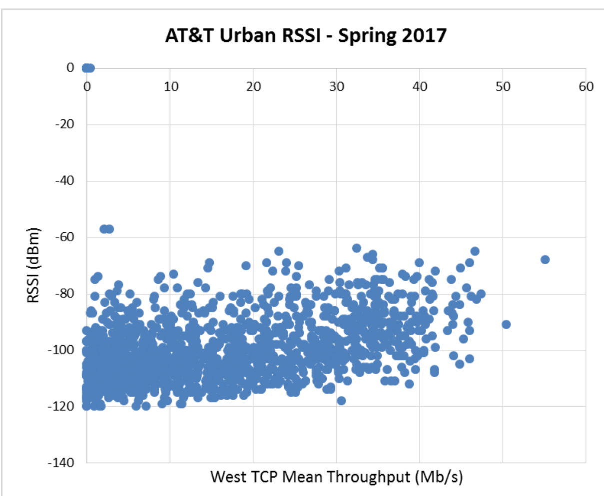
There is much confusion about the relationship between "bars" of signal on a phone or tablet, and the quality of the service. Even today, a phone can be set to show RSSI (Received Signal Strength Indicator) rather than bars but there remains confusion on whether more RSSI or more bars, yields improved service.

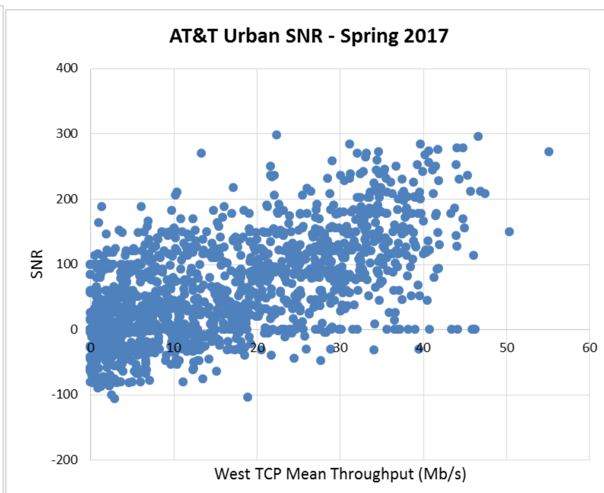
Beginning with spring 2017, CalSPEED was updated to capture both RSSI and the effective signal quality (SNR - signal to noise ratio) during each measurement. Different mobile technologies represent these values differently with, unfortunately, no common standard - but the preponderance of LTE service in the CalSPEED dataset lets us analyze RSSI and SNR for LTE networks.

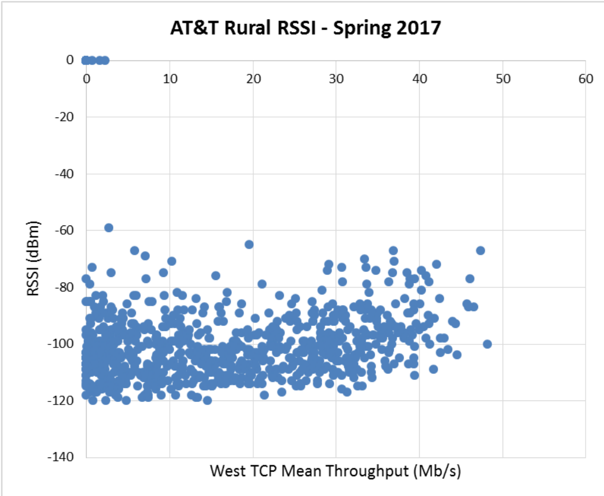
The following scatter plots show the relationship between both signal strength and SNR for both urban and rural demographics for each carrier. There is a shared set of conclusions for all carriers.

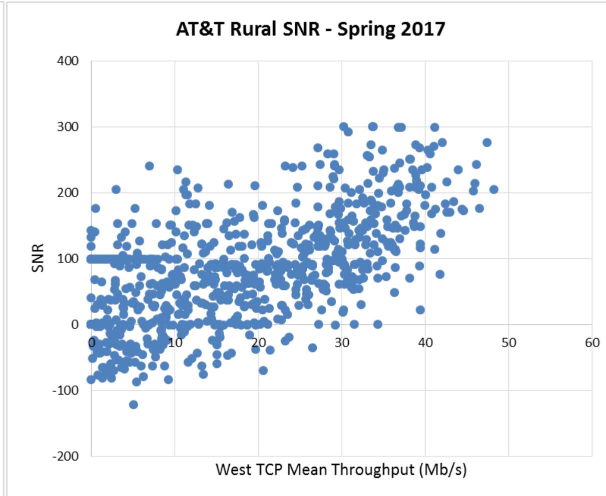
- There is a similar pattern for all carriers.
- There is no substantial difference between rural and urban.
- There is a weak correlation between signal strength (and perhaps bars of service) and TCP throughput.
- There is a moderate positive correlation between SNR and TCP throughput. Higher SNR, on average, generally results in higher TCP throughput.
- <u>However</u>, there is poor predictive relationship between either RSSI or SNR and TCP throughput. That is, a given RSSI or SNR can correspond with a wide range of values for throughput (from zero to 10s of Mb/s). Pick an SNR value and note the large range of possible TCP throughputs that were observed in the spring 2017 data - for all carriers.

AT&T

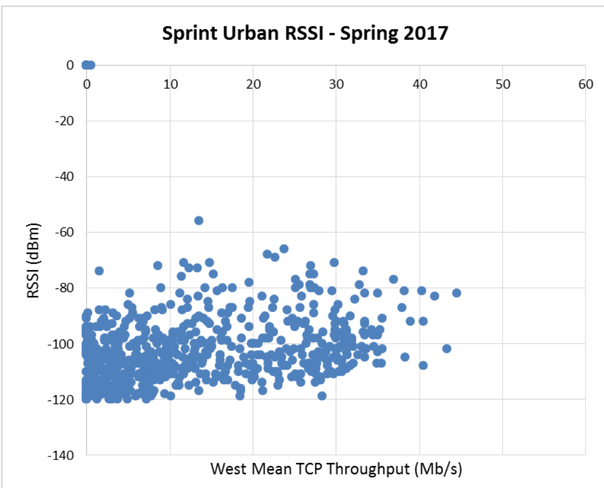


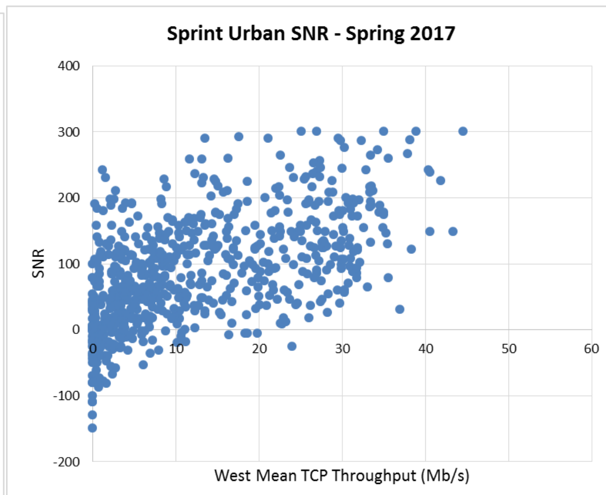


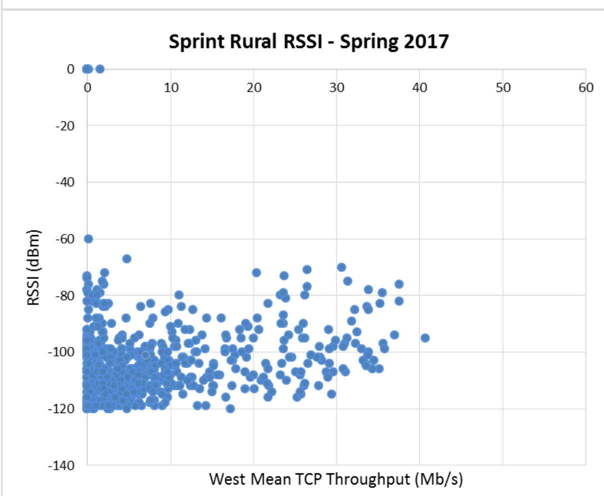

AT&T Rural RSSI - Spring 2017
RSSI (dBm)
West TCP Mean Throughput (Mb/s)
0
-20
-40
-60
-80
-100
-120
-140
0
10
20
30
40
50
60

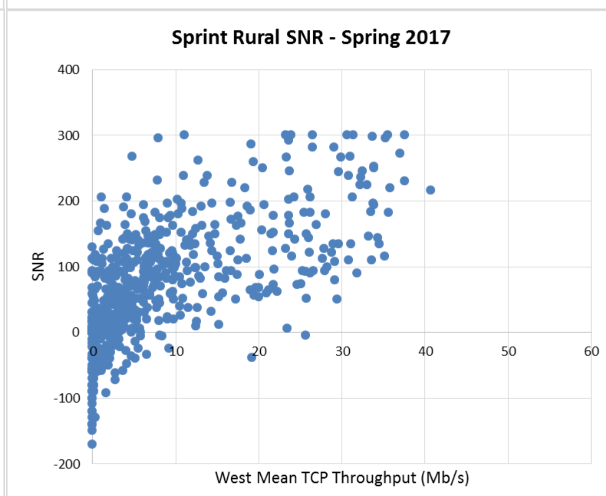

AT&T Rural SNR - Spring 2017
SNR
West TCP Mean Throughput (Mb/s)
400
300
200
100
0
-100
-200
0
10
20
30
40
50
60

Sprint

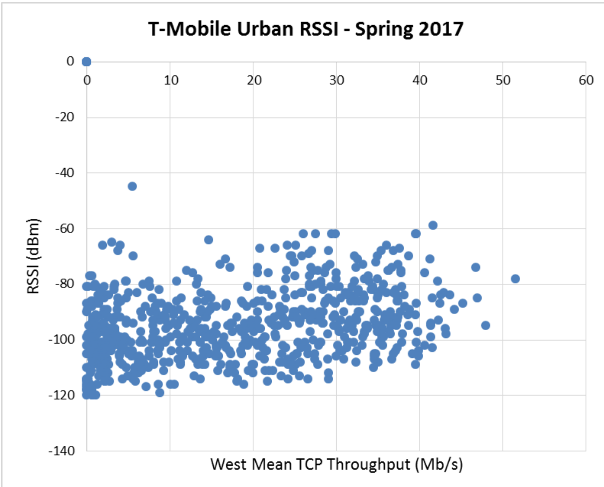

Sprint Urban RSSI - Spring 2017
RSSI (dBm)
West Mean TCP Throughput (Mb/s)
0
-20
-40
-60
-80
-100
-120
-140
0
10
20
30
40
50
60

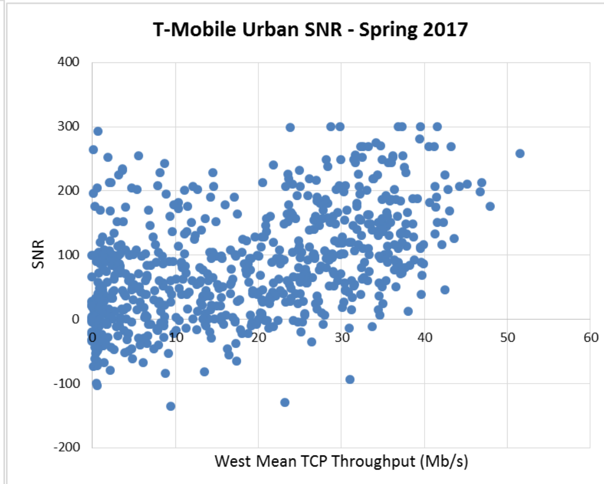

Sprint Urban SNR - Spring 2017
SNR
West Mean TCP Throughput (Mb/s)
400
300
200
100
0
-100
-200
0
10
20
30
40
50
60

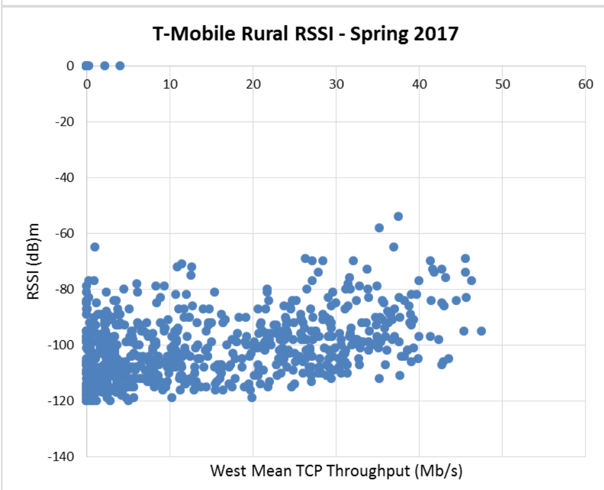

Sprint Rural RSSI - Spring 2017
RSSI (dBm)
West Mean TCP Throughput (Mb/s)
0
-20
-40
-60
-80
-100
-120
-140
0
10
20
30
40
50
60

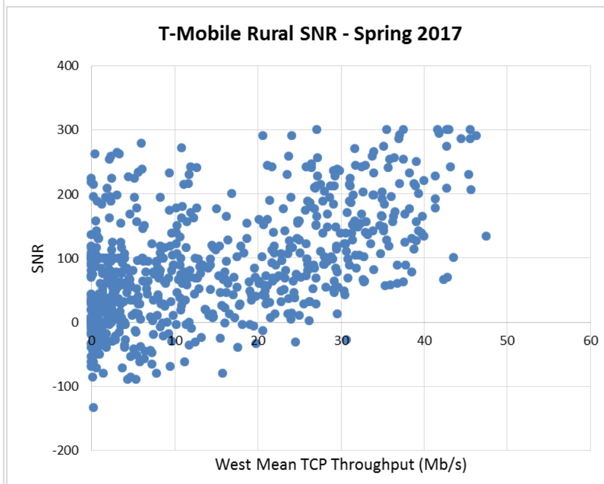

Sprint Rural SNR - Spring 2017
SNR
West Mean TCP Throughput (Mb/s)
400
300
200
100
0
-100
-200
0
10
20
30
40
50
60

T-Mobile

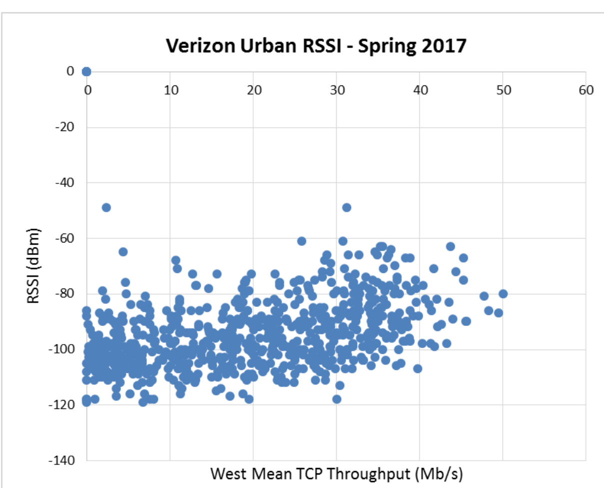


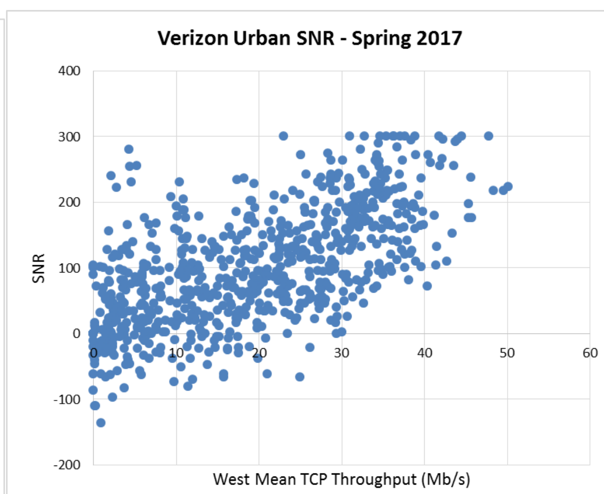


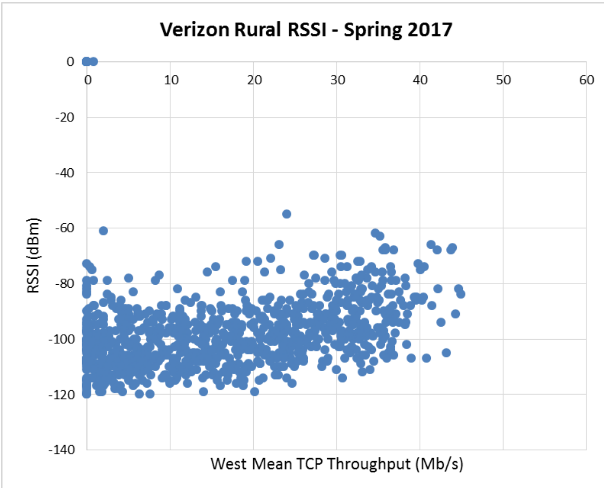


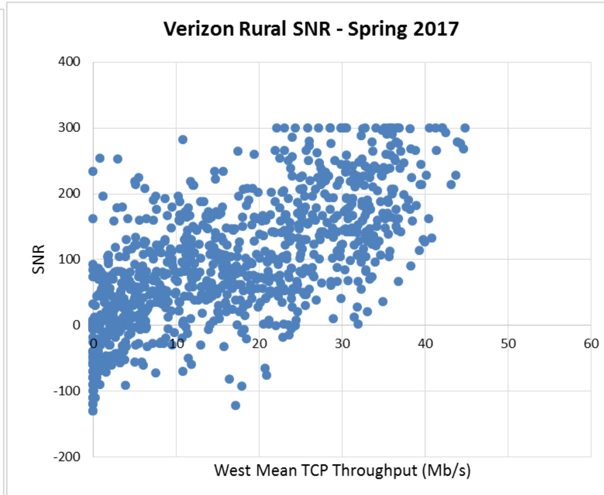


Verizon

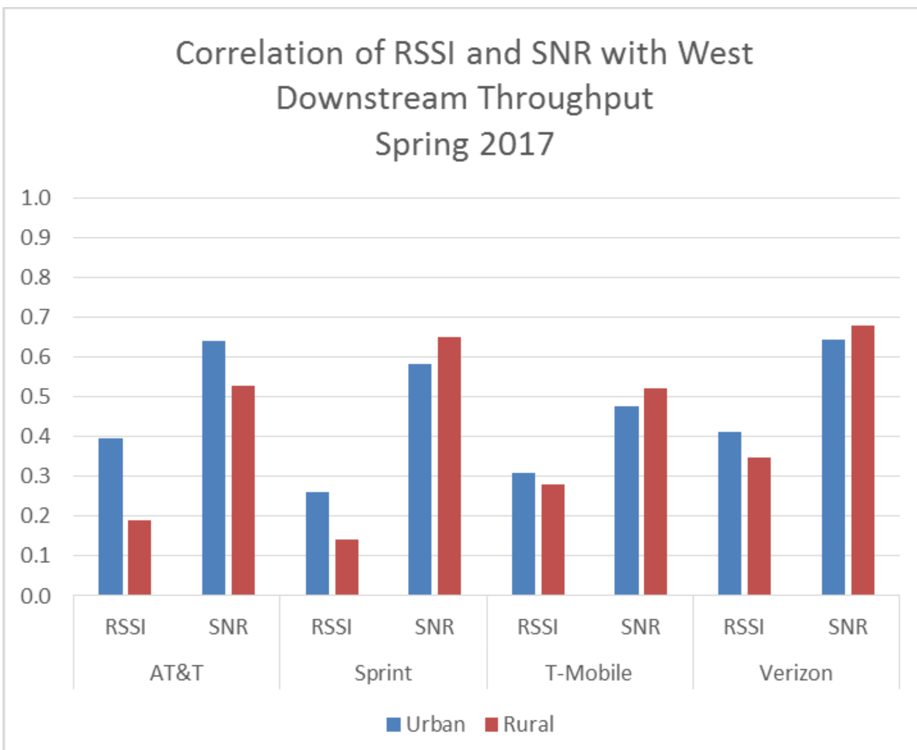








Looking at the correlation coefficients for each carrier, urban and rural, for RSSI and SNR to west TCP throughput, a weak relationship of RSSI to throughput is apparent, and a much stronger relationship between SNR and TCP throughput appears.



While there is moderate correlation between SNR and throughput, the scatter plots demonstrate the weak predictive relationship between SNR and throughput. Better RSSI, and particularly lower SNR, is generally good … but does not guarantee higher throughput.

12. Conclusions

This is an analysis of the measurement Round 11, spring 2017 dataset for CalSPEED. The key results for California mobile broadband include the following.

Persistent mobile digital divide	The rural/urban mobile digital divide appears to be persistent with rural users having material (about 1/3) poorer mobile broadband service over a period of years with little indication of improvement. This is true for throughput, latency, packet loss, MOS, jitter, broadband coverage and deployed technology. Spring 2017 shows additional incremental degradation.
Mean throughput worsens	Mean throughput worsens for all carriers (small increase for Sprint downstream and for Verizon upstream) and returns to levels last seen at least a year ago.
Carrier throughput throttling continues	Throughput throttling for all carriers continues from fall 2016 into spring 2017. The downstream throttling threshold continues from fall 2016 at ~42 Mb/s. The upstream throttling threshold continues from fall 2016 at ~20 Mb/s (15 Mb/s for Sprint).
Mobile broadband coverage decreases	Broadband coverage at 25 Mb/s down, 3 Mb/s continues below year ago levels at ~13%. Using the benchmark of 10 Mb/s down and 1 Mb/s up, improves “coverage” to ~50% for all carriers.
Underlying service quality mixed	Mean rural latency worsens, jitter worsens, packet error rate improves, and TCP connection reliability worsens for all carriers.
Rural and Tribal TCP connection failure rates 3-7x urban	TCP connection attempts fail much more often for rural users than for urban users for all carriers. An urban AT&T or Verizon user can expect 2% of TCP connection attempts to fail (often invisibly retried by the using applications) while ~20% or rural users can expect TCP connection failures.
Over the Top VoIP quality modestly improved, continued relative impairment for rural and tribal	VoIP quality continued improved after substantial degradation in spring 2016. Rural and tribal VoIP quality remains degraded.
LTE deployment coverage has peaked	Penetration of LTE in both urban and rural geographic categories appears to have peaked with a floor on 1/2G legacy replacement and on a cap on LTE deployment. Notably, there was no legacy 1/2G service detected for AT&T in California.

Internet latency stabilizes	The latency difference between east and west servers has stabilized at ~80 msec.
Internet video and conferencing results mixed	Internet OTT streaming video and conferencing availability modestly improved from fall 2016. A Valley of Video Death appears as a consistent area of No Service for OTT video in rural Southern California for all carriers.
East/West throughput differences continue at all time high	Ratio of east/west throughput continues pattern of last year with an all-time high of 60% for all carriers but Sprint at 40%.
Little difference between devices	There continues to be no material throughput or latency difference between current smartphones and tablets.
Weak relationship between signal strength and throughput	There is a modest correlation between Signal to Noise Ratio (SNR) and west throughput, but not for Received Signal Strength Indicator (RSSI). Moreover, the wide range in throughput values for any particular SNR or RSSI means both are poor predictors of throughput.

Appendix A: CalSPEED: Capturing the End to End User Experience

How CalSPEED Measures Broadband

CalSPEED performs the following sequence of measurements to gather its information:

1. ICMP ping to the west server for four seconds for connectivity checking. If the ICMP ping fails, CalSPEED presumes that there is no effective connectivity to the Internet and records that result.
2. iPerf TCP test (4 parallel flows) to the west server - both downstream and upstream. CalSPEED uses four parallel flows to ensure that the maximum capacity is measured during the test.
3. ICMP ping to the west server for 10 seconds to measure latency to the west server.
4. UDP test to the west server. CalSPEED constructs a UDP stream of 220 byte packets to emulate a VoIP connection with 88kb/s throughput. This UDP stream is used to measure packet loss, latency and jitter.
5. iPerf TCP test (4 parallel flows) to the east server to measure downstream and upstream TCP throughput.
6. ICMP ping to the east server for 10 seconds to measure latency to the east server.
7. UDP test to the east server to measure packet loss, latency and jitter with a simulated VoIP data stream.

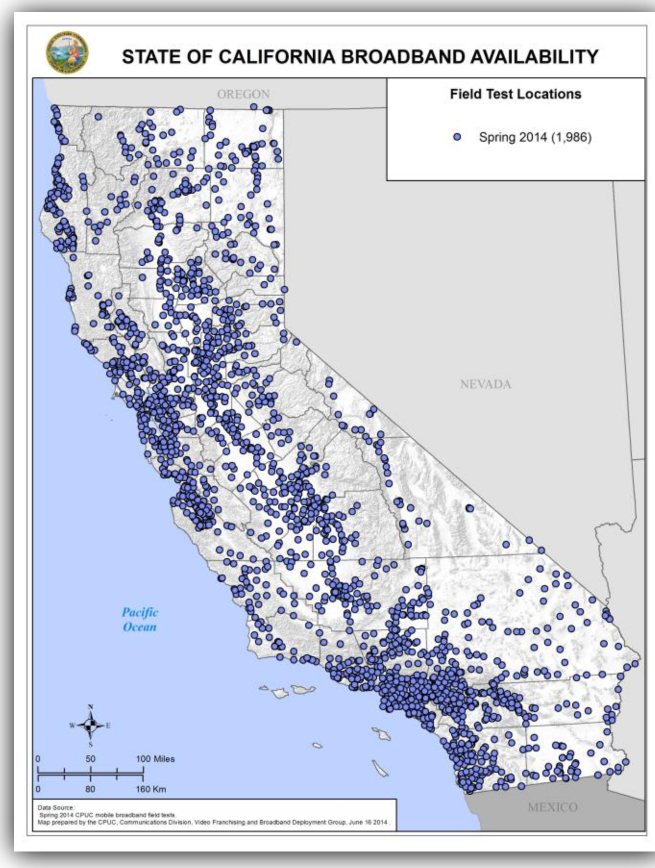
CalSPEED uses two identical measurement servers on the opposite ends of the US Internet. One hosted in the Amazon AWS near San Jose, CA and for many California users has performance like a CDN server. The second measurement server is in the Amazon AWS in Northern Virginia.

CalSPEED uses two device measurements - a current smartphone and current tablet.Both are upgraded for each measurement round to match the latest wireless technology deployed by each carrier.

Open Source. CalSPEED is an open source network performance measurement tool that is in turn based on an industry standard open source performance measurement tool - iPerf[14]. iPerf provides the foundation network measurement engine for both the TCP and UDP protocols. CalSPEED packages this engine in both Windows and Android client tools for measuring and recording mobile network performance.

End-to-End User Experience. A foundation assumption of CalSPEED, uniquely among network measurement tools, is an attempt to replicate the end to end user experience. In particular, CalSPEED recognizes that the Internet resources that a typical user accesses are scattered across the entire Internet … and despite the use of content delivery networks to speed Internet performance by caching frequently accessed content, are not always “local” to the user. Many measurement tools focus on evaluating just the local radio access network - the last few miles - and not the backhaul network to the ultimate server resource used. CalSPEED instead tests the complete network path, from the client device, through the local access network, through the Internet backbone, to several ultimate server destinations.

[14] http://en.wikipedia.org/wiki/Iperf



While it is impossible to measure all Internet servers, CalSPEED emulates this user experience with two fixed servers - one physically located in Northern California and the other in Northern Virginia - both in the Amazon AWS cloud. CalSPEED reports performance both to each individual server and the average between them. Not only does this method measure the different local access methods, but provides a network interferometry that gives insight into the different backhaul strategies chosen by carriers. We find carrier unique up to 2:1 differences in end to end latency and jitter and material difference in upstream and downstream throughput between the two servers.

These differences in fundamental network performance illustrate that location matters - Internet performance delivered to the user - the Internet user experience - will vary based on where on the Internet the desired server is located. And desired servers are scattered across the Internet, not just close to every user. Measurement to a local server only results in an overly optimistic expectation of service quality than a typical user will actually experience.

CalSPEED measures a complete portfolio of network metrics including end-to-end packet latency, bidirectional TCP throughput, UDP packet loss and jitter.

Just the Facts. CalSPEED does not filter any of its results - throughput, coverage, latency or other network metric - rather uses the results of all tests performed and recorded. We believe that just like the user experience with sometimes failing web page loading, all results are valid representing the user experience. Other testing systems filter results in a way that biases results to give a more optimistic expectation of network performance than a user will typically experience.

Not Just for Crowds. Crowdsourcing is a fashionable method for collecting data at scale - but it has an inherent selection bias of only collecting data from where it is chosen to be used by those people who choose to use it. Where there is no crowd there is no data. And even where there is data, it is biased towards those who collected it, why, when and where.

CalSPEED has two complementary methods of testing - the first is a structured sampling program of 1,986[15] measurement locations scattered throughout California (tribal, rural and urban) that are each periodically (every six months) visited and methodically measured with CalSPEED on both the latest Android phones and a tablet for each of the four major carriers. The use of multiple contemporary user devices gives a good snapshot of the best user experience.

[15] Originally 1200, but later increased to improve predictive precision of the interpolation models.

The second method is the independent use of CalSPEED to provide crowd-sourced data. The structured sampling program avoids selection bias of when and where measurements are made, giving a full map that covers the entire state, including places not often visited by smartphone users but having mobile broadband service. The crowd sourced data adds additional detail to areas where there are people who choose to use the test and adds additional detail about the range of the installed base of phones (particularly legacy mobile devices) and the performance those user devices are seeing. The structured measurement program uses the most current user devices available at the time of each round of field measurement and thus gives a snapshot of the latest deployed network technology. Older user devices, with older wireless technology still in use by many, will likely get slower performance in many locations.

Because CalSPEED samples all areas of California - urban (37%), rural (56%) and tribal (7%), analysis of its results explicitly measures the state's mobile digital divide.

Not Just Data but Voice and Video. CalSPEED measures not only the underlying basic Internet data transmission of datagrams and TCP connections, but also interactive voice (the Internet's replacement for POTS), streaming video and interactive video (video conferencing).

CalSPEED constructs an over-the-top interactive voice model, using the LTE voice digitization method, that gives an estimate of the Mean Opinion Score (MOS) of the voice service.

CalSPEED uses a derivative of the Google's video quality metric[16] to construct a metric of Internet video quality. CalSPEED measures both downstream streaming video (such as YouTube or Netflix) as well as interactive video (such as Skype or FaceTime). Streaming video is measured using downstream performance from CalSPEED's west server - assuming that most such video is cached closer to the user. Interactive video is measured both to the west and east servers (to assess the effect of the Internet backbone) and uses both upstream and downstream performance measures.

Maps for decision-makers not just for information. We then take the measurement data and create geospatial kriging[17] maps interpolating CalSPEED measurements of (but not limited to) latency, downstream and upstream throughput, jitter and packet loss over the entire state.

These maps can be overlaid with other geo-statistical data on population, income, ethnicity, education, and census areas to provide more informed choices for consumers, businesses and governments. The CPUC web site uses this data to suggest what mobile service is available and at what performance at locations of the consumer's choice.

Massive Dataset. CalSPEED has now had nine rounds of sampling California (spring 2012, fall 2012, spring 2013, fall 2013, spring 2014, fall of 2014, spring 2015, fall 2015, and spring 2016) and is shortly to finish a tenth round (fall 2016). In each sampling round, we have surveyed the entire state and all four of the major wireless carriers - AT&T Mobility, Sprint, T-Mobile and Verizon Wireless.

[16] https://www.google.com/get/videoqualityreport/#methodology
[17] http://en.wikipedia.org/wiki/Kriging

Appendix B: Terms

Term	Definition
Downstream	The Internet direction from a server to a client.
East Server	Test server located on the east coast in Northern Virginia
Jitter	The variation in end to end packet latency between user and server.
Kriging	A geo-statistical technique for interpolating data from a sample set.
Latency	The end to end round trip delay for a single packet to traverse the Internet from user to server and back.
MOS	Mean Opinion Score. A measurement of VoIP quality
Packet Loss	The rate of loss of packet delivery end to end.
TCP	Transmission Control Protocol. The essential end to end protocol for the Internet that creates a reliable, sequentially delivered byte stream via a sequence of individual IP datagrams.
TCP Connection Failure	Each TCP connection requires a bidirectional packet handshake to initialize data flow. If the handshake cannot occur within a timeout period, the connection fails. The rate of failure is one measurement of the quality of the Internet connection.
Throughput	The number of bytes per second of user data communicated end to end.
Upstream	The Internet direction from a client to a server.
VoIP	Voice over Internet Protocol. Generic name for a family of IP based protocols to replace legacy circuit switched voice with packet based voice.
West Server	Test server located on the west coast in the San Francisco Bay Area