TUTELA

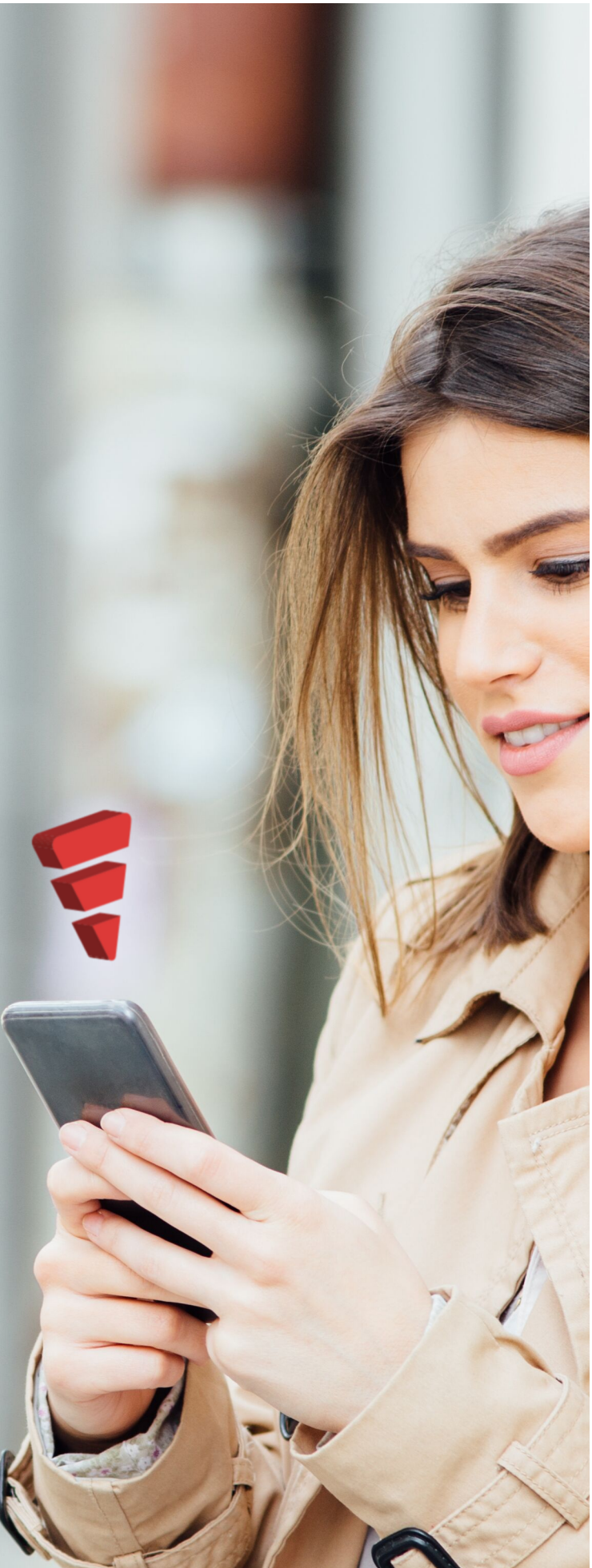
United States of America

State of Mobile Networks

Annual Report

SEPTEMBER 2019

www.tutela.com



2019 has been a banner year for the US wireless industry. 5G has been on everyone's lips, and the deployment of commercially-available next-generation networks by all four nationwide carriers is a significant milestone in the evolution of wireless networks as the US looks to establish itself as a leader in the race to 5G.

At the same time, consumer habits have continued to evolve, and wireless plans along with them. Unlimited data has never been cheaper, mobile data consumption continues to grow(1), and mobile-oriented streaming video services have dethroned traditional pay TV as the most popular entertainment option(2).

However these changes in consumer behavior mean that we're also in a time of unparalleled demands on the network. The new technology and new spectrum that 5G promises are clearly the long-term solution to a step-change increase in demand, but for now, 4G LTE networks carry the vast majority of the burden in the United States.

To see how the four nationwide carriers' 3G and 4G networks stack up, Tutela has collected and analyzed more than 36 billion records. Those records include over 200 million speed tests and 3.8 billion latency measurements, taken from over 14 million unique iOS and Android smartphones between March 1st and August 31st, 2019.

(1) Tefficient, Mobile data continues to grow - a majority of operators now rewarded with ARPU
https://tefficient.com/mobile-data-operators-1h-2019/
Retrieved 29 August 2019

(2) Deloitte, Digital media trends survey, 13th edition
https://www2.deloitte.com/us/en/insights/industry/technology/digital-media-trends-consumption-habits-survey/summary.html
Retrieved 29 August 2019

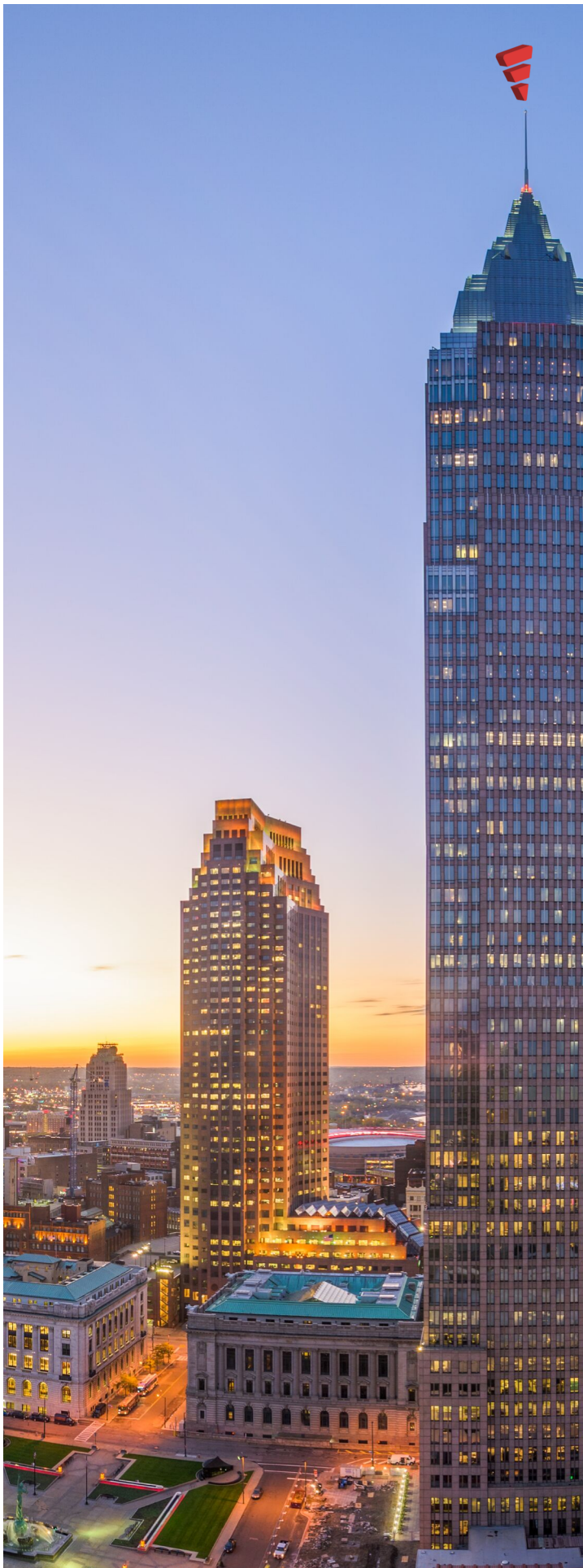
Key findings

- Verizon is the best network for Excellent Consistent Quality, and it takes the crown with a significant margin: there's a gap of over 5% to second-place T-Mobile, and 18% to fourth-place AT&T. Verizon's home state of New Jersey saw the highest single operator performance in any state across the US, with 86.5% of tests for Verizon meeting the Excellent threshold. Verizon's network advantage also showed up in median download speed, where Verizon was comfortably in first place.

- AT&T was the best operator for Core Consistent Quality, Tutela's metric for a network connection good enough for simple use-cases like social media image sharing or SD video streaming. However, the field was much more crowded for Core Consistent Quality: just four percentage points separated first-place AT&T from fourth-place Sprint.

- T-Mobile put in a strong showing, finishing as the runner-up for both Excellent and Core Consistent Quality, as well as taking the crown for the fastest upload speed.

- Verizon users spent the highest proportion of their time on 4G networks, although users of all four operators comfortably spent less than 10% of their time on 3G.



Results overview

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Mobile experience results

US, September 2019

	verizon	T-Mobile	Sprint	AT&T
Excellent Consistent Quality	★ Winner			
Core Consistent Quality				★ Winner
Download throughput	★ Winner			
Upload throughput		★ Winner		
Latency	★ Winner		★ Winner	

Results from 1,385,066,516,744 measurements taken in Common Coverage Areas between March 1st to August 31st 2019.

"Verizon delivered the highest percentage of Excellent Consistent Quality in Tutela's tests"

TUTELA
Best Mobile Network Experience
SEPTEMBER 2019

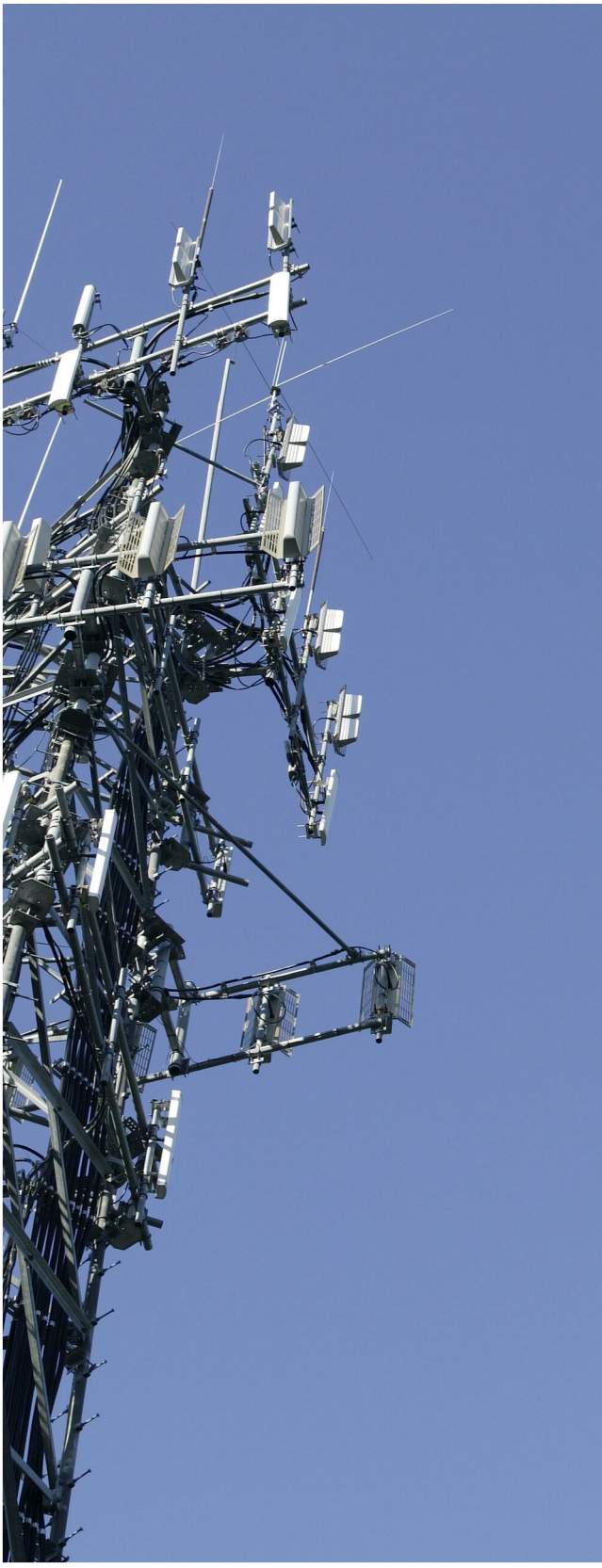
Based on the highest Excellent Consistent Quality in Common Coverage Areas.

Understanding this report

Tutela uses two key methodological components to best compare user experience across operators: Consistent Quality and Common Coverage Areas. Consistent Quality is a set of metrics that Tutela has developed to objectively evaluate when networks are (and are not) enabling users to do almost everything that they want to do on their smartphones.

The methodology is covered in detail at the end of this report or on our website, but simply put, there are two sets of thresholds, Excellent and Core. A connection that hits the Excellent threshold is sufficient for use-cases like 1080p video streaming or multiplayer gaming, while a Core connection will stream standard-definition video or handle things like web browsing or uploading photos to social media. The percentages you see in this report represent the percentage of tests on a given operator that were above the Excellent or Core thresholds, taken when a user has signal. These were most recently re-assessed and updated September 1st, 2019.

Common Coverage Areas are parts of the country where the majority of operators offer service. In this report, we present results nationally and from Common Coverage Areas, which helps present both a full national picture, as well as highlighting network conditions wherever operators are directly in competition.



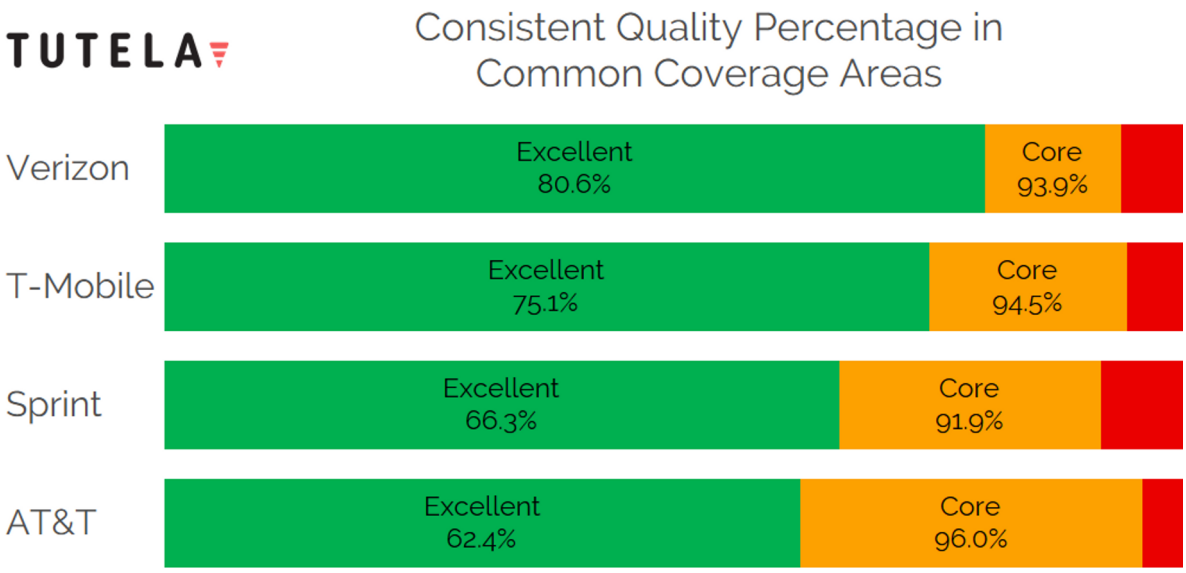
Consistent Quality

For Excellent Consistent Quality, Tutela's metric that quantifies how often users have a wireless connection good enough for demanding applications like HD video streaming or group video calls, Verizon took a commanding lead over other US network operators.

When they had signal, the network connection of Verizon subscribers passed the Excellent Consistent Quality thresholds over 80% of the time. Second-place T-Mobile was over five percentage points behind, and there was an even more significant gap to Sprint and AT&T, who achieved percentages of 66.3% and 62.4% respectively.

For Core Consistent Quality, the picture was very different -- not just in terms of how the operators rank, but also the gap between first and fourth place. AT&T had the best Core Consistent Quality, meaning that its users were most often able to do things like standard-definition video streaming or VOIP calls.

AT&T's network performance and coverage have been buoyed by its buildout of the FirstNet network using the dedicated spectrum, which provides additional coverage and capacity over the Band 14 700 MHz frequency. Tutela's data shows that FirstNet coverage has doubled over the last year, which goes some way to explaining AT&T's leadership in the provision of base-level data services.



Consistent Quality

Critically, however, the gap between operators was small: AT&T took first place with a Core Consistent Quality percentage of 96.0%, but T-Mobile and Verizon were just 2% behind, and fourth-place Sprint was barely 4% behind. When users have signal, mobile internet for Core use cases is nearly ubiquitous; all four nationwide operators delivered a Core Consistent Quality comfortably better than 90% in Common Coverage Areas.

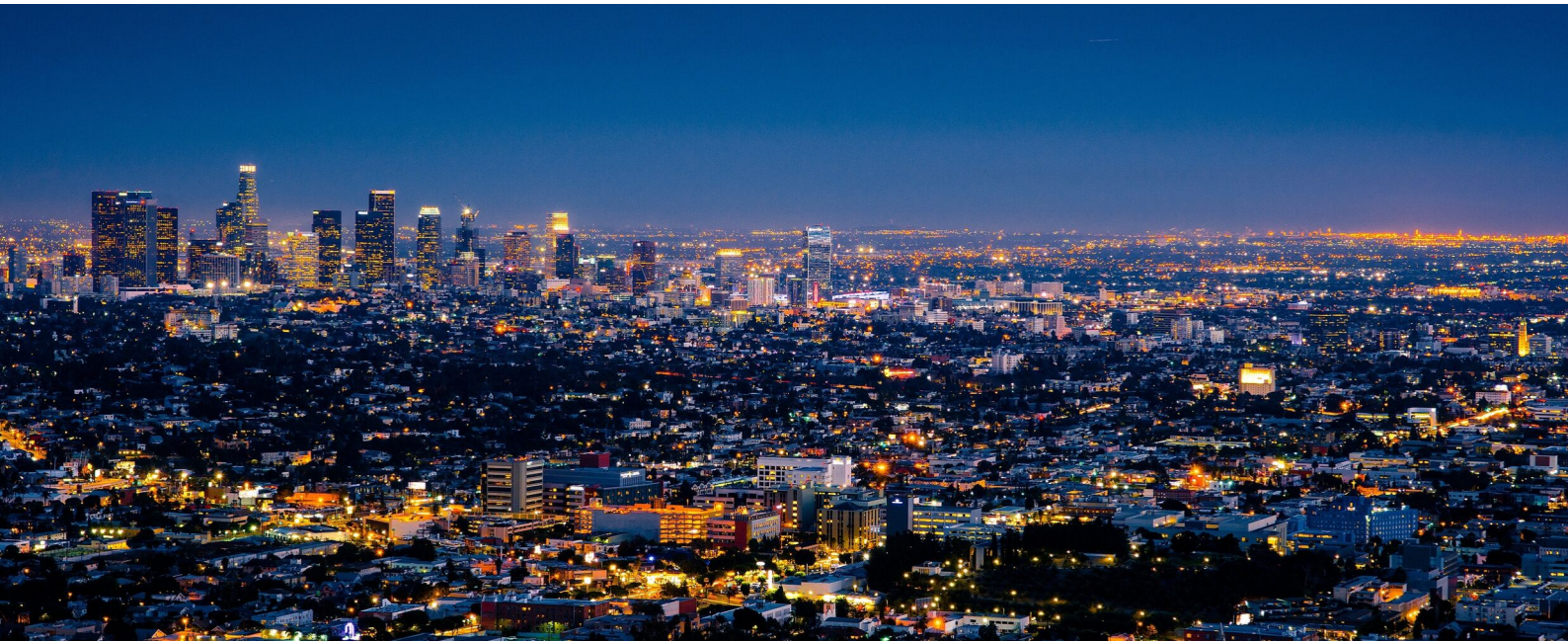
Key performance indicators

Excellent Consistent Quality

Download throughput > 5 Mbps
Upload throughput > 1.5 Mbps
Latency < 50 ms
Jitter < 30 ms
Packet loss < 1%

Core Consistent Quality

Download throughput > 1.5 Mbps
Upload throughput > 0.5 Mbps
Latency < 100 ms
Jitter < 50 ms
Packet loss < 5%



On the state level, a similar pattern emerges for Consistent Quality as the one we see nationwide. Verizon dominated Excellent Consistent Quality, taking outright victory in 35 of the lower 48 states, while T-Mobile was the best operator for Excellent Consistent Quality in 12 of the states.

The state with the single best operator result was New Jersey, where Verizon's hometown advantage saw it deliver an Excellent Consistent Quality network 86.5% of the time. For Core Consistent Quality, AT&T won in the majority of states, while T-Mobile came top in nine, and Sprint took first place in South Dakota.

When looking at state-level results, the impact of Common Coverage Areas and roaming agreements become clearer. The percentages above are taken using tests from Common Coverage Areas, defined as places where the majority of operators offer service -- in the US, this means areas where three of the four national carriers provide coverage.

It is a way to measure network experience in places where users would expect operators to provide high-quality due to the direct, head-to-head competition. This also reduces the impact of a network's coverage footprint, particularly in rural areas.

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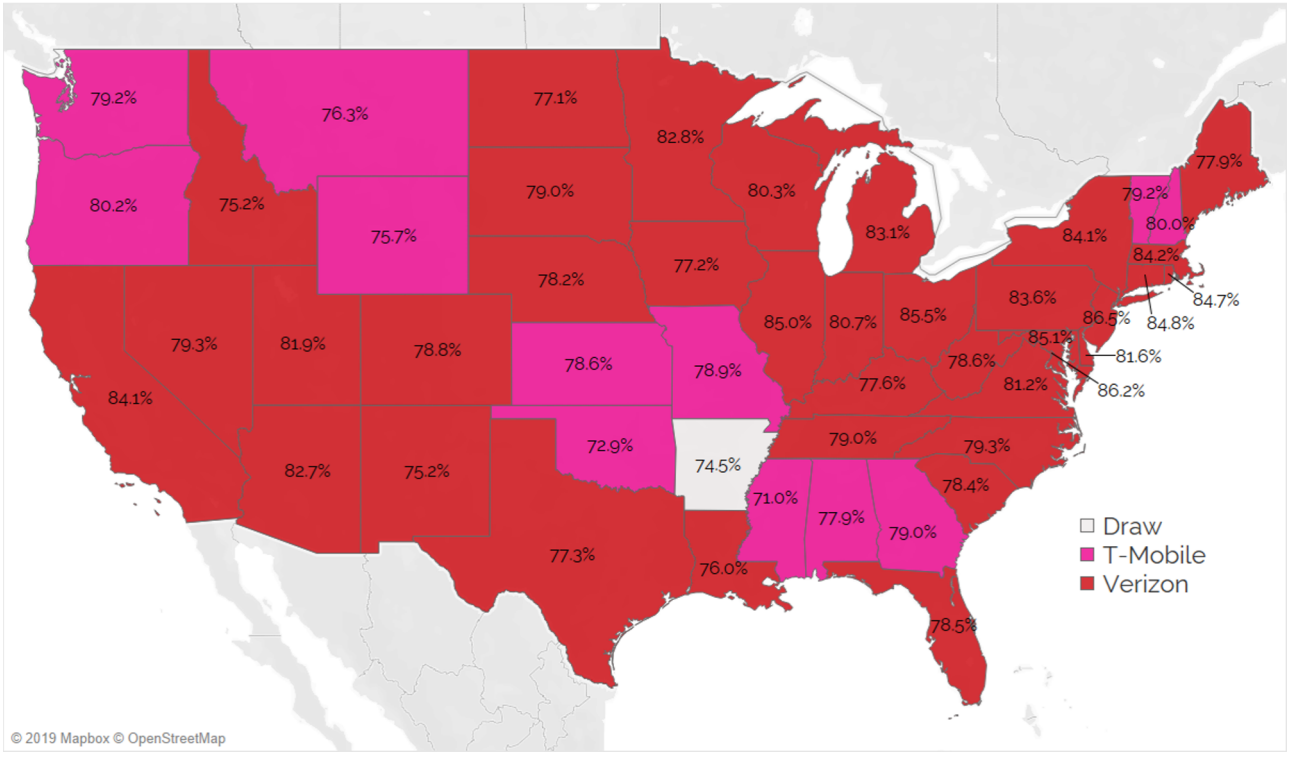
Best Provider for Excellent Consistent Quality Percentage in Common Coverage Areas



However, it is important to note that even in Common Coverage Areas, results do not necessarily reflect performance across the entire region; instead it represents experience where users of a particular network have signal. The Consistent Quality percentages for every operator and state can be found in the Appendix to this report.

For some states, operators also have domestic roaming agreements, which allow their users to connect to other operators' networks.

For example, Sprint only covers a small proportion of South Dakota with its own LTE network. For the rest, it relies on roaming agreements.

As Tutela's Consistent Quality metric is focused on the experience of real-world users on their chosen provider, regardless of the operator of the underlying infrastructure, the performance of those partner networks is included in the Consistent Quality percentage for the chosen provider in these cases.

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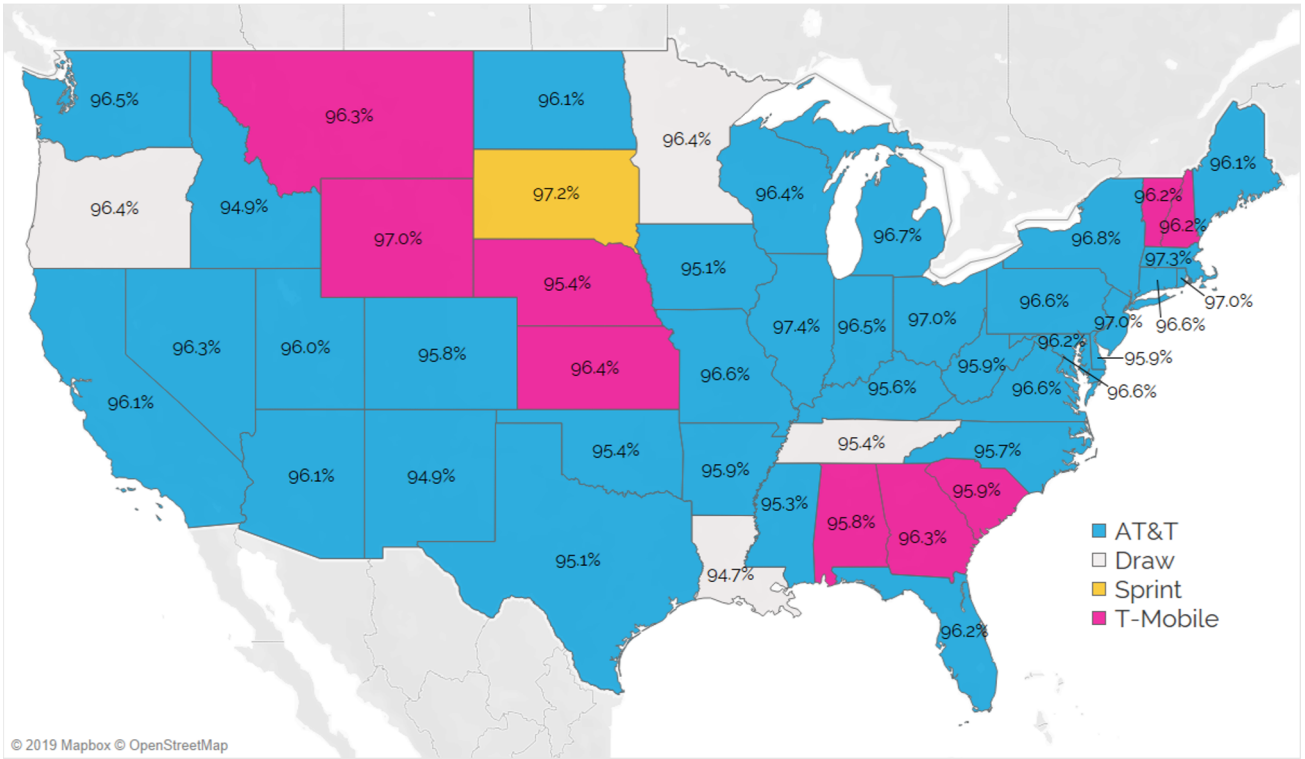
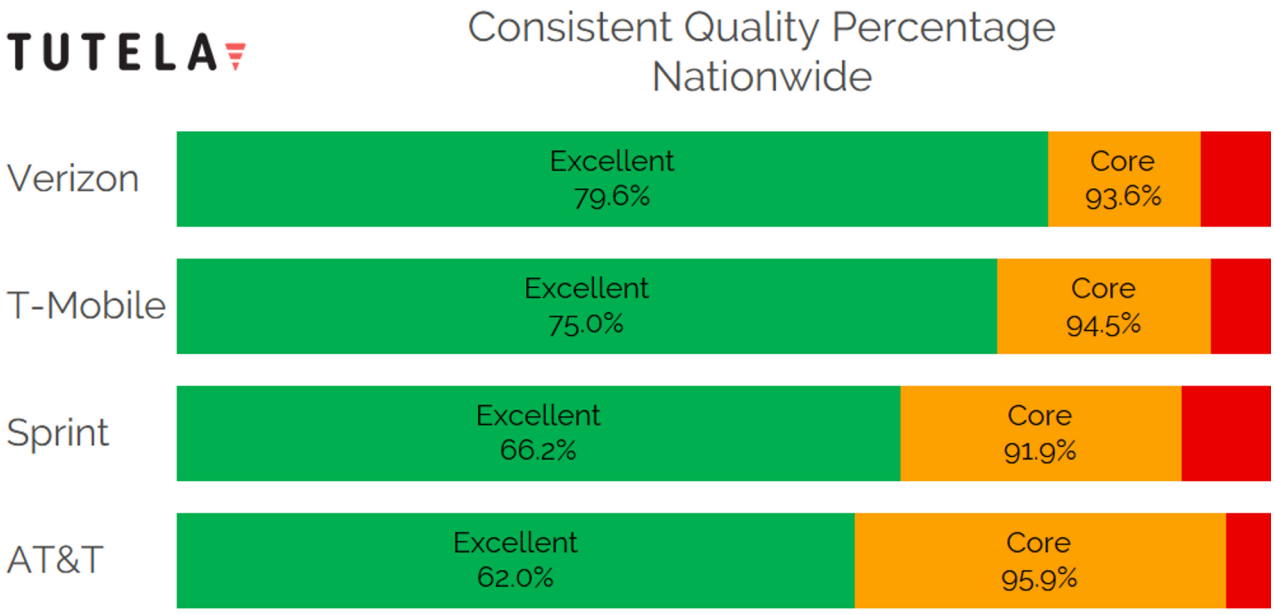
Best Provider for Core Consistent Quality Percentage in Common Coverage Areas



Although the focus of this report is on network performance in Common Coverage Areas, the tens of millions of users contributing data to Tutela are spread out nationwide, and looking at the results taken from all areas can show individual networks' relative strengths and weaknesses. The areas outside of Common Coverage Areas tend to be those in places that are harder to cover -- for example, rural areas or national parks.

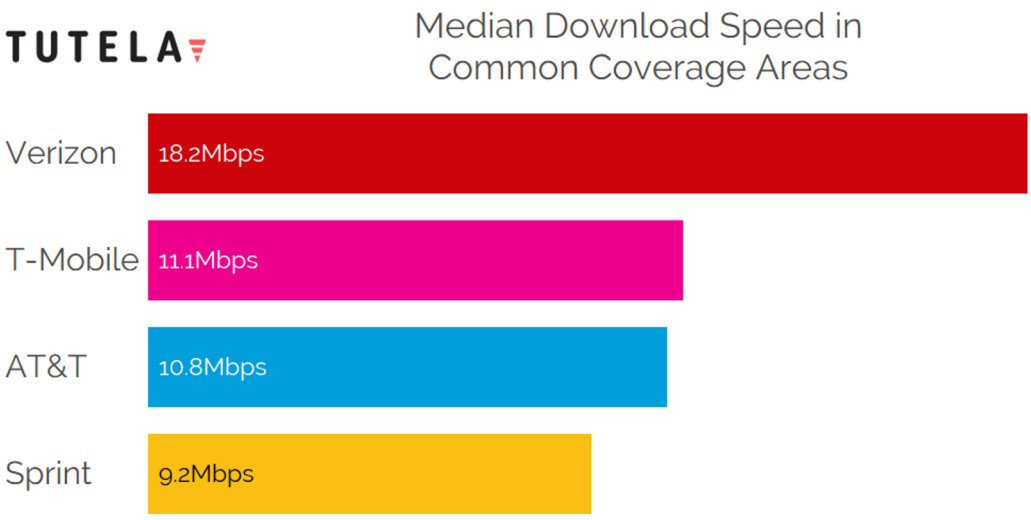
Therefore, when shifting from Common Coverage Area to nationwide results, we expect to see a slight decrease in performance. Unsurprisingly, AT&T and Verizon, which have more users outside of cities and populated areas, see the biggest decrease when moving from CCAs to nationwide results.

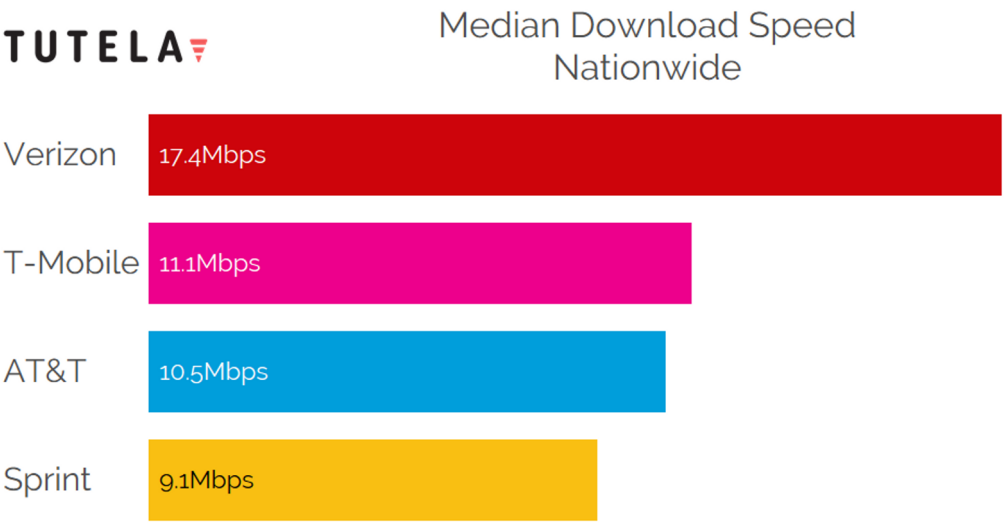


Download throughput

Verizon's significant lead in Excellent Consistent Quality compared to the other US carriers is a trend also borne out in a comparison of its average download throughput, where Verizon delivered a median performance of 18.2 Mbps. In Common Coverage Areas, Verizon had a 7.1 Mbps lead over second-place T-Mobile, and was almost double the speed on average of fourth-place Sprint.

Looking at a national level, Verizon saw the largest change in results, falling to 17.4 Mbps. This is likely reflective of Verizon's significant rural coverage footprint; sparse rural areas are often harder to provide the same network experience in that one might expect in denser cities. It is interesting too that AT&T's median also falls by 0.3 Mbps, while T-Mobile and Sprint stay more or less the same (with no change, and 0.1 Mbps decrease respectively).

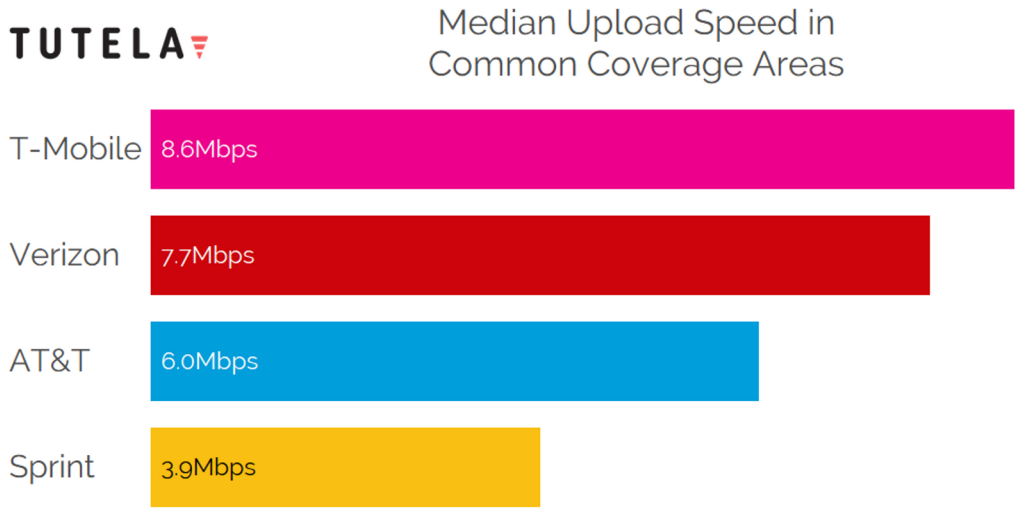


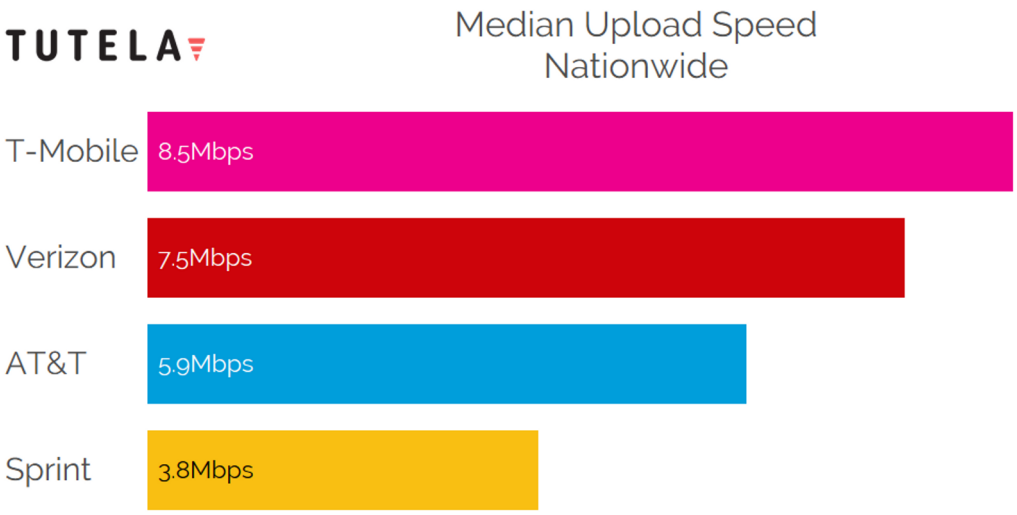


Upload throughput

Upload speed saw an interesting shift in the ranking order, with T-Mobile in first place at 8.6 Mbps in Common Coverage Areas. This was despite Verizon's clear advantage in median download speed.

Particularly interesting in the results is Sprint's significantly lower average upload throughput – less than half that of leader T-Mobile. There are many potential explanations for this, but one likely contributing factor may be Sprint's chosen ratio of download/upload configuration. In 2017, it was reported that Sprint would now use a 3-to-1 configuration to support a reported 12-to-1 traffic ratio(3).



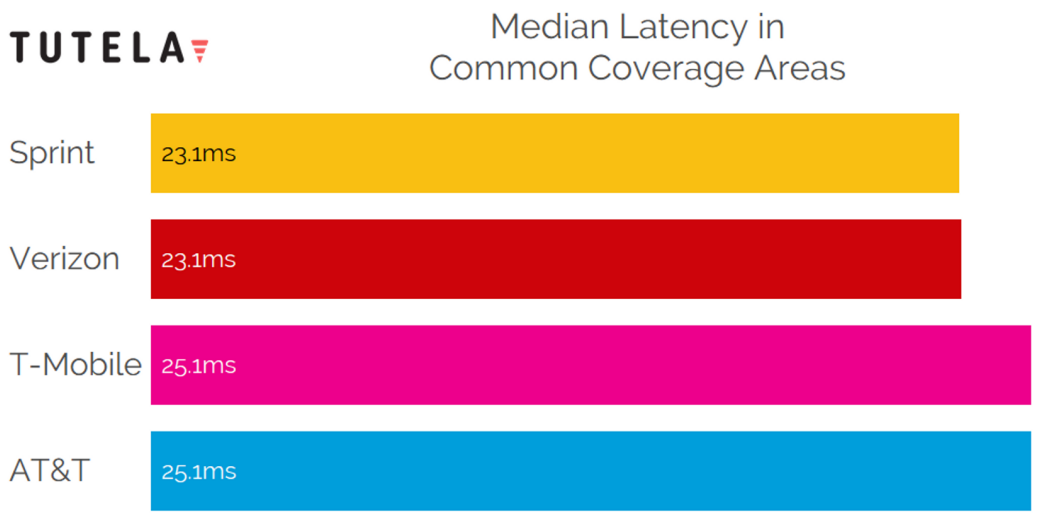


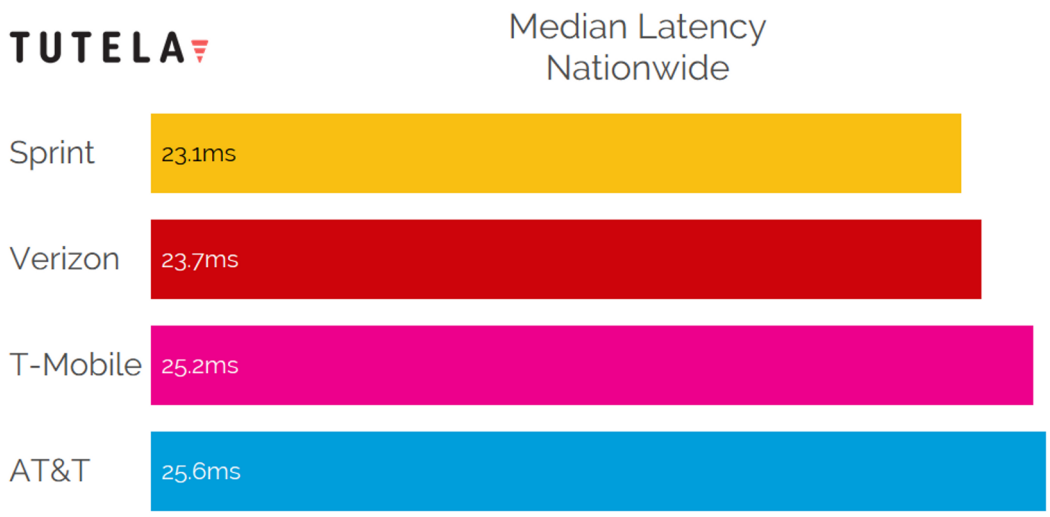
(3) Fierce Wireless, On path to gigabit LTE, sprint moving download/upload configuration to 3-1 to support 12-1 traffic ratio, https://www.fiercewireless.com/tech/path-to-gigabit-lte-sprint-moving-upload-download-configuration-closer-to-12-1-traffic-ratio
Retrieved 27 August 2019

Latency

Sprint's network provides an impressively low one-way latency – tying with Verizon for first place with a median of 23.1 ms. The competition was particularly fierce around latency in the US, with joint third-place T-Mobile and AT&T just 2.0 ms behind the winners in common coverage areas.

The picture changes somewhat when looking at a national level. Once again, Verizon's rural coverage leads to it having a slightly higher latency than Sprint when looking at all measurements for operators across the entire country. However, the change is by fractions of a ms, and still leaves Verizon ahead of T-Mobile and AT&T.





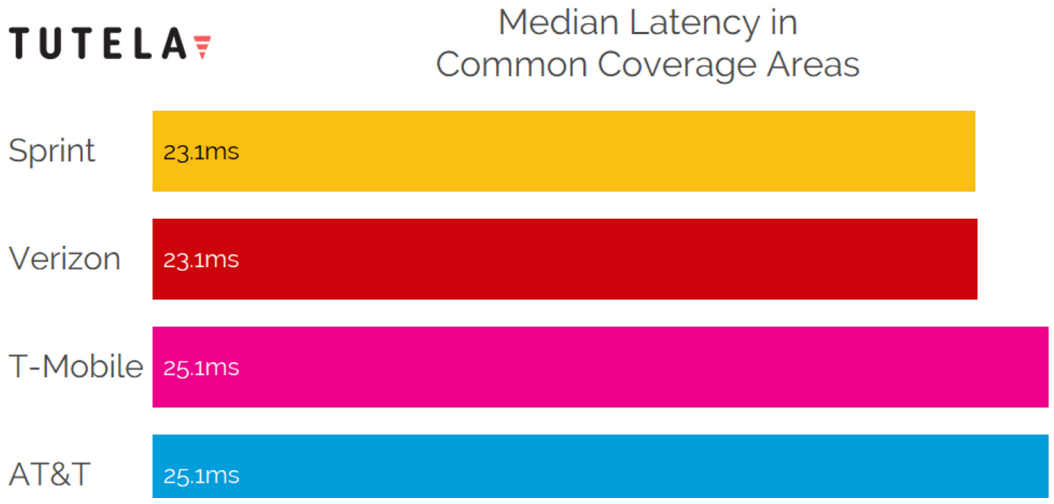
Latency

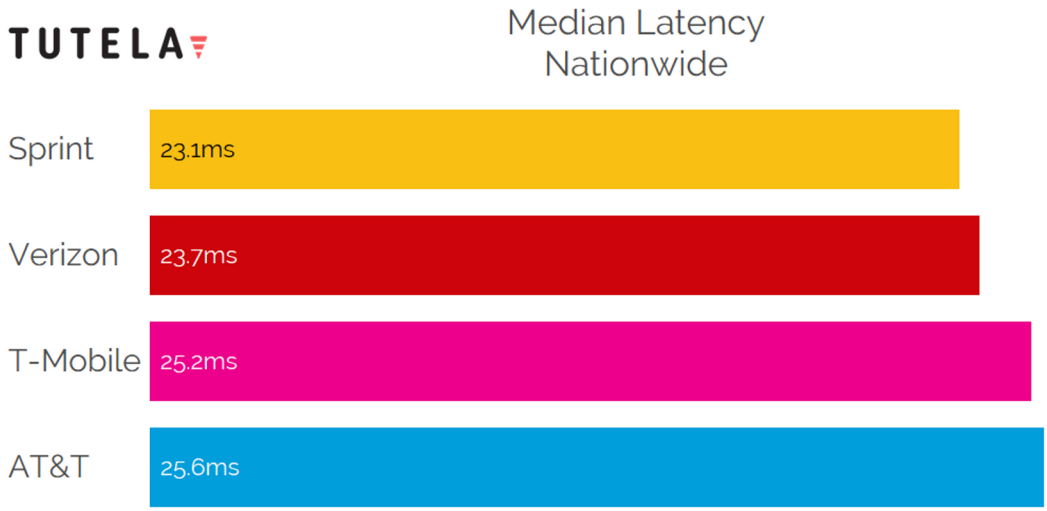
The median latencies for all four operators are significantly better than the 50 ms threshold for Tutela's Excellent Consistent Quality threshold which means that in most cases, which is important for how fast a network "feels" to users in cases such as web browsing.

However, it is interesting that median latencies across the board are all greater than 20 ms, given the high percent of time users spend on 4G rather than 3G connections. For comparison,

in Tutela's recent UK State of Mobile Networks report, the highest median one-way latency for any operator was 3 at 17.3ms, despite users spending just 74.1% of time on 4G. This is likely a product of the size of the US. In a smaller country, traffic has to travel

less distance between host servers and users, whereas in a country like the US, the geographic distance between user equipment and end servers means that networks have to work "harder" to move traffic around at the same speeds.

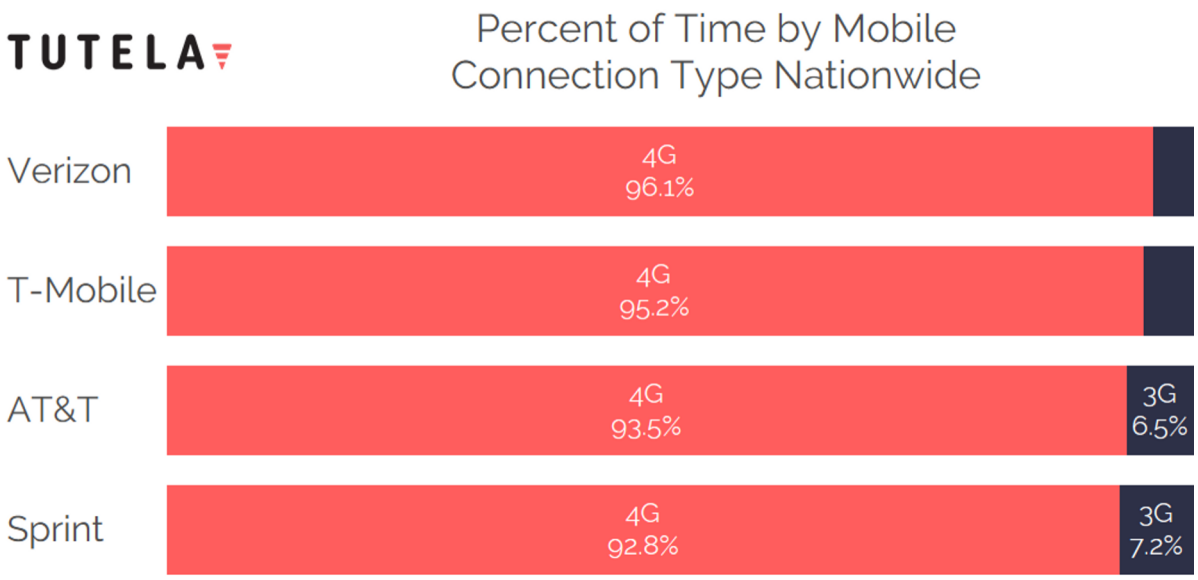




Data and spectrum usage

Verizon's leadership in the provision of 4G technology is no surprise, when you consider Verizon's performance in Excellent Consistent Quality. It's extremely challenging for a 3G network connection to surpass the Excellent Consistent Quality thresholds, and this is reflected in that Verizon users spent the highest proportion of their time on 4G networks out of all four operators.

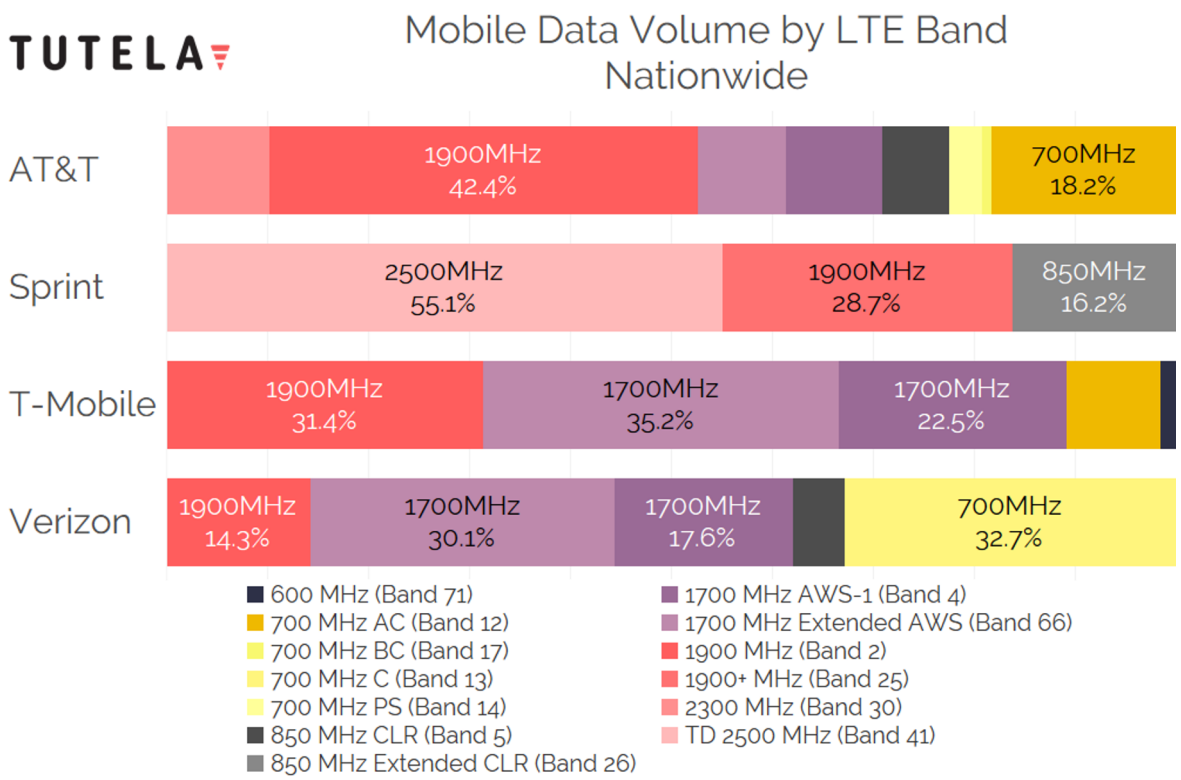
However, it's also notable that users of all four operators spent more than 90% of their time on 4G, showing how pervasive the technology is in the US. The ubiquity of 4G means that plans are already well advanced(4) to sunset 2G and 3G networks, which will free up hugely valuable spectrum for new 4G and 5G services.



(4) Multitech, Anticipated cellular carriers 2g/3g sunset dates
https://www.multitech.com/documents/publications/marketingguides/MT_Anticipated_Sunset_Cellular_Carriers_PDF.pdf
Retrieved 29 August 2019

Looking at the data volume transferred by band by operator shows some of the structural differences in how the four operators' LTE networks have been designed. Sprint, for example, relies heavily on its 2500 MHz and 1900 MHz mid-band spectrum, in which it has ample capacity. By contrast, Verizon relies most heavily on its 700 MHz low-band spectrum. Since low-band radio waves travel further and penetrate buildings or obstacles better, they provide better coverage -- which goes some way to explaining the coverage gap between AT&T/Verizon and Sprint/T-Mobile.

The change in spectrum utilization in the past year is also notable, since both T-Mobile and AT&T have embarked on ambitious and far-reaching deployments of new spectrum. Both companies have made impressive strides, with AT&T adding FirstNet coverage to an additional 34% of the population in the last year, and T-Mobile adding brand-new coverage to wide swathes of over a dozen states(5). New spectrum adds capacity to networks that are under an ever-increasing load; although the focus for new spectrum is on 5G, these 4G spectrum deployments are bringing real and tangible improvements to millions of consumers right now.



(5) Tutela, Mapping t-mobile's 600 mhz rollout
https://www.tutela.com/blog/mapping-t-mobiles-600-mhz-rollout-how-coverage-and-deployment-have-improved-over-two-years
Retrieved 29 Aguust 2019

Methodology

Tutela is an independent crowdsourced data company with a global panel of over 300 million smartphone users. We gather information on mobile infrastructure and test wireless experience, helping organisations in the mobile industry to understand and improve the world's networks.

Tutela collects data and runs network tests via software embedded in a diverse range of over 3,000 consumer applications, which enable the measurement of real-world quality of experience for mobile users, 24/7. For this report, we gathered 1,385,066,516,744 measurements, including over 205 million speed tests and 3,827,571,062 latency measurements, from 21.540,068,945 devices (iOS and Android smartphones) between March 1st and August 31st 2019.

Tutela measures network quality based on the real-world performance of actual network subscribers, inclusive of occasions when a network or tariff may be throttled or congested. Results in this report are based on a testing configuration designed to represent the typical (rather than maximum) performance that users experience. We use a 2 MB file to perform our download testing and a 1 MB file to perform our upload testing. Latency performance in this report reflects one-way UDP latency. Tests are conducted against the same content delivery networks that power many of the world's most popular consumer applications, and as such reflect the end-to-end performance of the network.

Consistent Quality

Download speed is most often used as a proxy for network quality, but while download throughput is important, it's just one of several crucial requirements for a "good" connection.

As operators have upgraded 3G networks to LTE-Advanced technology, theoretical (and even real-world) peak throughput speeds have increased to where they vastly outstrip the maximum needed for any current use-case. Real-world speeds above 100 Mbps are now common in parts of the world, and with a 4K video stream -- which itself is rarely something smartphone users need -- using a fifth of that, average download speed has lost some of its relevance as the dominant statistic used to measure the quality of wireless networks.

At its most basic, a good connection is one that doesn't get in the way of users doing what they want to do. In the real world, smartphone users aren't running speed tests all day -- they're browsing the web, using apps, voice calling their friends, streaming Netflix and YouTube, or making video calls.

Consistent Quality

To more objectively evaluate when networks are (and are not) enabling users to do those things, Tutela has developed a standard called consistent quality. Simply put, it's two sets of thresholds, called Excellent and Core. If a connection hits the Excellent standard, it's sufficient for the most demanding mobile use-cases, like HD group video calling or 1080p video streaming. A Core connection is good enough for SD video streaming, web browsing, emails, and VOIP calling, but users are more likely to experience delays or buffering when trying to use more demanding apps. Tutela bases the threshold values on the minimum performance requirements published by popular apps. We most recently updated our Consistent Quality thresholds on September 1st, 2019.

Tutela's consistent quality metric, as used in our reports, simply measures the percentage of time that users can hit the thresholds. The higher the number, the more often users have a Core or Excellent quality connection.

Excellent Quality

KPI	Download throughput	Upload throughput	Latency	Jitter	Packet loss
Minimum acceptable value	5 Mbps	1.5 Mbps	50 ms	30 ms	1%

Core Quality

KPI	Download throughput	Upload throughput	Latency	Jitter	Packet loss
Minimum acceptable value	1.5 Mbps	500 Kbps	100 ms	50 ms	5%

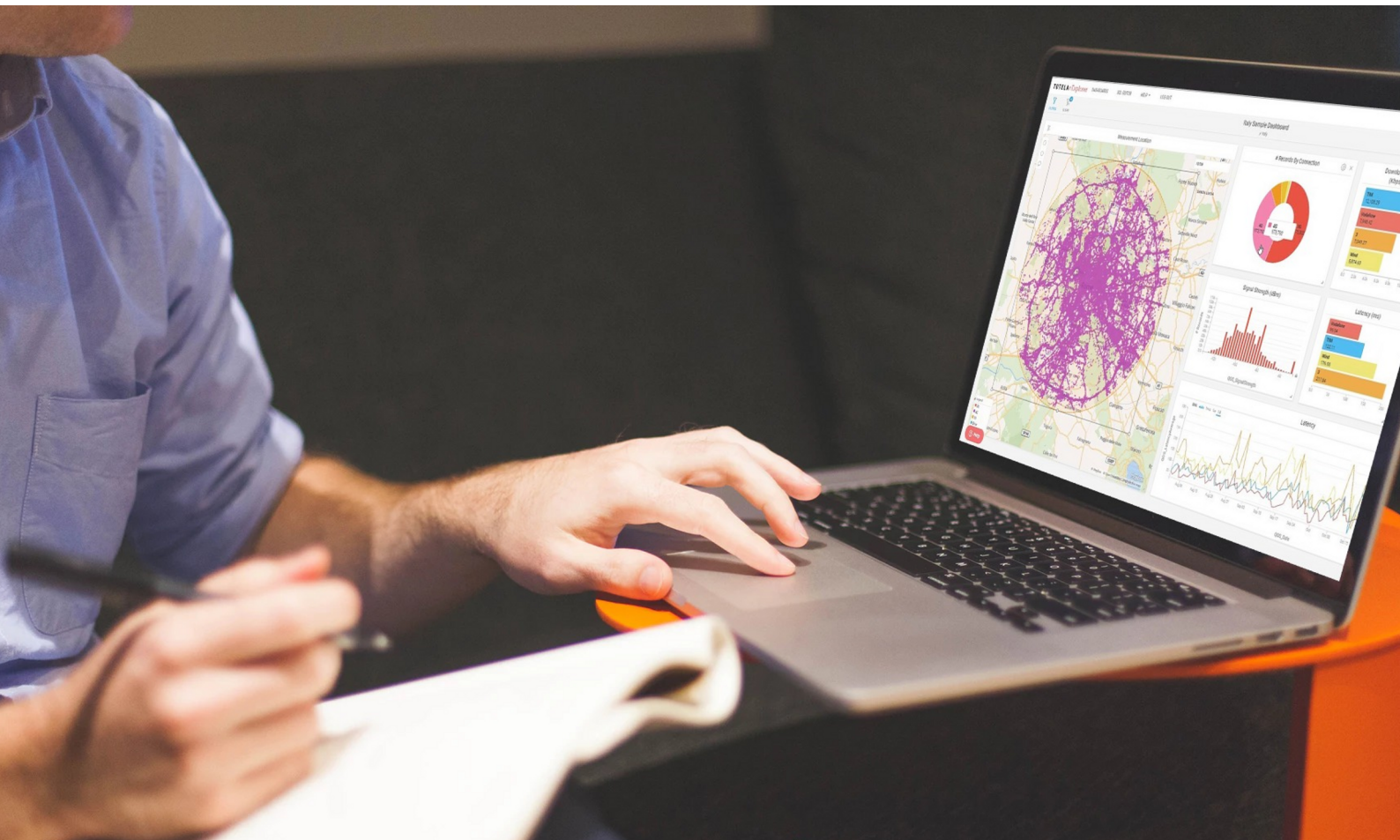
Discover Tutela Explorer

Tutela Explorer is a powerful cloud-based solution for real-time analysis of crowdsourced data. Using the platform, mobile operators can:

- Create coverage and quality maps
- Benchmark network quality and coverage across all operators
- Drill down to any KPI at city, street or even building level
- Analyse spectrum utilisation, performance and more

Visit www.tutela.com/explorer to learn more

Learn more



Appendix

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Error Margins

		Download Median	Upload Median	Latency Median	Excellent CQ	Core CQ
Common Coverage Areas	Sprint	±0.01Mbps	±0.00Mbps	±0.0ms	±0.0%	±0.0%
	Verizon	±0.01Mbps	±0.00Mbps	±0.0ms	±0.0%	±0.0%
	T-Mobile	±0.00Mbps	±0.00Mbps	±0.0ms	±0.0%	±0.0%
	AT&T	±0.01Mbps	±0.00Mbps	±0.0ms	±0.0%	±0.0%
Nationwide	Sprint	±0.01Mbps	±0.00Mbps	±0.0ms	±0.0%	±0.0%
	Verizon	±0.01Mbps	±0.00Mbps	±0.0ms	±0.0%	±0.0%
	T-Mobile	±0.00Mbps	±0.00Mbps	±0.0ms	±0.0%	±0.0%
	AT&T	±0.01Mbps	±0.00Mbps	±0.0ms	±0.0%	±0.0%

Appendix

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Consistent Quality Percentage in Common Coverage Areas

	Excellent				Core			
	AT&T	Sprint	T-Mobile	Verizon	AT&T	Sprint	T-Mobile	Verizon
Alabama	57.4%	61.7%	77.9%	73.4%	94.8%	89.6%	95.8%	91.1%
Arizona	54.6%	67.0%	75.0%	82.7%	96.1%	91.8%	94.9%	93.7%
Arkansas	59.9%	61.2%	74.5%	74.4%	95.9%	88.9%	95.6%	91.5%
California	64.4%	69.6%	69.2%	84.1%	96.1%	93.8%	91.9%	94.7%
Colorado	53.5%	71.4%	71.2%	78.8%	95.8%	93.9%	94.5%	93.0%
Connecticut	66.1%	68.0%	76.0%	84.8%	96.6%	92.0%	94.6%	95.5%
Delaware	68.6%	66.5%	77.8%	81.6%	95.9%	92.8%	95.0%	94.3%
District of Columbia	66.5%	72.5%	71.4%	86.2%	96.6%	94.0%	93.0%	95.5%
Florida	59.7%	60.5%	76.7%	78.5%	96.2%	87.6%	95.4%	93.8%
Georgia	61.8%	64.2%	79.0%	78.5%	95.5%	91.3%	96.3%	92.8%
Idaho	55.4%	65.2%	72.3%	75.2%	94.9%	92.9%	93.3%	91.4%
Illinois	67.2%	70.6%	76.7%	85.0%	97.4%	94.0%	95.0%	95.4%
Indiana	67.8%	68.0%	73.3%	80.7%	96.5%	93.1%	94.4%	94.3%
Iowa	59.7%	63.2%	72.1%	77.2%	95.1%	89.2%	94.7%	91.5%
Kansas	58.9%	65.9%	78.6%	78.5%	96.2%	91.9%	96.4%	92.9%
Kentucky	62.2%	64.1%	73.7%	77.6%	95.6%	89.9%	95.2%	93.5%
Louisiana	62.0%	58.5%	70.4%	76.0%	94.6%	87.8%	94.7%	93.0%
Maine	66.8%	64.2%	77.0%	77.9%	96.1%	92.3%	95.7%	92.4%
Maryland	65.8%	69.3%	73.3%	85.1%	96.2%	93.6%	93.5%	95.2%
Massachusetts	67.2%	69.2%	77.3%	84.2%	97.3%	93.2%	94.8%	95.5%
Michigan	69.2%	63.9%	80.1%	83.1%	96.7%	92.4%	96.0%	94.7%
Minnesota	68.4%	68.9%	82.7%	82.8%	96.4%	91.8%	96.4%	94.5%
Mississippi	57.8%	54.8%	71.0%	60.7%	95.3%	87.5%	94.9%	88.2%
Missouri	67.6%	65.4%	78.9%	77.7%	96.6%	92.0%	95.8%	93.3%
Montana	18.4%		76.3%	51.7%	95.3%	76.2%	96.3%	92.5%
Nebraska	53.7%	65.2%	77.9%	78.2%	94.5%	90.3%	95.4%	91.8%
Nevada	63.4%	72.0%	65.2%	79.3%	96.3%	94.6%	91.4%	92.5%
New Hampshire	66.1%	67.3%	80.0%	77.3%	95.5%	93.9%	96.2%	91.9%
New Jersey	69.4%	66.4%	77.9%	86.5%	97.0%	91.0%	94.9%	96.5%
New Mexico	53.4%	59.5%	63.9%	75.2%	94.9%	90.1%	91.7%	90.5%
New York	65.1%	71.4%	78.6%	84.1%	96.8%	94.0%	95.4%	95.1%
North Carolina	61.4%	60.6%	74.8%	79.3%	95.7%	91.3%	95.2%	93.6%
North Dakota	47.4%	67.6%	70.9%	77.1%	96.1%	90.5%	95.5%	93.4%

Appendix

Ohio	65.9%	68.4%	77.4%	85.5%	97.0%	93.7%	95.6%	95.7%
Oklahoma	60.3%	55.2%	72.9%	71.4%	95.4%	88.2%	94.4%	89.9%
Oregon	63.7%	71.9%	80.2%	76.2%	96.4%	94.9%	96.3%	92.4%
Pennsylvania	64.6%	70.5%	75.6%	83.6%	96.6%	94.5%	94.4%	95.2%
Rhode Island	67.3%	71.3%	78.7%	84.7%	97.0%	93.6%	94.8%	95.5%
South Carolina	60.6%	58.8%	77.0%	78.4%	95.7%	90.6%	95.9%	93.3%
South Dakota	55.4%	77.4%	63.3%	79.0%	96.5%	97.2%	95.3%	93.3%
Tennessee	57.7%	56.7%	75.5%	79.0%	95.4%	86.3%	95.3%	93.0%
Texas	58.6%	64.7%	73.8%	77.3%	95.1%	91.0%	94.2%	93.0%
Utah	60.2%	69.1%	71.8%	81.9%	96.0%	94.6%	94.1%	94.4%
Vermont	65.5%	69.7%	79.2%	78.8%	95.4%	93.2%	96.2%	92.4%
Virginia	68.1%	66.0%	76.8%	81.2%	96.6%	91.9%	94.9%	93.7%
Washington	67.0%	71.4%	79.2%	78.1%	96.5%	93.5%	95.6%	93.6%
West Virginia	63.4%	69.5%	71.3%	78.6%	95.9%	94.2%	94.4%	93.5%
Wisconsin	64.0%	61.5%	69.8%	80.3%	96.4%	89.3%	93.4%	93.9%
Wyoming	10.6%	60.2%	75.7%	60.9%	95.1%	92.5%	97.0%	88.9%

About Tutela

Tutela Technologies, Ltd., is an independent crowdsourced data company with a global panel of over 300 million smartphone users. It gathers information on mobile infrastructure and tests wireless experience, helping organizations in the mobile industry to understand and improve the world's networks. Data and insights provided by Tutela are trusted by the engineering teams at mobile network operators and network equipment manufacturers around the world and used to compare operators as well as inform decisions in network and infrastructure planning and optimisation. The organization is headquartered in Victoria, British Columbia.

Tutela does not collect any sensitive personal data and is compliant with international privacy regulations including GDPR.

For further information about the methodology, data and tools used to create this report, please contact analysis@tutela.com or visit www.tutela.com.

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