Fixed wireless access

Technical best practices for deploying fixed wireless access

White paper

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Executive summary

Enterprise networking staff are tasked with providing fast, secure and reliable network access to applications in a cost-effective manner. Balancing this objective requires an understanding of the challenges involved, as well as the strategies to mitigate them.

The fixed wireless access (FWA) market is heating up, as businesses seek faster speeds and quicker deployment of access services to both public and private networks. The global FWA market is projected to register a compound annual growth rate (CAGR) of 73% between 2021 and 2026,[1] as carriers make significant investments[2] to overcome the restrictions of legacy broadband networks, including speed, reliability and availability of wireline access.

In this white paper, we explore the challenges associated with wired broadband and discuss how FWA may help to mitigate these challenges.

Broadband access services

The most widely used broadband internet access services span both wired and wireless technologies, and fall into four categories: DSL, cable, fiber and cellular. Each has different performance characteristics, transport technology and download vs upload speeds, and they are generally asymmetrical, which can make comparison challenging.

Most broadband services are also considered variable speed, meaning various environmental conditions may impact their speed at any time.

The median performances for wired broadband DSL, cable and fiber referenced in the chart reflect the aggregate of the major U.S. carriers, as measured by the Federal Communications Commission (FCC).[5] The average performance for mobile wireless referenced reflects the aggregate of major U.S. carriers as measured by Speedtest.[6] Verizon LTE Business Internet performance is based upon the average of lab tests at a single location. Verizon 5G Business Internet speeds are based upon customer trials at nine locations. Note that these performances offer only a sample reference, and factors such as network load, distance to data centers and environmental factors may impact performance on any connection at any time.

	Transport technology	Download speed (Mbps)	Upload speed (Mbps)	Latency (ms)
Wired	DSL (median)[3]	8.90	1.05	35.33
Wired	Cable (median)[3]	163.81	16.06	20.94
Wired	Fiber (median)[3]	174.43	103.40	9.42
Mobile wireless	Mobile cellular (average)[4]	76.15	13.42	40.00
Fixed wireless	Verizon LTE Business Internet (average, 50 Mbps speed plan)	41.65	12.09	89.47
Fixed wireless	Verizon 5G Business Internet (average, 400 Mbps speed plan)	386.33	100.33	26.37

Figure 1. Sample performance references

The challenges with wired broadband access

Wired broadband access services, such as DSL and cable internet service, come with challenges that can inhibit the rapid deployment of quality network service. Those challenges can include:

- Determination of service availability
- Deployment agility
- Reliability and diversity of last-mile access
- Quality of service (QoS) features
- Access to private networks
- Remote management and automation
- Cost of multivendor coordination

We'll talk a bit about each.

Determination of service availability

Determining the availability of wired broadband service at locations spread across the country is a challenge. For organizations with offices located in multiple states, establishing service may entail the engagement of multiple providers with unknown success for service availability, delivery and network speed performance. A typical wireline broadband connection could require any or all of the following steps:

- Placing an inquiry with a local provider to determine a "desktop estimate" for an initial indication of service availability and network speed
- Placing an order with the local provider to make a more definite service availability determination
- Scheduling a site visit to validate service availability, determine the actual speed based upon distance from a central office and provide cost estimates for wired installation, if service is not available in the desired part of the building
- Construction of wire installation to the site, if service is unavailable

Performing each of these steps for a variety of locations across several local providers is a complex endeavor. Many organizations in this position will rely upon service aggregators to mitigate these efforts.

Deployment agility

The wait for wireline broadband services can be lengthy. If a wired infrastructure already exists at the site, it can take several weeks for service to be deployed. If wired infrastructure does not exist, deployment can take months.

Reliability and diversity of last-mile access

The last mile is the relatively expensive and complex delivery of cables or wiring from the service provider's facility to a customer's location. Last-mile diversity describes the physical separation of access wires traveling this distance. This level of diversity is typically unavailable to small office locations, or too costly to provide. When seeking high network availability for a critical location, enterprises will oftentimes order a redundant circuit from an alternate service provider. However, obtaining wireline services from different carriers can give a false sense of security. It is often very difficult to ascertain the fiber-optic routes between carriers; paths may cross or even use the same conduit to the customer premises. When more than one local access circuit travels in the same path for the last mile, there is a lack of local access diversity. This creates business risk, as both network connections can be severed at the same time at a single point of failure.

QoS features

QoS is a set of technologies that work across local area and wide area networks to support high-priority applications and traffic under limited network capacity. However, wired broadband service providers generally lack network QoS features to support mission-critical applications.

Access to private networks

The lack of inherent privacy features and complex IP-VPN configurations may be a challenge when deploying wired broadband services.

To achieve privacy over the internet, companies often leverage IPsec VPN technologies as a less expensive alternative to MultiProtocol Label Switching (MPLS) networks and dedicated access. Wired broadband is inherently an internet-based service and does not offer privacy service features. Therefore, an IPsec VPN-capable router is required. In addition, if full-mesh communications are needed, IPsec VPN configurations can become complex and increase the cost requirements of the on-premises router.

Remote management and automation

Legacy broadband service activations, deactivations and speed changes are generally configured by central office administrators, and generally don't happen immediately. But today's consumers have come to expect agile, cloud-based services, along with application programming interfaces (APIs), to support changing network requirements and gain competitive advantage.

Cost of multicarrier coordination

Terrestrial broadband service providers are regulated in the U.S. and allowed to provide services in specific, limited geographic areas. As such, procuring terrestrial broadband services across a wide geography from a single provider is rarely possible. Enterprises with widespread locations often turn to ISP aggregators to relieve the burden of dealing with multiple service providers, but the markup fees for aggregation services can range from 20% to 30% of the broadband connection. These overlay services required often include purchasing, billing, customer service, location tracking and service portals to facilitate the complex commercial management of multiple internet connections.[5, 6]

Mitigation strategies using fixed wireless access

The following FWA capabilities can help mitigate the limitations of wired broadband.

Ease of determining service availability

While a site visit and signal survey are recommended before installing an FWA device or router at the premises, savvy enterprises may make their own initial determination of service availability and download/upload speeds for FWA prior to installation. For example, Android® phones can download and install a free app called "Network Cell Info LITE" or "LTE Discovery" to measure the LTE signal. iOS devices can also be used to test signal strength, by dialing *3001#12345#*.

Factors that can affect signal values

There are many factors that influence signal strength and quality, including:

- Proximity to the cellular tower
- Tower usage load vs capacity (large groups of users)
- Physical barriers (mountains, buildings, trains, etc.)
- Competing signals
- Weather events
- Signal degradation (going through a cellular repeater)

Signal 4G LTE	Signal power (RSRP)	Signal quality (RSRQ)	Signal quality noise ratio (SINR)
Excellent	> -85 dBm	> -10 dB	> +15 dB
Good	-85 to 95 dBm	-10 to -15 dB	+15 to +4 dB
Medium	-95 to -115 dBm	-15 to -20 dB	+4 to -6 dB
Edge	< -115 dBm	< -20	< -6

Figure 2. Signal measurements for 4G LTE

Self-service signal measurements for Reference Signal Received Power (RSRP), Reference Signal Received Quality (RSRQ) and signal-to-interference-plus-noise-ratio (SINR) can be determined from a typical smartphone connected to the FWA carrier's network. RSRP values are measures of a cellular signal's power, whereas SINR and RSRQ are values that show the signal's quality.

Deployment agility

FWA using 4G LTE is designed to be "plug and play," enabling speedy deployment. The service can be up and running in a matter of hours or days, rather than weeks or months. Self-service and professional deployment options are available, depending on the enterprise's needs.
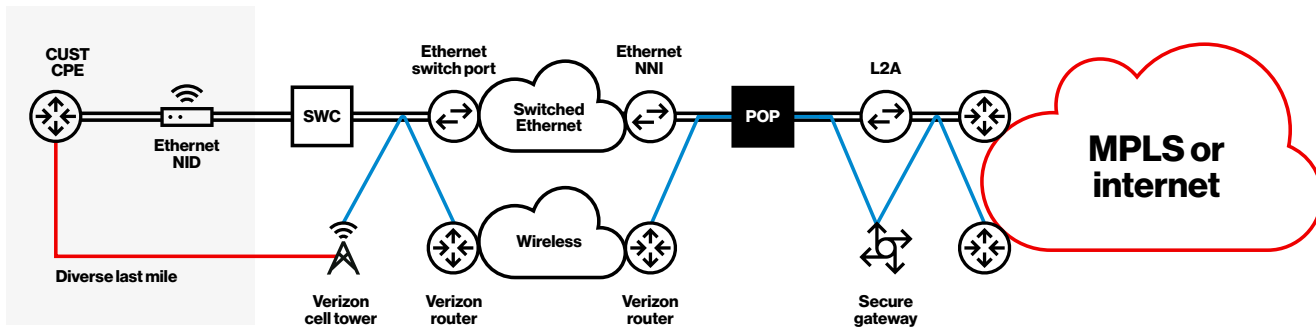
That said, in the initial stages of deployment for FWA using 5G Business Internet services, professional deployment may be required to help achieve the best performance of service. This helps ensure line-of-sight from the receiver at the client site and the microcell servicing the location. Self-service options may become available in the future.

Figure 3. Creating last-mile network access diversity.

Achieving last-mile network access diversity as a strategy for business application resilience

FWA provides diversity for last-mile access as depicted in the reference diagram. This diversity is valuable for keeping critical locations and applications up and running and can complement other wireline access methods to provide resiliency. The diagram illustrates diversity of the last mile, as well as transparency for potentially shared network elements.

Helping to ensure security of corporate data with private networks

Verizon Wireless Private Network[7] is a security service solution using Verizon 4G LTE technology (and, where available, 5G). Private Network enables wireless devices to send and receive data to and from the customer's IP network without traversing the public internet. It provides a fast, direct connection to internal systems and applications, without compromising network control and manageability, giving organizations a competitive edge to fuel growth and privately integrate wireless devices into their network.

With Private Network, enterprises can deliver mission-critical information to workforces and connected devices on the largest high-speed wireless network in America, while reducing security concerns and reliability issues related to the public internet. Having data communications segregated from the public internet blocks unsolicited traffic and unauthorized devices, thereby reducing security risks.

With Private Network, the organization has its own network, where traffic is kept isolated from the public internet.

1. Devices are authenticated and authorized for each private network (only authorized data can traverse the designated network)

2. Data is routed per customer-specific IP pools

3. Dedicated Private Network gateways are designated

4. A direct connection is created between Private Network gateways and the customer
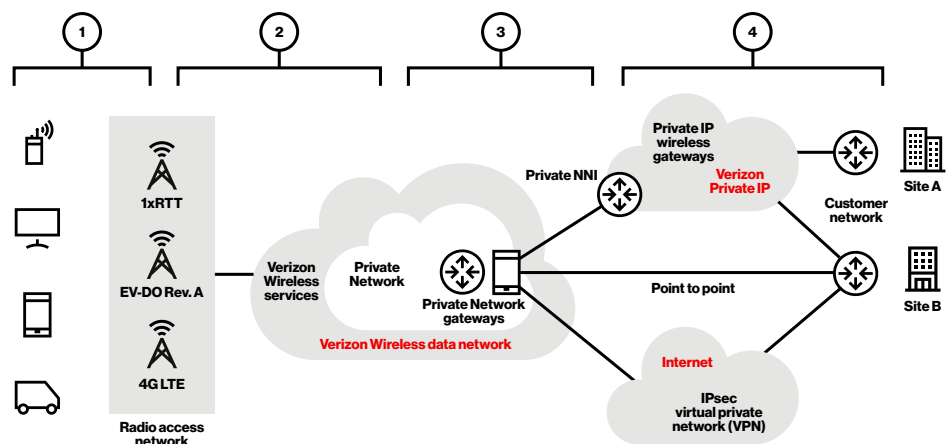

Figure 4. Private Network isolates traffic from the public internet.

QoS service features for FWA networks to enable priority traffic management

Private Network Traffic Management[8] offers Verizon customers an express forwarding feature on the 4G LTE network. It can help improve user experience by:

- Prioritizing IP traffic for business-critical applications

- Delivering more predictable application performance during peak demand

- Giving priority access to the 4G LTE Radio Access Network (RAN) and Preemption for qualified first responders, public safety and critical infrastructure

This feature is available when used in conjunction with Verizon Private IP and Mobile Private Network.

Cloud-based remote management and automation to enable enterprise self-service

Verizon ThingSpace Manage[9] is an online self-service portal where customers can manage their IoT and machine-to-machine (M2M) devices. It enables provisioning of devices; usage monitoring; reporting; device tracking; connectivity troubleshooting; alert configuration; SIM purchasing; security service implementation; firmware update scheduling; geofence establishment and much more.

The ThingSpace Connectivity Management API[10] platform allows users to add and activate devices and monitor usage, connection status and reachability for data and SMS communication, as well as perform other device connectivity management tasks through a RESTful API. The API can be used to add connectivity management to anything from small apps to enterprise software systems, including enterprise resource planning (ERP), supply chain management and customer service management.

Cost reduction using single-carrier service provider

Leveraging a single wireless provider for FWA, as opposed to managing multiple broadband providers, can eliminate the costs associated with using a broadband aggregation service. Fixed wireless access via 4G or 5G connectivity is nearly ubiquitous in the U.S., which mitigates the need to manage disparate purchasing, billing, customer service, location tracking and service portals.
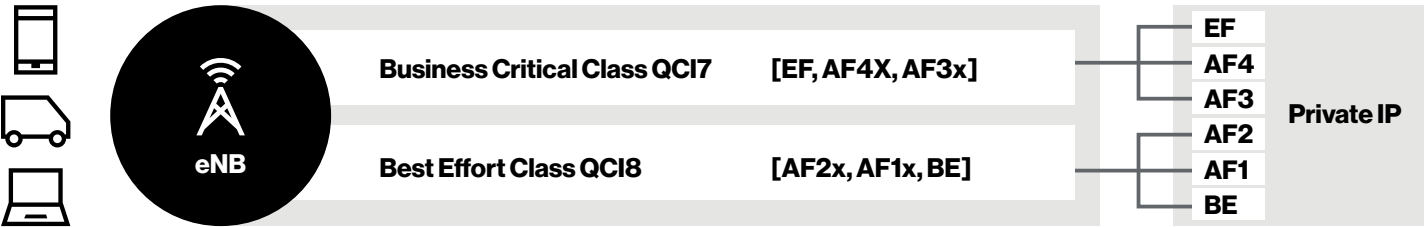

Figure 5. Private Network Traffic Management and Private IP classes mapping

Solutions using fixed wireless access

Primary access to public and private networks

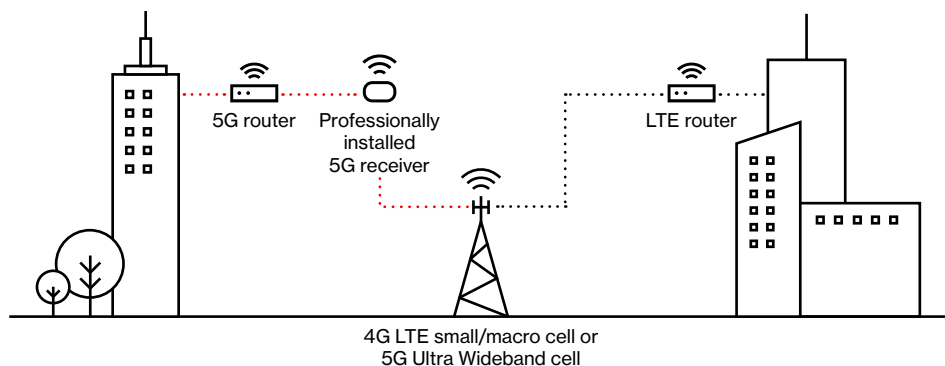- 5G Business Internet (with 5G receiver)

- 4G LTE Business Internet

Figure 6. Primary access to public and private networks

Parallel network connections for SD WAN

- Parallel FWA connections, active load sharing with wireline

- Software-defined wide area network (SD WAN)

- For mission-critical locations and business applications that require access diversity
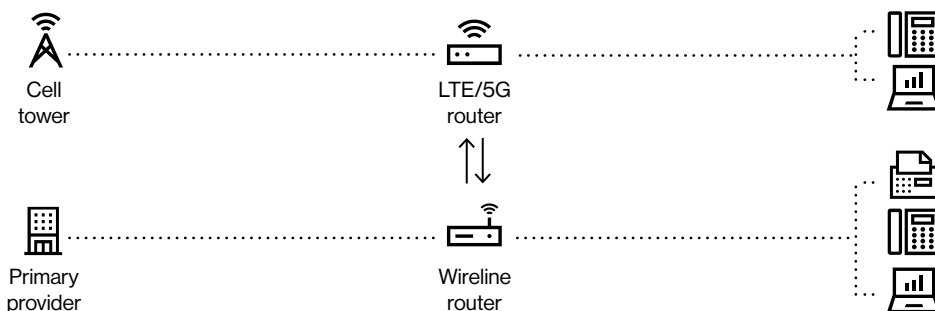

Figure 7. Parallel network connections for SD WAN

Backup network connections and remote out-of-band access services

- Failover from primary wireline access

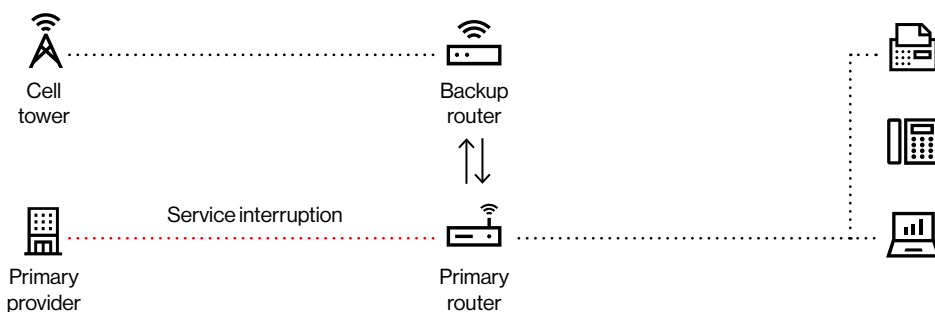- Network resiliency option to help support operation in extreme weather conditions

Figure 8. Backup network connections and remote out-of-band access services

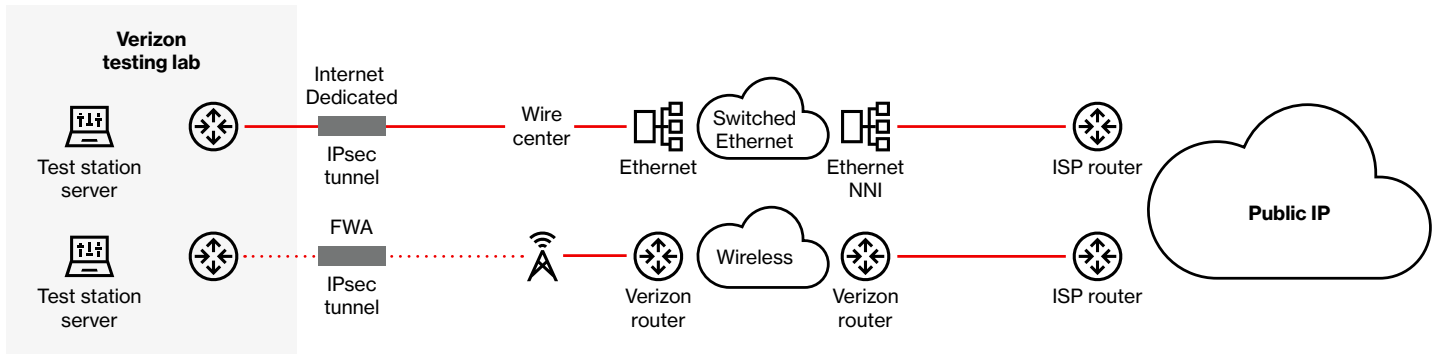# Fixed wireless access technical best practices

Figure 9. The Verizon testing lab setup

In this section, we take a look at a series of lab tests that we conducted to help determine best practices for a successful FWA deployment. We'll share our recommendations for application performance requirements, sizing FWA cellular plans based upon user needs, QoS techniques and hardware selection. We believe that careful consideration of these factors can lead to enhanced performance over an FWA network.

Our lab environment and setup

The lab was set up to test various configurations, QoS, application performance and network throughput by emulating a traditional data center and client edge sites. The data center was equipped with a 100 MB wired internet circuit and a VPN head-end router with traditional QoS rate limited to 50 MB. The client edge site was equipped with a 50 MB Verizon LTE Business Internet FWA connection and a cellular-enabled VPN router setup with auto QoS for the queuing mechanism.

We simulated five concurrent SIP/Voice over IP (VoIP) calls (g.711), 4 Mbps of bidirectional video streaming and varying loads of HTTP session traffic, leveraging IXIA IxLoad and iPerf as our traffic generation and measurement tools. There were IXIA and iPerf devices located in both the data center and client edge locations.

In addition to simulated traffic, we also administered two Verizon IP/SIP trunks to a session border controller and PBX to make live calls. This allowed us to run two concurrent live voice calls while the simulated IxLoad traffic was running, adding a network stress element to the test.

We measured Mean Opinion Scores (MOS) for the simulated and live VoIP/SIP calls, as well as download and upload speeds and observed packet loss.

The table below lists the different call qualities and the lowest MOS Score limit for each of them. The limit values are from the ITU-T G.107 and ITU-T G.109 standards.

Maximum for G.711 codec 4.4	MOS
Very good	4.3–5.0m
Good	4.0–4.3m
Just ok	3.6–4.0m
Bad	3.1–3.6m
Very bad	2.6–3.1m
Not recommended	1.0–2.6m

Figure 10. Call qualities and MOS score measures

Test results and observations

Our observations are that FWA can be suitable for real-time and mission-critical traffic, assuming that specific application requirements can be accommodated by the FWA signal and throughput available at the location. It should be noted that our lab had excellent signal strength.

MOS for voice: 4.41 average (A rating)

(IXIA IxLoad)

Voice quality assessment **A** 4.41	The average voice quality across all users and all content is 4.41. **Average MOS:** 4.41 **Best MOS:** 4.41 **Worst MOS:** 4.26

Download and upload speeds

(iPerf — 30 second averages)

Download and upload speeds varied throughout the tests. These were the ranges we observed:

- **Download:** 18.79 to 49.68 Mbps
- **Upload:** 2.27 to 17.99 Mbps

Client edge FWA throughput during test

(IXIA IxLoad)

During this test, we saw sustained throughput on the Verizon 50 MB LTE Business Internet FWA connection. The chart shows that it may be possible to spike over and under the limit of the connection. However, it's worth stating again that FWA connections are variable speed, and this test under ideal conditions may not depict your expected throughput.
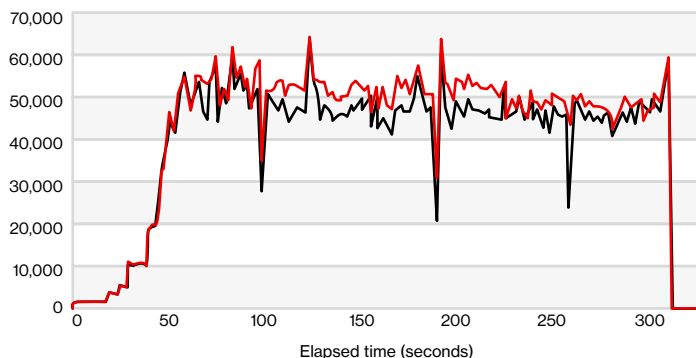

Figure 11. Throughput on Verizon 50 MB LTE Business Internet FWA connection

Packet loss

(IXIA IxLoad)

Packet loss performance for VoIP was not explicitly observed as a measure. However, the average MOS of 4.41 would imply that for VoIP it was below 1%.

Packet loss for HTTP traffic became a function of throughput of the download and upload speeds. When HTTP simulated demands exceeded the throughput of our FWA connection, we saw packet drops increase significantly. That said, we saw consistently good results in sending a bidirectional flow of 20 Mbps of simulated HTTP traffic (concurrent to the 4 Mbps of video streaming and SIP calls). The Simulated Users/Concurrent Connections (SU/CC) chart depicts the number of simulated sessions required to generate that sustained level of HTTP traffic.

HTTP performance (A rating)

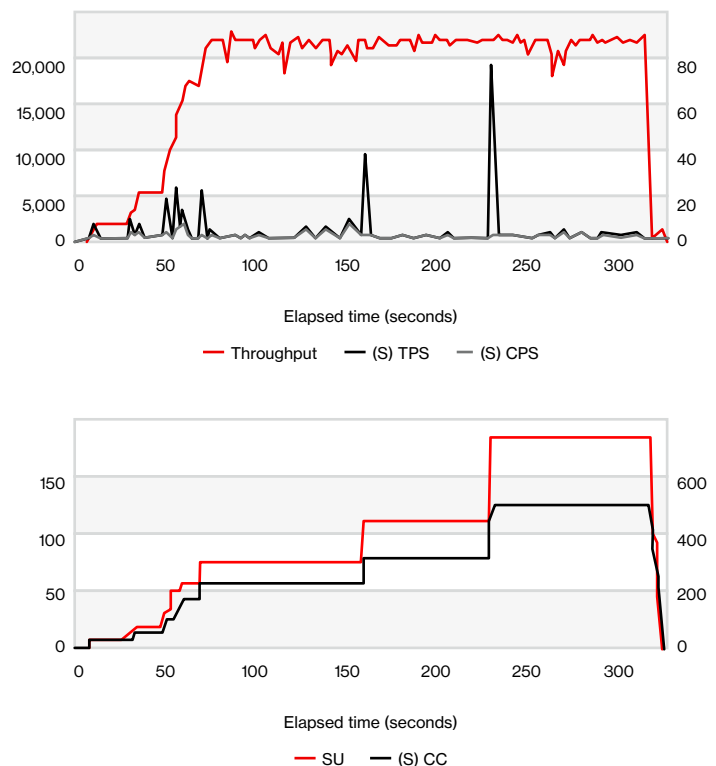| HTTP throughput performance **A** 98.01%	HTTP throughput performance is at 98.01% of the configured objective, the TCP connections failures was 0.00% of the total TCP connections and HTTP transaction failures was 0.00%.* **HTTP throughput:** 0.01% (0.02 Gbps) **TCP failures:** 0 (0%) **HTTP failures:** 0 (0%)

Figure 12. HTTP key performance indicators

* Activities not reaching sustain time or with advanced timelines are not used in grading competition.

Application performance requirements

The following table represents the required estimated bandwidth, latency, jitter and packet loss for typical real-time applications. While designing a network, it's important to pay attention to the parameters that applications require for optimal functionality. Make sure that you have a clear understanding of the network requirements for mission-critical applications in particular.

Application	Latency RTT	Jitter	Packet loss	Bandwidth per session
VoIP G.711 (bitrate 64 Kbps)	< 300 ms	< 30 ms	< 1%	87.2 Kbps
VoIP G.729 (bitrate 8 Kbps)	< 300 ms	< 30 ms	< 1%	31.2 Kbps
VoIP G.722 (bitrate 64 Kbps)	< 300 ms	< 30 ms	< 1%	80 Kbps
Cisco Webex	< 300 ms	< 30 ms	< 1%	2 Mbps
Skype®	< 300 ms	< 30 ms	< 1%	1.7 Mbps
Microsoft Teams®	< 300 ms	< 30 ms	< 1%	1.2 Mbps

Figure 13. Estimated bandwidth, latency, jitter and packet loss

How much data do I need for FWA cellular data plans?

When designing an FWA solution for your organization, you need to consider the anticipated data utilization and bandwidth requirements of all applications. Verizon 5G Business Internet plans presently come with unlimited data allotments. However, Verizon 4G LTE Business Internet plans offer a selection of various speed tiers and robust data sets.

For 4G LTE FWA, data usage and allotment are important considerations. On 4G networks, it makes sense to limit the types of traffic that users are allowed to consume. For example, restricting nonessential personal applications is strongly recommended. The table offers some estimated data usages for your planning.

We recommend that you run an FWA pilot at one of your sites for a month to measure the bandwidth and data you use. Your Verizon account team can help you get started with a trial for that purpose.

This table reflects estimated data usages for several common applications. These estimates will vary based upon users' individual habits.

Application	Data rate (Kbps)	Data per minute (Megabytes)	Data per hour (Megabytes)	Hours per user per day	Hours per user per month (20 working days)	Data use per month per user GB
VoIP G.711 (bitrate 64 Kbps)	87.20	1.31	78.30	2.0	40	3.13
VoIP G.729 (bitrate 8 Kbps)	31.20	0.48	28.80	2.0	40	1.15
Cisco Webex (voice and video)	2,000.00	30.00	1,800.00	2.0	40	72.00
Skype (voice and video)	1,700.00	25.50	1,530.00	2.0	40	72.00
BlueJeans (voice and video)	1,000.00	15.00	900.00	2.0	40	61.20
Microsoft Teams Video Conferencing	1,2000.00	18.00	1,080.00	2.0	40	36.00
Email (140 per day at 75 KB each)					40	0.21
General web browsing (100 web pages per day at 1 MB per page)						2

Figure 14. Estimated data usage per user, per month by application

QoS router configuration

Broadband networks—including FWA—are generally known to offer best-effort traffic handling with variable and asymmetrical speeds. These characteristics require special consideration when it comes to providing real-time and mission-critical traffic. While broadband internet lacks QoS features to honor packet tags (with the exception of Verizon Private Network Traffic Management), QoS mechanisms will still benefit the egress of traffic from your network, from both the client edge and data center perspectives.

Traffic egress from the data center will likely use traditional low-latency queueing (LLQ) techniques to allow real-time and mission-critical traffic to leave the network first. Here, it is important to estimate the client edge site's average download and upload speeds. (Only an estimate is possible, as broadband network connections are variable speed.)

The QoS egress policies from client edge locations, however, should consider alternative options to traditional LLQ. Router vendors handle QoS for variable-speed internet connections differently, with options such as Auto QoS or Adaptive QoS. An interesting queuing algorithm,

CoDel,[11] offers a no-knobs configuration that handles variable bandwidth and round-trip time (RTT), and a simple active queue management (AQM) and packet scheduling algorithm. We used this approach in our lab testing and found it both effective and easy to use.

FWA router selection

Router choice for FWA should be carefully considered. In addition to normal routing functions, you will want to determine if you want the cellular modem internal to the router, what types of QoS are supported by the router and what management features are specific to cellular.

Internal modem vs external modem/bridge

Having the modem internal to the router is convenient, as you manage a single device. However, when routers are located behind thick walls with metal cabinets surrounding them, cellular signals may be inhibited. For situations where signals have difficulty penetrating data closets, consider using an external modem/bridge. This option is helpful because the modem/bridge can be located remotely from the router via ethernet, in a location with a better signal.

Router QoS capabilities

Variable-speed connections are a challenge for traditional LLQ techniques. As noted, cellular router manufacturers have created unique queuing tools that are effective at handling the variable nature of FWA (and wired) internet connections. Furthermore, the CoDel standard for buffer management can be effective at the network edge in place of traditional LLQ QoS. This can simplify network edge administration and accommodate the variable speeds characteristic of broadband.

Tunable cellular parameters

Cellular routers vary greatly in the number of parameters that you can set. These settings may include items such as keepalive timers or connection dormancy. Some routers do not offer any settings for cellular performance. Research carefully to avoid unfortunate surprises later on.

Management software

Consider how well the management portal or router Internetwork Operating System (IOS) supports the reporting of cellular stats, modem configuration and management of multiple devices. Cellular feature sets in router IOS and management systems vary in maturity and should be chosen to suit your specific needs.

Modem selection

Note that modems are manufactured specifically for compatibility with each cellular service provider. The cellular connectivity type will be the main driver in the modem selection. Also consider whether the modem supports multiple cellular communications protocols, such as LTE CAT-20 and 5GNR.

4G LTE (indoor or outdoor)

Due to the low radio frequencies where LTE is implemented, signal propagation is generally less impacted by environment and building materials. Therefore, internal modems can often be utilized.

Modem recommendation:
LTE CAT-20

5G C-Band (maybe indoor/ maybe outdoor)

C-Band is the sweet spot, as it combines better signal propagation than millimeter-wave (mmWave) with its high bandwidth. While C-Band is expected to penetrate some buildings, others will require an outside-in approach that combines C-Band coverage from macro sites with in-building setups.

Modem recommendation:
5GNR

5G mmWave (outdoor)

Verizon 5G mmWave utilizes mmWave or higher frequency radio bands. mmWave 5G networks are ultrafast, but the signals are short range, making them suited for dense, urban areas and specific targeted spots, such as airports, stadiums, large campuses and entertainment venues. mmWave spectrum propagation can also be limited by doors, windows, trees and walls. Therefore, the majority of 5G mmWave installations will require an exterior antenna/receiver.

Modem recommendation:
5GNR

User equipment (LTE category)	Maximum downlink (Mbit/s)	Maximum uplink (Mbit/s)	User equipment (LTE category)
Narrowband IoT (NB-IoT)	0.68	1	Rel 13
CAT-M1	1	1	
CAT-1	10	5	
CAT-3	102	51	Rel 8
CAT-4	151	51	
CAT-6	301	51	Rel 10
CAT-9	452	51	
CAT-11	603	51	Rel 11
CAT-12	603	102	
CAT-16	979	102	Rel 12
CAT-18	1,174	210	Rel 13
CAT-19	1,566	300	
CAT-20	2,000	315	Rel 14

Figure 15. Modem comparison chart

Antenna selection

Cellular modems require reception of the cellular signal to send and receive data. A common challenge is that cellular modems are installed in data closets. Antenna choice and location can help improve the reception of the cellular signal to improve data throughput.

Your wireless router or modem is likely to come equipped with paddle antennas. If they have clear access to the cellular signal with excellent measures, external antennas are not required. In fact, adding cable between the modem and an external antenna may actually degrade the signal.

However, if you need improved signal reception, an external antenna can help. Antennas are a quick and easy solution for both indoor and outdoor areas; they can be temporarily installed with magnetic mounts or placed in windows. They can also be wall or roof mounted, depending on accessibility. Be sure to place the antenna away from the modem, in a place with good access to the cellular signal.

LTE antennas generally leverage coaxial cable and introduce cable signal loss. However, modern 5G antennas with built-in modems, and 4G LTE deployments with external modems, offer the ability to leverage power over ethernet, minimizing cable-related signal loss, as well as lowering cable expenses.

There are two types of antennas that provide distinct radiating patterns.

Omnidirectional antennas

Omnidirectional antennas radiate and receive energy equally in all horizontal directions. These antennas are best suited for applications requiring all-around coverage and are used both indoors and outdoors.

Directional antennas

Directional antennas are more commonly used outdoors, when all-around coverage is not required, or the focus of available energy needs to be radiated by the antenna in a particular direction.

Cellular booster

If the outdoor signal is weak even with an antenna, a cellular booster (aka amplifier or repeater) can be used to strengthen the signal within a frequency range. The amplified signal can be directly connected to a single device, or broadcast within a specific area, such as a large building. Keep in mind that when boosting signals within a frequency range, you might also be boosting radio frequency (RF) noise. Boosters only work when receiving a consistent signal from the macro network.

Outside antenna pulls in tower signal.

Signal booster amplifies the signal.

Inside antenna rebroadcasts the signal.

Cellular device gets the signal.

Conclusion

Rank	Overall	Reliability	Accessibility	Speed	Data	Call	Text
1	96.0	96.5	94.8	97.5	97.6	94.5	96.7 96.8
2	95.6	95.9	93.6	95.7	97.1	93.2	
3	90.3	90.9	90.6	91.4	93.6	85.5	92.3

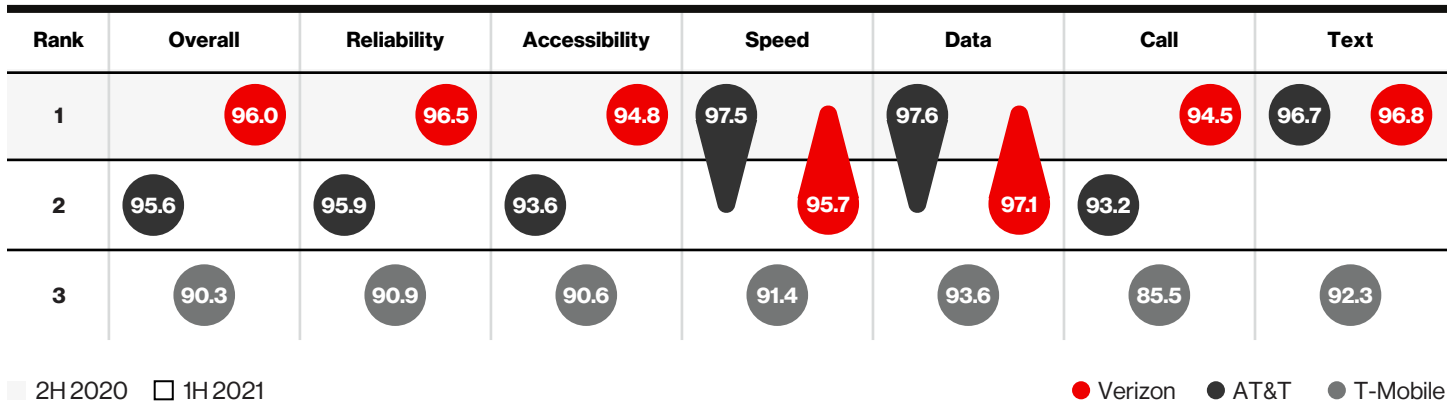☐ 2H 2020   ☐ 1H 2021   ● Verizon   ● AT&T   ● T-Mobile

Figure 16. United States RootScore 1H 2021

Testing of Verizon FWA has demonstrated that it is a solid alternative to wireline broadband, as it supports both real-time and general traffic for a simulated small office. FWA has been identified as an excellent choice for primary, concurrent and backup network connections, as well as for out of-band remote access to managed devices, such as routers and servers.

Also, when seeking the best-quality wireless connection, two things matter most: the quality of the network signal and the capability of the cellular network to provide reliability and speed. In other words, the best FWA requires the best wireless network. The following are 1H 2021 U.S. network performance results as measured by RootMetrics.*

	Overall	Reliability	Accessibility	Speed	Data	Call	Text	Total
AT&T	25	26	18	41	36	28	43	**217**
T-Mobile	0	1	2	4	0	1	8	**16**
Verizon	41	43	38	24	27	45	46	**264**

Note: Award tallies include both outright wins and ties.

Figure 17. State RootScore Award tally by category

RootMetrics U.S. State of the Mobile Union 1H 2021

Verizon wins the most RootScore® Awards, with great reliability, strong speeds and rapid 5G expansion.

Verizon remains the U.S. carrier to beat.

Verizon once again delivered excellent performance in 1H 2021, winning or sharing five out of seven U.S. RootScore Awards and earning more State and Metro Area RootScore Awards than any other carrier. Verizon also continued its trend of offering strong speeds and great reliability in major cities. And as shown in our last 5G Scorecard, Verizon has also delivered outstanding Everyday 5G data reliability more often than the other carriers.

Providing strong service across the entirety of the U.S. is a tall order. To earn U.S. RootScore Awards, a carrier needs to offer outstanding performance across all the different spaces where consumers use their smartphones, from cities and towns of all sizes to roadways, rural areas and all the places in between.

Verizon also continued its record-setting streak of winning U.S. RootScore Awards in the categories of overall performance, network reliability and call performance for the 16th straight test period, spanning eight years.

* RootMetrics did not test fixed wireless access, only the wireless network.

State-level performance

Verizon again won the most State RootScore Awards of any carrier in 1H 2021, taking home 264 total state-level awards out of 350 total opportunities. That includes 41 State Overall RootScore Awards and 43 State Network Reliability RootScore Awards, easily the most in both of those crucial categories. Verizon also won or shared 45 state-level call awards and 46 state-level text awards.

Verizon also remained the top-performing carrier at the metro level, delivering excellent speed and reliability results and earning the most Metro Area RootScore Awards.
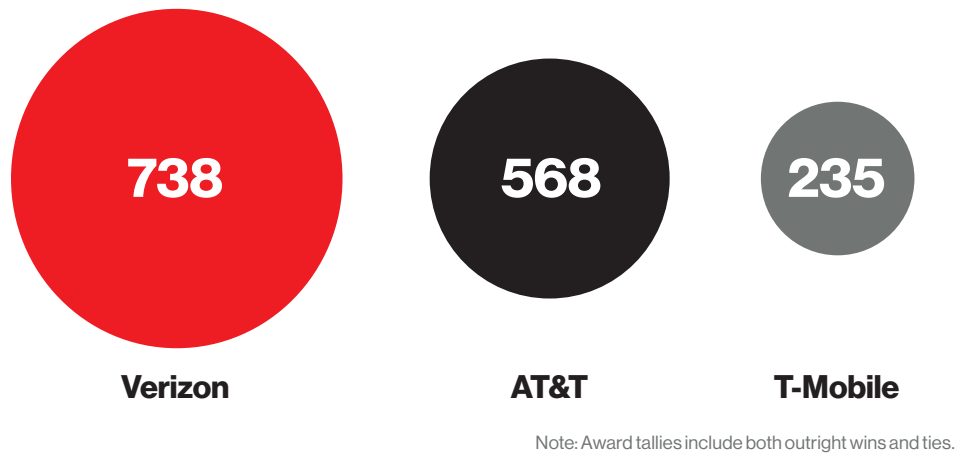
738	568	235
Verizon	**AT&T**	**T-Mobile**

Note: Award tallies include both outright wins and ties.

Figure 18. Metro Area RootScore Award tally

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Based on rankings from the RootMetrics® U.S. National, State, and Metro RootScore Reports: 2H 2013-1H 2021. Tested with best commercially available smartphones on three national mobile networks across all available network types. Your experiences may vary. The RootMetrics award is not an endorsement of Verizon.

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