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**5G UWB (mmWave) Wireless Networks Analysis
San Diego, CA and Chula Vista, CA**

Date: December 2021



This study was commissioned by the Communications Workers of America.

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EXECUTIVE SUMMARY

EJL Wireless Research was able to survey and conduct 5G UWB (mmWave) downlink (DL) and uplink (UL) speed tests on the 5G UWB networks for Verizon Wireless in the cities of San Diego, CA and Chula Vista, CA.

We surveyed and tested 40 5G UWB small cell sites in San Diego and another 34 5G UWB small cell sites in Chula Vista for a total of 74 sites.

We chose one site in San Diego to analyze how the 5G UWB signal and UL/DL speeds changed as the distance increased from the 5G UWB small cell site location. Our conclusion is that the 5G UWB signal does not behave like a 4G LTE signal because of the higher frequency band for 5G UWB and the line of sight (LoS) qualities that these frequencies exhibit. Rather than seeing a steady drop in the signal strength and UL/DL data speeds like 4G LTE signal behave as the mobile phone increased in distance away from the small cell site, any obstruction, such as a house or tree, would immediately degrade the 5G UWB signal and the mobile phone would lose its lock and downgrade to 5G Nationwide frequency bands which are the same as 4G LTE frequency bands. We also note that the highest data rates were around 300 Ft. away from the 5G UWB small cell site and that the radius was approximately 500 Ft.

We also conclude that the 5G UWB coverage maps shown on the Verizon Wireless website are basically correct, however actual 5G UWB signal availability cannot be correctly assessed with the coverage map information and must be verified with address confirmation on the 5G Home Internet webpage. Due to the LoS nature of the 5G UWB mmWave signals, there will be residences or businesses that will not be able to sign up for the 5G Home Internet service as they may be in a "blind spot" within the coverage zone of the 5G UWB small cell.

Both 5G UWB networks indicated DL data rates above 1Gbps and well above the typical data rates of 300Mbps advertised on Verizon Wireless' website for 5G Home Internet services. We believe that a fully loaded 5G UWB network may see subscribers experience the lower DL data rate however we believe that the 5G UWB networks in both San Diego and Chula Vista were not loaded at all and that is why the DL speeds were between 1.0-1.9Gbps and not around 300Mbps.

We continue to believe that from a financial perspective, there is a low success of Verizon Wireless receiving monetary compensation that would equal the CAPEX costs for its 5G UWB networks across the United States. We also continue to be bearish that Verizon Wireless can achieve a high enough coverage area within a city to offer reliable 5G UWB mobile or Home Internet services compared to its current 4G LTE coverage within the same city.

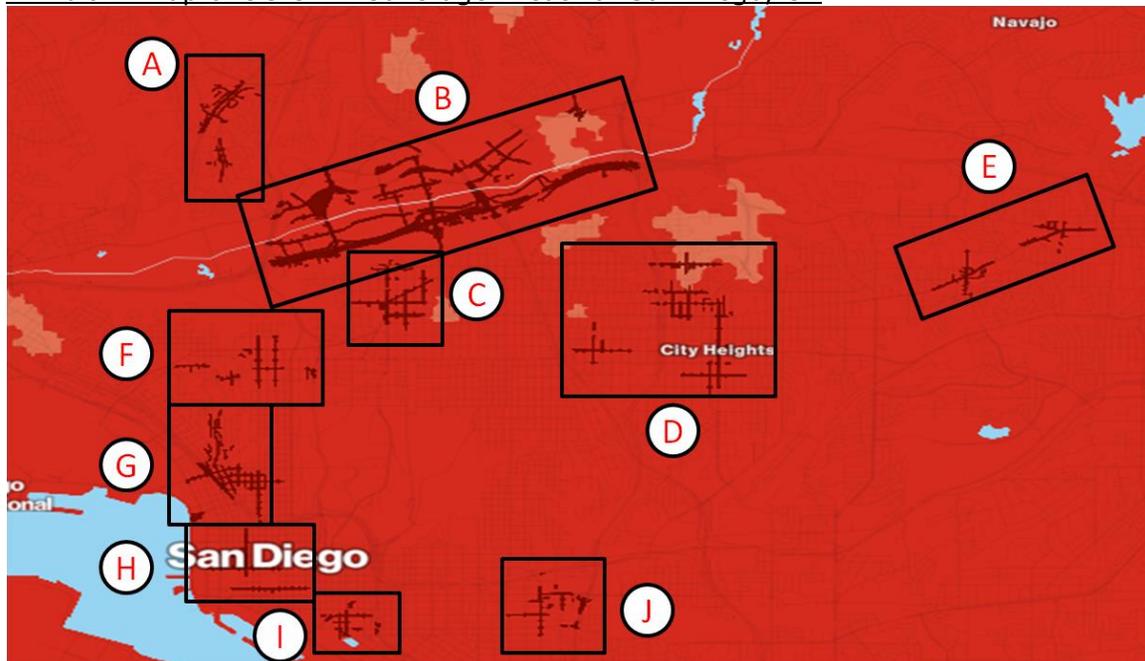
Additionally, we do not see any direct benefits to a city who is willing to partner with Verizon Wireless in a P3 (Private Public Partnership) agreement in exchange for potential benefits from Verizon Wireless that would connect the urban unconnected or close the broadband gap in low income areas within a city.

Finally, the latest generation of the 5G UWB customer premise equipment (CPE), while touted as an indoor self install unit instead of a professional truck roll outdoor installed unit is technically challenging for the average consumer subscriber due to the myriad of network IT settings required and knowledge of Wi-Fi 802.11ax networks, the poor operational capabilities of the mobile app, and the potential 5G UWB signal blockage issues due to indoor window treatments.

CITY OF SAN DIEGO ANALYSIS

EJL Wireless Research used the latest available 5G UWB coverage from the Verizon Wireless website to create a strategy for sampling the different coverage areas for the City of San Diego, CA. The dark red lines on the map indicated 5G UWB signal availability.

Exhibit 1: Map of 5G UWB Coverage Areas for San Diego, CA



Source: Verizon Wireless, EJL Wireless Research LLC

We have highlighted 10 different locations having 5G UWB signal coverage for the city.

Test measurements were conducted when the 5G UWB signal was present, as shown in Exhibit 2. We note that it was difficult to lock the phone onto the 5G UWB signal as it is much weaker than the 5G nationwide signal that is also present in the area where the 5G UWB small cell site is located.

Exhibit 2: Samsung Galaxy A42 5G UWB Icon



Source: EJI Wireless Research LLC

UL/DL Speed vs. Distance Test

We conducted an uplink (UL)/downlink (DL) speed test vs. distance on the first day of the project to understand any potential limitations due to the line of sight (LoS) issues related to mmWave radio propagation and signal strength.

The site where we performed this test was located in the Linda Vista area of San Diego. The 5G UWB small cell site was located on the corner of Linda Vista Road and Fulton Street and had many large trees that could potentially block the 5G UWB mmWave signal. Additionally, Fulton Street is not straight and the curvature of the street could have a potential impact for receiving the 5G UWB mmWave signals.

Our prior experience indicated that it was unlikely for the small cell edge to be more than 500 ft. away from the 5G UWB small cell site location.

The peak UL and DL data rates for the 5G UWB mmWave small cell site is somewhere between 300-450 ft. away from the small cell site. This is due to the very LoS nature of the radios and antenna arrays and the limited ability for them to be pointing down to the ground very close to the site. There is somewhat of a "dead signal zone" if the mobile phone is placed underneath the 5G UWB mmWave radios at the small cell site. The signal that the mobile phone is receiving in this situation is due to indirect LoS reflections from the surrounding buildings and objects and not due to a direct LoS reception.

Although we did not take a measurement in close proximity to the 5G UWB small cell site, we would expect that the data rates for both the UL/DL tests would be slightly lower than the measurement at the 150 ft. mark. Beyond the location for Test 3, the 5G UWB signal on the mobile phone was lost and dropped to just 5G nationwide.

Once the mobile phone loses the lock on the 5G UWB signal, it is difficult to reacquire it as the 5G nationwide signal is much stronger in the same location. Simply walking back towards the 5G UWB small cell site several feet does not accomplish this. We had to walk back between 50-100 ft. towards the small cell site for the 5G UWB signal to be strong enough for the mobile phone to achieve a lock.

We note that the increase and decrease in data rates for the DL test is 22% at the nearest point and 6% at the furthest point from the peak of 1.632Gbps.

For the UL test, the delta at the near edge was 20% below the peak and 34% at the far edge with the peak slightly further away at the 430 ft. location. We are not surprised by the larger delta in the UL test at the furthest distance as the mobile phone's mmWave output power is limited by the battery and antenna of the mobile phone which is not the case for the network radios.

Average DL/UL Speeds Across the 5G UWB Network

The average DL and UL data rates recorded within each area is based on a small sample size of several sites.

We note that the 5G UWB sites that were powered on and we were able to test indicated DL data rates above 1Gbps with the outlier area being North Park at 895Mbps. The average was 1.241Gbps which is well within our expectations for the network performance given "real world" conditions present during the tests.

However, we performed these tests under near "ideal" conditions given that the 5G UWB network is not under any loaded conditions due to multiple users within the same sector/cell using up the available resources. We do not believe there were any users or very few when we tested each 5G UWB small cell site. We would expect the data rates for both the UL and DL to drop as the network traffic increases over time.

The UL data rates average 57Mbps which is again not a surprise since the network is provisioned for DL performance. This results in a DL/UL ratio of 21.7 which is higher than expected. We typically expect a 10:1 or 15:1 DL/UL ratio in 4G LTE networks and had expected something similar for the 5G UWB spectrum.

Coverage Area – Actual vs. Verizon Wireless Website

One of the key purposes of the field testing is to verify the actual coverage of the 5G UWB signal when compared with the Verizon Wireless coverage map website. We decided to use a site in the Linda Vista area for our test case.

In the exhibit below, the dark red lines indicate roughly where 5G UWB signal is available for 5G Home services from Verizon Wireless while the red area is the 4G signal coverage area. We have indicated with a white rectangle the areas where the 5G UWB signal is not available.

Exhibit 3: 5G UWB Signal Availability Linda Vista



Source: Verizon Wireless

We then logged into Verizon Wireless' website and entered all of the street addresses on surrounding streets for the corresponding area on Google Maps. We note that the website limits the number of addresses that can be used before a CAPTCHA verification pop up box requires the user to correctly click on the squares containing an image of the required item to proceed to verify if the street address is able to sign up for 5G Home services.

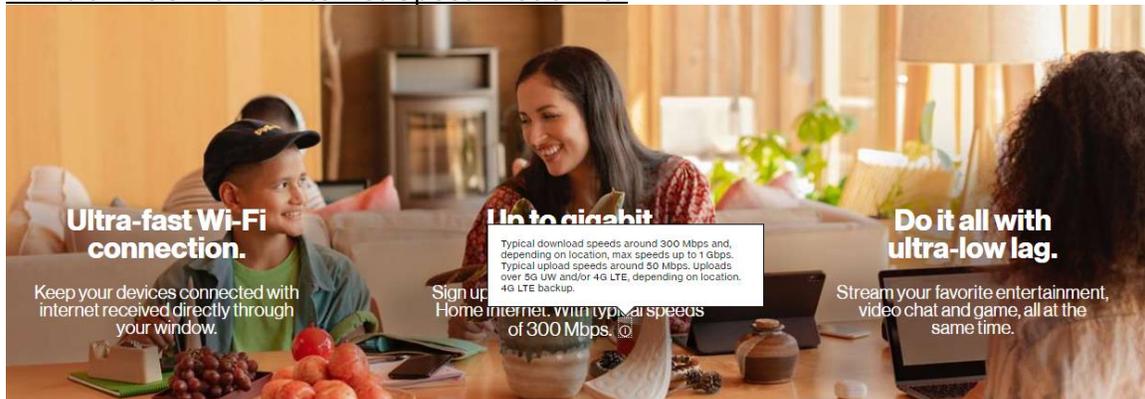
We note that for the Verizon 5G Home Internet service, there is a disclaimer on the website of:

"Typical download speeds around 300Mbps and, depending on location, max speeds up to 1Gbps. Typical upload speeds around 50Mbps. Uploads over 5G UW and/or 4G LTE, depending on location. 4G LTE backup."

We interpret the disclaimer as indicating that should the 5G UW signal become unavailable (due to weather or other issues), the connection to the Verizon Wireless network will be across the 4G LTE network. This is notable because Verizon advertises 4G LTE Home speeds as "able to handle download speeds between 5-12 Mbps and upload speeds between 2-5 Mbps¹," which are significantly lower than the typical 300 Mbps DL and 50 Mbps UL speed 5G Home customers subscribe to.

¹ <https://www.verizon.com/articles/4g-lte-speeds-vs-your-home-network/>

Exhibit 4: 5G Home Internet Speed Disclaimer



Source: Verizon Wireless

When we completed entering all of the street addresses indicated on the Google Maps area around the 5G UWB small cell site, we mark each street address with three possible indicators:

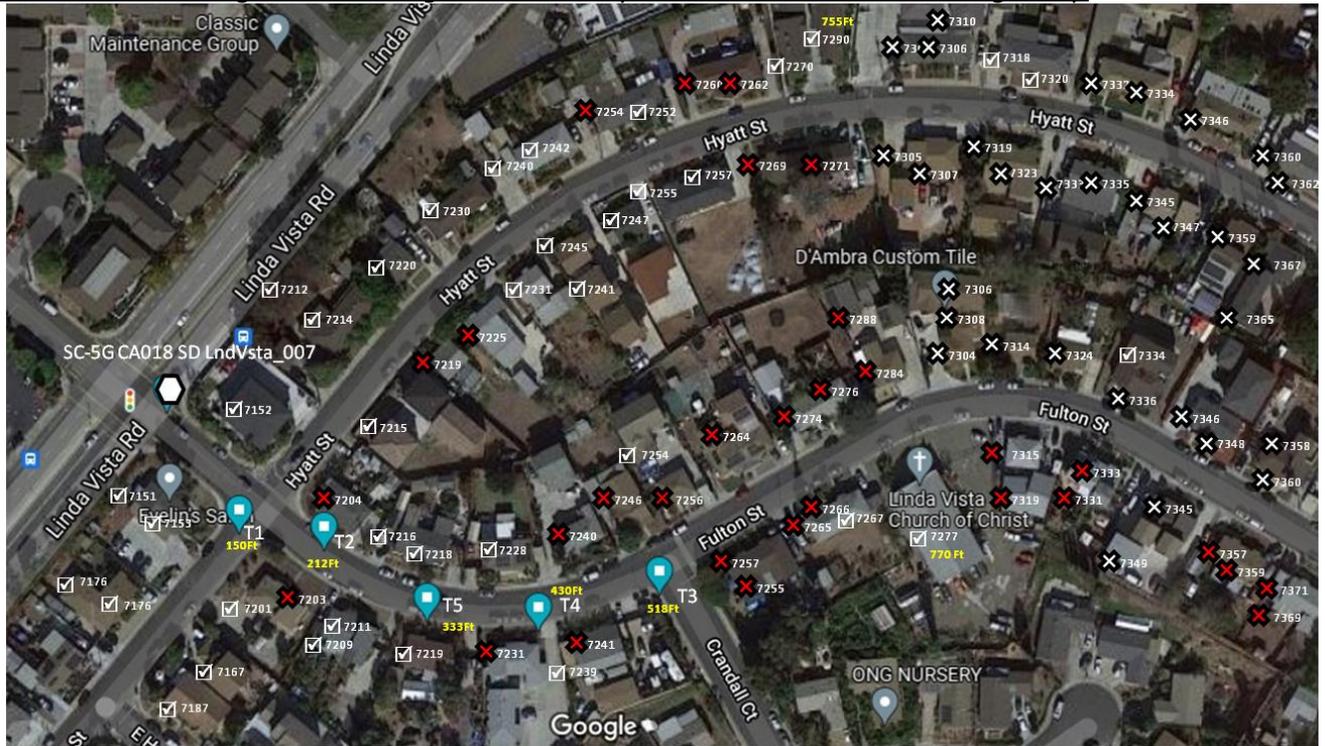
- White check box for both 5G UWB and LTE Internet availability
- Red X for no 5G UWB Internet but LTE Internet availability
- White X for no 5G UWB Internet and no LTE Internet availability

When we compared the actual availability map to the website coverage map, we note that the map is somewhat accurate for the general street, however there are gaps within the website coverage map that are not shown. The website map is used as a general area indicator but the actual street address verification step is the final determination whether 5G Home Internet service is available or not.

Based upon our findings for this specific 5G UWB small cell site, we conclude the website coverage map is fairly accurate for the 5G UWB signal for 5G Home Internet service but is not accurate at all for mobile 5G UWB coverage.

However, we note that the coverage zone is not uniform as indicated by the red X's within the imaginary radius of the 5G UWB signal coverage zone due to obstructions such as trees, houses, etc. To have ubiquitous coverage within the neighborhood, Verizon Wireless would need to deploy a 5G UWB small cell site every 300-500 ft. along a street which would make the network deployment economically unfeasible.

Exhibit 5: San Diego 5G UWB Signal Availability Actual vs. Website Coverage Map



Legend

			
5G UWB Site	5G/4G Home	4G Home	No Internet Service Available

Source: EJL Wireless Research LLC

CITY OF CHULA VISTA, CA

EJL Wireless Research used the latest available 5G UWB coverage from the Verizon Wireless website to create a strategy for sampling the different coverage areas for the City of Chula Vista, CA. The dark red lines on the map indicated 5G UWB signal availability.

Exhibit 6: Map of 5G UWB Coverage Areas for Chula Vista, CA



Source: Verizon Wireless, EJL Wireless Research LLC

Average DL/UL Speeds Across 5G UWB Network

EJL Wireless Research was able to take 5G UWB signal measurements at all of the 5G UWB sites in Chula Vista. The average DL speed was 1343 Mbps and UL speed was 55Mbps, slightly higher (+8%) for the DL and slightly lower (-4%) for the UL than the average for the City of San Diego but well within the range for what we expected.

Coverage Area – Actual vs. Verizon Wireless Website

We used the same methodology as we did for the San Diego location to confirm 5G and 4G Internet availability using the Verizon Wireless 5G Home Internet website and mapped out the surrounding areas for 5G Home Internet service availability.

The conclusion is that there are 11 single family homes and 1 church within the 5G UWB coverage zone for this specific site.

We do not believe this is a financially positive model for Verizon Wireless to continue as we do not see how it could possibly recover the CAPEX costs for the 5G UWB site deployment, even if it managed to secure 5G Home Internet contracts with the church and every household.

Our conclusion is that the City of Chula Vista 5G UWB coverage map on Verizon Wireless' website is generally accurate. However, similar to our example for the City of San Diego, there will always be homes where the 5G UWB signal is unable to

reach, resulting in random pockets of coverage instead of a broad area of coverage like for 4G LTE.

5G INTERNET GATEWAY

The 5G UWB Home Gateway installation guide recommends the subscriber to scan the QR code and download the Verizon Wireless app via the website <http://setup.verizon.com/5ginternetgateway>.

Exhibit 7: QR Code for Self Installation of 5G Home Gateway Unit

Please do not remove anything from the box yet.

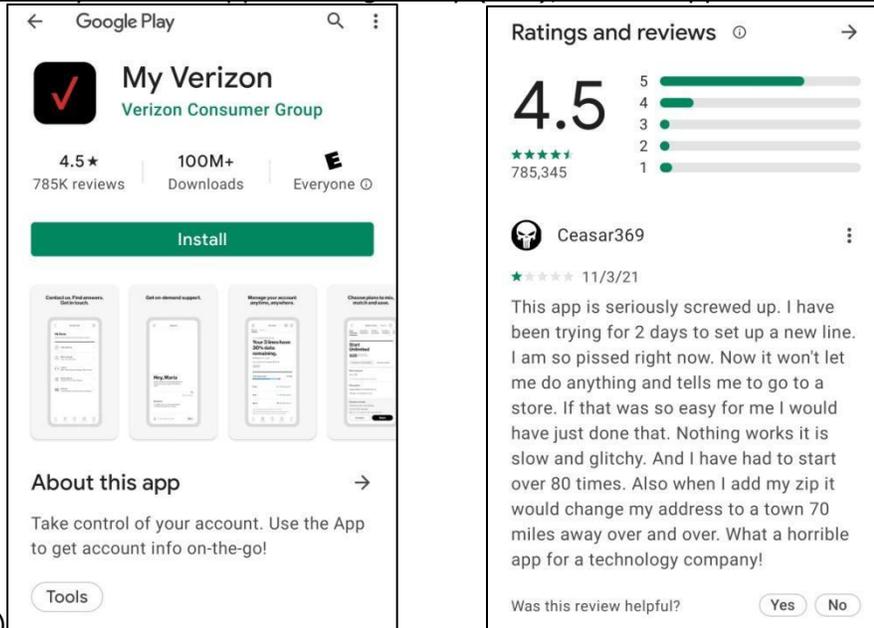
Scan the QR code to visit the URL on your mobile device or access

<http://setup.verizon.com/5Ginternetgateway>



Source: Verizon Wireless 5G Internet Gateway User Guide

Exhibit 8: My Verizon App on Google Play (Left), Recent App Review on 11/3/21



(Right)

Source: Verizon Wireless, Google Play

APPENDIX A

Site Testing Methodology

Match current coverage maps from Verizon Wireless 5G UWB website <https://www.verizon.com/coverage-map/> with known small cell site locations (red, orange, & yellow dots, squares, & diamonds) from San Diego Small Cell Availability Suite.

Mobile Phone Specifications

- Samsung Galaxy A42 equipped with 5G mmwave (n260/n261) + 5G C Band (n77/n78) frequency band support

Test Measurement Matrix

Measurements to be taken at each site location:

1. DL/UL Data Rate (Mbps) at Cell Center **[Performed]**
2. DL/UL Data Rate (Mbps) at Cell Edge where signal is -110dbm **[Partially Performed]**
3. Distance from Cell Center to Cell Edge (Ft.) **[Partially Performed]**
4. Geolocation of cell edge (Lat/Long) East/West or North/South **[Not Performed]**
5. # Radios **[Performed]**
6. Azimuth Direction for each radio (0-360 degrees) **[Performed]**
7. Ookla Speed Test Ping for Latency **[Not Performed]**

Visible obstructions in LOS for each radio in Z axis

Test Files for DL/UL

1. Video DL: High Definition QVGA You Tube (~2GB) **[Not Performed]**
2. Video UL: Highest Frame Rate and Definition Setting on Phone, 30 Seconds **[Not Performed]**
3. Picture: High Definition (Highest Resolution Setting on Phone) **[Not Performed]**

Actual Performed Test Measurement Matrix

Due to the time required to discuss the technical issues with the Samsung Galaxy A42 phone not being able to lock on the mmWave signal from the Verizon Wireless network as well as the situation with the way the mmWave signals propagate from the small cell site, and the potential data download maximum cap of 50GB before being throttled down, EJM Wireless Research had to modify the test measurement matrix to maximize the number of sites to be surveyed.

Speedtest

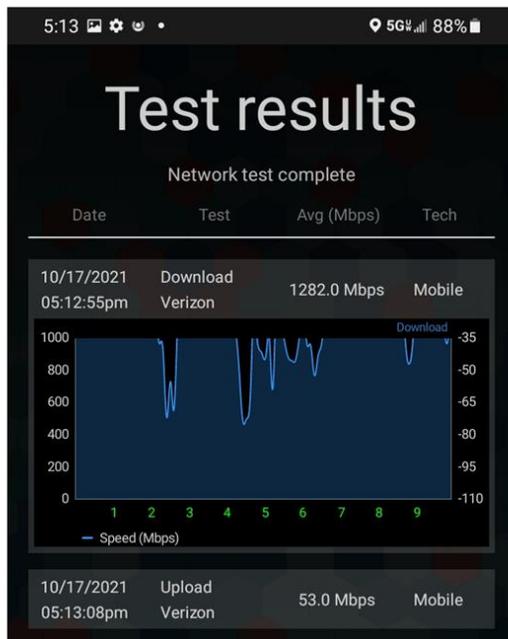
We performed the first two tests using the RootMetrics Coverage app as shown in the exhibit. We then switched to the Ookla Speedtest app for test locations 3, 4, and 5 to better understand how this app functioned and compared with the RootMetrics Coverage app.

Our analysis and use of both apps shows that the RootMetrics Coverage app provides a clearer view of both the UL and DL data streams via the graphs over 10 cycles of tests than the Ookla Speedtest which graphs a simpler chart of the UL and DL speeds overlaid into a single chart. We do note however that the Ookla Speedtest app also tests for Ping, Jitter, and Loss (Packet) that the RootMetrics Coverage app does not. These metrics would be more useful to better understand latency issues of the network instead of raw speeds.

One issue with the RootMetrics Coverage app is the speed graphs are limited to 1000Mbps and the app is unable to graph beyond this level but can continue to record the actual speed. The final speed shown is the average over a 10 cycle test period for the downlink and uplink.

Exhibit 9: RootMetrics Coverage App Test Data for Test Locations T1 and T2

T1



Source: EJL Wireless Research LLC

T2



Exhibit 10: Ookla Speedtest App Test Data for Test Locations T3, T4, & T5



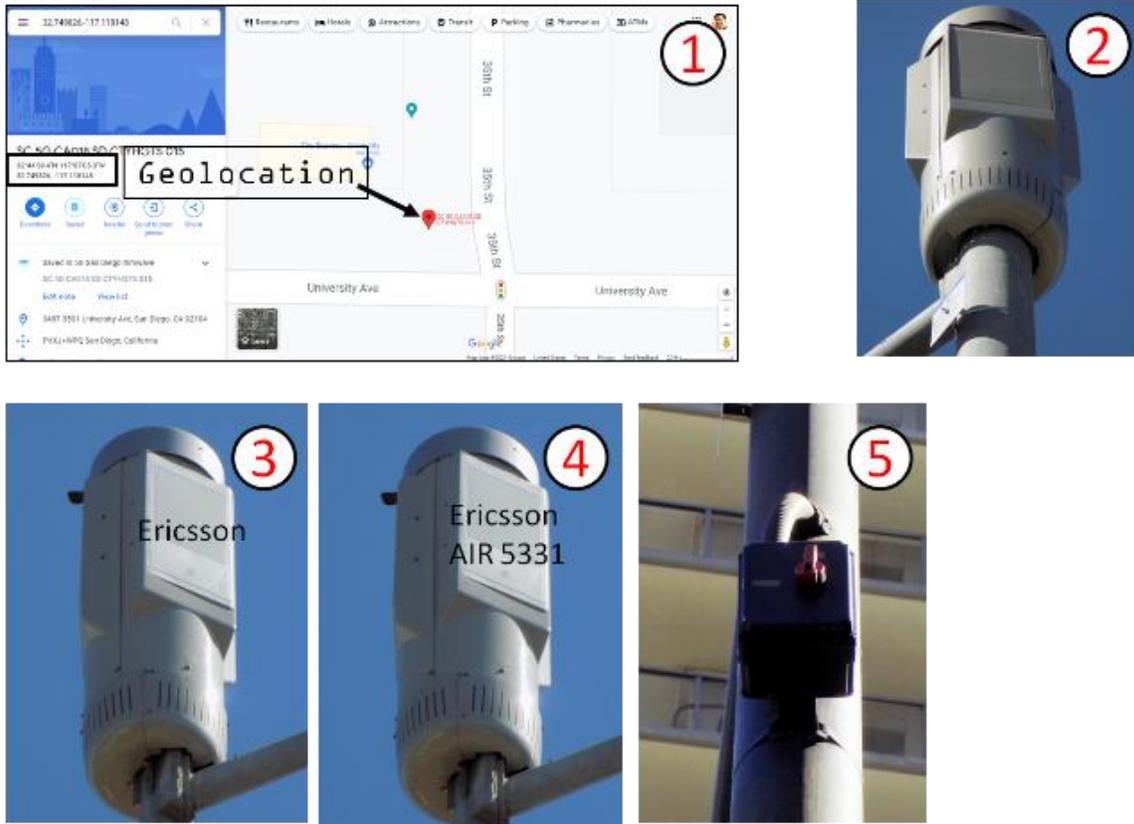
Source: EJL Wireless Research LLC

We opted to use the RootMetrics Coverage app since it provided a better way to graphically see how the performance varied over the entire test period for the downlink and uplink.

Actual 5G UWB Small Cell Site Data Recorded Per Site

1. 5G UWB Small Cell Site Geolocation (Latitude/Longitude)
2. Picture of 5G UWB Small Cell Pole/Radios
3. Picture of Small Cell Site Power Switch/Position
4. Classification of 5G UWB Small Cell Radio Supplier
5. Classification of 5G UWB Small Cell Radio Model Type
6. Picture of Azimuth Coverage for each 5G UWB Radio

Exhibit 11: Dataset Examples 1- 5



Source: EJL Wireless Research LLC

APPENDIX B

Table 1: San Diego 5G UWB Average DL/UL Speeds Across Areas

Map Area	Neighborhood	Downlink Speed (Mbps)	Average	Uplink Speed Average (Mbps)
D	City Heights	1,207		48
E	College	1,883		91
H	Downtown	1,088		65
E	Eastern	NA		NA
D	Kensington	1,223		53
A	Linda Vista	1,344		56
B	Mission Valley	1,055		55
C	Normal Heights	NA		NA
C	North Park	895		36
G	Uptown	1,232		54
Total		1,241		57

Source: EJL Wireless Research LLC

Table 2: Chula Vista 5G UWB Average DL/UL Speeds Across Areas

Map Area	Neighborhood	Downlink Speed (Mbps)	Average	Uplink Speed Average (Mbps)
A	North Chula Vista	1,081		58
B	Central Chula Vista	1,229		46
C	Mid Center	1,575		51
D	Harborside	1,532		57
E	Castle Park	1,297		63
Total		1,343		55

Source: EJL Wireless Research LLC

APPENDIX C

5G Internet Gateway Self-Installation

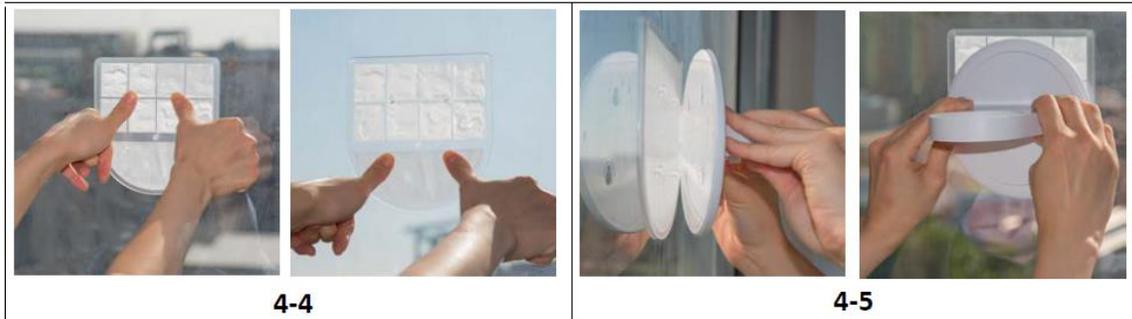
1] The 5G Internet Gateway unit **ONLY** uses the 5G UWB mmWave signal as the backhaul link for the Internet Gateway unit to the 5G UWB network. The only wireless signals transmitted within the subscriber's residence are Wi-Fi 802.11b/.11n/.11ac/.11ax 2.4GHz and 5GHz signals.

The 5G Internet Gateway supports the following 4G and 5G frequency bands:

- **5G n260 (39GHz) UWB**
- **5G n261 (28GHz) UWB**
- 5G n2 (1900MHz)
- 5G n5 (850MHz)
- 5G n66 (2100MHz)
- 4G n2 (1900MHz)
- 4G n4 (2100MHz)
- 4G n5 (850MHz)
- 4G n13 (700MHz)
- 4G n48 (3500MHz CBRS)
- 4G n66 (2100MHz)

The 5G and 4G frequency bands are not available as "access frequency bands" for the home subscribers to use for their Verizon Wireless mobile phones.

Exhibit 12: Placement/Installation of Mounting Bracket and Adhesive Plate



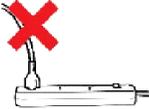
Source: Verizon Wireless 5G Internet Gateway User Guide

Exhibit 13: 5G Internet Gateway Mounting Locations
Installation Notes

Window installation		
		
Ensure glass is smooth and that no thermal paper is affixed.	Avoid installing in windows located above objects that could be easily damaged. Keep the area below the window clear.	Avoid installing in windows that may change shape.
		
Avoid installing in movable windows, unstable windows, or any windows subject to high wind gusts.		

Source: Verizon Wireless 5G Internet Gateway User Guide

Exhibit 14: Installation of Mounting Bracket Problems

Not recommended		
		
We do not recommend that you use the device with extension cords.	Do not hang anything from the bracket or place anything on the device.	Do not cover the device with anything (i.e. curtains)

Source: Verizon Wireless 5G Internet Gateway User Guide