Holographic Beam Forming Improves Mid-Band Radio Link Performance

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When beamforming is deployed to transmit or receive an RF signal, it is typically done using multiple antennas to target the signal in a specific direction. Pivotal Commware invented Holographic Beam Forming® (HBF) to accomplish this at lower cost, size, weight, and power consumption than legacy systems like phased array. Pivotal has incorporated HBF into its ecosystem of mmWave repeaters and planning tools. Can HBF improve signal quality and user experience at mid-band frequencies? This white paper provides evidence from the field that it can.

Figure 1: HBF mid-band antenna

Mid-band

5G mid-band spectrum is considered to span frequencies from 3.30 GHz to 7.125 GHz. The bands getting the most attention today are the TDD bands: n77 ("C-band"), n78, n79, and n48 (3.35 GHz to 3.7 GHz for "CRBS" in the US). Mid-band suffers increased in-building penetration loss, compared to low-band, when the signal propagates from outside and into buildings. Signal loss can range from 7 to 22 dB depending on the materials and path of the signal into the premise[1]. Studies from Nokia[2] and others show that beamforming from either the base station or user equipment offers corrective action.

[1] Path Loss Validation for Urban Micro Cell Scenarios at 3.5 GHz Compared to 1.9 GHz. Rodriguez, Ignacio; Nguyen, Huan Cong; Jørgensen, Niels T.K.; Sørensen, Troels; Bundgaard; Elling, Jan; Gentsch, Morten Brok; Mogensen, Preben. Published in: Proceedings of the 2013 IEEE Global Communications Conference (GLOBECOM)
[2] Nokia white paper: "Optimizing 5G Coverage" https://onestore.nokia.com/asset/206766

HBF vs. Omni

Typical CPE/UE made for LTE or 5G NR FR1 frequencies use omnidirectional antennas with gain in the range of 1 – 3 dBi. By using HBF antennas with CPE instead of omnidirectional ones, signal strength improves in both directions (uplink and downlink), leading to improved user experience, i.e., throughput. Improvement is the most obvious when the signal conditions are poor, e.g., NLOS (Non-Line of Sight) between UE and base station. In addition, the improved signal strength allows for extensions in both cell range and cell area[3].

In this paper, Pivotal shows that, compared to an omni antenna, HBF improves mid-band signal quality and user experience from the user equipment (UE) side in all-outdoor environment.

Set-Up

Field tests were conducted in three locations using LTE band 48 frequencies (CBRS). Since band n48 spans the same range in 3.5 GHz as LTE band 48, the test results are equally applicable to 5G NR mid-band implementation as they are to LTE or other technologies, at the same frequencies.

The setup consisted of:

- An HBF mid-band antenna (prototype, 9.5 square inches)
- A receiver CPE (Sierra Wireless Airlink RV55 Global LTE-A Pro) with 2 omni antennas
- Promira Serial Platform for the HBF antenna beam management
- EPIQ PRiSM PCI scanner (https://epiqsolutions.com/rf-sensing/prism/) to acquire RSRP (Reference Signal Received Power) readings
- A laptop for reading off KPIs, interfacing with the controller and running throughput tests
- Power, RF and data/USB cables

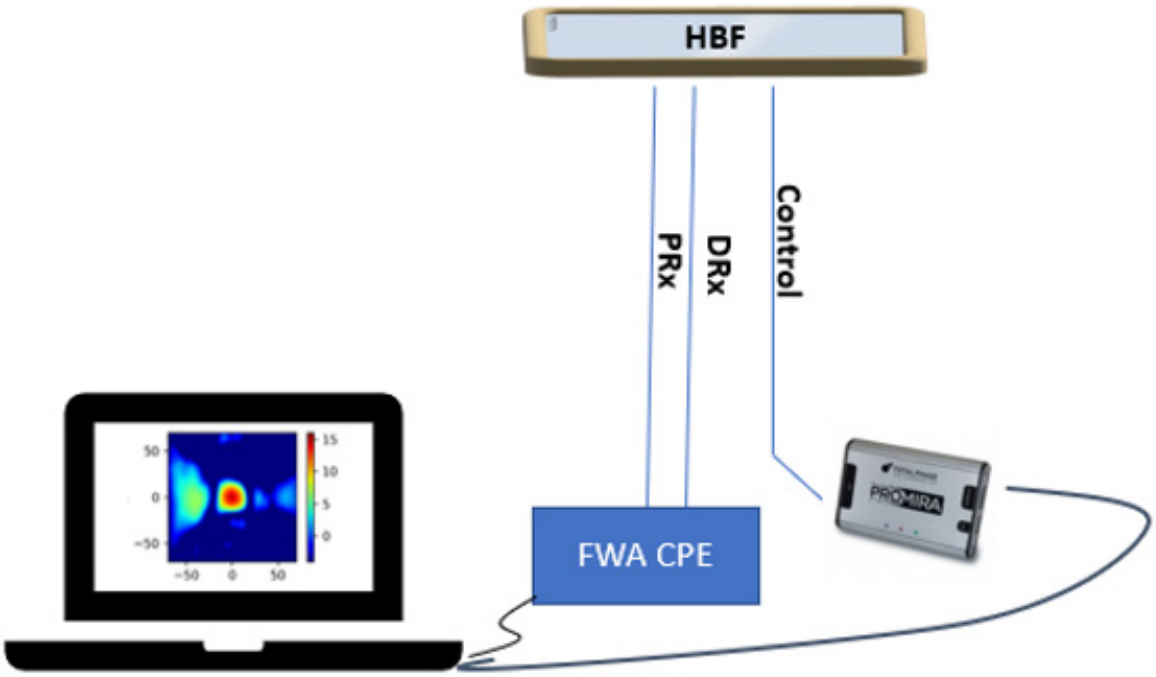

Figure 2: High level diagram of set-up

[3] Nokia white paper: "Optimizing 5G Coverage" https://onestore.nokia.com/asset/206766

The Sierra CPE was tethered to a laptop, providing internet and admin-portal connectivity. Signal KPIs were read from Sierra Wireless' Web-GUI interface and throughput ("TPut") testing was conducted using https://www.speedtest.net via laptop browser.

In each location a commercially available CPE (Sierra Wireless Airlink RV55 Global LTE-A Pro) was connected to either omni antennas (as in Figure 3) or a dual polarized HBF antenna (as in Figure 4).

Figure 3: Sierra CPE with omnidirectional antenna

Figure 4: Sierra CPE connected to HBF antenna

Using the CPE's exposed SMA antenna connectors, the two manifestations were tested, omnidirectional and HBF.

At each location, the following steps were taken:

1. Baseline signal strengths (RSRP, in dBm) and throughput values were collected with the Sierra Wireless CPE using omnidirectional antennas. This configuration was designated as "Baseline" results (See Tables 1 and 2).

2. HBF scanning was performed with the EPIQ PRiSM PCI scanner used to acquire RSRP readings. This helped determine where to electronically steer (or point) the HBF antenna. The result of this scan was a "RSRP heat map" as depicted in Figure 6. Brighter colors in the center indicate stronger RSRP emanating from that direction.

Figure 5: Close up of HBF antenna connected to Sierra CPE

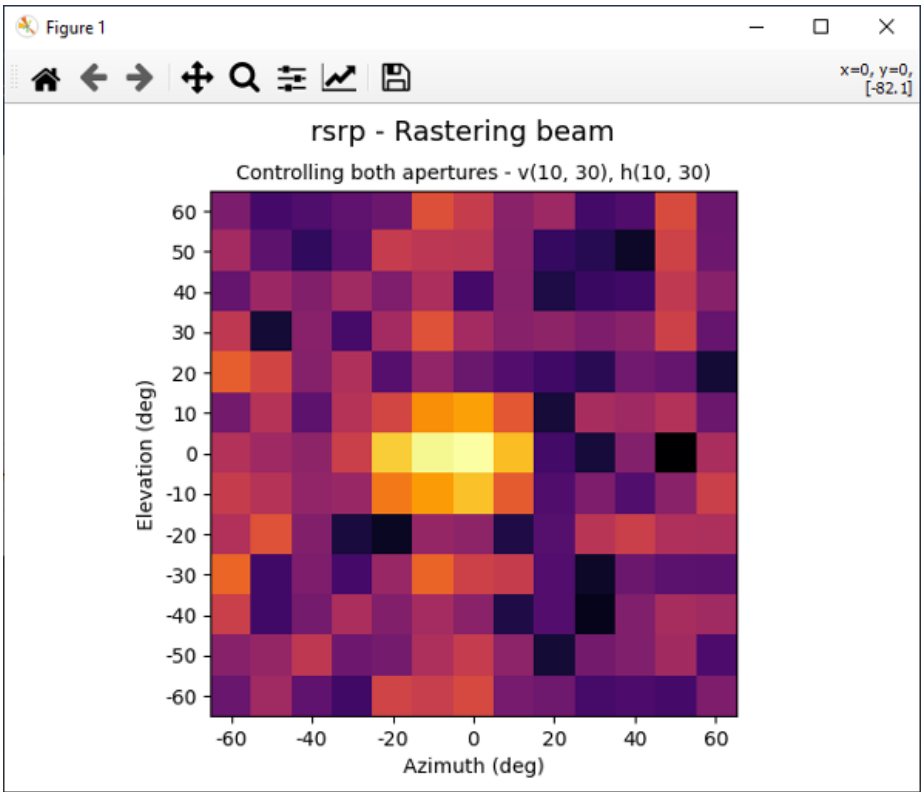

Figure 6: Heat map of HBF antenna, representing two-dimensional view of signal strength

3. Sierra CPE was then connected to the HBF antenna and electronically steered, to point to direction of the strongest RSRP.

4. Signal strength readings and throughput tests were collected from the Sierra CPE and HBF combination as "Improved" results (See Tables 1 and 2).

Field testing occurred at 10 different locations across 3 states. Results were documented in Tables 1 and 2.

Test Results

Figure 7: Elementary school

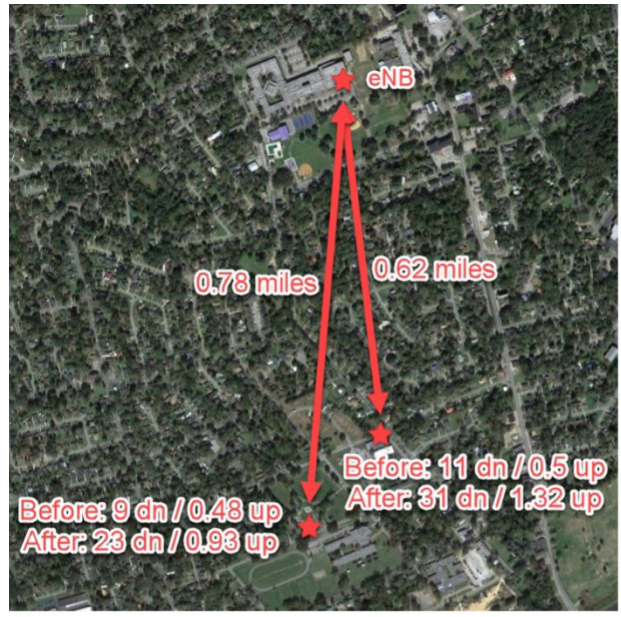

Figure 8: High school

Figure 9: Office parking lots 1 and 2

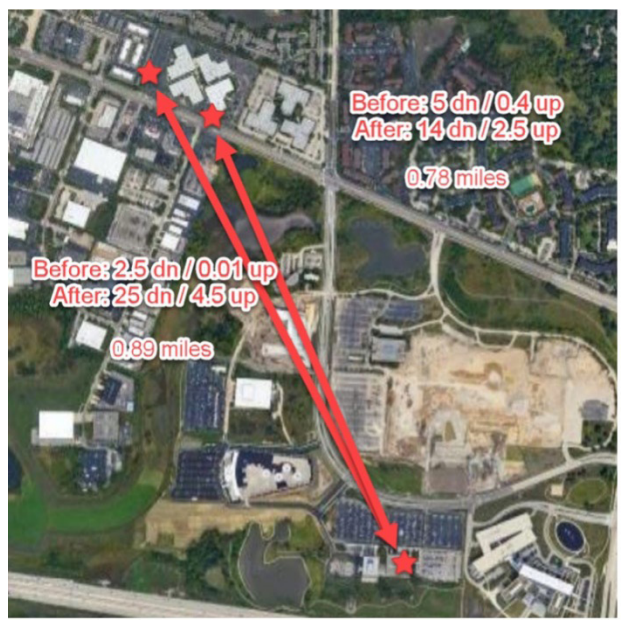

Figure 10: Office parking lot 3

Figure 11: Tested in three neighborhoods

Field Test Results Summary - Throughput

Test Location	Miles	DL TPUT Baseline	DL TPUT Improved	DL Improvement	UL TPUT Baseline	UL TPUT Improved	UL Improvement
Elementary School 1	0.70	17	32	1.9X	3	8	2.7X
Elementary School 1	1.06	7	15	2.1X	0.7	1	1.4X
High School 1	0.78	9	23	2.6X	0.5	0.9	1.8X
High School 2	0.62	11	31	2.8X	0.5	1.3	2.6X
Office Parking 1	0.89	2.5	25	10X	0.01	4.5	450X
Office Parking 2	0.78	5	14	2.8X	0.4	2.5	6.3X
Office Parking 3	0.78	4	11	2.8X	1.5	4	2.7X
Neighborhood 1	0.74	8.5	66.8	7.8X	2.2	7.3	3.3X
Neighborhood 2	1.04	4.9	40	8.2X	0.9	2.8	3.1X
Neighborhood 3	0.94	15.7	72	4.6X	6.4	8.6	1.3X

Table 1: “Baseline” - only omni antenna used;
“Improved” - HBF antenna is deployed

Field Test Results – Signal KPIs

Test Location	Miles	RSRP Baseline	RSRP Improved	RSRP Delta	SINR Baseline	SINR Improved	SINR Delta
Neighborhood 1 (NLOS)	0.74	-124	-113	11	.09	9.6	8.7
Neighborhood 2 (NLOS)	1.04	-126	-120	6	-1.4	3.7	5.1
Neighborhood 3 (NLOS)	0.94	-116	-110	6	2.7	5.8	3.1

Table 2: “Baseline” - only omni antenna used;
“Improved” - HBF antenna is deployed

Results Summary

In non-line-of-sight locations, key performance indicators showed consistent improvement using HBF in place of omni:

- RSRP typically improved by 8 dB
- SNR typically improved by 6 dB
- 5x improvement in DL throughput
- 3x improvement in UL throughput

Besides the KPI improvements documented above, HBF confers other benefits, such as reduced interference by exploring directionality; increased cell coverage by 2-4 times; faster installation indoors and outdoors because HBF automatically aligns – and can be re-aligned – to the strongest signal.

Surveyed operators were drawn to these HBF-enabled business efficiencies:

- Lower customer acquisition cost by enabling self-install
- Increased installation success rate by enabling automatic alignment
- Enable remote diagnostics to investigate performance issues
- Eliminate customer visits to re-align antenna due to wind gusts and seasonality
- Reduce network costs due to increased capacity and cell coverage area, serving more customers
- Improve throughput and user experience

Conclusion

In mid-band, HBF antenna is an enabling factor improving the network operator business model, CAPEX, and user experience. Testing in the field has proven the technology outside of the lab. It is now ready for commercial deployment. The mid-band HBF antenna measuring roughly 5 square inches can achieve a gain of 9-11 dB. This represents an additional 8 dB gain compared to an omni-antenna at the same frequencies. The HBF antenna can be integrated with a FWA CPE with no additional increase in power consumption.

CPE manufacturers can now focus on other aspects of the product, knowing that holographic beamforming is sure to increase the value to their customer: **the operator deploying the mid-band network.**