Beamforming to expand 4G and 5G network capacities

Eric Black - December 18, 2017

Most wireless subscribers believe all is well with their network coverage. The wireless industry knows the future tells a different story. 4G LTE has reached the theoretical limits of time and frequency resource utilization, while 5G will need new technology to meet its full potential.

The wireless industry is working feverishly to open a new degree of freedom and space for enhancing network capacity and performance to address growing connectivity demands. Engineers are looking at spatial dimension innovations, falling under the category of space division multiple access (SDMA), that will help deliver significant network capacity and performance.

![Figure 1 Keeping pace with demand](image)

With SDMA, the idea is to use software-driven, beamforming antennas to enable multiple concurrent transmissions using the same frequency without interference, thus allowing for abundant spectrum reuse with higher intensity signals delivered to both stationary and mobile users. This way, mobile operators can continuously reuse the same band of spectrum, at the same time, within a given spatial region, and direct coverage to where it’s needed, when it’s needed.

Wireless carriers and OEMs are considering two technologies that enable electronic beamforming to 4G and 5G networks to meet the boundless growth in wireless data consumption: multiple-input and multiple-output (MIMO) and beamforming.

Early MIMO deployments in 4G systems have been both exciting and disappointing. Exciting because real network capacity gains have been shown. Disappointing because hardware costs have outpaced performance gains. That is, scaling and costs have been sharply sublinear. Despite impressive near-field spectral efficiency achievements like those from the University of Bristol in
2017 (130 bps/Hz), the lack of applicability to far-field systems such as cellular suggests that single user MIMO (SU-MIMO) has maxed out.

**Enter MU-MIMO**

That leaves multi-user MIMO, where independent data beams are transmitted along diverse vectors. MU-MIMO is not without challenges, however. Practical MU-MIMO demos have shown that it is difficult to achieve linear capacity gain with the number of antenna/radio pairs used. In practice, the observed capacity gains have been more like one-tenth the number of radio/antenna combinations. The reason for this is obvious. Users are rarely spaced on an angularly uniform grid and so the use of so many radios results in overkill. Reducing the radio count does not help as the beams widen, thus exacerbating the problem.

More recently, attention has been drawn to MU-MIMO power consumption in cellular bands. Several researchers have pointed out that multi-GHz clockrate 8-bit ADCs (analog-to-digital converters) require significant power. For a 128-element MU-MIMO array this implies at least half a kilowatt of power needed just for the ADC components. The dissipated thermal load is substantial, which in turn drives cooling requirements, resulting in a heavy, bulky, power hungry, and costly system for MU-MIMO. It remains an open question if the cost of 128 radio chains is justifiable for 10× improvement. This situation does not get better in millimeter-wave bands where even larger arrays are needed for sufficient antenna gain while power amplifier efficiencies plummet to under 5% at 60 GHz.

**Holographic beamforming**

Holographic beamforming (HBF) is a new technique that is substantially different from conventional phased arrays or MIMO systems in that it uses software defined antennas (SDAs). It is the lowest C-SWaP (cost, size, weight, and power) dynamic beamforming architecture available.

HBFs are passive electronically steered antennas (PESAs) that use no active amplification internally. This leads to symmetric transmit and receive characteristics for HBF antennas.

Where phased-array type PESAs use discrete phase shifters to accomplish beam steering, HBFs perform the task using a direct amplitude hologram. **Figure 2** shows two different digital overlays on the HBF representing the bias states of the varactors generating the hologram. The hologram in **Figure 2a** steers an RF beam in one direction while the hologram in **Figure 2b** steers the beam to broadside.

![Figure 2](image-url)  

**Figure 2** HBF with color overlay of the hologram used to steer the beam off broadside (a) HBF with color overlay of the hologram used to steer the beam to broadside (b)

All components used in the construction of HBF antennas are high-volume, commercial off-the-shelf (COTS) parts. These incredibly low-cost control components take advantage of their widespread use in handsets, leading to economies of scale that silicon implementations can only dream of.
Equally important, the beam pointing function is accomplished using a large array of reverse biased varactor diodes. This leads to a nearly negligible power draw by the antenna’s pointing operations. Most HBFs need only USB or PoE (power over Ethernet) levels of power to operate. This then eliminates the need for active or passive cooling solutions and drives a significant size and weight reduction.

MIMO uses antenna/radio pairs to achieve beamforming with a very complex baseband unit coordinating the system. Holographic beamformers have simple control and use more densely packed antenna arrays. Roughly 2.5-3× as many elements are used by HBF systems. Fortunately for HBF, the control elements needed are trivially priced. These differences are summarized in Figure 3.

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<td>Holographic Beam Former</td>
<td><img src="image" alt="Diagram" /></td>
<td>Super-sampled COTS design enables low price</td>
<td>Thin, Conformable</td>
<td>Single beam per polarization per sub-aperture.</td>
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| MU-MIMO           | ![Diagram](image) | Radios behind every element and complex BBU drives high price and power consumption | Usually thick but antenna thickness can be reduced by hiding BBU in baseband cabinet | No FDD  
Unworkable at mmW  
Spectral Efficiency vs. cost scales poorly |

**Figure 3** Summary of key differences among holographic, phased array and MIMO beamformers

The benefits of beamforming will not materialize in the commercial market without the low C-SWaP architecture that only HBF provides. MIMO’s C-SWaP is exorbitantly high. HBF represents a breakthrough beamforming technology that finally provides a viable C-SWaP profile for commercial 4G and 5G networks.

*Eric Black is CTO of Pivotal Commware. With a Ph.D. in electrical and computer engineering from Carnegie Mellon, Black has 10 years of research experience developing optical and microwave components in academic and industry research labs. Currently, he is involved in state-of-the-art advancements in holographic metamaterial beamformers in the microwave domain.*

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