Multi-beam MIMO Prototype for Real-Time Multiuser Communication at 28 GHz

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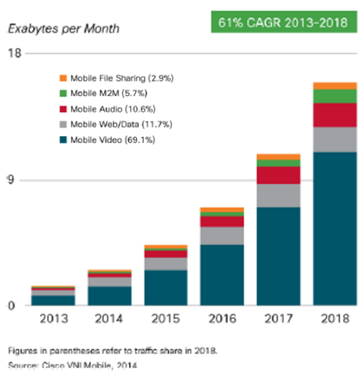
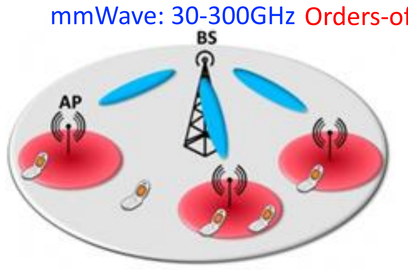
I. Beamspace MIMO for 5G Gigabit Applications



mmWave: 30-300GHz Orders-of-magnitude larger bandwidth (GHz)

Key 5G Use Cases:
Backhaul
Last Mile
Small-Cell Mobile Access



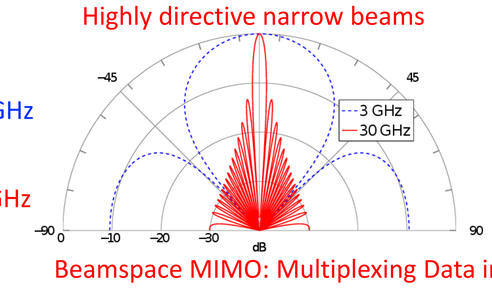
Key 5G Requirements:
Multi-Gbps speeds
sub-millisecond latency

Highly directive narrow beams

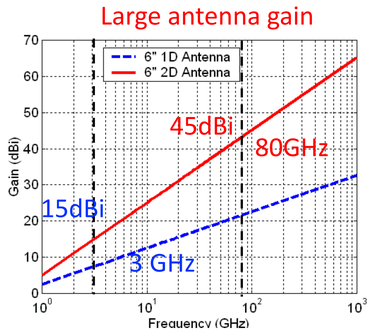
6" antenna

35 deg @ 3GHz
(15dBi Gain)

4 deg @ 30GHz
(45dBi Gain)

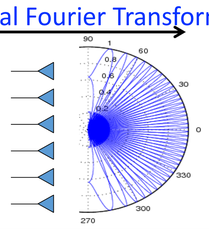


Large antenna gain



Beamspace MIMO: Multiplexing Data into Beams

Spatial Fourier Transform



Antenna space multiplexing

n-element array ($\frac{\lambda}{2}$ spacing)

n orthogonal beams

Beamspace multiplexing

array steering vector

$$a_n(\theta) = \begin{bmatrix} 1 \\ e^{-j2\pi\theta} \\ \vdots \\ e^{-j2\pi\theta(n-1)} \end{bmatrix}$$

spatial freq. $-\frac{1}{2} \le \theta < \frac{1}{2}$ $\theta = \frac{1}{2}\sin(\phi)$ physical angle $-\frac{\pi}{2} \le \phi < \frac{\pi}{2}$

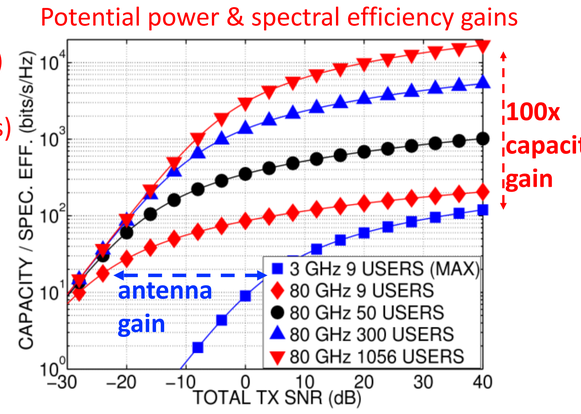
II. Dense Beamspace Data Multiplexing

6" x 6" antenna: 9 elements @3GHz vs. 6000 elements @80GHz

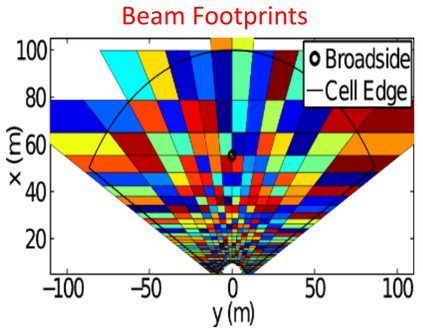
Potential power & spectral efficiency gains

mmWave (80 GHz)
5 GHz BW
10 Tbps (100 users)
100 Gbps/user

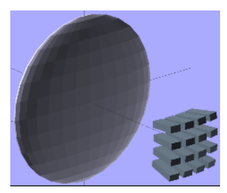
LTE-A (3 GHz)
100 MHz BW
10 Gbps (9 users)
1 Gbps/user



Beam Footprints

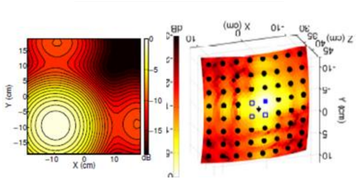


2D Lens Array

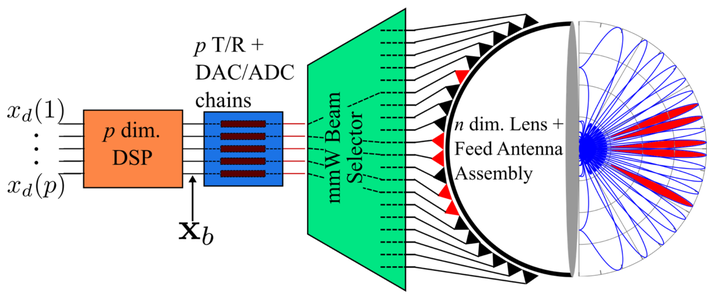


Key Functionality:
Multi-beam Steering & Data Multiplexing

Key Challenge:
Complexity (hardware & computational)

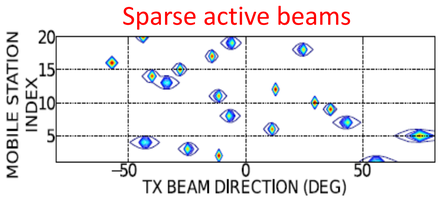


Continuous Aperture Phased (CAP) MIMO



Scalable performance-complexity optimization

Sparse active beams

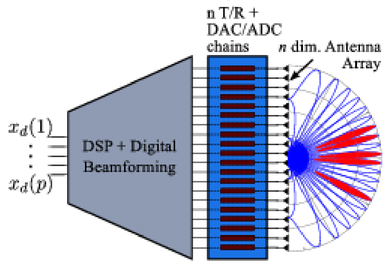


CAP-MIMO Features

- Beamspace MIMO transceiver
- Lens array for analog multi-beamforming
- Optimum exploitation of mmW T/R chains
- Scalable architecture

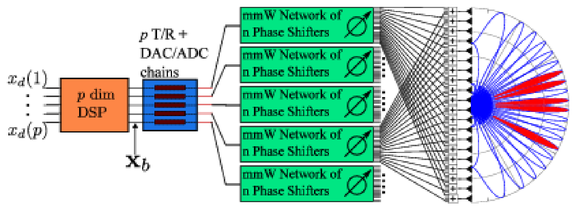
III. CAP-MIMO vs Competing Architectures

Conventional MIMO: Digital Beamforming



Prohibitive complexity

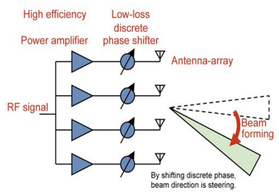
Phased Array Architecture
(All Competing Prototypes)



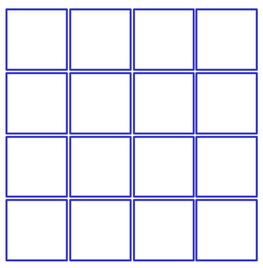
Limited to single-beam (no MIMO)

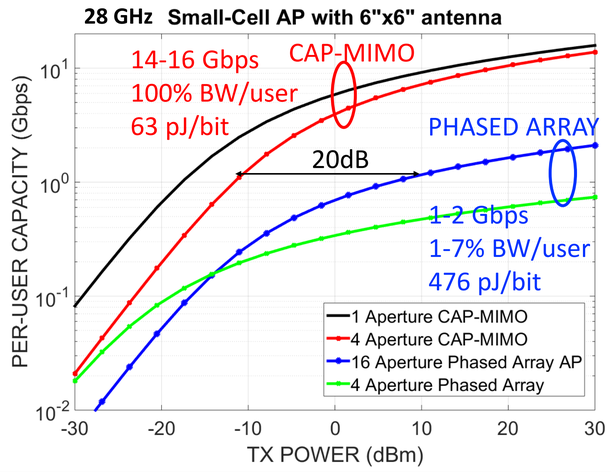
Key CAP MIMO differentiators

- Electronic multi-beam steering & data multiplexing
- Dramatic reduction in hardware & computational complexity
- Scalable performance-complexity optimization

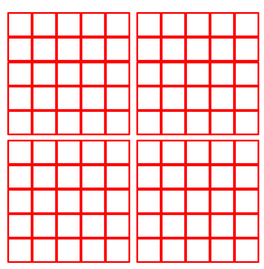


16, single-beam
Phased Arrays
(16 total beams)
(7 users/beam)

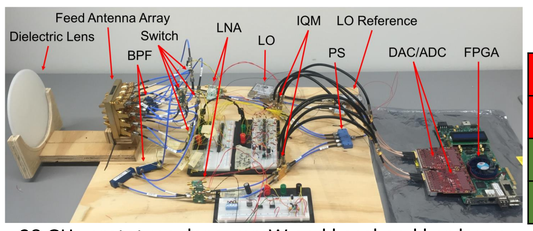


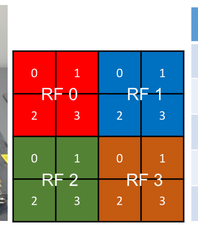


4, 25-beam
CAP-MIMO Arrays
(100 total beams)
(1 user/beam)



IV. Multi-beam CAP-MIMO Prototype

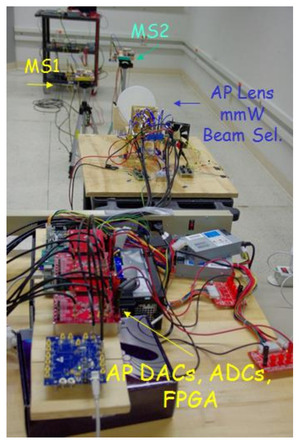




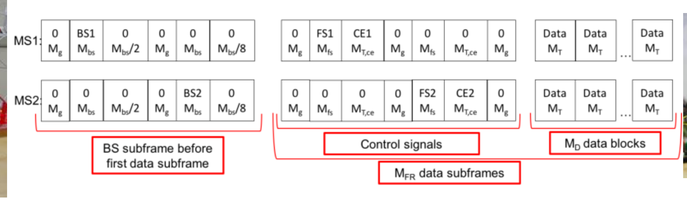
28 GHz prototype: lens; mmW and baseband hardware

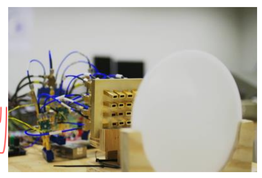
Prototype Specs	28 GHz
Lens Size	6 in diameter
Feed Antenna	WR-28 WG
Feed Array Dim.	4 x 4 (16 feeds)
Channels	2 x 4 MU-MIMO
Current sampling rate	125-370 MS/s

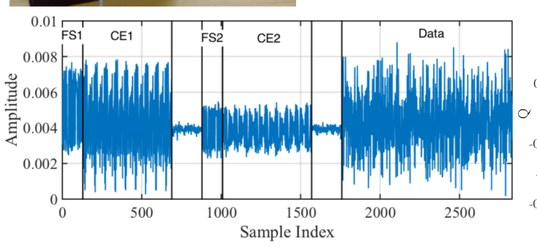
28 GHz Real-Time Multiuser Communication

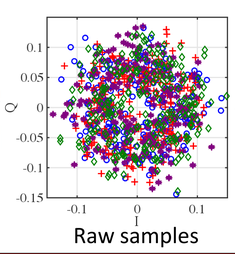


- Frame design: beam selection (BS), frame synch (FS), channel estimation (CE), interference suppression, and temporal equalization for MU communication
- Both uplink/downlink OFDM communication; currently uplink
- Real-time receive processing implemented in the FPGA: beam-selection, beam-frequency channel estimation, beam-frequency MMSE filtering
- PCIe interface used for data offload from the AP to a PC

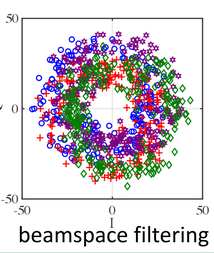




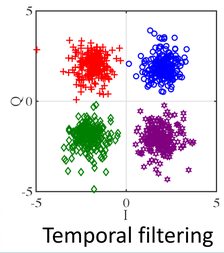




Raw samples



beamspace filtering



Temporal filtering

Potential Applications and Impact

- Disruptive 5G technology
- Multi-Gigabit speeds
- Millisecond latency
- Key use cases: Backhaul, Last Mile, & Mobile Access
- Scalability to meet performance metrics with minimum complexity
- New channel sounding architecture for multi-beam measurements