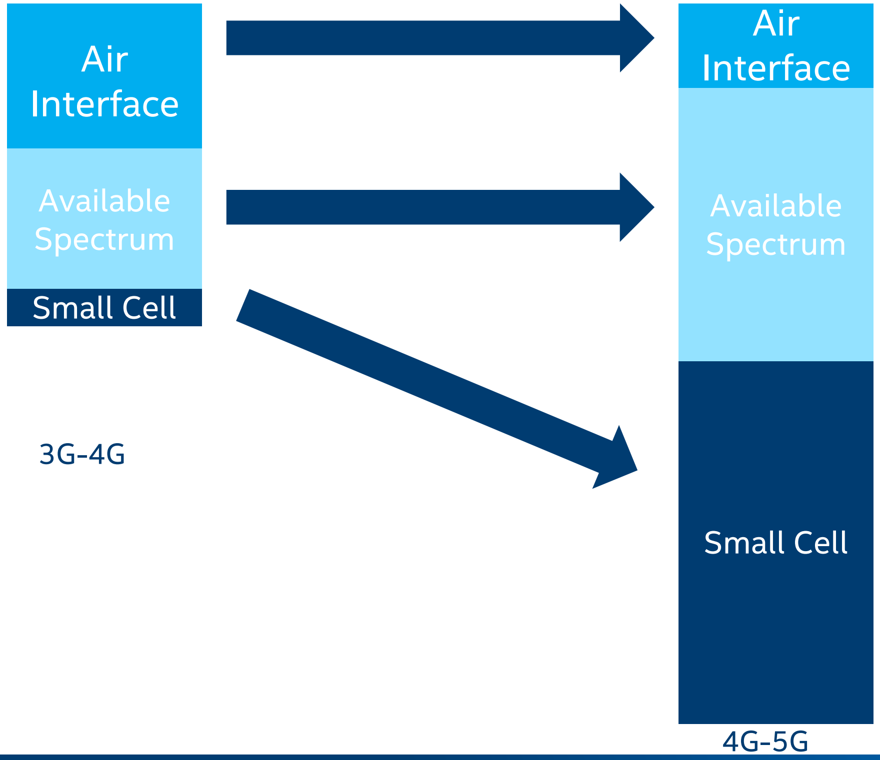
Heterogeneous Systems of mmwave Access and Backhaul for 5G Densification

Ali Sadri, PhD

Sr. Director

Intel Corporation

Past and Future Capacity Improvement

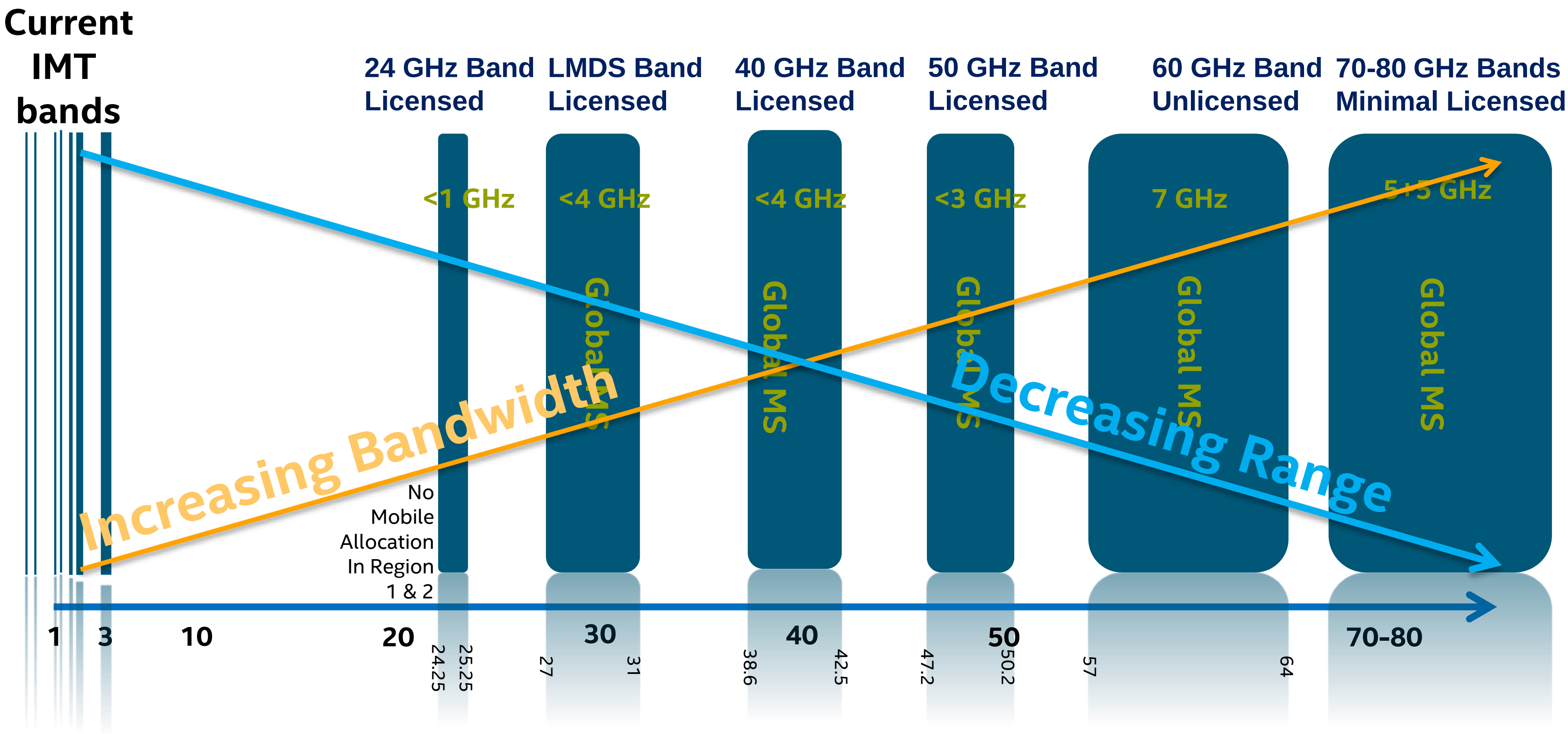


Interference Mitigation, Full Duplex
New Waveform, MU-MIMO
Beamforming, etc

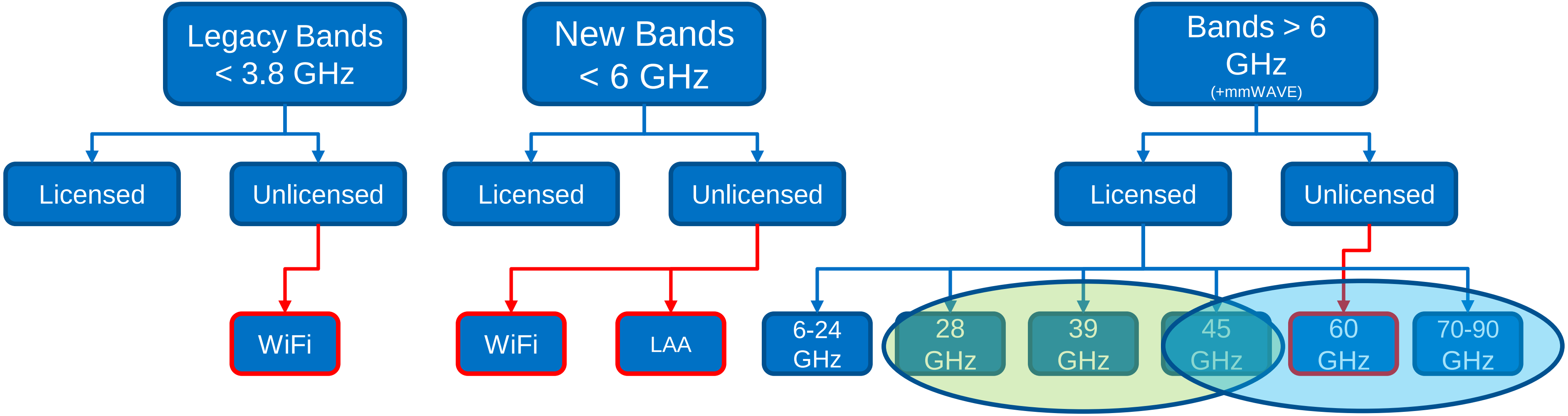
Licensed, Unlicensed, Shared
mmWave

Densification
Relay
Edge Cloud
Mesh Backhaul
Fronthaul

Search for Alternate Spectrum



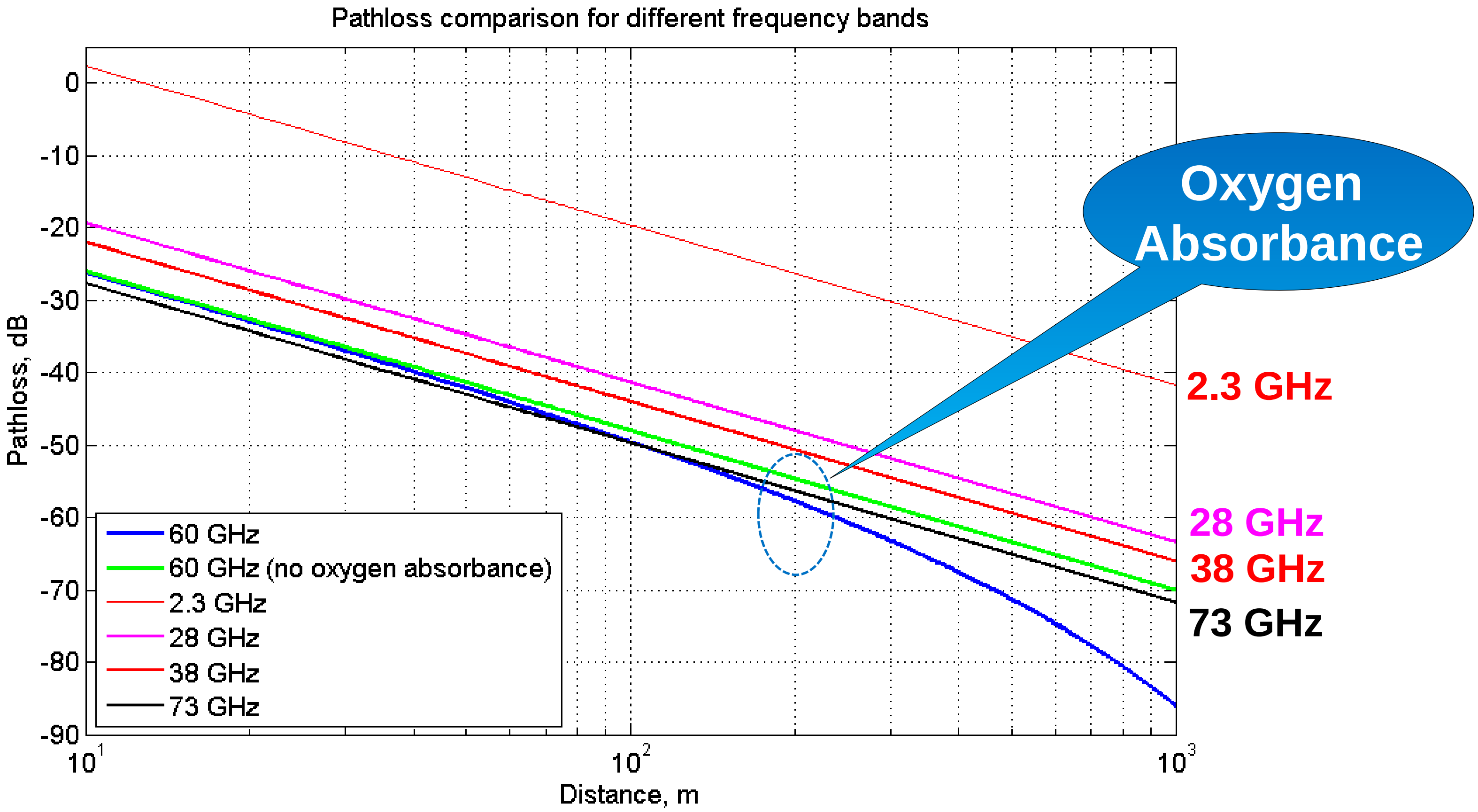
Reuse mmWave Knowledge



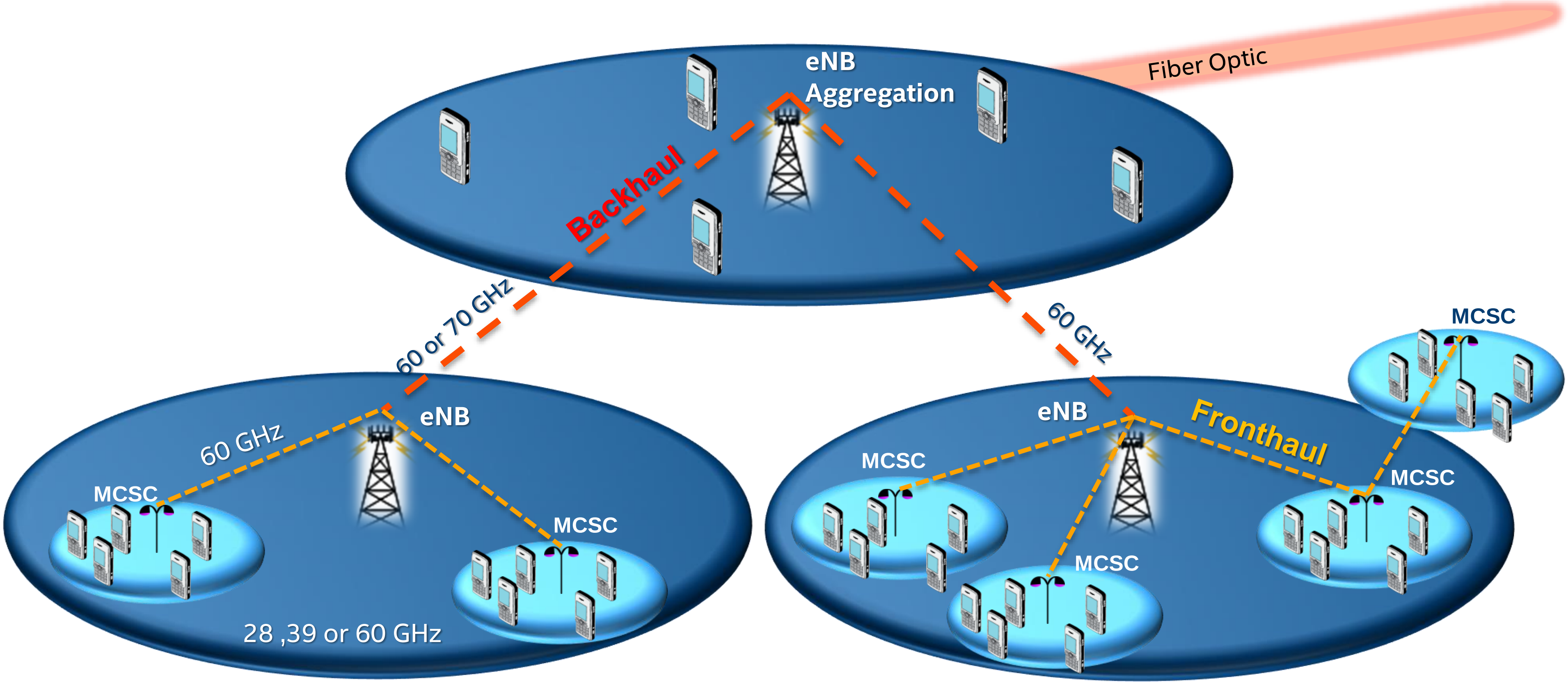
* Categorized based on channel models and path loss

** Potentially the same technology elements could be used across a range of frequencies

mmWave Path-Loss Comparisons



HetNet with mmWave Capable Small Cells (MCSC)

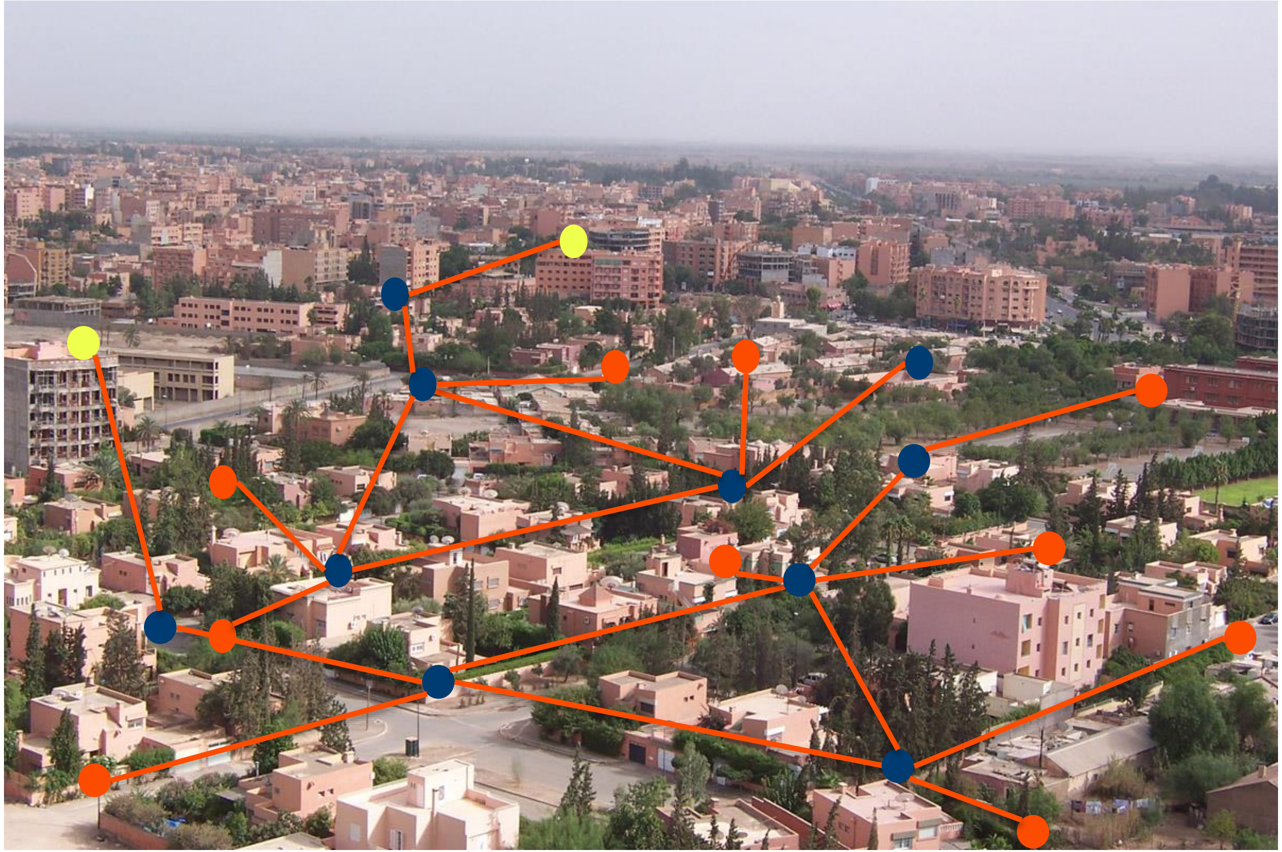


Network Densification Topology

Fiber Node

Distribution Node

Access Node



High Frequency Beam Forming

Challenges in mmWave Systems Design

- **Higher Path Loss**
  - **To compensate with the high path loss higher gain antenna and/or higher transmit power is required**
  - **EIRP, TX power and RF exposure limit are regulated**

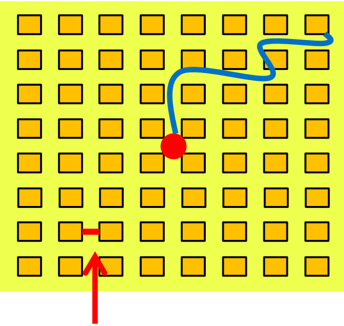
- **Massive MIMO is required for high gain antennas**
  - **Transmission becomes highly directional**
  - **With Narrow beams, tracking of the UE becomes challenging**

- **Feed line loss**
  - **Diminishing return occurs as size of array increases**
  - **Transmission loss increases as function of frequency**

Challenges in RF & Antenna

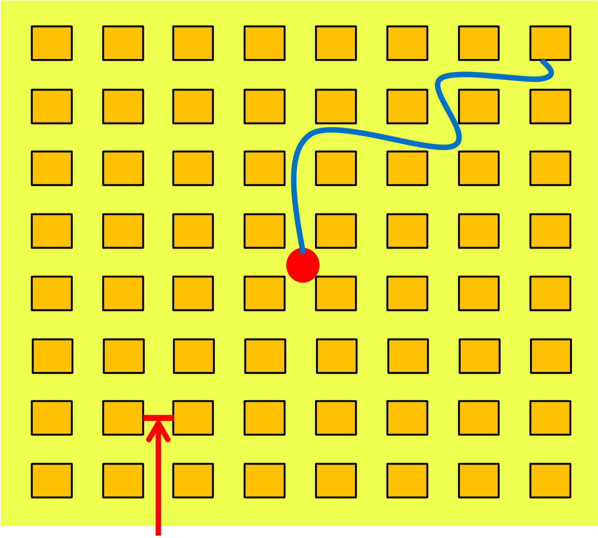
- Feed line loss: (8-by-8) elements

60 GHz



Antenna spacing: $\frac{\lambda}{2} = \frac{c/f}{2} = \frac{5mm}{2} =$ ***2.5mm***

28 or 39 GHz



Antenna spacing: $\frac{\lambda}{2} = \frac{c/f}{2} = \frac{7.69mm}{2}$

@ 28 GHz is 5.36mm and @ 39 GHz is 3.85mm

From 60 GHz to 28 GHz (or 38 GHz),

- The required area getting bigger then feed line getting longer (roughly double).
- Feed loss is also a function of frequency (higher loss at 60 GHz)

Modular RFEM Configurations

Antenna Side

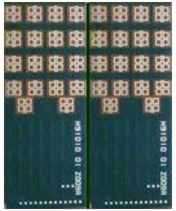
Shield Side

60GHz Operation

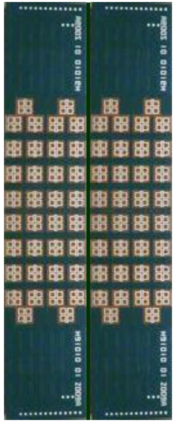
16 Elements

25.2 mm x 9.8 mm

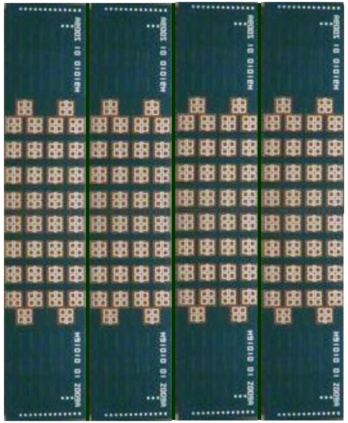
16 elements



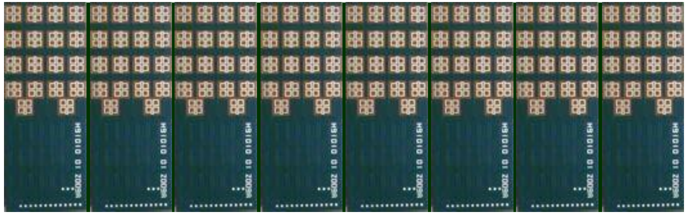
32 elements



64 elements



128 elements



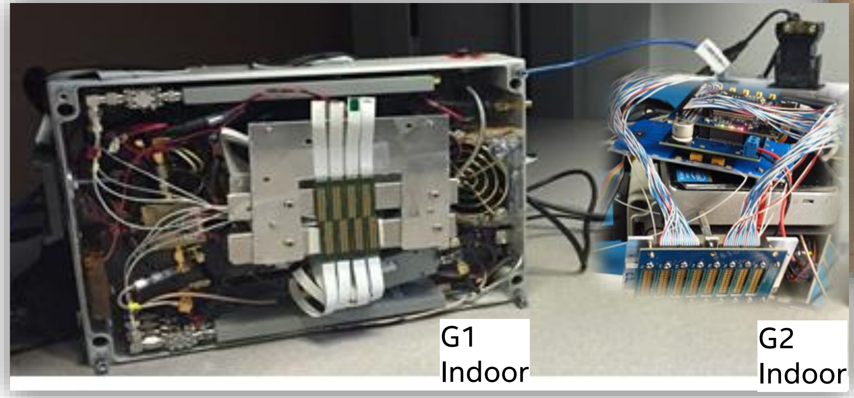
128 elements

MAA POC Evolution

2013

- Discrete
- MAA 128 (2x4)
- Maple-M & R
- EIRP ~ 43 dBm
- 300 x 220 x 150

- Partial PCB
- MAA 128 (1x8)
- Maple-M & R
- EIRP ~ 43 dBm
- 160 x 140 x 110

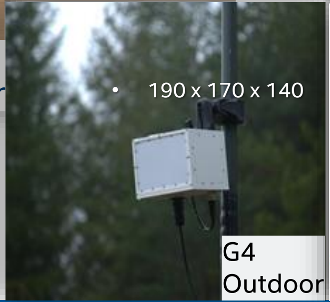


2014

- Stack up PCB
- MAA 128 (1x8)
- Maple-M & R
- EIRP ~ 43 dBm
- 160 x 140 x 110

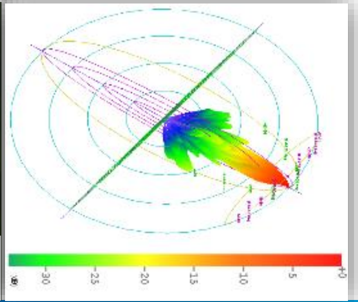
2015

- Stack up PCB
- MAA 128 (2x4)
- Maple-M & R
- EIRP ~ 43 dBm
- Reduce Side lobe



2016

- Stack up PCB
- MAA 128 (2x4)
- Maple-M
- MAA-RFEM
- EIRP ~ 48 dBm
- 160 x 140 x 110



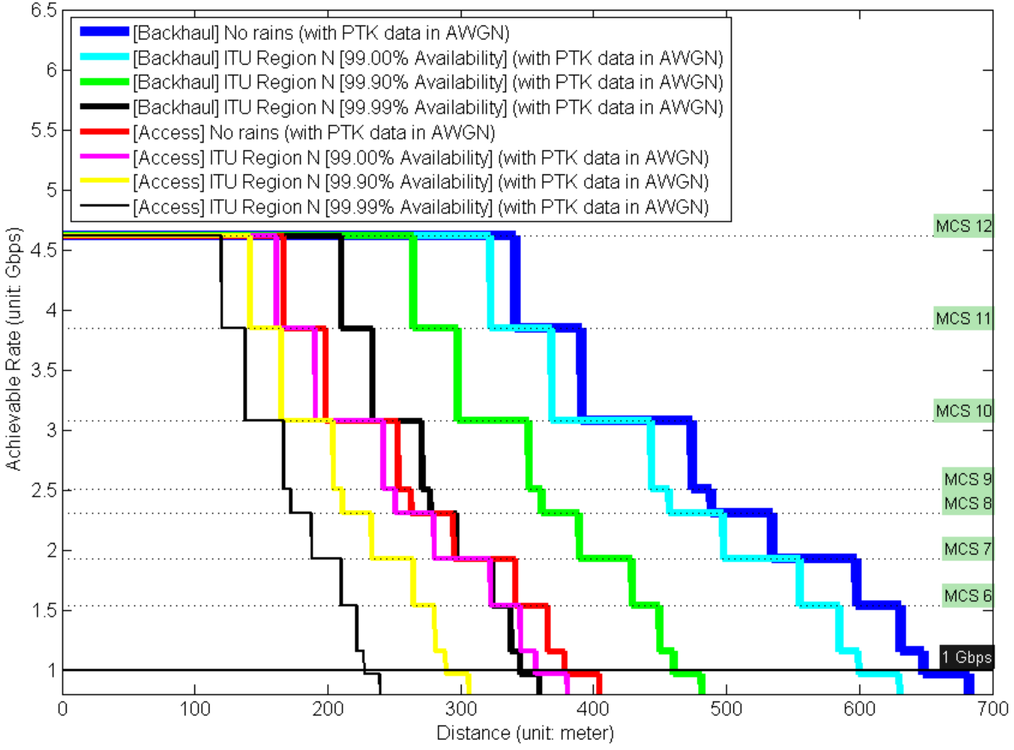
GEN3+ Evaluation Kit

Hardware Overview

- **Indoor Design**
  - Easy access to ports
  - Easy signal breakout for chamber tests
  - Easy tabletop, tripod, post, ceiling installation
- **Antenna Array**
  - 128 elements - 8x16 array - balanced feeds
  - Tiled 8x RFEMs based on Intel WiGig product
  - 1x Intel WiGig Baseband Modem Module

Link Budget Calculation

Calculate SNR values and find supportable MCS in AWGN channels



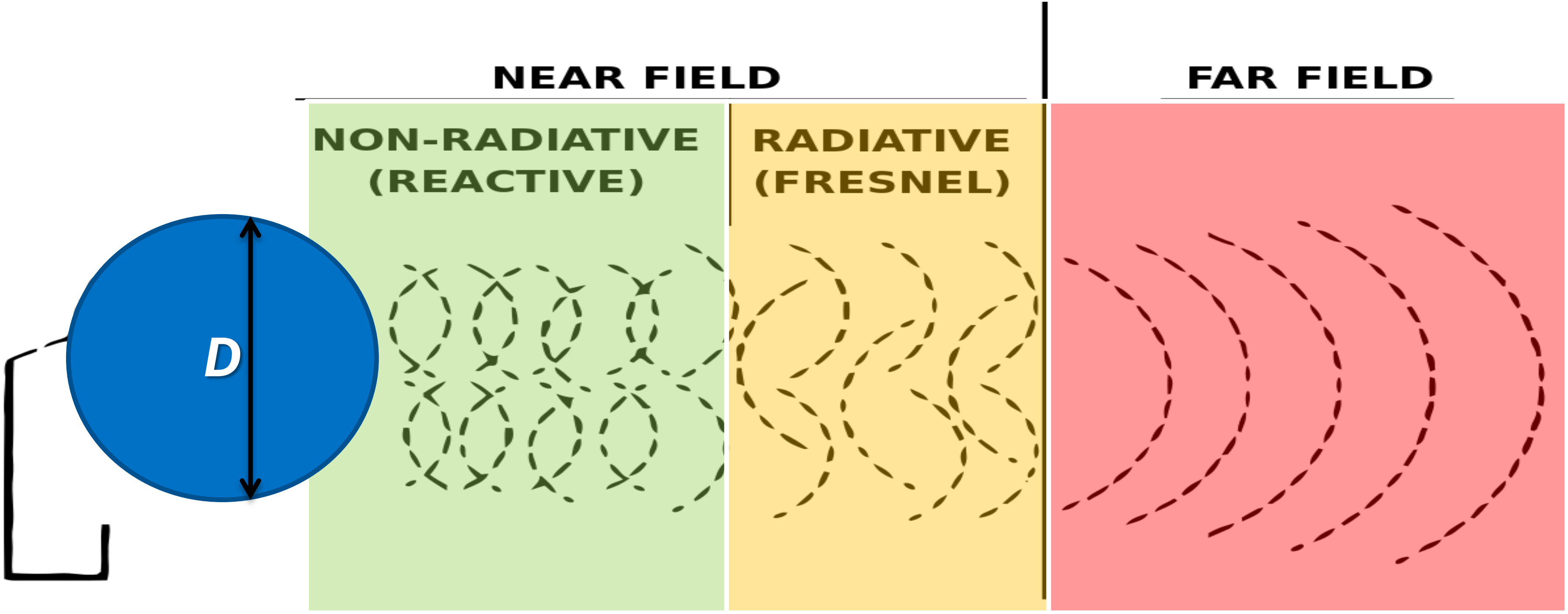
ITU Region N (1 Gbps threshold)

LOS	Backhaul	Access
No rain	650 m	380 m
99.00% availability	600 m	360 m
99.90% availability	470 m	290 m
99.99% availability	350 m	230 m

Assumptions

- Noise figure + implementation loss: (10.5 + 3) dB
- PER < 1%
- AWGN channel (phase impairment considered)

Antenna Field Regions



$R < 0.62\sqrt{\frac{D^3}{\lambda}}$ $\quad 0.62\sqrt{\frac{D^3}{\lambda}} < R < \frac{2D^2}{\lambda}$ $\quad R > \frac{2D^2}{\lambda}$

Modular Sparse Array

Anant Gupta, UCSB

Under the direction of:

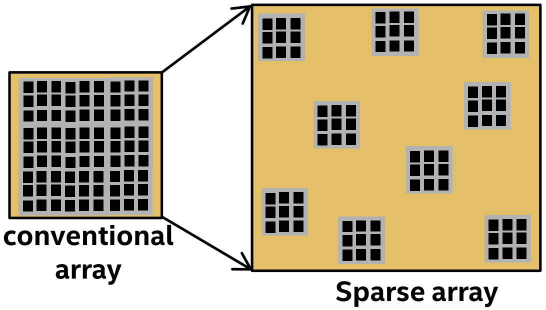
Professor Madhow of UCSB and Professor Amin of Standard

Oct 31, 2016

Sparse Array of Sub-Arrays

Goal: Sparse array of subarrays for *directive* & *steerable* beams with:

- **Sparse placement** of subarrays (4x4 element arrays).
- **Optimal phase** shifts for beamsteering.

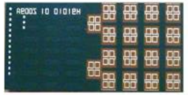


Attribute:

- Larger aperture → **Directivity** ↑ and **BW** ↓
- Sparse arrays with same/fewer elements

Challenge:

- Sub-Nyquist generates aliasing and grating lobes
- Problem different from traditional 2D placement (subarray elements are fixed)



Intel MAA-RFEM 4x4 Module

Approach: Non uniform configurations perform better in all metrics

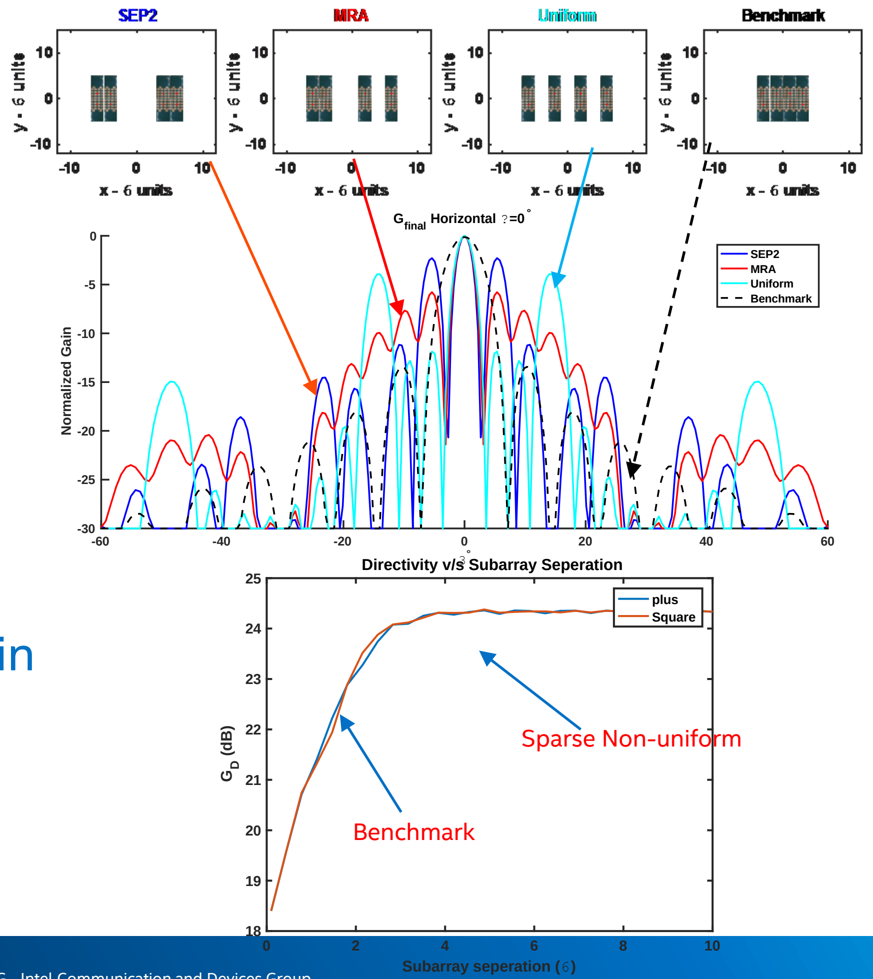
- Optimal placement of sub-arrays and phase processing
- Algorithmic/application-level resiliency to aliasing (e.g. for imaging)

Early Insights

Trade-offs in different architectures:

Metrics:

BW, Grating/side lobes, Directivity



Directivity saturates beyond certain aperture size

Major Metrics & Approach

Cost functions

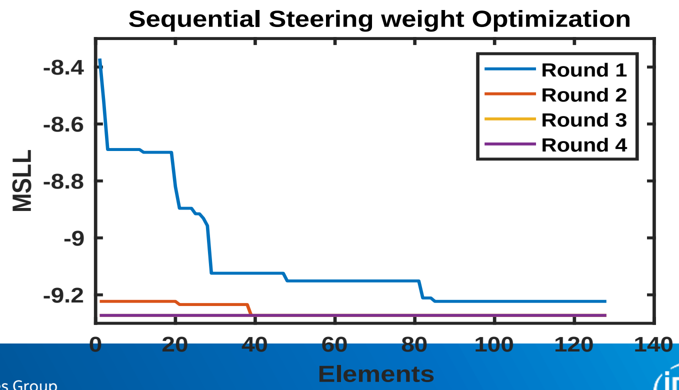
- MSLL: Maximum Side lobe level(relative to main lobe)
- Directivity Gain-
- 2D Beamwidth: $(3\ \text{dB beam})_{Max} * (3\ \text{dB beam})_{Min}$
- ASLL (Average Side Lobe Level)

Sub-Array Placement: Greedy search

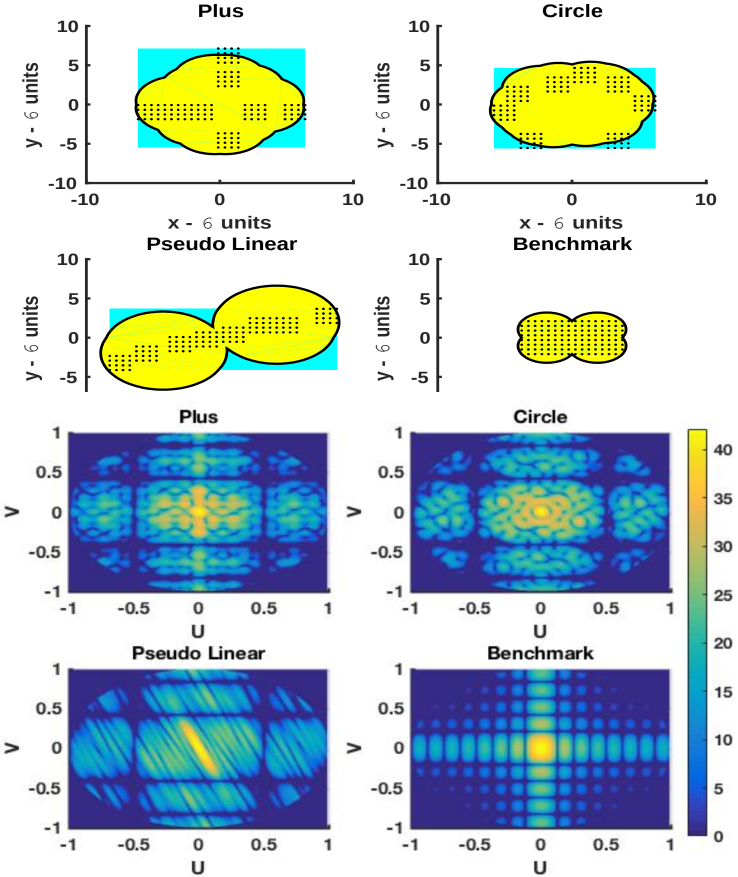
- Sequentially search for subarray positions on all possible locations of grid (dx=0.5λ, dy=0.6λ).

Steering weight optimization: Sequential Optimization

- Scan for best steering weight across all elements to reduce MSLL.



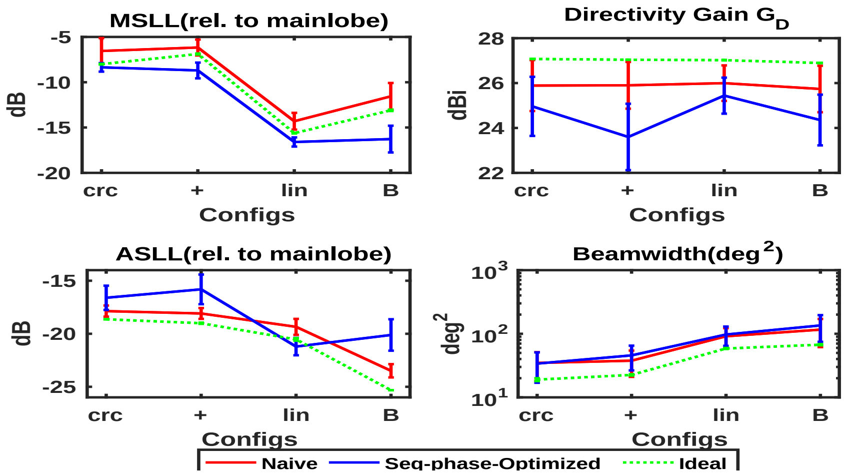
Tradeoffs in Performance



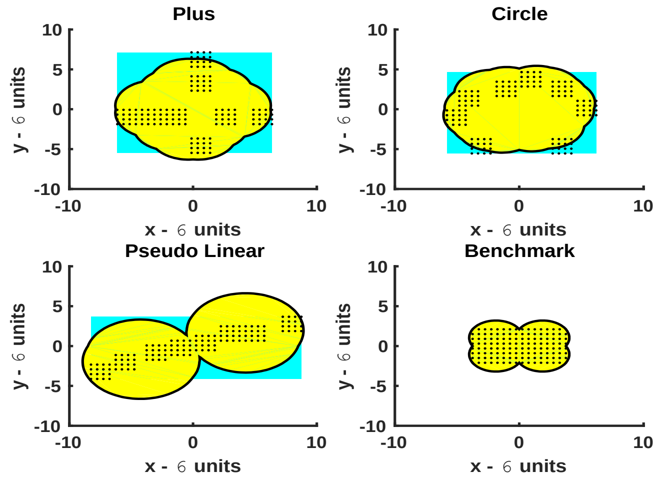
Observations and tradeoffs

Tradeoff between beamwidth and sidelobe level as aperture size increases.

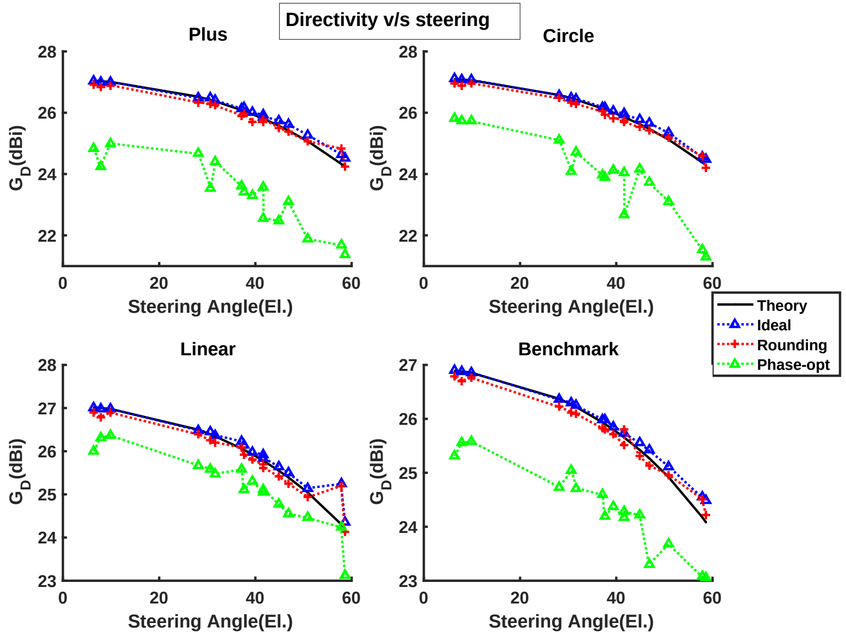
Beamwidth ∝ $(\text{Aperture area})^{-1}$



Early Results; trade-offs in beam steering



Phase optimization to ↓ MSLL causes ↓ Directivity.

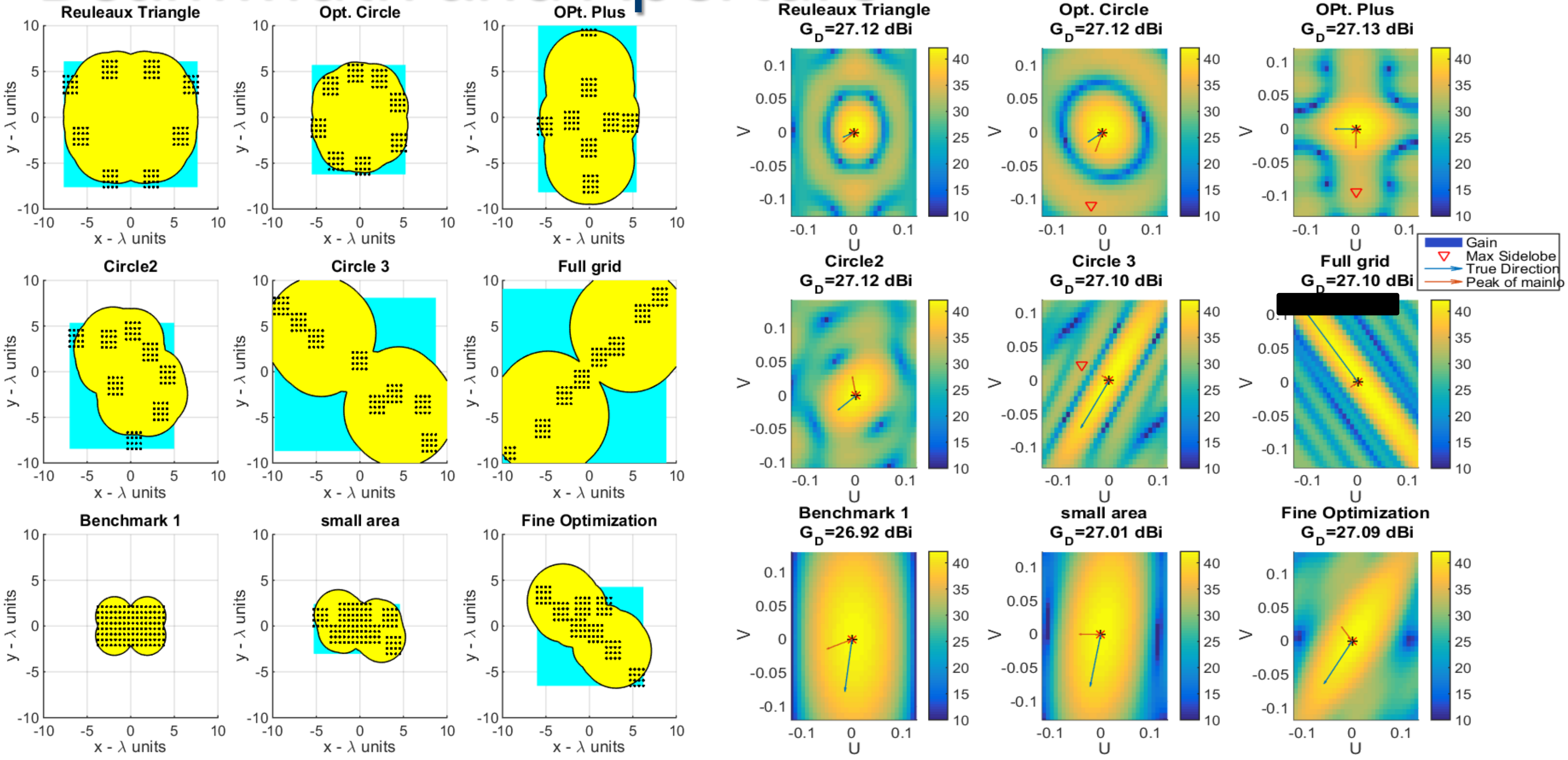


Observations and tradeoffs

Tradeoff between Directivity gain & sidelobe level with phase optimization

Beamwidth ∝ (Aperture area)$^{-1}$

Beamwidth and Aperture



Beam width is roughly inverse of physical array aperture width

Conclusion

- Substantial effort has been focused in the industry on the 5G access technology to improve capacity, latency, throughput, scalability and quality of service;
- Access technology alone cannot significantly improve network capacity;
- An end-to-end 5G system need be augmented by flexible and high throughput backhaul and fronthaul;
- mmWave technology is a great candidate for both access and backhauling to increase network throughput and capacity, and lower interference;
- Sparse array architecture provides additional feature to optimize array performance