mm-Band MIMO in 5G Mobile

Arogyaswami Paulraj
Stanford University

IEEE 5G Summit
Santa Clara University
November 16, 2015

Service Vision and Performance

Universal Connectivity

Immersive Experience

Tele-Control, Tactile, V2X

Low Power

Low Latency

High Reliability

High Speed

Technologies

Multi-RAT SDN Dense Cells

Virtualization MTC Support WiFi Integration

U-, C–Plane Splitting Multi-Link Integration

Het-Net CA D2D CoMP ICIC

SRAN Multi-Service Platforms • • •

mm-Band MIMO

Multiple Access, Waveforms Modulation

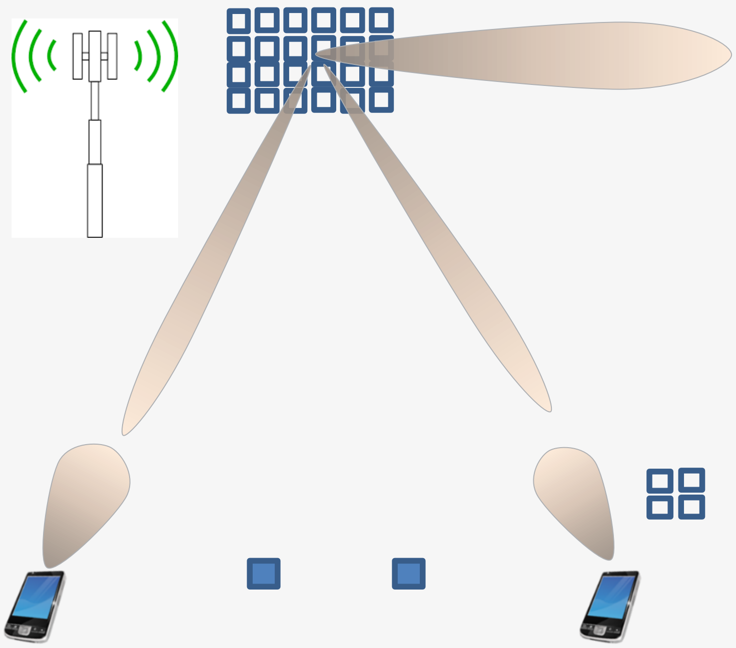
mm-Band MIMO

Multiple Access, Waveforms and Modulation

Spatial Modes

Large MIMO

- Antennas
  - BS   100 to 10,000 !
  - Large number of RF chains, PAs
  - UE   2 - 8
- BS Beam widths
  - 10 to 1 deg
- Channel BW 500 - 1500 MHz
- Use of LOS – MIMO
- U-plane carrier, Data Only
- Main access mode - MU-MIMO
- Back / Front Haul P2P Modes

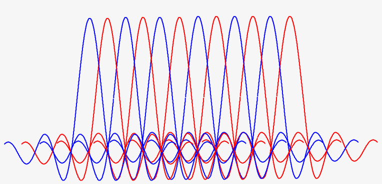


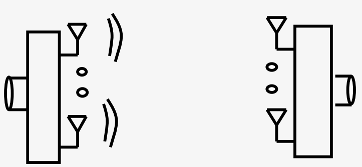
mm-Band

- Proposed US Bands
  - 28, 37, 39, 57 - 71 GHz
- Propagation mode
  - Generally LOS, but NLOS also present, strong shadowing, stronger fading
  - No significant loss in free space (outside 60 GHz) – but foliage and precipitation induce losses
- Deployment
  - Small cells ~ 150m
  - High BS antennas
- Green !

Some History

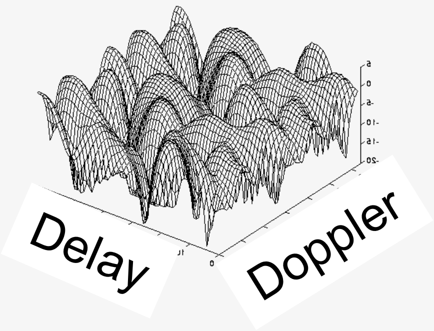
- Iospan Wireless (1998) built a Broadband Wireless Internet system. Acq. by Intel in 2003
- Married MIMO & OFDM (DS-SS was then reigning waveform)
- Iospan Technology
  - Cellular architecture (nomadic access, layer 3 hand over)
  - CP-OFDM, MIMO (2 streams) and M-QAM with Rep. Coding, OFDMA, STC, ….
- Iospan technology became precursor for WiMAX (2005) and adopted by LTE (2009) and WiFi 11n (2009)



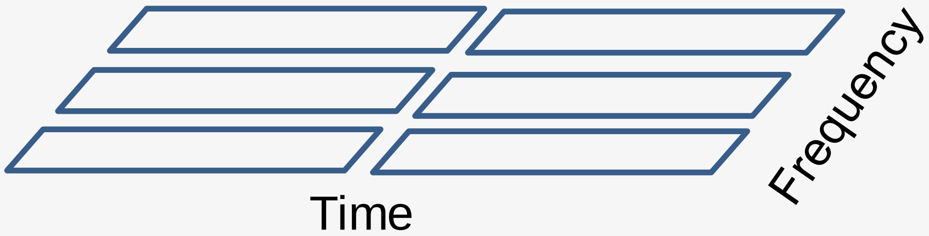


Why OFDM + MIMO ?

Channel Spreading



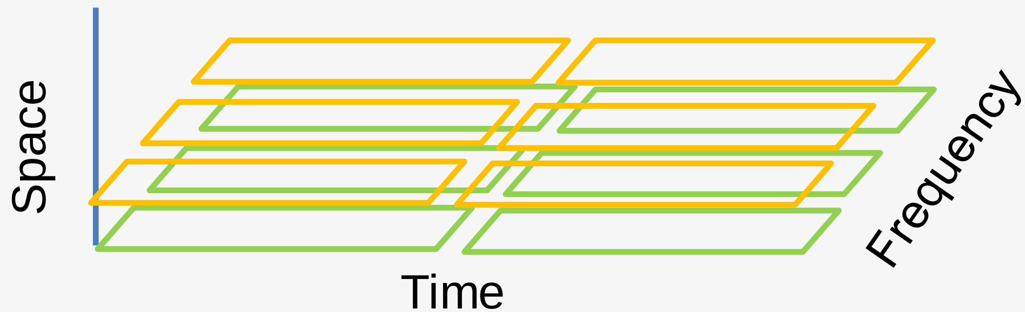
Waveform
Tiling

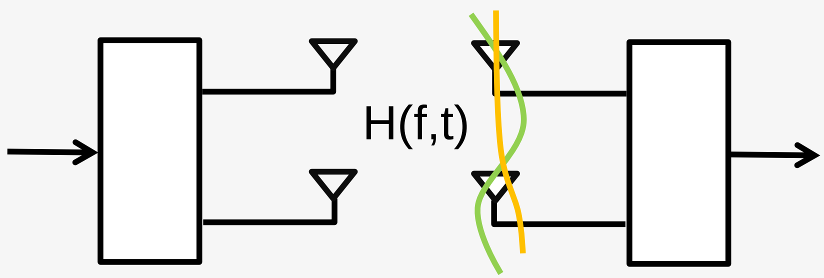


Pre-MIMO
Waveforms designed to be orthogonal in one dimension and equalized in the other dimension (per user)

Why OFDM + MIMO ?

Post-MIMO



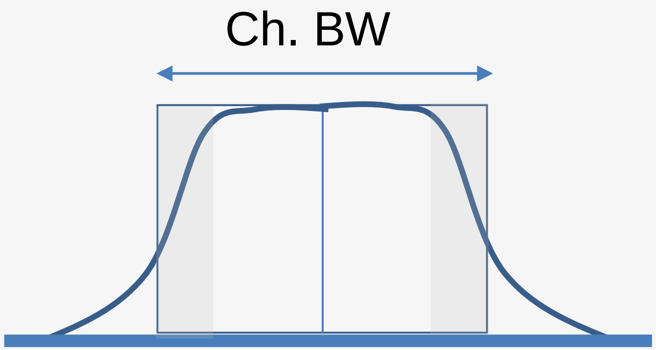


Spatial dimension is inherently non-orthogonal, so

strict orthogonality preferred in Freq. and Time - > CP-OFDM

4G Waveforms

- CP-OFDM
  - Sub-Carriers were Freq. Flat and Orthogonal > Great for MIMO, MIMO decoding can be done per sub-carrier
  - Pain Points - High PAPR, Guard Time (CP), Guard Band, Out of Band Emission, Strict clock and time Sync. on UL, …
- WiMAX and WiFi stayed with OFDM
- LTE modified UL to DFT - OFDM to reduce PAPR



5G Waveform Candidates

- BW < 100 MHz current OFDM LTE is OK
- BW > 100 MHz < 1000 MHz – OFDM needs some changes
- BW > 1000 MHz, OFDM not attractive

OFDM for > 100 MHz < 1000 MHz

- FBMC – Filter Bank Multi Carrier
- UFMC - Universally Filtered Multi Carrier
- f-OFDM - Spectrum Filtered OFDM
- GFDM – Generalized FDM

(Windowing Choices)

Trade Offs

- Time Orthogonality
- Freq. Orthogonality
- Out of Band Emission
- MIMO friendly
- UL Synchronization
- Flexible Raster

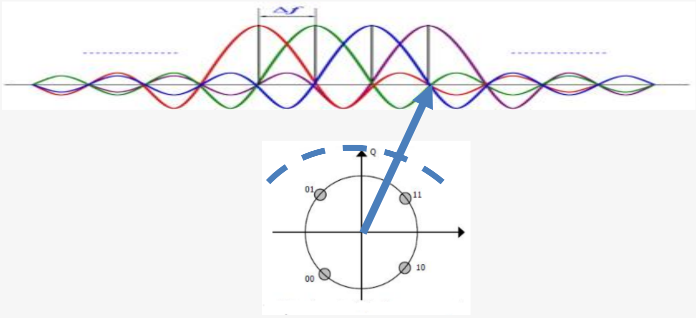
5G Waveforms BW > 1000 MHz

- Single Carrier (SC) seems more attractive
- OFDM's high PAPR complicates high rate ADC / DACs, SC is low PAPR
- OFDM's PAPR also complicates low power / efficient PA design for large arrays
- Low delay spread of narrow mm-Band beams makes SC equalization manageable. Freq. domain turbo equalization
- SC waveforms – Constant Envelop, Continuous Phase, Linear (QAM) …

Modulation

- 4G
- M-QAM for high SNRs and Repetition Coding (RC) for low SNRs
- RC is not energy efficient at low SNR (cell edge) and also increases PAPR for narrowband UL (IoT)

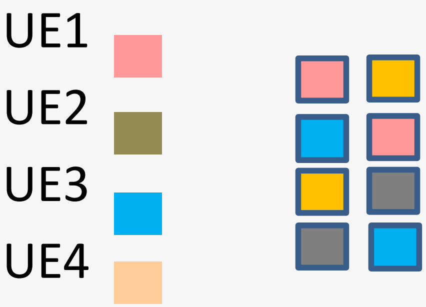
- 5G (< 6 GHz)
- M-QAM at high SNR and FSK at low SNR
- Encode N + 2 bits by choosing one of 2^N sub carriers and 4-QAM modulation on the chosen sub carrier



Multiple Access

4G

- Time-Frequency - Strict Ortho



- Space

  Single User - Quasi Ortho

  Multi User - Strict Ortho DL

5G (< 6 GHz)

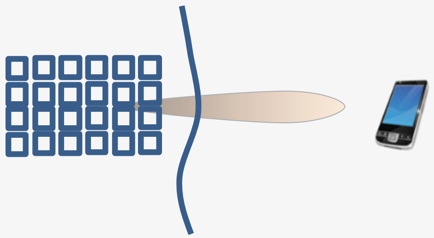
- Time-Frequency - Quasi Ortho
  - SCMA (Sparse Coded MA) (overloading and spreading)
  - QOMA (Quasi Ortho. Mul. Access a.k.a NOMA) ~ SP coding with power allocation to exploit path loss differences, SIC Rx
- Space

  QO-MIMO - Quasi Ortho

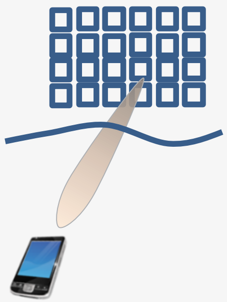
  for Multi User DL also

MIMO Modes

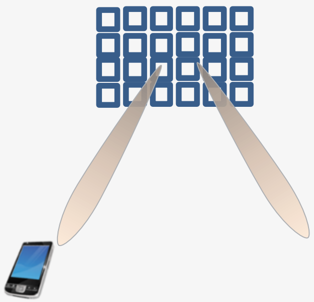
- Vertical Dimension (FD – MIMO)



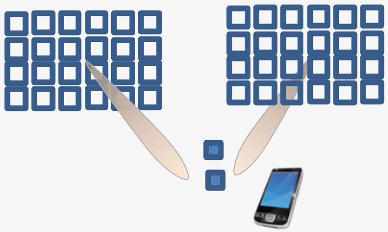
  - Single User (streams limited by UE antennas)



- Multi User (streams limited by BS antennas and power) LOS



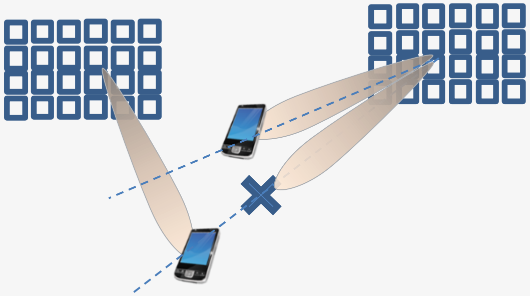
  - Distributed Multi User LOS

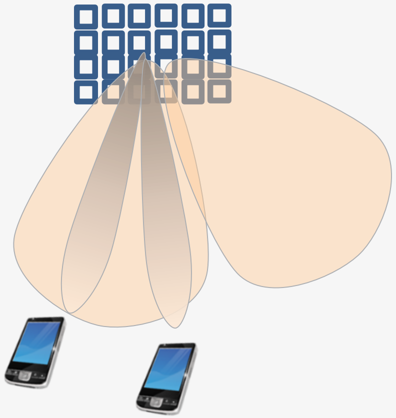


Interference Management

- Inter BS interference is localized along beam / sector axis, no collision - no interference
- Avoid interference collision by inter-BS coordination (topological interference alignment)

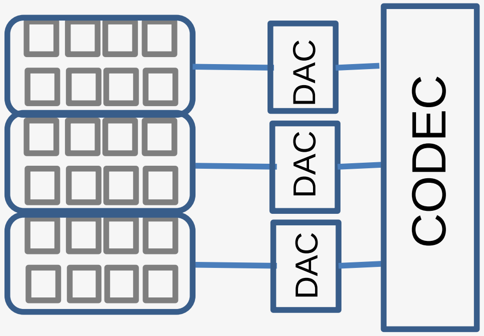
- Inter-sector and inter user interference can be handled by SIC Rx and NAIC (Network Assist IC)

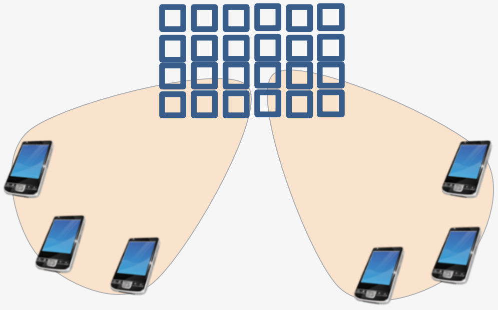




Large MIMO – Pragmatism

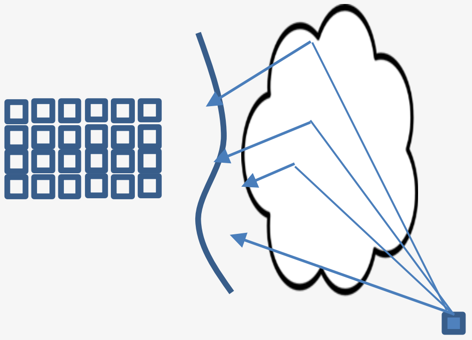
- Grouped analog front end with reduced digital Tx, Rx (hybrid front ends)
- Adaptive sectorizaton to separate UE clusters followed with per sector MIMO processing
- Low BPS/Hz waveforms to tolerate MU interference, poor channel estimates. Low PAPR
- Also ML and SIC Rx to handle multi-user interference (QO-MIMO)

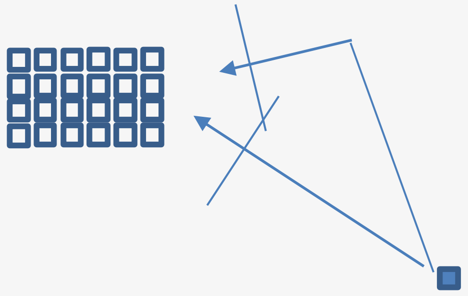




Channel Estimation - Pilots

- Pilots confined to sector
- UL – Easy, pilot overhead depends on UE antennas
- DL – Hard, pilot overhead depends on BS antennas
- TDD – needs expensive calibration
- Model based channel estimation in sparse scattering environments
  - Array calibration manageable
- Exploit sparsity in all dimensions





Summary

Large MIMO, mm-Band propagation, large BW and small cell size changes the existing LTE design tradeoffs on

> waveforms, multiple access, modulation, RF architecture, interference management and MIMO modes

Hardware integration with 2,3 and 4G (Soft RAN)

Many open issues!