# Discussion Points for HW-CSP Breakout Session

Jan 18, 2017

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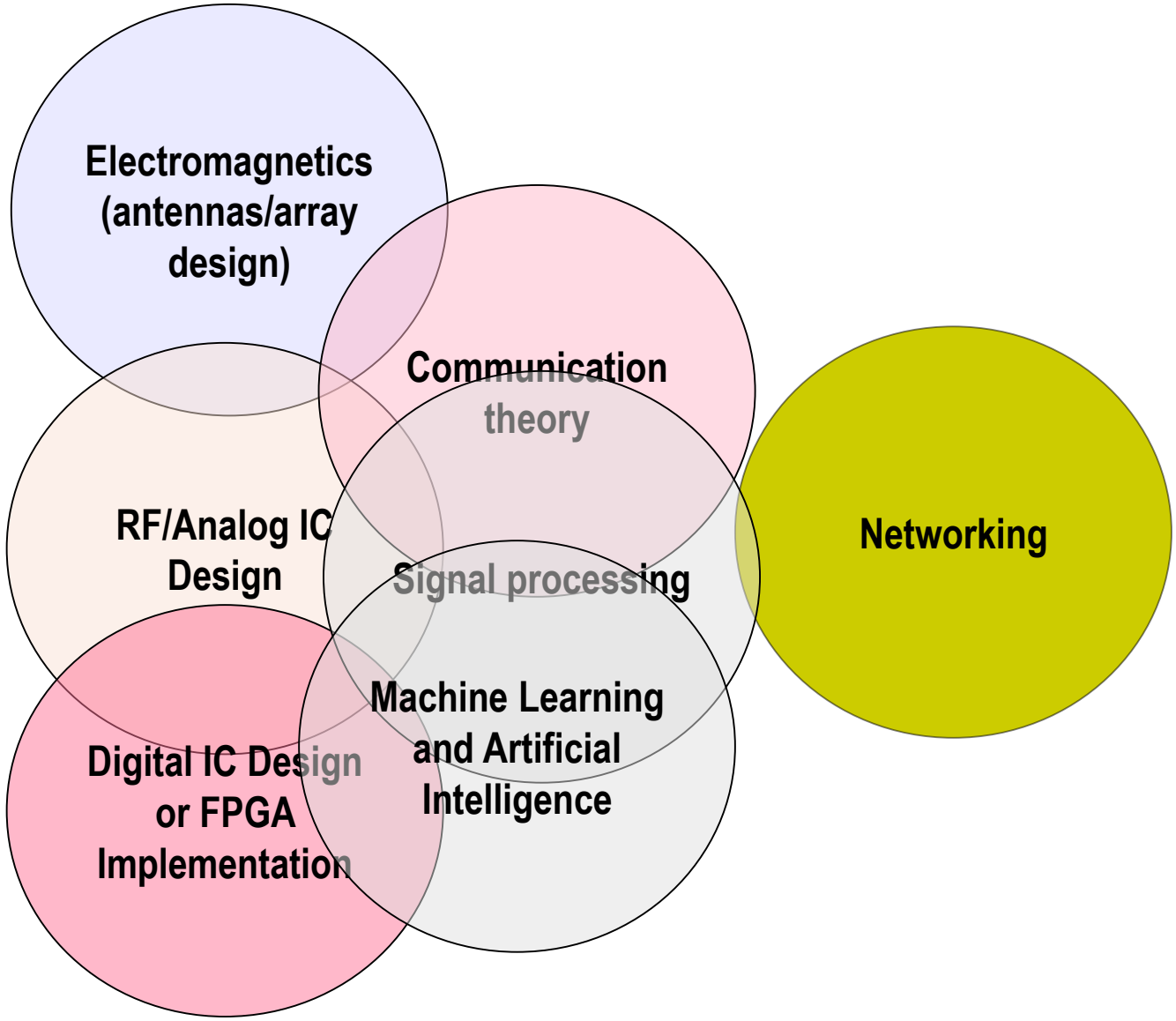
Electromagnetics (antennas/array design)
Communication theory
RF/Analog IC Design
Signal processing
Networking
Machine Learning and Artificial Intelligence
Digital IC Design or FPGA Implementation

# Summary from July 2017 Panel

- Traditional radio design methodology of operating in silos between HW and CSP no longer valid at mmW
- HW-aware CSP and CSP-aware HW design to avoid prohibitively high cost and energy consumption at mmW.
- Advanced beamforming solutions
  - Closed-loop beamforming – computational needs
  - Implications of MIMO algorithms on power amplifiers efficiencies
- Energy-efficient HW
- Beam management for Integrated Communication and Sensing, Imaging and Radar
- Physical layer security and methods to enable it
- Testbeds – NSF PAWR program, NIST
  - How can researchers work with instrument vendors instead of providing specifications ? Need for programmable/reconfigurable testbeds?

# Open Questions

- What are the main issues at the HW-CSP interface that drive system design at the physical layer
  - Scalability between AP and UE
  - Partitioning the signal processing across RF/analog/digital vs all-digital
  - Expected blocker strength in freq and out of freq band
  - Multi-user and multi-beam scenario
  - Efficient power amplifiers and ADC design for mmW Massive MIMO
  - Co-existence with radar
  - Co-existence with sub-6GHz 5G solutions
  - Thermal management – 200W in pole mountable “canister” unit

- What are the HW-CSP pros/cons of alternative beamforming approaches
  - photonic, lens-based
- What are the most promising directions to pursue in advanced systems beyond 5G at mmW?
  - Higher frequencies – 28GHz, 37-40GHz, 64-71GHz, 71-76GHz, 81-86GHz, or 95G+…
  - Spectral-efficiency: high-order modulation and full-duplex
  - Integrated AP and backhaul
- What role can machine learning play at the hardware, physical and network levels?
  - DARPA RFML program
  - Application of ML to train the RF hardware/microwave circuit parameters themselves
- Physical-layer security
  - Key modes of exploiting physical-layer security
  - Can hardware-based protocols be unconditionally secure in information-theoretic sense ? Pros/Cons.
- Training/Education: How should we train researchers with sufficient breadth for effective collaboration at the HW-CSP interface? How must university curricula adapt?

# Viewpoints by

- Greg Chance – Intel
- Kate Remley – NIST
- Swaminathan Sankaran – Texas Instruments

# System Issues

- Massive MIMO
  - Large-scale arrays – phase-noise, heat distribution
  - Coexistence with existing sub-6GHz 5G bands and coexistence with multiple BSs
  - Phased-array design with built-in calibration and self-test
  - Dynamic switch between access and backhaul
  - Physical layer with high spectral efficiency – 4096 QAM
  - PAPR below 52 GHz and E-band frequencies

- MIMO approaches
  - Will digital beamforming be viable? If so, in what scenarios?
  - Is hybrid beamforming the answer? What are the big issues? How to scale?

- Interference-limited vs noise-limited
- Are in band blockers intermittent (can be handled at the MAC level with CSMA) or persistent (link expected to function in presence of blocker)
- Can uplink power control be used to address in band blockers
- Silicon partitioning
- What role can machine learning play?

# Signal Processing & Algorithms

- Lots of current research on new algorithms for mm-wave communication systems
  - Channel estimation, beam acquisition and tracking, precoding and (de)modulation, training, equalization etc.
  - OFDM vs single-carrier FDMA (threshold frequency: 52.6 GHz)
- Are their underlying assumptions valid?
  - Modeling of hardware structures and imperfections
  - Sparsity of channel models – performance bounds
- What is the energy footprint of these algorithms?
  - Compressive algorithms?
  - Basestation vs mobile
- How should we intelligently partition the signal processing across RF, analog and digital domains?

# Chip-level Challenges

- Transmitter (i.e., PA's at back-off)
- Designing for ultra-wide mm-wave frequency ranges
- Design for low-resolution mmWave for V2X and V2V applications
- Frequency synthesis and LO distribution → phase-noise & spurs
- ADC's and DAC's
- Digital power consumption

- What co-existence and interference issues to consider?
  - Communication with radar?
  - Persistent blockage scenario

# Testbeds, Packaging & Non-chip Challenges

- Packaging issues on UE and AP
  - Single chip or multi-chip
  - Data throughputs in 100's of GBps or few TBps
  - Silicon Partitioning
- Antenna design
  - Reconfigurable?
  - Multi-band?
- What about other forms of RF-domain beam-steering?
  - Lens-based beamforming
  - beamspace MIMO
  - Combining lens arrays and phased arrays (e.g. a phased array on the focal surface of a lens array)

# HW/CSP Issues in Future Systems

- What approaches to increase spectral efficiency and network capacity?
  - Integrated sensing and communication
  - Polarization MIMO
  - Full-duplex
  - High-order modulation schemes

- Combined sensing (radar/imaging) + comms @ mm-wave