The Future of RF Systems
Prof. Daniel W. Bliss
School of Electrical, Computer, and Energy Engineering
Director of WISCA Center
Wireless Information Systems and Computational Architectures
Arizona State University

- Largest U.S. University ~100,000 students
  - Established 1885

- Reinventing itself to be a dominant research university

- Largest U.S. Engineering School
  - $105 M External Research
  - 22,500 students, ~350 Faculty

- Electrical, Computer, & Energy Engineering
  - $32 M in External Research
  - ~70 Faculty (EE)
  - Students: 315 PhD, 650 MS, 2200 Undergrads

Research Expenditures

- #9 in Research*
- > $600 Million

*U.S. Universities without medical schools

Year

$1M $2M $3M $4M $5M $6M $7M

2012 2013 2014 2015 2016 2017 2018

ASU is one of the fastest growing research enterprises in the united States.
ASU’s WISCA Center
Wireless Information Systems and Computational Architectures

- Move from new concept, to new theory, to new algorithms, to implementation
  - Advanced communications, radar, sensing, positioning and navigation
- Enable next generation advanced RF system research
- Perform experimental demonstrations
- Develop new high-performance flexible computational architectures
  - Heterogeneous architectures

New Chip Architectures

Theory
\[ c = \log_2(1 + snr) \]
Topics

- Introduction
- Underlying Tech Development
- Important Developing Areas
How Will RF Systems Change?

Needs

• Support wider range of users types and needs
  – Humans have a narrow range of needs

• Increase node’s real-time flexibility
  – Efficiently support several orders of magnitude of computational rates

• Support more sophisticated and collaborative use of spectrum
  – Why do we isolate functions spectrally?
Nonhuman User Dominance

• Address needs of nonhuman users
  – Nonhuman radios dominate in terms of number of users

• Require larger performance dynamic range
  – Much wider range of communications needs
    • Heartbeat signaling
    • Relay multidimensional video
  – Much wider computational range
    • Measure temperature
    • Reconstruct 3D model from image library

• May require much lower SWaP-C
  – Attritable systems
  – Years on a given charge
Topics

• Introduction
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Implications of Commercial Forces

• Accelerate research with interesting low-cost tools
  – Broad availability of flexible RF
  – New flexible computational tools

• Exploit grab-bag of new 5G tech
  – Carrier aggregation
  – mmWave
  – Massive MIMO
  – Small cells
  – IoT (narrowband OFDM and non-orthogonal RSMA)
Fixing Processor Technology
DARPA DSSoC DASH Program

• Break traditional trade between flexibility and performance

• Lead DARPA processor program
  – Domain-Specific System-on-Chip
  – $17M

• Enable new low-cost high-performance systems
• Broaden system designers’ views of what is possible

![Graph showing computational power efficiency vs. technology node](graph.png)
RF Interference-Mitigation Approaches

• Enable higher RF density by mitigating interference
• Exploit space-delay correlations of interference sources to mitigate
  – Space-time adaptive processing (STAP)

\[ Z \in \mathbb{C}^{(n_{\text{ant}} \cdot n_{\text{tap}}) \times n_{\text{samp}}} \]
\[ w = (Z \hat{Z}^H)^{-1} Z \hat{s}_m^H \hat{v}_m \in \mathbb{C}^{(n_{\text{ant}} \cdot n_{\text{tap}}) \times 1} \]
\[ = \hat{C}^{-1} \hat{v}_m \]

• Exploit known temporal structure to mitigate
  – Temporal mitigation (estimation-subtraction)
  – Decodable interference

\[ \hat{z} = z \left[ I - B^H (B B^H)^{-1} B \right] \]
\[ = z - \hat{h} \ast b \]
\[ B = \begin{pmatrix} b_{r_1} \\ b_{r_2} \\ \vdots \end{pmatrix} \]
Topics

• Introduction

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Fluid Communications Systems

• Address needs of non-human users (IoT)

• Match waveform to environmental needs

• Break rigid standard paradigm

• Employ fluid radio system
  – Need flexibility not higher performance
  – Modify waveform, transceiver, computations to address needs

• Scale consumption to needs
  – Joint hardware/software adaptivity
  – High power efficiency

• Redesign entire radio system
  – Frequency synthesizers are problematic
Automotive Radars

- Provide vehicle situational awareness

- Accepted broadly
  - New safety requirement
  - Mass production

- Drive system lower costs
  - Short and “long” range automotive radars ~ $100
  - 24 GHz and 77 GHz

- Need improved system integration and functionality

https://semieengineering.com/here-comes-high-res-car-radar/

NXP-TEF8102

https://spectrum.ieee.org/transportation/advanced-cars/long-distance-car-radar
Personal Radars

- Expect single-chip radars to be the next camera phone tech
  - RF convergence for mmWave
- Address new application areas
  - Human interface
  - Health monitoring
  - Situational awareness
MIMO Radar Channel
Multiple-Input Multiple-Output

**Notional Model**
\[
\mathbf{z}(t) = \sum_{\delta} \mathbf{H}^{(\delta)} \mathbf{s}(t - \delta) + \mathbf{n}(t)
\]

- Received Signals
- Channel Matrices
- Transmitted Signals

\[
(\mathbf{H})_{m,n} \propto e^{i \mathbf{k} \cdot (\mathbf{y}_m + \mathbf{x}_n)}
\]

- \( \eta = \mathbf{k} \cdot \mathbf{d} \)

**Array Responses**

- \( \mathbf{H}^{(\delta)} \) is the channel matrix

**MIMO Virtual Array**

- Use MIMO virtual array to increase degrees of freedom
  - Convolution of real arrays produces virtual array
- Disentangle MIMO channel by exploiting transmitter diversity
- Consider new geometries
  - Virtual array may over-represented elements
  - Sparse arrays

RF Convergence

- Provide more effective use of RF spectrum
- Reuse RF signals and receivers
  - Node performs multiple tasks simultaneously with same RF energy
- Remove artificial separation between communications, radar, EW, & RF SA
- Improve rather than degrade performance by friendly RF systems
  - Radios can estimate channels
  - Radars can decode and transmit communications signals
  - Radar waveform is the communications signal

Multi-Access Communications & Radar

**Example Approach**

- Recover radar return and communications simultaneously
- Explore joint estimation, detection and information theory
  - Interactions between sensing and communications

Joint Radar-Communications System

MATLAB-in-the-Loop Experiments

- Demonstrate feasibility of joint radar-communications system
  - Use dynamic network of software defined radios
  - Chirp and QPSK waveforms
  - Intelligent power and rate control between systems

- Decode communications
- Remove communications
- Observe chirp with little communications residual

Performance Evaluation

Multiuser Communications & Multi-Static SAR

MATLAB Simulation

- Design joint radar-communications system
- Develop multi-static channel model
- Approach performance bounds
- Perform SAR imaging

Distributed Coherent Systems

• Allow disparate systems to act like they have a common clock
  – Phase-cohere systems
  – Phase-accurate time transfer

• Employ co-use communications and positioning waveform

• Enable new functionalities
  – Distributed beamforming: Power \( \sim N^2 \)
  – Carrier-phase accurate position and navigation

Joint Communications and Positioning

• Exploit flexible radio technology to enable range of time and position critical applications
  – Automated vehicles
  – Urban air mobility

Automotive Comms & Positioning

• Pursuing advanced position estimation techniques
  – MIMO phase recover
  – Distributed coherent
  – Secure & reliable

Distributed Coherence

Ambiguity Function

Theoretical Ranging Performance

Summary

• Introduced ASU and WISCA

• Observed users are becoming less human

• Identified important driving tech development

• Provided examples of new RF application directions