Joint Sensing and Communication Design: Applications, State-of-the-Art and the Road Ahead

Would This Become the 6G 'Killer Application'?

Based on Liu, Masouros, Petropoulu, Griffith & Hanzo, TCOM, 2020

Presented by
Lajos Hanzo
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The Marconian Legacy...
Southampton Wireless Research Group
Historic Preamble...

Wireless Past, Present & Futures...
Overview

- Wireless Past, Present & Futures
- History & Motivation of RadCom - Hardware Co-design
  Beyond Spectrum Sharing
- What Will 6G Be?
- From Conflicting Design Trade-offs to Fully-Fledged
  Pareto-Optimal RadCom
- The Future?
Wireless History

- Liu, Qin, Elkashlan, Ding, Nallanathan & Hanzo: Nonorthogonal Multiple Access for 5G and Beyond, Proceedings of the IEEE, 2017
The world’s first DFRC scheme is proposed in [85], in which the communication bits are modulated on the radar pulse interval.

- The first patent on MIMO communication system is granted [94].

- The Advanced Multifunction RF Concept (AMRFC) Program [41] is initiated by the Office of Naval Research (ONR) of the US.

- The first DFRC scheme that exploits chirp signals is proposed [86].

- The concept of the collocated MIMO radar is proposed [99].

- The HAD structure is introduced into MIMO communication [115].

- T. L. Marzetta’s seminal work [122] on massive MIMO communication is published.

The concept of the phased-MIMO radar is proposed [120], which achieves a balance between phased-array and MIMO radars.

- The OFDM based DFRC signaling scheme is proposed [91].

- NYU WIRELESS’s landmark paper [22] on mmWave mobile communication is published.

DARPA launches the project “Shared Spectrum Access for Radar and Communications (SS-PARC)”, which aims at releasing part of the radar spectrum for use of commercial communication.

- The first information-theoretical analysis for the DFRC system is presented [40].

- The HAD technique is applied to the mmWave massive MIMO communication system [116].

The first signaling scheme for MIMO DFRC systems is proposed [106], where communication data is embedded into the sidelobe of the MIMO radar beampattern.

This work proposes to combine both the phased-MIMO radar and the HAD communication techniques for designing mmWave massive MIMO DFRC system.
Is RadCom Only On About Spectrum Sharing or Hardware Sharing?
’Killer’ Applications...

Service Layer
- Intelligent Transportation
- Emergency Rescue
- Immersive Tourism
- Smart City

Distributed Cooperative Control Layer
- Satellite Controller
- Terrestrial Controller
- Rotary-wing UAV
- Fixed-wing UAV
- Base Station

Resource Layer
- Users

Service’s Requirement Analysis
- Service Repository
- Knowledge Repository
- Resource Discovery
- Resource Monitoring

Service’s Intent Abstraction
- Service’s Intent Translation
- Service Decomposition

Micro-service
- Micro-service
- Micro-service

Hardware Resource
- Hypervisor
- Kernel
- Micro-service

Resource Interface
- Cooperative Control Inter-domain

Micro-service
- Service's Intent Abstraction
- Service's Intent Translation
- Service Decomposition

Knowledge Repository
- Intelligent Schedule
- Knowledge Abstract

Resource Monitoring
- Resource Discovery
- Resource Repository

Hardware Resource
- Hypervisor
- Kernel
- Micro-service
Spectrum Sharing

Super Data Layer
Addressing specific use cases requiring extremely high data rates

Above 6 GHz
800 MHz assignments (contiguous)

Coverage and Capacity Layer
Best compromise between capacity and coverage

2 – 6 GHz
100 MHz assignments (contiguous)

Over-sailing Layer
Wide area and deep indoor coverage

Below 2 GHz
Up to 20 MHz paired/unpaired

SOURCE
4G & 5G Spectrum Sharing: Efficient 5G Deployment to Serve Enhanced Mobile Broadband and Internet of Things Applications by Wan, Guo, Wu, Bi, Yuan, Elkashlan & Hanzo, IEEE VTM, 2018
Hardware Sharing:
1/ Joint Waveform Design (PAPR, ACF, CCF);
2/ Synchronization;
3/ MIMO;
4/ ML/AI in the Face of Uncertainty

SOURCE
- Mobile Radio Communications by Steele & Hanzo, 1999, Chapter 2, Bello Functions
The Future - What Will 6G Be?

Global Coverage
- Satellite
- UAV
- Terrestrial
- Maritime

Sub-6 GHz
mmWave
THz
Optical

6G Vision

All Spectrums

Full Applications
- AI
- Big data

Network Security

Physical layer
Network layer

SOURCE
So, Dr Shannon - which MIMO is best for RadCom?

\[ C = B \cdot \log(1 + SINR) \]

\[ C \approx \min(M; N) \]

- Diversity – STBC, etc.
- Beamforming
- Multiplexing – BLAST, etc.
- Space Division Multiple Access
The Pathloss Escalates vs. the Carrier Frequency

ATMOSPHERIC ATTENUATION dB/Km

Frequency GHz

H₂O

O₂

H₂O
No. of Antennas Required for Compensating the Pathloss

- 100m with $P_t=40$ dBm
- 250m with $P_t=40$ dBm
- 500m with $P_t=40$ dBm
- 100m with $P_t=20$ dBm
- 250m with $P_t=20$ dBm
- 500m with $P_t=20$ dBm
Separate vs. Joint Beamforming

**SOURCE**
- MU-MIMO Communications With MIMO Radar: From Co-Existence to Joint Transmission Liu, Masouros, Li, Sun & Hanzo
  IEEE TWC, 2018
Separate vs. Joint Beamforming; SINR=10 dB; K=4; \(N_R=14\); \(N_C=6\); PSLRs are 7 and 15 dB

SOURCE
- MU-MIMO Communications With MIMO Radar: From Co-Existence to Joint Transmission Liu, Masouros, Li, Sun & Hanzo
  IEEE TWC, 2018
The Future: Pareto-Optimal Multi-Functional MIMOs

SOURCE

- Near-Capacity Wireless Transceivers and Cooperative Communications in the MIMO Era, by Hanzo et al. Proc. of the IEEE, 2011
Multi-Component Pareto Optimization: Bandwidth, BER, Delay, Power & Complexity, etc

SOURCE

- Thirty Years of Machine Learning: The Road to Pareto-Optimal Wireless Networks, ©Wang, Jiang, Zhang, Ren, Chen & Hanzo IEEE COMST, 2020
Pareto-Optimal RadCom Transceiver Design

Available Techniques

- OFDM
  - Multi-dimensional Sphere Packing Modulation
- CDMA
- SDMA
- IDMA
- STF-Coding
- Cooperative MIMO
- Relay aided Scheduling
- Beamforming
- Multi-function MIMO
- Non-Coherent Schemes
- Sevices
- SDR Design
- Turbo Principle
- Joint Source and Channel Encoding
- Irregular Schemes
- Channel Estimation
- MIMO MUD
- EXIT Chart Matching & Hybrid Schemes
- Intelligent Agents
- etc.

Kernel Problem

- limited resources
- Radio Spectrum
- Power Supplied
- Capability of Chips
- Space of MS
- Structure of Transceiver
- Affordable Antennas

- unlimited QoS is desired
- Design Conflict
- High Data Rate
- Real-time or Short Delay
- High-Speed Mobility
- Reliability & Robustness
- Multi-Standards Compatibility
- Last for a long time after one-time charge

Trade-Off

Constraints

Design

Efficiency

Aim

SOURCE

- Near-Capacity Wireless Transceivers and Cooperative Communications in the MIMO Era, by Hanzo et al. Proc. of the IEEE, 2011