Tampere University

Full-Duplex (FD) Integrated Sensing and Communication (ISAC)

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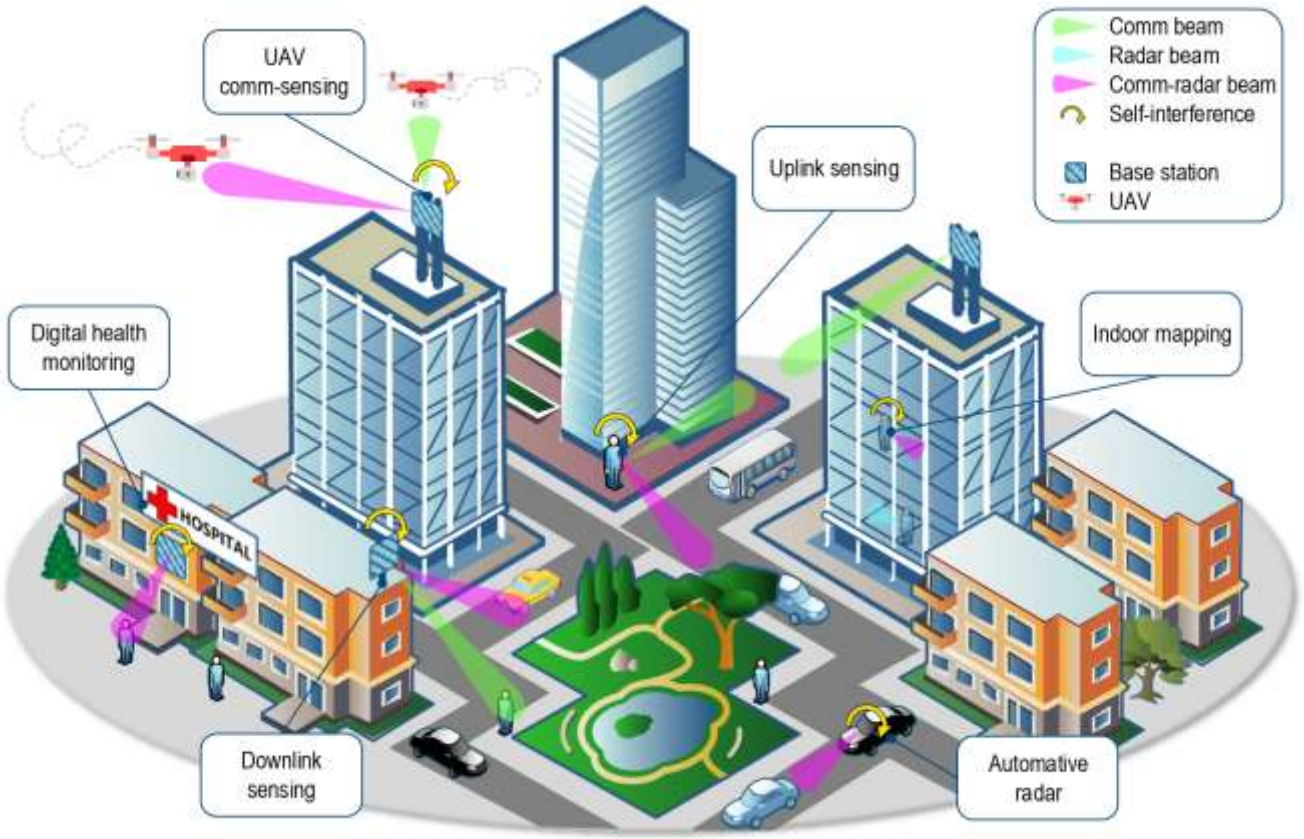
October 22, 2021

General Trends in Wireless Communications



- **5G NR and future 6G networks:**
  - Peak data rates
  - Network capacity
  - Number of connected devices
  - Radio access latency & reliability
  - …
- **Full-duplex (FD) communication and self-interference cancellation (SIC)**
  - ➢ Emerging technology initiative (ETI)
- **Integrated sensing and communication (ISAC)**
  - ”RF convergence”
    - Sharing frequencies, transmit waveforms and even hardware platforms
  - ➢ Emerging technology initiative (ETI)

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Aim & Scope

ISAC is a very multi-disciplinary theme

- **Aim of the ETI**: To explore and support a wide variety of research directions and industrial opportunities related to ISAC; More importantly, promote our research area here.
- **Scope of the ETI**: Integrate ongoing research efforts and initiatives to become the catalyst and future reference for experts working in different aspects of ISAC, including:
  - **Information Theory** to reveal the fundamental limits and tradeoffs in ISAC
  - **Signal Processing** to design dual-functional waveforms and joint SP frameworks
  - **Mobile Computing** to detect and recognize events and activities via commercial devices
  - **Aerospace & Electronic Systems** (Radar Systems) to embed communication function into radar
  - **Vehicular Technology & Intelligent Transportation Systems** to leverage ISAC in V2X and Autonomous Vehicles

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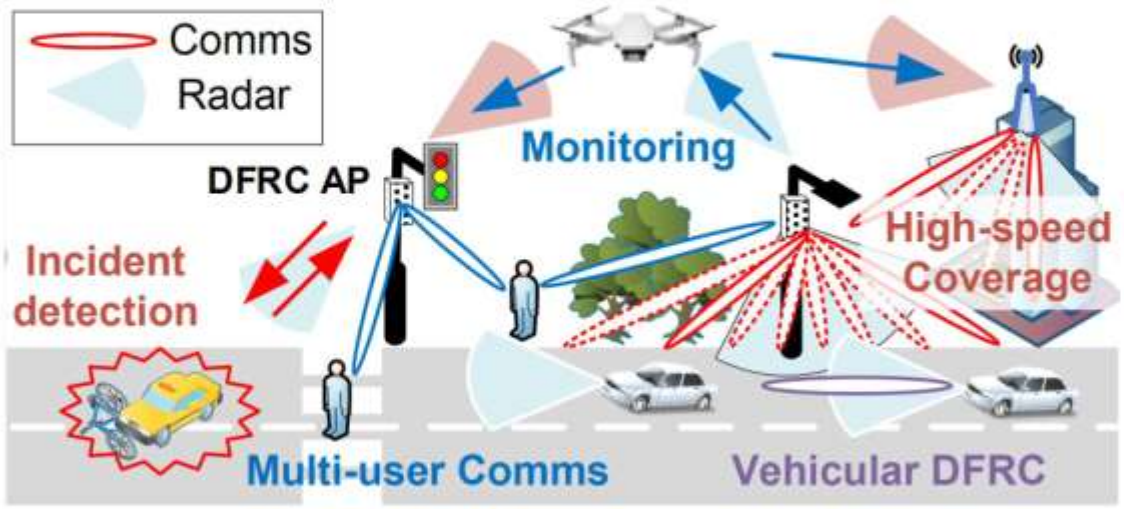
ISAC Gains

Integration Gain



- **Efficiency Improvement:**
  - Spectral Efficiency
  - Energy Efficiency
  - Hardware Efficiency
- **Cost Reduction:**
  - Hardware Cost
  - Signaling Cost

Fundamental Theory: ISAC Information Theory, ISAC Signal Processing, ISAC Resource Allocation

Y. Cui, et al. Integrating Sensing and Communications for Ubiquitous IoT: Applications, Trends and Challenges. submitted to ***IEEE Network***

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ISAC Gains

Coordination Gain

Y. Cui, et al. Integrating Sensing and Communications for Ubiquitous IoT: Applications, Trends and Challenges. submitted to ***IEEE Network***.

Sensing-Assisted Comms

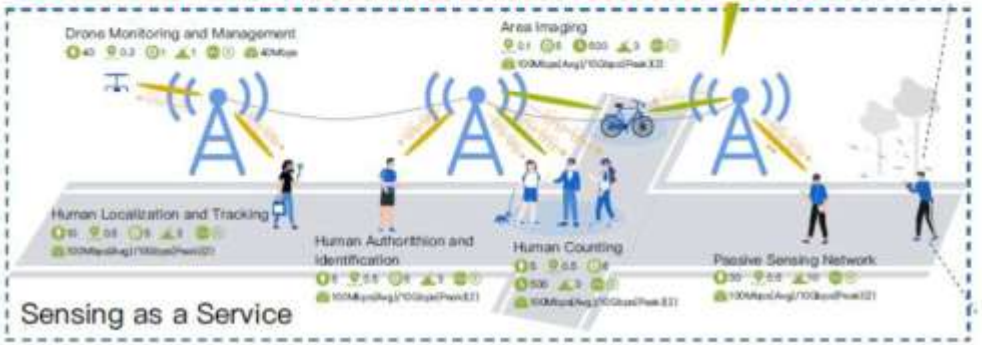
Application Scenario:

- V2X

Key Techniques:

- Sensing-Assisted Resource Management
- Sensing-Assisted Platooning
- ...

Comms-assisted Sensing (Sensing as a Service)



Application Scenario:

- Perceptive Cellular Network

Key Techniques:

- Cooperative Sensing
- Beyond LoS Sensing
- Networked Sensing Performance Analysis
- ...

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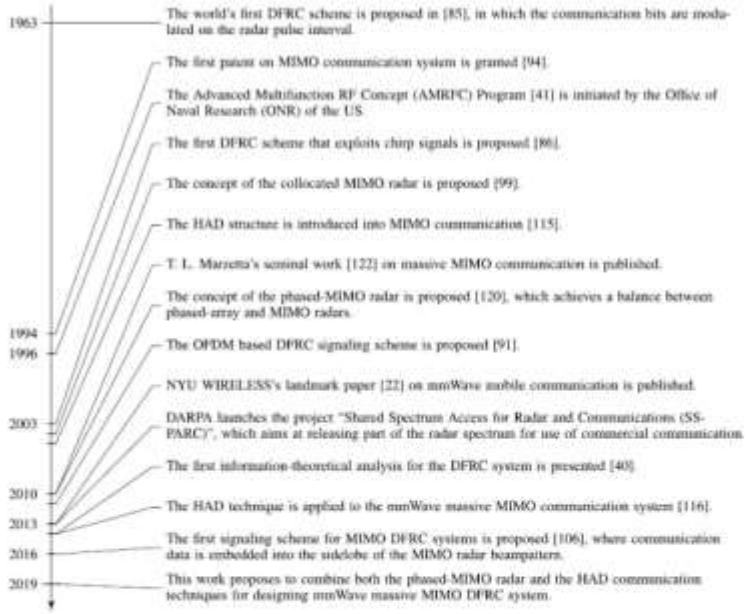
Research Progress

- 1963 - 2013, 1st 100 IEEE papers on ISAC
- 2013 - 2017, 2nd 100 IEEE papers on ISAC
- 2017 - 2019, 3rd 100 IEEE papers on ISAC
- 2019 - 2020, 4th 100 IEEE papers on ISAC

ISAC research has been tremendously accelerated,

and, worldwide!



We witnessed a significant research interest in

- SPS
- AESS
- ComSoc

(1) IEEE JSAC Special Issue on "Integrated Sensing and Communication"
(2) IEEE JSTSP Special Issue on "Joint Communication and Radar Sensing for Emerging Applications"
(3) IEEE SPM Special Issue on "Radar Systems for Modern Civilian and Commercial Applications"
(4) IEEE JSTSP Special Issue on "Machine Learning for Cognition in Radio Communications and Radar"
(5) IEEE TAES Special Section on "Spectrum Sharing"
(6) Digital Signal Processing Special Issue on "Joint Radar-Communication"
(7) Digital Signal Processing Special Issue on "Co-operation and Joint Design of Communications and Radar Systems in a Crowded Spectrum"

Several papers published in

- CS
- ITSoc
- ITSS
- VTS

We would like to encourage ISAC activities in these societies.

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Industrial Efforts

B5G/6G

Huawei identifies ISAC as one of the 3 major scenarios in their vision of 5.5G

Ericsson 6G White Paper

Extreme performance and coverage

The future wireless access solution must provide truly extreme performance in a multitude of dimensions and in all relevant scenarios in order to enable future in-demand services at acceptable costs. This includes, for example, extreme data rates and latency performance when so required, extreme system capacity to be able to deliver the services to a massive number of users, and truly global coverage of the wireless access. The key to enabling dense deployments with extreme system capacity in a cost-effective way is to introduce packet fronthaul and new wireless transport technologies, such as relay and mesh networking, free-space optics, and further integrated access and backhaul.

Enablers for sensing positioning

Cellular networks are widely deployed to support wireless connectivity, where the propagation of the radio waves depends on many factors in the environment. Using data analytics on the radio signals received, it is possible to sense and estimate quantities impacting the radio propagation. (For example, the received signal quality in microwave links is affected by the presence of rainfall — information that is valuable for weather forecasting.) Active sensing, where radio signals are transmitted solely for the purpose of sensing, is also possible, allowing a base station to act as a radar system in addition to serving the communication needs of an area. This can be used to build and continuously update a map of surrounding areas to, for example, detect changes in road traffic or set off alarms if a person enters a restricted area in a factory hall. Reusing cellular systems for sensing can provide more cost-efficient sensing compared to the dedicated systems specifically deployed for sensing only.

NTT DOCOMO 6G White Paper

3.6 Extreme-massive connectivity & sensing

Wearable user devices and an extremely large number of IoT devices that collect images and sensing information of the real world are expected to spread further in the 6G era, and an extremely large number of connections that are approximately 10 to(= 10 million devices per square km) more than the 5G requirements are expected. In addition to the approach of connecting a large number of IoT devices to a network, the wireless communication network itself is expected to evolve to have functions for sensing the real world such as positioning and object detection using radio waves. In particular, the study of positioning has already advanced for 5G evolution, and it is expected that ultra-high-precise positioning with the error of several centimeters or less can be achieved in some environments.

Figure 3-7 Extreme-massive connectivity & sensing

Nokia Bell Labs propose a unified mmWave system for combined communication and sensing

ZTE and China Unicom : The integrated communication and sensing is the potential key technology of 6G

ZTE and China Unicom have recently signed a strategic cooperation agreement on 6G.

As long-term partners, ZTE and China Unicom will carry out joint collaboration on 6G technological innovation and standards while actively promoting the in-depth integration of 6G technology with satellite networks, the Internet of Things (IoT), the Internet of Vehicles, and the industrial IoT.

The two companies will conduct joint research on the potential key technologies of 6G, including 'three dimensional' connectivity, Terahertz communication, and the integrated communication and sensing. ZTE and China Unicom will also verify the feasibility of these technologies through both the verification tests and the prototyping trials to achieve the 6G network performance targets, such as the peak data rate of 1 Tbps, the user data rate of 20 Gbps, the volume traffic capacity of 100Gbps/m3.

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Industrial Efforts

IEEE 802.11bf - WLAN Sensing

-- The first international standard for sensing

Definition

- **WLAN sensing is the use of received WLAN signals to detect feature(s) of an intended target(s) in a given environment.**[1]
  - Features = Range, velocity, angular, motion, presence or proximity, gesture, etc.
  - Target = Object, human, animal, etc.
  - Environment = Room, house, car, enterprise, etc.

Use cases [2]

1. Smart home

2. Presence and proximity detection (Home/Enterprise/Vehicle)

3. Gesture recognition

4. Gaming control

5. Liveness

6. Location in store

7. Audio with user tracking (Follow-me sound)

8. Sneeze sensing

KPI

Coverage		Resolution			Accuracy			Other performance			
Range (m)	Field of view (°)	Range (m)	Angle (°)	Velocity (m/s)	Range (m)	Angle (°)	Velocity (m/s)	Probability of detection (%)	Latency (ms)	Refresh rate (Hz)	No. of simultaneous targets

[1] https://www.ieee802.org/11/Reports/tgbf_update.htm
[2] https://mentor.ieee.org/802.11/dcn/20/11-20-1712-02-00bf-wifi-sensing-use-cases.xlsx

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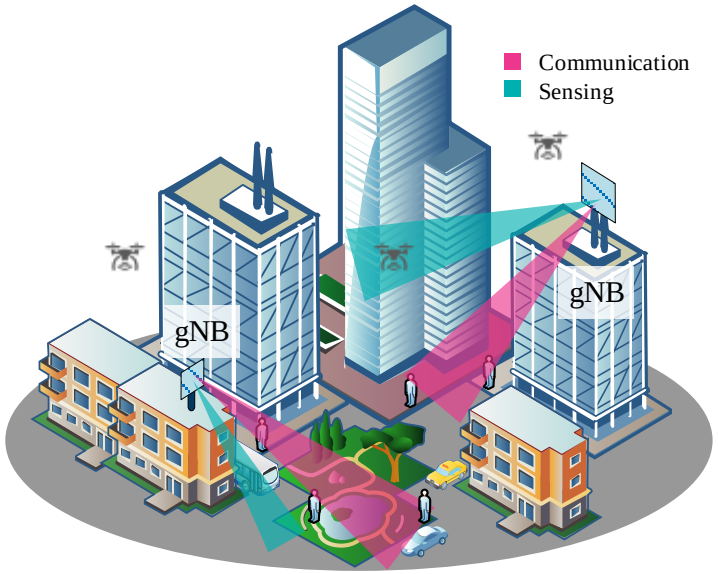
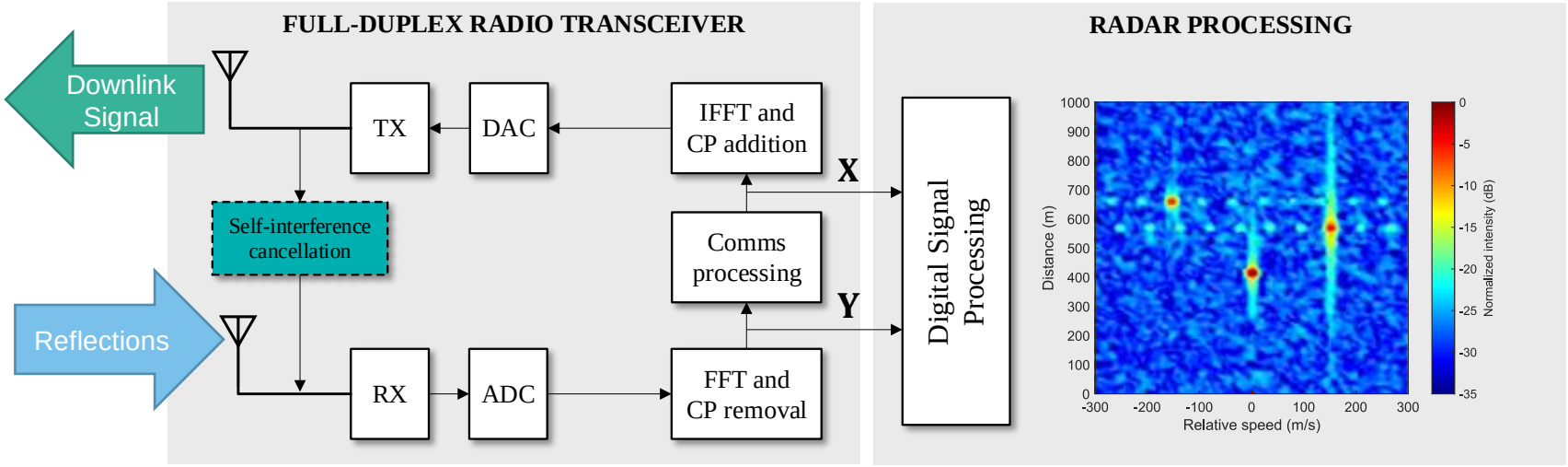
Full-Duplex Base Station for Sensing

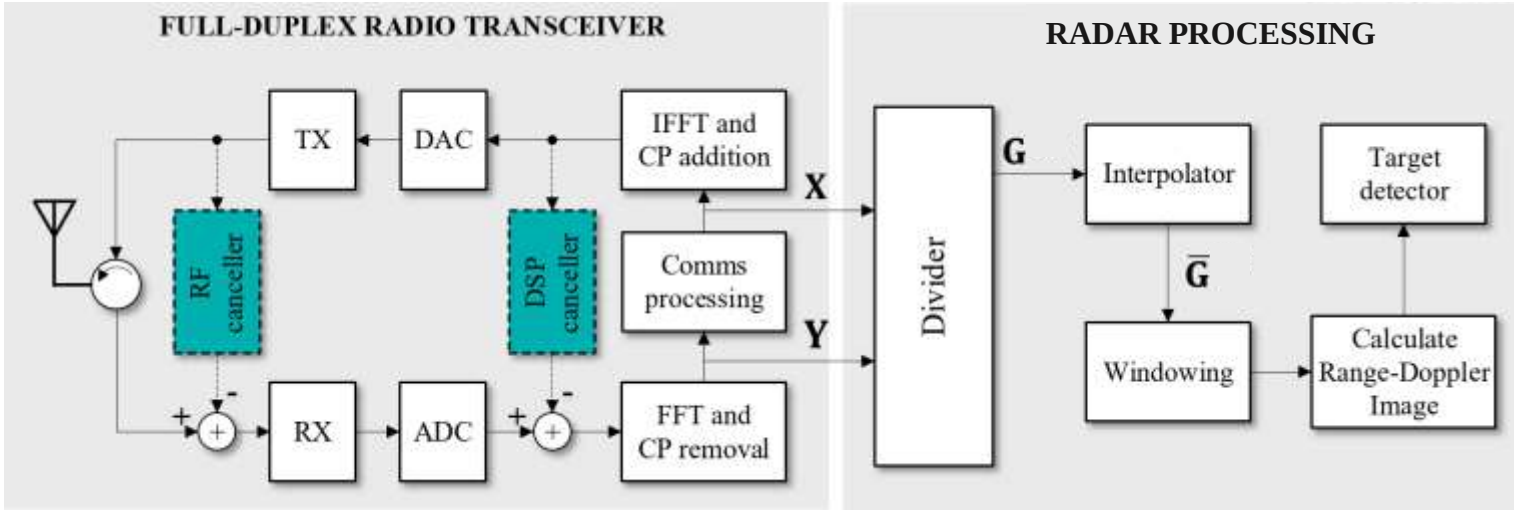




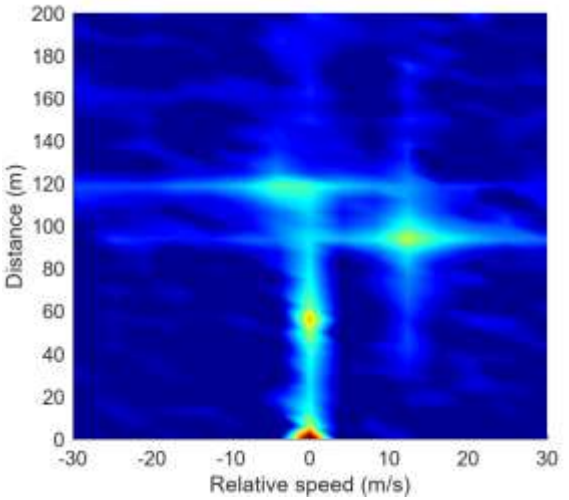
Autonomous vehicles networks
Unmanned aerial vehicle (UAV)
Building analytics
Digital health monitoring
Search and tracking of potential users
Search potential reflectors in case of NLOS

- Using **NR Base Station** (gNB) also as **monostatic radar**, while transmitting the standard **downlink signal**
- **The receiver must be operating simultaneously while transmitting**
  - no targets within tens of kilometers could be detected otherwise

Self-interference in Full-Duplex ISAC



RADAR IMAGE WITH LOW SI



- **The receiver must be operating simultaneously while transmitting**
  - implementation challenge: sufficient transmitter–receiver isolation
- Essentially an **in-band full-duplex radio**:
  - direct TX-RX leakage can be interpreted as a strong static target at a very short distance
  - powerful SI component can largely mask the true echoes and targets
    - particularly those that are static, but also other slowly moving targets
  - efficient isolation/suppression mechanisms needed, though not as high as in two-way communications

RADAR IMAGE WITH HIGH SI