UTS:GBDTC Global Big Data Technologies Centre

JOINT WIRELESS COMMUNICATIONS AND SENSING (JCAS)

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Background

Wireless communication and sensing (C&S) systems have been advancing independently for decades. However, these two systems share many commonalities in terms of signal processing algorithms, devices and, to a certain extent, system architecture. They can also potentially share the spectrum. These have recently motivated significant research interest in the coexistence, cooperation, and joint design (or co-design) of the two systems.

The joint design of co-located C&S systems considers the integration of these two functions in one system, using a single transmitted signal. Recently, we are witnessing a rapidly increasing interest from both academia and industry on C&S system, thanks to its great potentials in emerging defence applications and more recently in a range of Smart-Cities applications such as intelligent vehicular networks and more general, the Internet of Things (IoT). Integrating the two systems into one can significantly save infrastructure costs, achieve reduced device size and power consumption, lead to more efficient radio spectrum usage, and significantly expand the capabilities and performance of both communication and wireless sensing.

Based on the design priorities and the underlying signal and systems, current joint communications and sensing (JCAS) systems can be classified into the following three categories [1, 2]:

- *Communication-centric design:* In this class, radar sensing is an add-on to a communication system, where the design priority is on communications. The aim of such design is to exploit communication waveform to extract sensing information from the scattered signals. Enhancements to hardware and algorithms are required to support wireless sensing. Possible enhancements to communication standards may be introduced to enable better reuse of the communication waveform for wireless sensing purposes. In this design, the communication performance can be largely unaffected, however, the sensing performance may be scenario-dependent;
- *Sensor-centric design:* Conversely, such approaches aim at modulating or introducing information signalling in known sensor waveforms. Since the sensor signalling remains largely unaltered, the resulting approaches benefit from a near optimal sensing performance. The main drawback of such approaches is the limited data rates achieved. Some performance loss may be tolerated by the sensing system to enable better communication functionality; and
- *Joint design and optimisation:* This class encompasses systems that are jointly designed from the start, to offer a tunable trade-off between C&S performance. Such systems may not be limited by any of the existing communication or sensor standards. This is potentially one of the hallmarks of 6G.

Owing to the significant differences between traditional C&S systems, the design problems in these three categories are quite different. In the first two categories, the design and research focus is typically on how to realise the secondary sensing/communications function based on the signal formats of the primary communications/sensing system, in a way that does not significantly affect the primary system. The last category considers the joint design and optimisation of the signal waveform, system, and network architecture, with a flexible trade-off achievable between C&S.

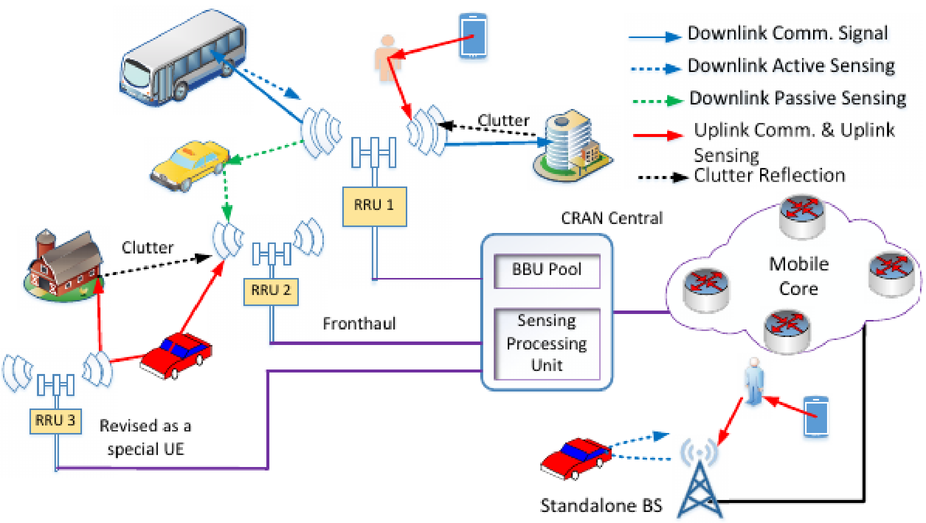
The UTS Radio Sensing and Pattern Analysis (RaSPA) laboratory in GBDTC specialises in joint communications and sensing, leveraging our expertise on wireless signal processing and machine learning. The lab focuses on two major research areas: (1) Building ubiquitous radio sensing infrastructure using JCAS technologies. In one project, we are studying how to enhance mobile networks (such as 5G) with simultaneous sensing functionalities by sharing the transmitted signals and most of the system modules; and (2) Harvesting information from radio signals by combining wireless signal processing, pattern analysis and machine learning techniques. The aim is to extract information from the received radio signals for detecting, tracking, and identifying objects, activities and events in the surrounding environment. In one project, we are developing an integrated solution for Health, Safety and Security using WiFi Sensing; and in another project, we are developing integrated miniature Video and Radio Sensors for 3D sensing and object tracking. We have done extensive research in the three mentioned categories of JCAS technologies, with numerous publications in top-tier international journals.

This white paper provides a brief introduction on our work in this area. More details are available from the websites [Andrew Zhang's Google Site] and [Radio Sensing and Pattern Analysis Lab (RASPA)].

Perceptive Mobile Networks

JCAS has the potential of integrating wireless sensing into large-scale mobile networks, creating what we call Perceptive Mobile Networks (PMNs) [1, 3]. By "perceptive", we mean the added capability of perceiving the environment via wireless vision and inference to existing mobile networks. Such perception can go far beyond localisation and tracking, enabling the mobile network to "see" and understand the environment. Evolving from the current mobile networks, the PMN is expected to serve as a ubiquitous wireless-sensing network, whilst providing uncompromising mobile communication services. It can be built on top of the existing mobile network infrastructure, without requiring significant changes on network structure and equipment. With a large coverage, the integrated communication and sensing capabilities are expected to enable many new applications for which current sensing solutions are either impractical or too costly.

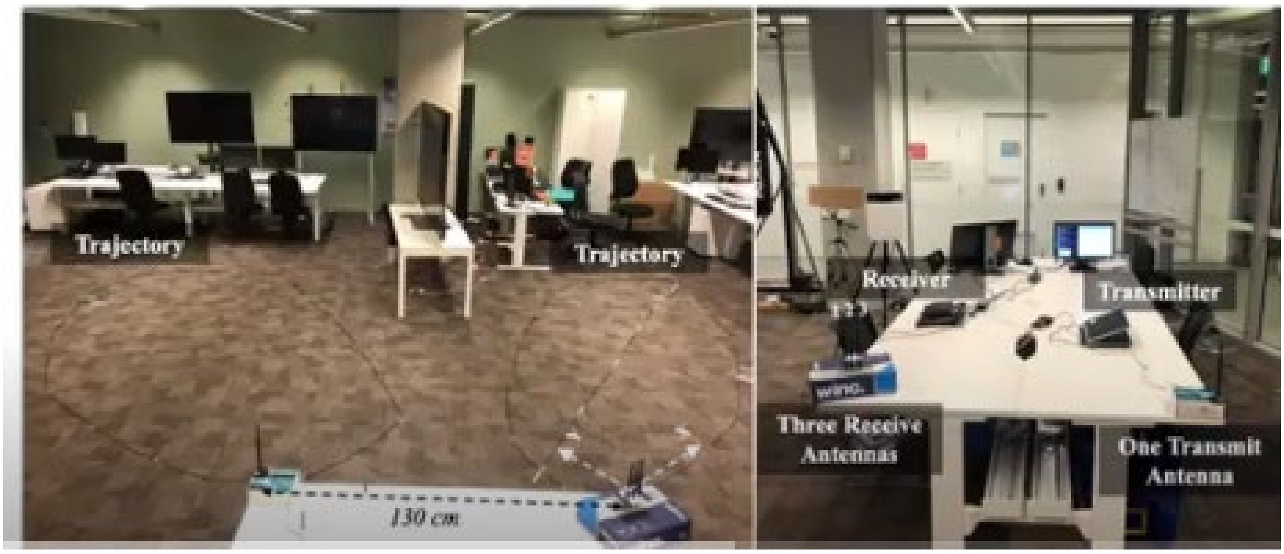
We are one of the pioneering research teams in realizing JCAS in mobile networks. We initiated the concept of PMN and systematically studied its network structure, realisation, and key technical solutions [3]. We have conducted extensive research on joint waveform optimization, clutter suppression, and sensing parameter estimation for PMN, and published more than 10 journal papers. We have also delivered several tutorials in leading international conferences, including IEEE ICC 2021 and IEEE WCNC 2021. We have also received significant research funding from both government and industry to tackle critical challenges in realising PMN.



Wireless Sensing - Harvesting Information from Wireless Signals

Just like the optical camera which receives optical signals reflected from objects and images the environment, received wireless signals also contain the environmental information and can be used to generate a radio image of the environment. The aim of the research is to extract maximum amount of information from either the estimated sensing parameters or the radio images directly, for detecting, tracking, and identifying objects, activities and events in the environment covered by wireless signals.

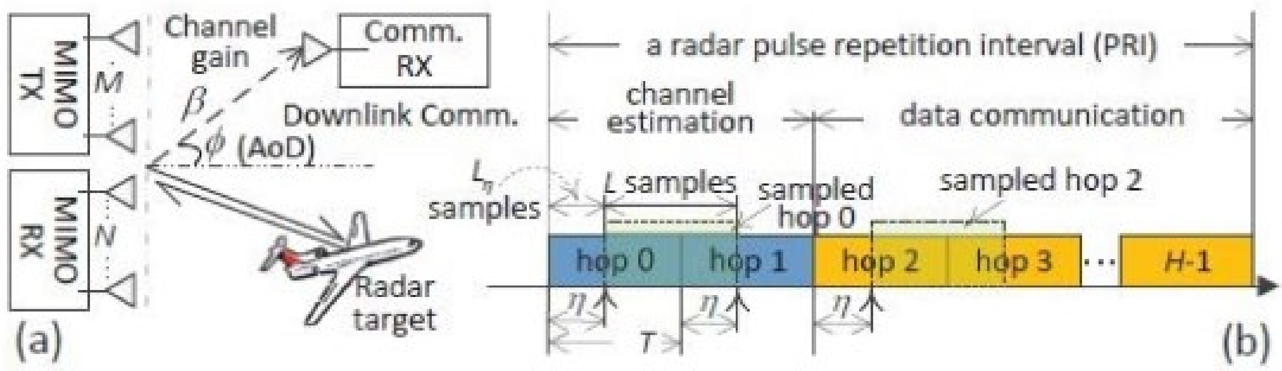
In one industrial project, we are developing an integrated solution for health, safety and entertainment based on WiFi sensing. We have developed advanced signal processing and machine learning techniques for reliable and robust WiFi-based behaviour recognition and object tracking. One important application of behaviour recognition is fall detection for the elderly; and object tracking can be used for localisation, movement surveillance, and security. WiFi based fall-detection and tracking enable device-free and low-cost sensing, and has great potential for home-based applications. Based on the developed innovative signal processing and machine learning techniques, we have now developed two real-time demonstrators that can do environment-robust human behaviour recognition and moving objects localisation and tracking. The recorded videos are available from https://sites.google.com/view/andrewzhang/, together with the technical papers [4, 5].



(Long-range) Radar with Integrated Communications

Integrating communications into powerful radar infrastructure can provide almost unparalleled long-range communication links that current systems, such as VHF radio and satellite, can hardly provide. The integration can be realised via embedding information to conventional radar waveforms, such as pulsed and FMCW radar signals, or more advanced ones such as frequency hopping (FH) and frequency agile radars.

FH-MIMO JCAS enables communication symbol rate to exceed radar pulse repetition frequency and hence high-speed communications. However, it requires accurate estimations of timing offset and channel parameters. The estimations, however, are challenging due to unknown, fast-changing hopping frequencies and the multiplicative coupling between timing offset and channel parameters. We have developed novel signal processing techniques for communication receivers in FH-MIMO JCAS systems [6, 7].



FH-MIMO JCAS also enables secure communications in the presence of both jammers and eavesdroppers. For example, consider a scenario where radar, besides detecting targets, also performs downlink communication through a line-of-sight (LoS) link with a legitimate user named Bob. Meanwhile, there is an unintended user Eve who eavesdrops on the communication between the radar and Bob. We have developed novel baseband waveform processing highlighted on the left of the above figure to ensure a secure communication by scrambling constellations omni-directionally [8]. The proposed demodulation scheme, as highlighted on the right, can recover constellations by Bob to achieve high-speed data communications.

References

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