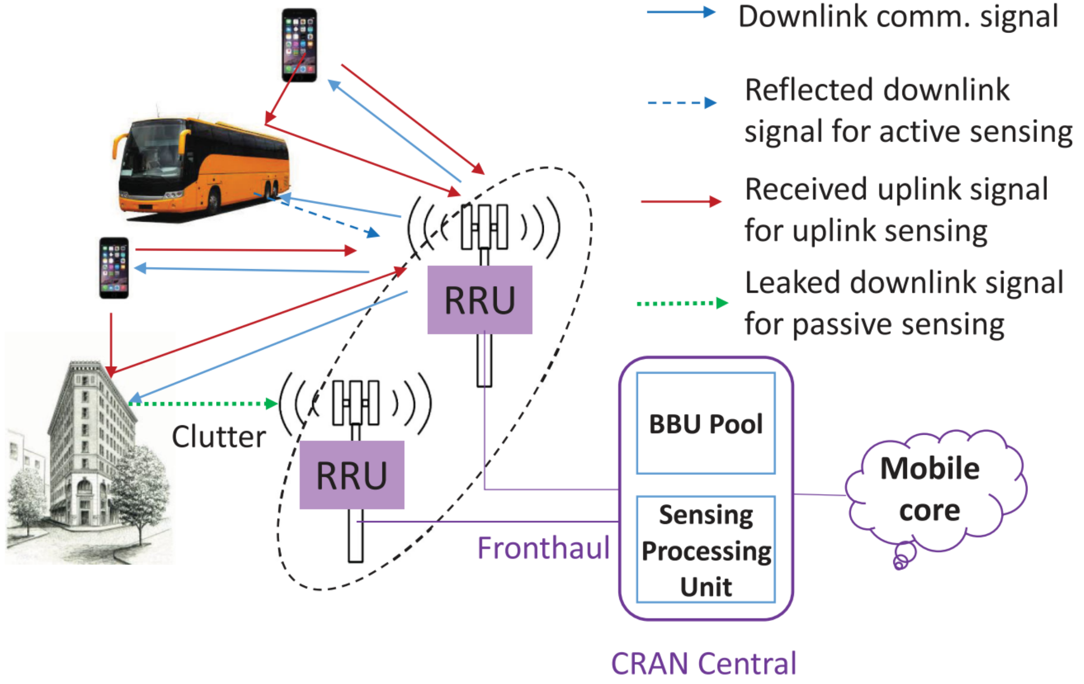
Framework for a Perceptive Mobile Network Using Joint Communication and Radar Sensing



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Framework for a Perceptive Mobile Network Using Joint Communication and Radar Sensing

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Abstract

Document Sections

I. Introduction

II. System Platform for the Perceptive Mobile Network

III. Formulation of Sensing Parameter Estimation

IV. Direct Estimation of Sensing Parameters

V. Indirect Estimation Using Signal Stripping

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Authors

Abstract:
In this paper, we develop a framework for a novel perceptive mobile/cellular network that integrates radar sensing function into the mobile communication network. We propose a unified system platform that enables downlink and uplink sensing, sharing the same transmitted signals with communications. We aim to tackle the fundamental sensing parameter estimation problem in perceptive mobile networks, by addressing two key challenges associated with sophisticated mobile signals and rich multipath in mobile networks. To extract sensing parameters from orthogonal frequency division multiple access and spatial division multiple access communication signals, we propose two approaches to formulate it to problems that can be solved by compressive sensing techniques. Most sensing algorithms have limits on the number of multipath signals for their inputs. To reduce the multipath signals, as well as removing unwanted clutter signals, we propose a background subtraction method based on simple recursive computation, and provide a closed-form expression for performance characterization. The effectiveness of these methods is validated in simulations.

Published in: IEEE Transactions on Aerospace and Electronic Systems (Volume: 56 , Issue: 3, June 2020)

Page(s): 1926 - 1941

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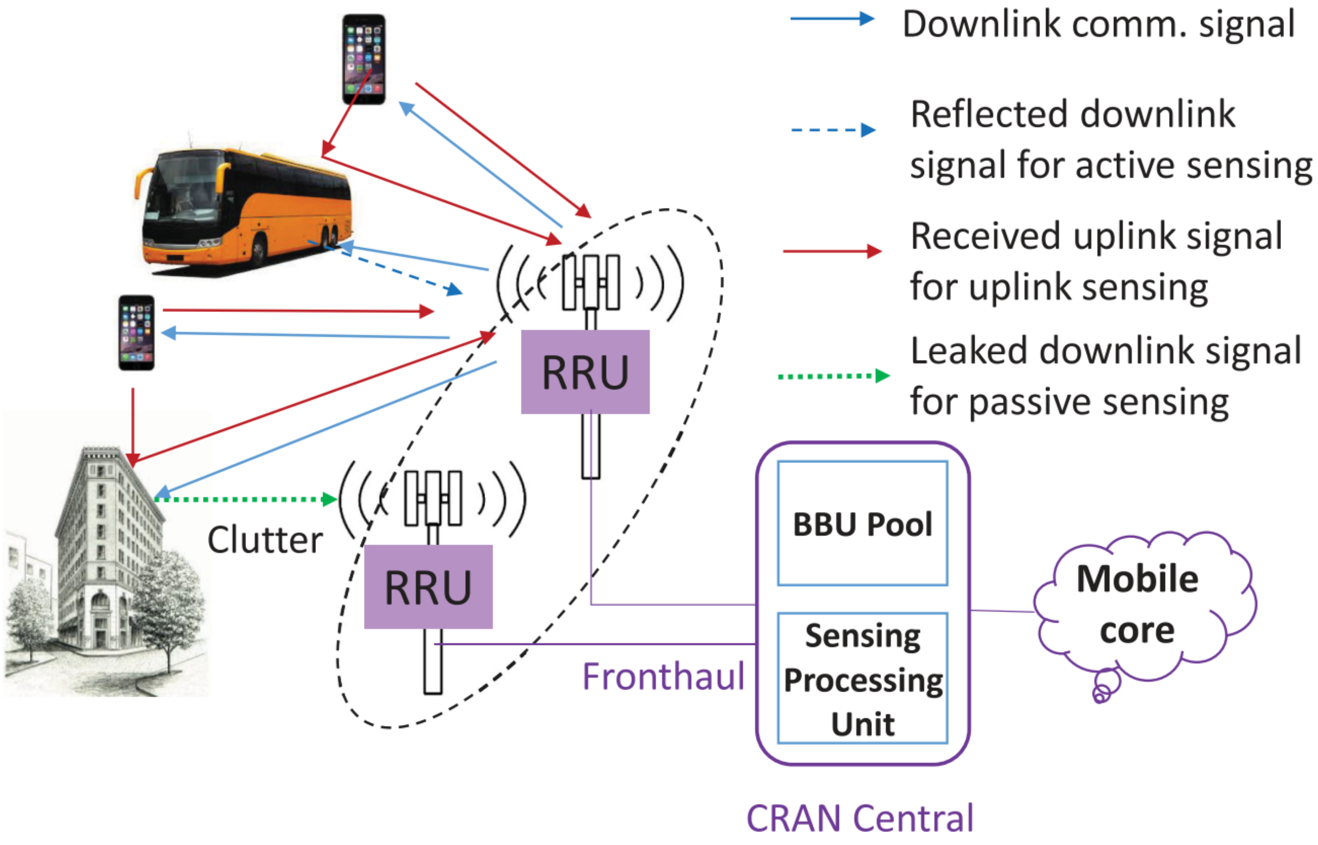
[1] M. L. Rahman, J. A. Zhang, X. Huang, Y. J. Guo and R. W. Heath, "Framework for a Perceptive Mobile Network Using Joint Communication and Radar Sensing," in *IEEE Transactions on Aerospace and Electronic Systems*, vol. 56, no. 3, pp. 1926-1941, June 2020.

介绍框架

- 背景/简要介绍
- 研究方法
- 实验结果
- 总结

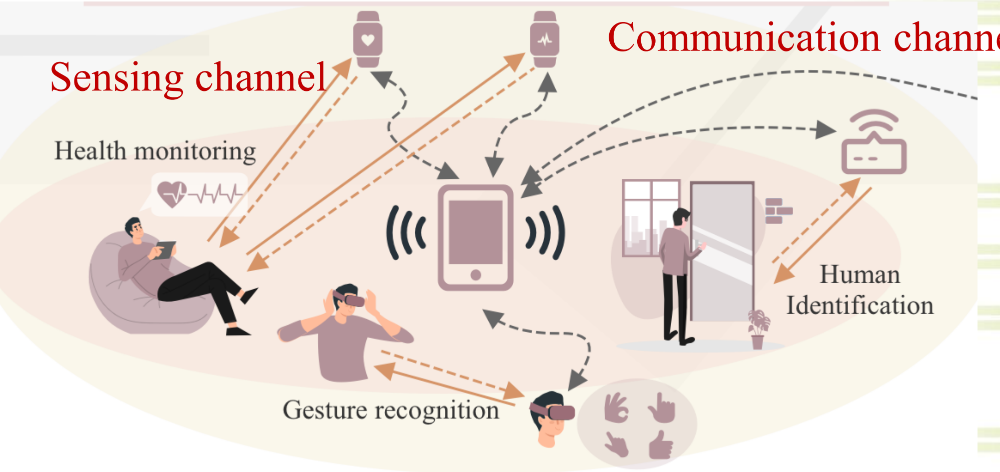


基于通感一体化的移动网络框架

- 什么是通感一体化?
  - ISAC系统通过共用同一个硬件平台与无线资源来同时实现无线通信与感知的功能。

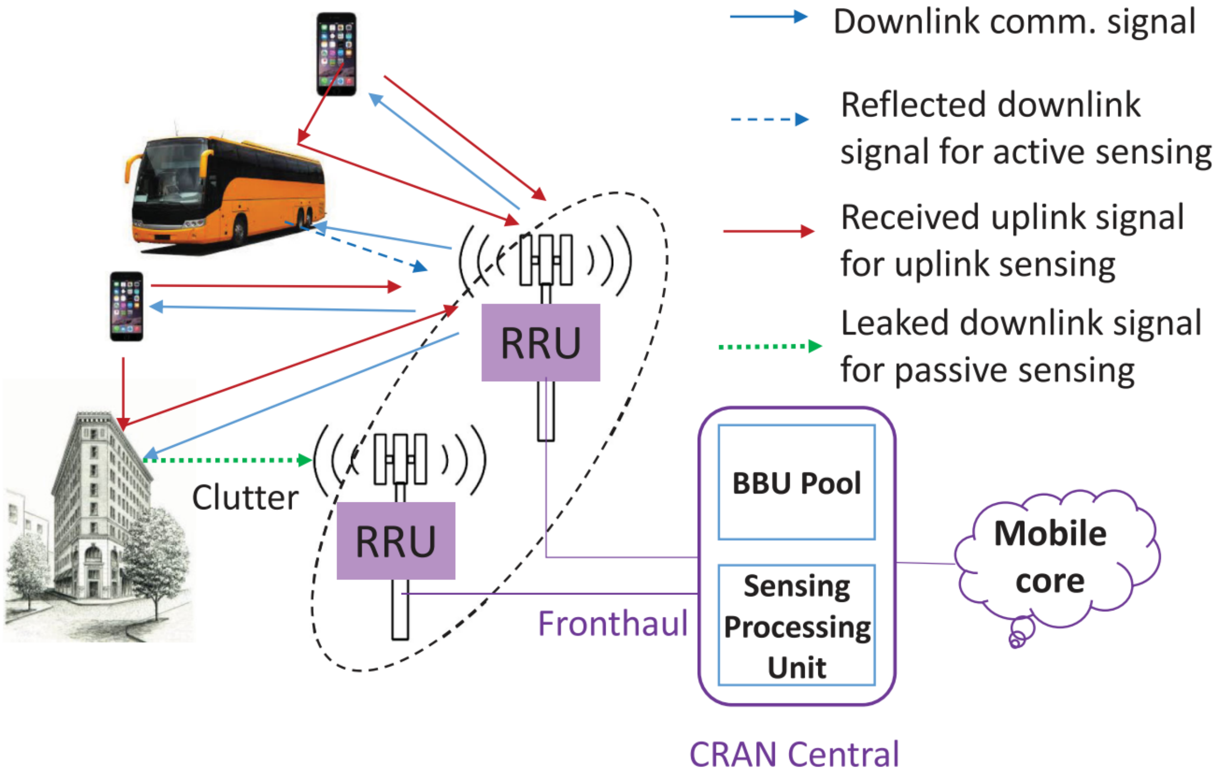
→ 为通信网络赋予新的感知功能
→ 感知信息可以提升通信功能
  - 如何从通信信号中恢复出感知信息?

- ISAC有什么应用场景?
  - 车联网 / 无人机通信网络 /智能家居
  - 定位 (localization) / 电磁特性感知 (EM property)



[2] J. Wang, N. Varshney, C. Gentile, S. Blandino, J. Chuang and N. Golmie, "Integrated Sensing and Communication: Enabling Techniques, Applications, Tools and Data Sets, Standardization, and Future Directions," in IEEE Internet of Things Journal, vol. 9, no. 23, pp. 23416-23440, 1 Dec.1, 2022.

基于通感一体化的移动网络框架



- ## 总体性能
  - 基于**OFDMA**，**多用户MIMO**通信系统
  - 基站以**全双工**的模式同时作为**收发端**
  - 每个基站会利用包括自己在内的**所有基站**发射信号的回波信号进行感知
  - 可以根据**接收信号**或是**CSI**来进行感知信息的估计
  - 估计环境内物体的**时延**（距离），**多普勒频移**（速度），**角度**
  - 可以减少环境中杂物对感知的影响

基于通感一体化的移动网络框架

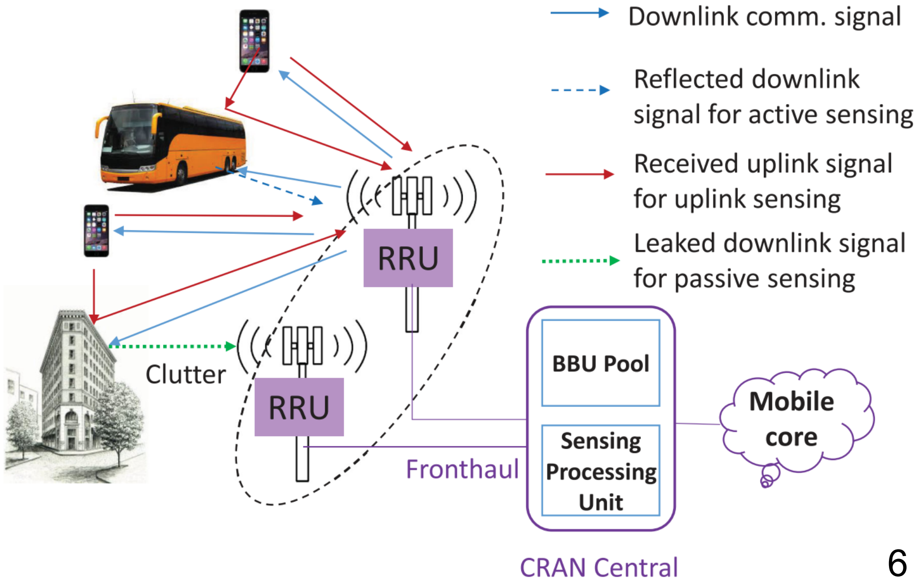
- 接收信号模型

$$\mathbf{y}_{n,t} = \sum_{q=1}^{Q}\sum_{\ell=1}^{L_q} b_{q,\ell} e^{-j2\pi n \tau_{q,\ell} f_0} e^{j2\pi t f_{D,q,\ell} T_s} .$$
$$\mathbf{a}(M, \phi_{q,\ell}) \mathbf{a}^T (M, \theta_{q,\ell}) \mathbf{x}_{q,n,t} + \mathbf{z}_{n,t} \qquad (4)$$

导向向量(steering vector)

- τ_l: 时延(距离)
- $f_{D,l}$: 多普勒频移(速度)
- ϕ_l, θ_l: 到达角，发射角

- 感知信息估计
  - 一维在网压缩感知 (1-D on grid compressive sensing)
  - 环境杂物消除 (clutter reduction)



基于通感一体化的移动网络框架

- 一维在网压缩感知算法 (1-D on-grid CS)

$$\mathbf{Y}_t \triangleq (\mathbf{y}_{1,t}, \ldots, \mathbf{y}_{n,t}, \ldots)^T = \mathbf{W}\mathbf{V}\mathbf{A}^T(M, \boldsymbol{\phi}) \qquad (13)$$

Fast marginalized block sparse Bayesian learning algorithm (BSBL-FM)

  - $\mathbf{W}$是已知的(sensing matrix), $\mathbf{V}\mathbf{A}^T$是块稀疏的 (block sparse)
  - 时延→带宽；角度→天线数；多普勒频移→信号时长
  - OFDM系统的带宽较大，因此利用时延估计的高精准度，辅助另外两个参数的估计

- 杂物消除 (clutter reduction)

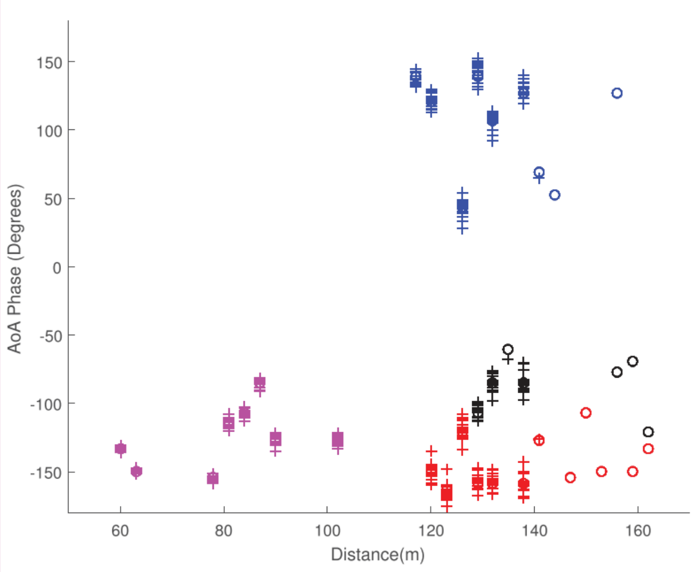
去除环境散射信号

  - 环境物体是静止的，多普勒频移为0
  - 将杂物带来的多径从CSI/接收信号中剔除

基于通感一体化的移动网络框架

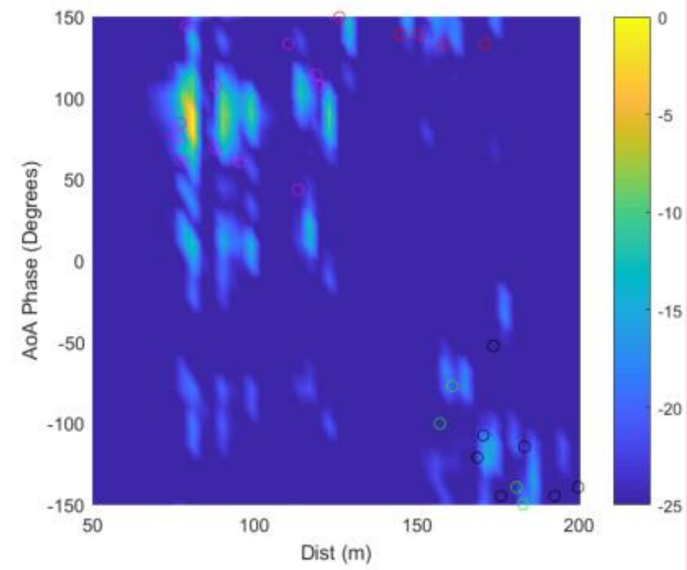
- 实验结果

1



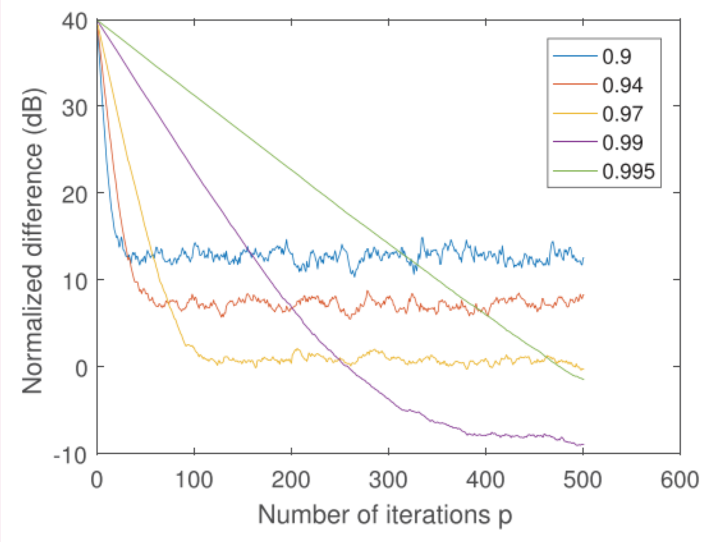
- 距离越近→路径损耗越小→SNR高→估计准

2



- DFT方法（基准方法）
- 数据量太少，效果很差

3



- 对clutter带来的multipath估计的精准度很高

基于通感一体化的移动网络框架

- 总结
  - 无线领域比较早期的通感一体化通信网络框架的研究
  - 指出了ISAC系统比较关键的目标（利用SV信道模型估计与感知有关的参数），以及一些必要的硬件端拓展（全双工）

An Overview of Signal Processing Techniques for Joint Communication and Radar Sensing IF 13.7 SCIE JCR Q1 计算机科学2区 EI 2021 Cited 777

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IEEE Journal of Selected Topics in Signal Processing

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Cited by: Papers (777)

TABLE II
COMPARISON OF SENSING PARAMETER ESTIMATION ALGORITHMS

Algorithms	Advantages	Main limitations
Periodogram such as 2D-DFT (typically based on the outputs of matched filtering)	Traditional technique. Simple and easy to implement. May be used as the starting point for other algorithms.	• Low resolution; • Generally require a full set of continuous samples in each domain, which may not always be satisfied.
Maximal Likelihood Estimation [35]	Statistically optimal formulation; Particularly suitable for low-dimension signals.	Typically require searching to find the solutions and hence complexity is high; Complexity also increases with signal dimensions exponentially.
Subspace methods such as ESPRIT and MUSIC [40], [41]	• Separate signal and noise subspaces and hence is resilient to noise; • ESPRIT can achieve very high resolution and can do off-grid estimation; • MUSIC can flexibly work with non-continuous samples.	• ESPRIT requires a large segment of consecutive samples, which may not always be satisfied; • Resolution of MUSIC depends on searching granularity; • High complexity associated with singular value decomposition.
Compressive sensing (On-grid) [24], [38]	• Flexible and does not require consecutive samples; • Various recovery algorithms available, allowing good tradeoff between complexity and performance; • Different dimensions of formulation can be used, adapting to sensing requirements and conditions; • Dense dictionaries can be used to improve resolution.	Although it may even work well for estimating a small amount of off-grid parameters, performance can degrade significantly when the number of parameters to be estimated is large.
Compressive Sensing (Off-grid) such as atomic norm minimization [38]	Have all the advantages of on-grid CS algorithms. Capable of estimating off-grid values.	Limitation in real time operation due to very high complexity. Still require sufficient separation between parameter values.
Tensor based algorithms [37]	High-dimension formulation and estimation are made easy. Reduce computational complexity and provide capability in resolving multipath with repeated parameter values.	Need to be combined with other algorithms such as ESPRIT and CS, thus facing their inherent problems.