Collaborative Interference Cancellation for Radio Astronomy

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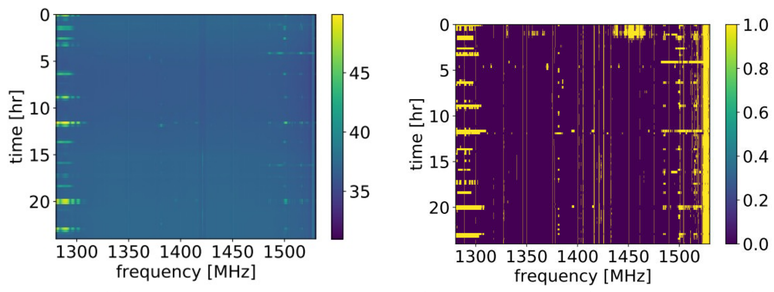
Motivation

- Necessary to use spectrum beyond current allocation for astronomical observations
  - Redshifting of signals • Wideband radio astronomy (continuum, spectroscopic, and pulsar)
- Radio Frequency Interference (RFI) is unavoidable in congested spectrum allocation
- RFI removal is done by spatial filtering or excision
  - Significant data loss (40% in L Band) • Reduces sensitivity of telescope • Loss of astronomical signal



(a) Before excision

(b) After excision (H1 line removed)

*It is critical to **cancel RFI** at the telescope through a **measured interference metric** at the communication network and **bidirectional collaboration** to facilitate coexistence between the xG networks and radio telescopes.*

Project Summary

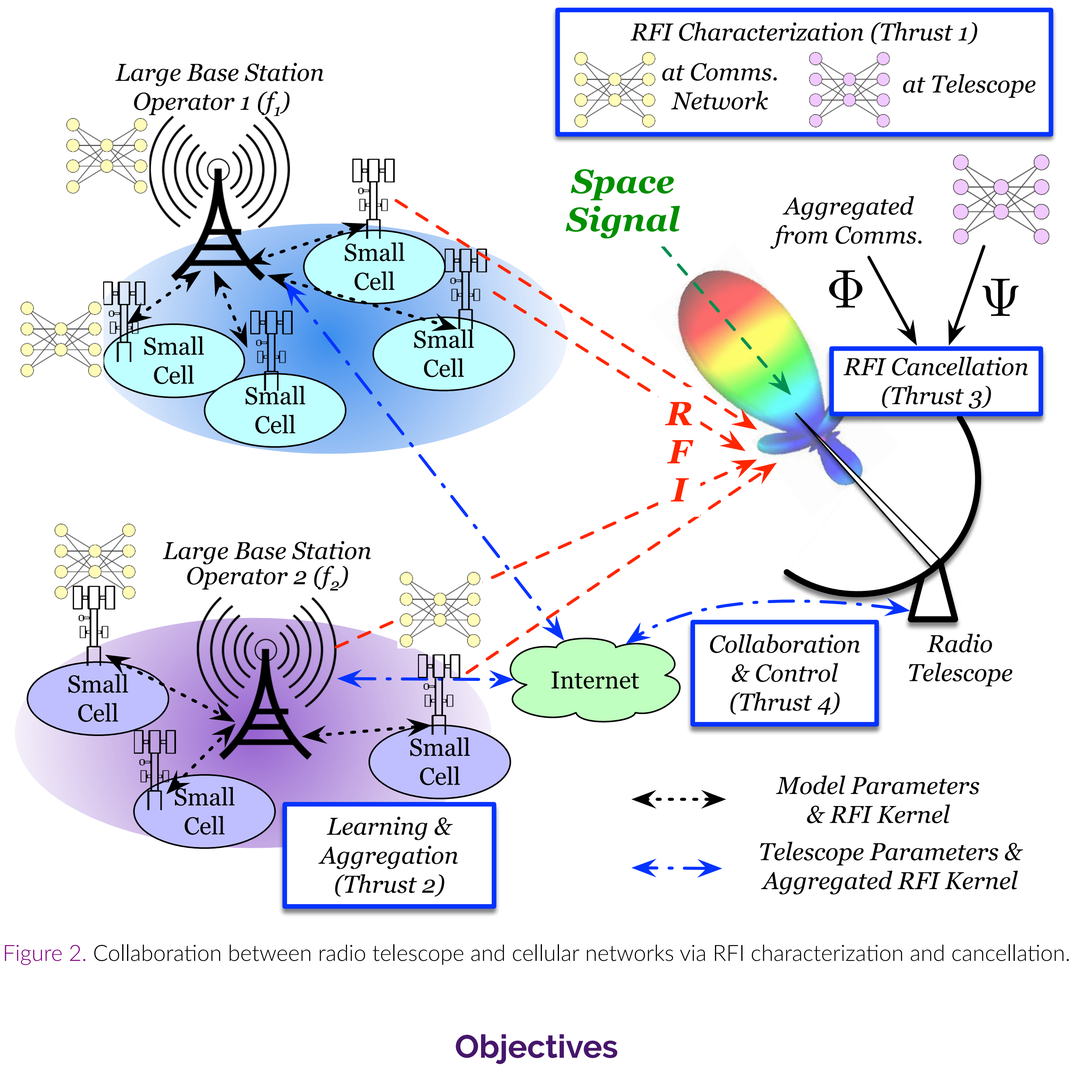
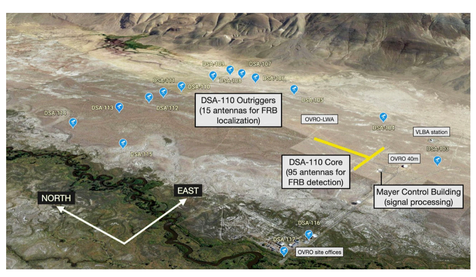


Figure 2. Collaboration between radio telescope and cellular networks via RFI characterization and cancellation.

Objectives

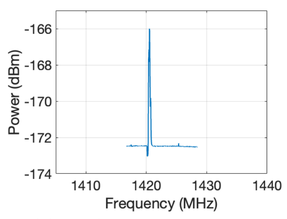
- *Characterize RFI* generated by communication networks with deep neural networks.
- *Distributed/federated learning* of RFI and aggregate local characterizations.
- *Cancel* incident RFI at the telescope using the aggregated interference metric.
- *Actively Collaborate* with bidirectional exchange of control parameters in real-time.
- *Validate* with experiments at Owens Valley Radio Observatory with DSA-110.

DSA-110 at Owens Valley Radio Observatory

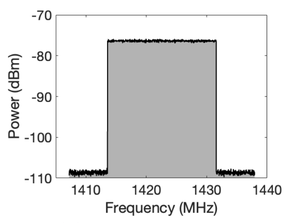


Total 110 dishes, 95 of them are in a Tee-shaped core for searching FRB, with 15 outriggers. Dish diameter - 4.65 m; Frequency band 1280 – 1530 MHz.

Temporal and Spectral Characteristics



(a) H1 line @ 1420 MHz



(b) LTE signal at BS

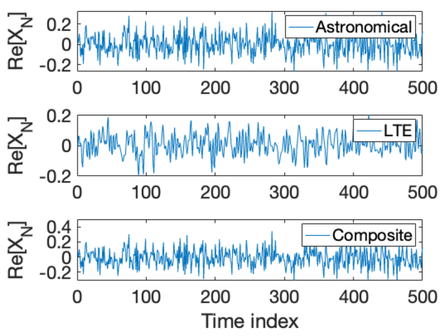


Figure 5. Signals in time domain

Composite Signal Model:

$$x_{f_c}[n] = x_A[n] + x_N[n] + x_R[n]$$

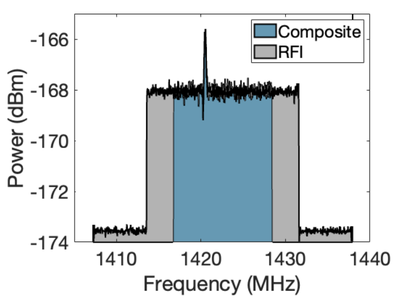
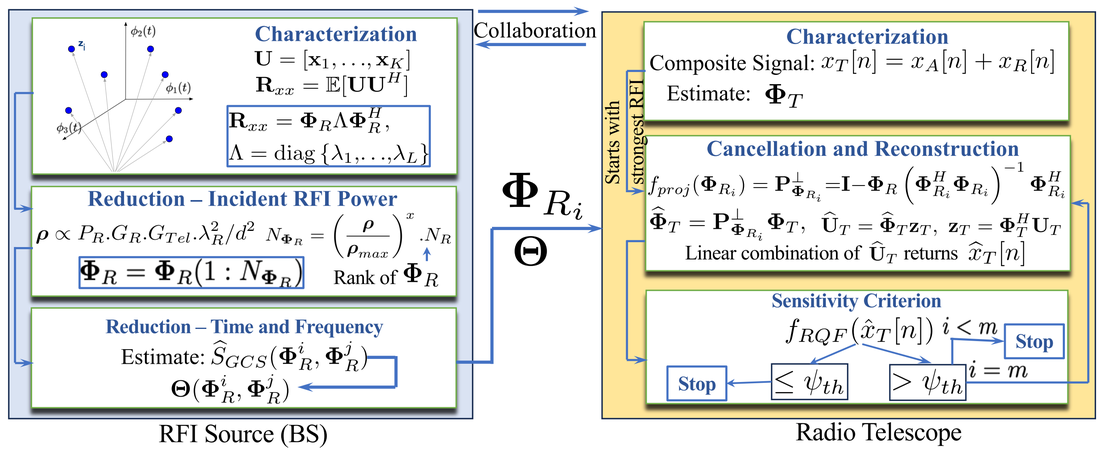


Figure 6. Composite Signal Spectrum

Low Overhead Multi-Source RFI Cancellation [4]

- RFI characterization based on Karhunen Lòeve Transform (KLT) [1].
- Overhead reduction based on incident power in time and frequency.
- Signal recovery using inverse KLT and successive cancellation.



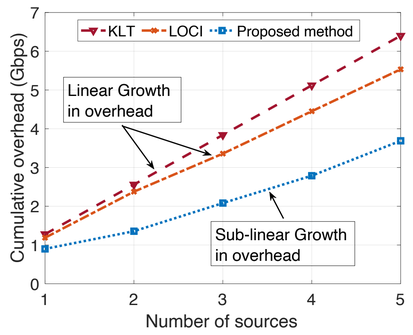


Figure 7. Overhead Growth sublinear.

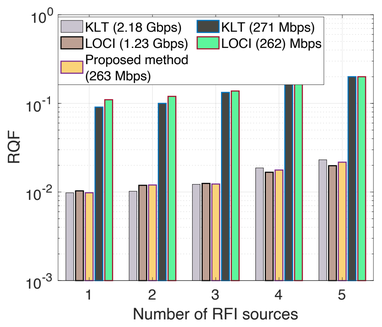


Figure 8. Improved Signal reconstruction.

- Overhead reduction 63%.
- Recovery accuracy 81.13% compared to 87% with full precision, 17.8% with overhead restriction.
- Reduction in computation load ($\mathcal{O}(n^2)$ to $\mathcal{O}(n^d)$, $(1 < d < 2)$.

Dynamic Protection Zone (DPZ) [5]

- Created a framework to analyze the Instantaneous Equivalent Power Flux Density (EPFD) from multiple satellites in different orbital planes.
- Derived a threshold for EPFD, beyond which it is detrimental to a radio telescope, Deep Synoptic Array (DSA-2000).
- Effect of In-band (IB) emission from the satellite constellation:
  - EPFD exceeds the threshold 25.45% of the time at elevation 90° (Figure 10).
  - EPFD exceeds the threshold 61.48% of the time at elevation 20° (Figure 11).
- Effect of Out-of-band (OOB) emission from the satellite constellation (Figure 12) based on different orientations of the radio telescope.

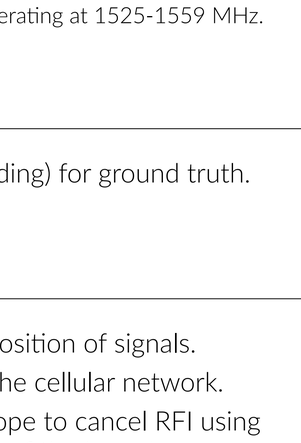


Figure 9. Position of Satellite and Radio Telescope with respect to Earth.

Figure 10. EPFD above detrimental threshold at telescope elevation of 90°.

Figure 11. EPFD above detrimental threshold at telescope elevation of 20°.

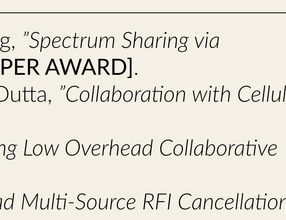


Figure 12. % data loss due to OOB emissions from LEO 5G-NTN satellites operating at 1525-1559 MHz.

Future Research

- Controlled RFI injection in 1420 MHz (experimental FCC license pending) for ground truth.
- Practical implementation via ORAN integration and open APIs.

Intellectual Merit

1. Fast neural networks with domain knowledge for orthogonal decomposition of signals.
2. Topology aware, distributed learning across small and macro cells of the cellular network.
3. Bidirectional collaboration between cellular network and radio telescope to cancel RFI using computationally efficient neural network based orthogonal projection of the kernel spaces.

Broader Impact

1. **Enable science and connectivity for the society** by enhancing protection to the radio astronomy science from detrimental RFI to improve the sensitivity of next-generation radio telescopes.
2. **Bridge between radio astronomy and wireless communication community**, initiating a platform for conversations among both groups of researchers.
3. **RFI dataset and NN models** will be available to wireless communication and the radio astronomy research communities for repeatable research.

Publications

1. Maqsood Careem, Shuvam Chakraborty, Aveek Dutta, Dola Saha, Gregory Hellbourg, *"Spectrum Sharing via Collaborative RFI Cancellation for Radio Astronomy"*, in **IEEE DySPAN 2021 [BEST PAPER AWARD]**.
2. Shuvam Chakraborty, Gregory Hellbourg, Maqsood Careem, Dola Saha and Aveek Dutta, *"Collaboration with Cellular Networks for RFI Cancellation at Radio Telescope"*, in **IEEE TCCN 2022**.
3. Shuvam Chakraborty, Dola Saha, Aveek Dutta and Gregory Hellbourg, *"LOCI: Learning Low Overhead Collaborative Interference Cancellation for Radio Astronomy"*, in **IEEE ICC 2023**.
4. Shuvam Chakraborty, Dola Saha, Aveek Dutta and Gregory Hellbourg, *"Low Overhead Multi-Source RFI Cancellation"*, in **IEEE DySPAN 2024**.
5. Sirajum Munira, Dola Saha, Gregory Hellbourg and Aveek Dutta, *"Dynamic Protection Zone for Radio Astronomy"*, in **IEEE DySPAN 2024**.

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