Reducing Satellite Interference to Radio Telescopes Using Beacons

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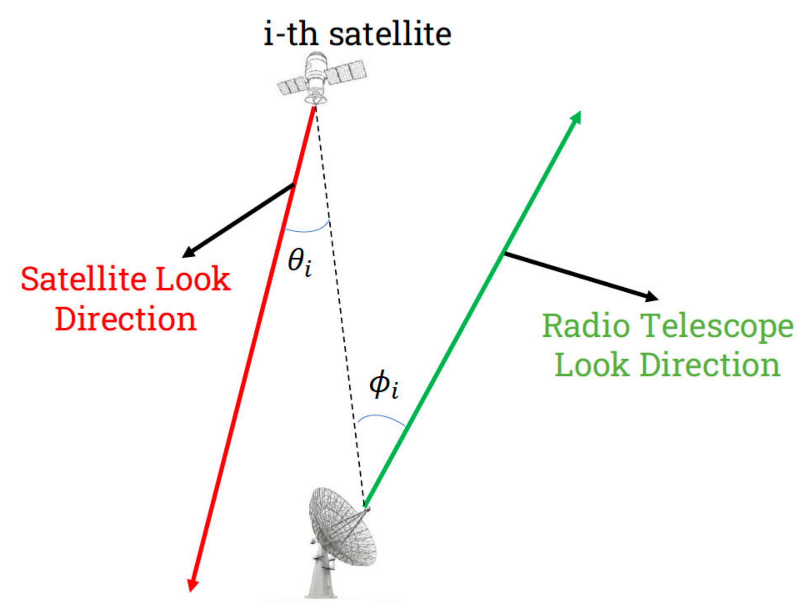
BACKGROUND

- Radio telescopes (RT) are about 150 dB more sensitive than a GSM phone.
- Strong Radio Frequency Interference (RFI) ⇒ saturation or non-linear regime ⇒ corrupted data.

PROBLEM

- How can we enable more efficient use of time, frequency and space for both science and broadband access?
  1. Fixed Quiet Zones
  2. Dynamic Quiet Zones
  3. Beacon Approach

SYSTEM MODEL



- $I_i = \frac{p_i w_t(\theta_i) w_r(\phi_i)}{FSL(d_i)} \xi_i$
  1. $p_i \rightarrow$ satellite transmit power
  2. $w_t(\cdot) \rightarrow$ satellite antenna pattern (3GPP TR 38.811)
  3. $w_r(\cdot) \rightarrow$ RT antenna pattern (ITU-RA 1631)
  4. $\theta_i, \phi_i \rightarrow$ off-axis angles.
  5. $d_i \rightarrow$ distance from the i-th satellite to the RT.
  6. $\xi_i \rightarrow$ uncertainty in the interference level.
  7. FSL$(\cdot) \rightarrow$ free-space loss.

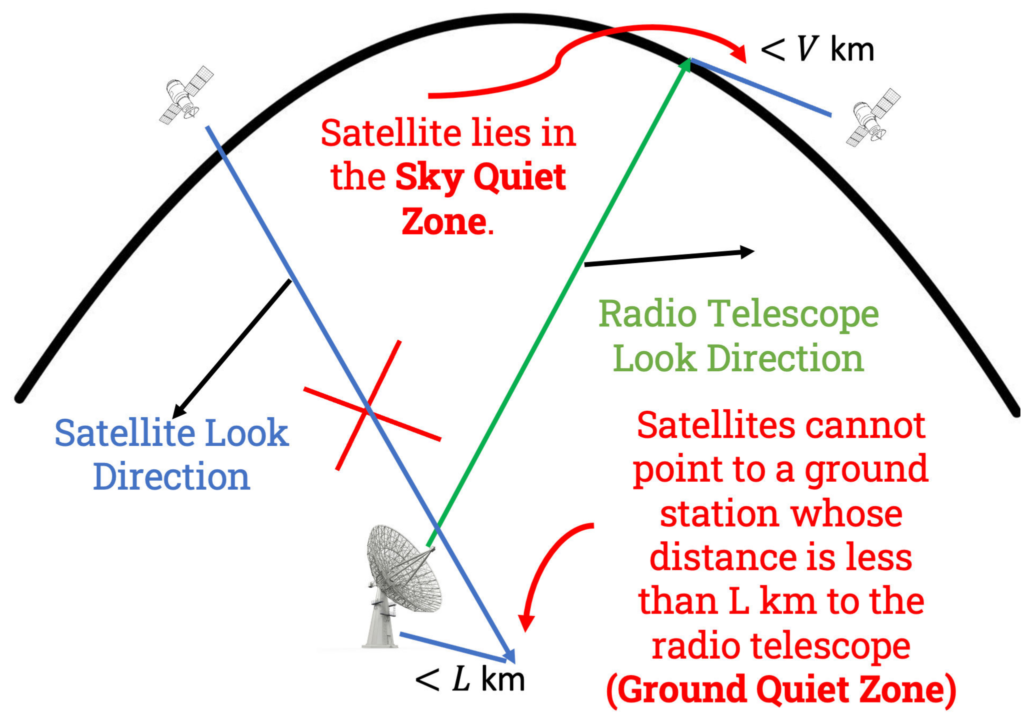
$$\mathrm{RFI} = \sum_{i=1}^{N_{sat}} I_i$$

- Outage Probability:

$$\mathrm{P_{out}} = \Pr\{\mathrm{RFI} \geq \mathrm{RFI_{max}}\}$$

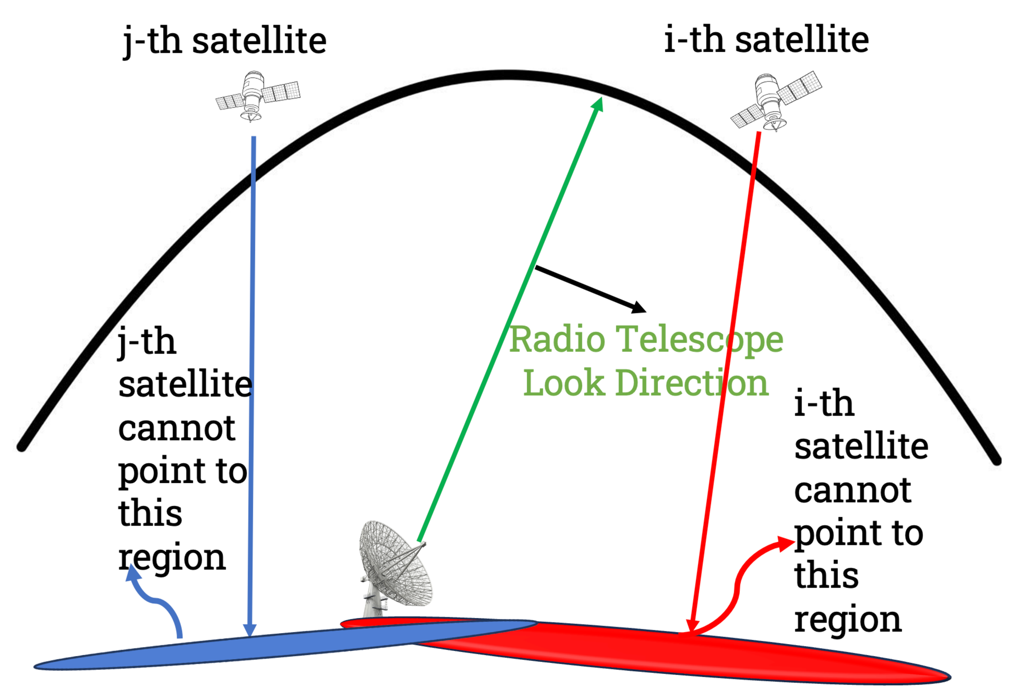
where $RFI_{\max}$ is the maximum allowable RFI.

FIXED QUIET ZONES



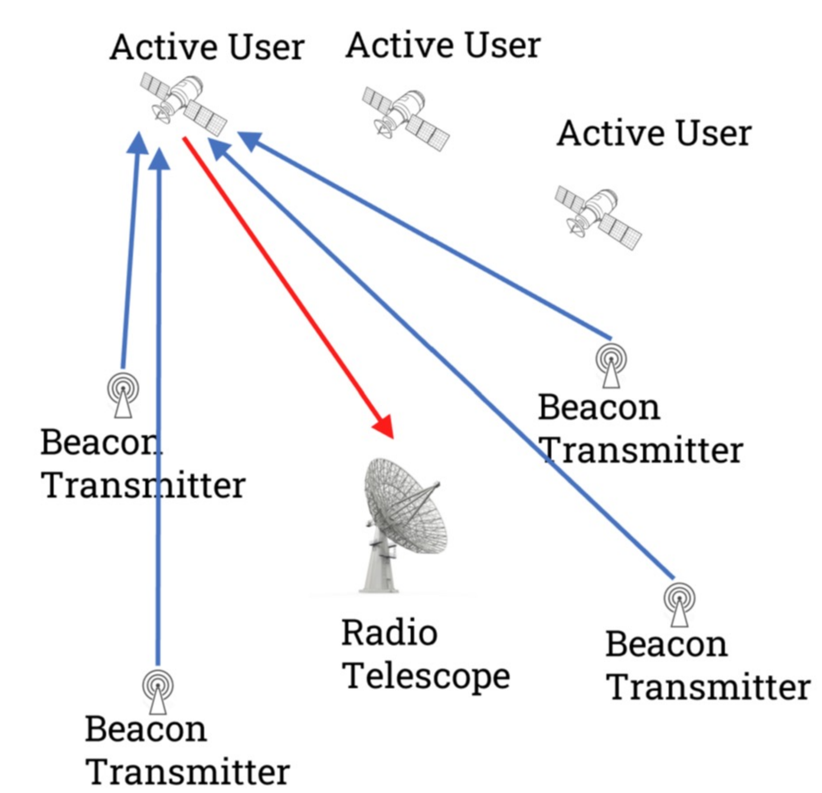
- The satellite link is active if and only if
  1. The satellite does not lie in the Sky Quiet Zone,
  2. The satellite does not point to the Ground Quiet Zone.
- The radii V and L are taken as design parameters.

DYNAMIC QUIET ZONES

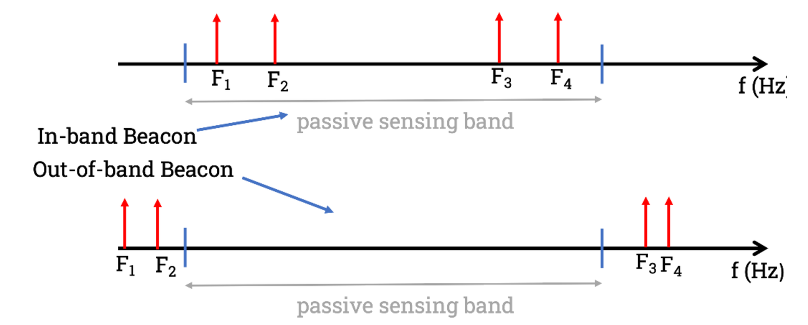


- Each satellite can autonomously determine the region on the ground where they cannot point to.
- These regions can change across satellites.
- This method requires significantly more computation than the Fixed Quiet Zones.

BEACON APPROACH

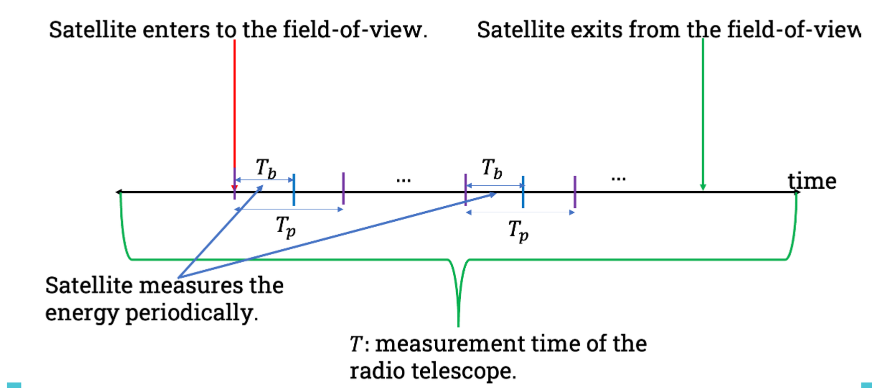


- Neither the fixed nor dynamic quiet zones methods capture short-term channel variations.
- Beacon approach can exploit the instantaneous channel reciprocity.
- The beacon power profile may be spread over time, frequency and space.
- **Design Considerations:**
  1. **Beacon duty cycle:** The beacons should be transmitted frequently enough to capture the time variations.
  2. **Ultra-wideband signaling:** The radio telescope may be needed to turned off during the beacon transmission periods (the large peak-to-average power of the beacon).
  3. **In-band versus out-of-band signaling:**



  4. **Spatial design:** Another degree of freedom is how to spread the beacon power across space, i.e., the beacon antenna pattern.
  5. **Placement of the beacon transmitters:** Beacon transmitters can be located either at or nearby the radio telescope.

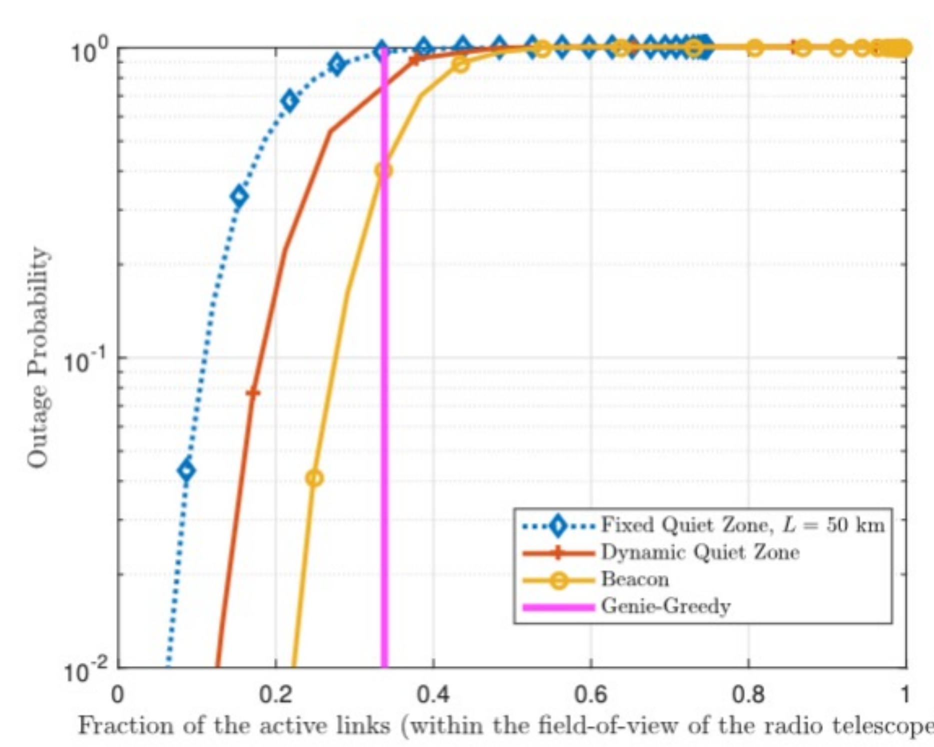
- **Satellite Transmissions:**



NUMERICAL RESULTS

- The network consists of 1000 satellites where their locations are generated according to the Binomial Point Process.
- $\xi_i \sim \mathcal{N}(0, \sigma_{dB}^2)$.
- Deactivation of the satellite links in the quiet zone approach depend only on their locations.
- For the beacon approach, on average T_b/T_p fraction of the satellites are listening for the beacon signal.

Carrier frequency	10.65 [GHz]
Bandwidth	100 [MHz]
$\mathrm{PFD_{max}}$	-240 [dBW/m^2/Hz]
Satellite altitude	550 [km]
Satellite transmit power	-8.3 [dBW/MHz]
Maximum gain of the satellite antenna	30 [dBi]
Satellite beam-width	5 [degree]
Maximum gain of the radio telescope ($G_{\max}$)	64 [dBi]
Beacon power (p_b)	10 [mW]
Maximum gain of the beacon transmitter	32 [dBi]
Threshold at the satellite (η)	9.6 [dB]
σ_{dB}	5 [dB]
Sky (Antenna) noise temperature (T_a)	300 [K]
Satellite receiver noise temperature (T_r)	100 [K]
Radio telescope antenna pattern	ITU-RA 1631 [15]
Beacon antenna pattern	ITU-RA 1631 [15]
Satellite antenna pattern	3GPP TR 38.811 [16]



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