Iridium:
Characterization & Countermeasures

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**Iridium as Interference**

- Constellation of satellites providing mobile phone service

- Downlink band is adjacent to the 1610 MHz protected band – infamous source of interference in that band

- Downlink signals are
  - Strong
  - Bursty (10’s of ms)
  - Narrowband (10’s of kHz)
  - Spread out over 10’s of MHz

- Not possible to mitigate using simple, fixed “avoidance” strategies
Argus

- Transient tone/pulse search instrument
- N = 36 element array, 24 instrumented
- 1200-1700 MHz tuning
- \(T_{\text{sys}} \approx 215 \, ^\circ\text{K}\) per element
- Digitizes 20 MSPS complex (14 MHz BW); processed to 78.125 kSPS complex & aggregated into a single 80-Mb/s serial data stream
- Data stream broadcast using UDP/IP over Ethernet to PC cluster for all subsequent processing
- Pulse sensitivity \(\approx 24 \, \text{kJy}\) at zenith in 0.2 s
- No confirmed extrasolar detections - yet. (All detections so far attributable to RFI)
- Iridium renders about 50 MHz of bandwidth around 1620 MHz unusable

http://www.ece.vt.edu/~swe/argus
Detection without Calibration

- A 24 x 24 “spatial covariance matrix” $R$, tabulating the cross-correlations between all possible pairs of elements, is formed from a single 209-ms data record.

- Assuming perfect calibration, the absence of a signal means all of the eigenvalues of $R$ are equal.

- Thus, detection can be defined as a condition in which the inequality of eigenvalues exceeds some threshold. This is a Rank Detector.

- The number of eigenvalues exceeding this threshold indicates the number of uncorrelated sources detected. For example:
  - At 1691.00 MHz, we should detect 1 signal (GOES-12 WEFAX)
  - At 1691.30 MHz, we should detect 0 signals (Cold sky)
  - At 1575.42 MHz, we should detect ~9 signals (US GPS constellation)

http://www.ece.vt.edu/~swe/argus
Observed eigenvalue spectra, 209 ms integration

Observed signal to noise ratios are consistent with anticipated 215 K / element system temp.

What Argus “Sees”

http://www.ece.vt.edu/~swe/argus
Following Up a Detection

- Beam formed on detected source, using eigenvector for beamforming coefficients
- Time series captured for storage for manual follow-up
- Eventually, calibration performed to refine estimate of sky position

http://www.ece.vt.edu/~swe/argus
All-Sky Imaging

1691 MHz (WEFAX signal from geostationary satellite GOES-12)
N=24 effectively isotropic elements
“Almost pseudorandom” geometry
Approx 215K per element
30 kHz BW (~ matched to WEFAX BW)
209 ms integration

GOES-12
(Other bright spots are aliases arising from redundant subnyquist spacings)

Argus Array (N=24)
Phase Center Geometry at 1691 MHz

Image before calibration
After calibration using a near-field noise source
Same procedure applied to adjacent (signal free) channel

http://www.ece.vt.edu/~swe/argus
What Iridium Looks Like to Argus

Argus:
Tuned to 1624.0 MHz

Spectrometer:
$\Delta \nu = 100$ Hz
$\Delta t = 10$ ms
Duty Cycle ~ 0.1%

Iridium:
~90 ms between bursts
Bursts 8-20 ms long
INR variable, up to ~30 dB
Burst Waveform

Sample Rate: 78.125 kSPS

Magnitude

Phase
Burst Waveform

Sample Rate: 78.125 kSPS

2.6 ms tone
Quasi-Constant Modulus, 5-18 ms

Magnitude

Phase

arbitrary voltage units

phase [deg]

time [ms]
“Payload” is revealed to be Quadrature Phase Shift Keying (QPSK), Symbol Rate = 25 kHz
Iridium Burst Mitigation Experiment

Form Beam Pointing at Zenith

Blanker

Sidelobe Canceller

Pulse-Matched Filter (W = 8 ms)

Eigenvalue Ratio (W = 8 ms)

Threshold Test (β=10σ)

Detection

Spectrometer
Detector Performance

Pulse Detector
(W = 8 ms)
Improves sensitivity by one order of magnitude over raw samples

Rank Detector:
(W = 8 ms)
Improves sensitivity by two orders of magnitude over raw samples, nominally
Pulse Detection + Blanking

Blue: N=24 Zenith beam
Red: N=  1 (Spiral element)
(Arbitrary offset for clarity)

Top: RFI mit off
Bottom: RFI mit on

Detector:
Total power pulse
W = 8 ms
β = 10σ at PMF output

Blanker:
Blank 56 ms window
Start 16 ms before trigger
~ 20% of data is blanked

PSD calculation:
Δν = 100 Hz
Δt = 10 ms
τ = 58.3 s
Adaptive Sidelobe Canceling

Signal contaminated with interference.
Here, $w_0 = [1 \ 0 \ ... \ 0]$
Blanking vs. Sidelobe Canceling

N=1 (Spiral element)

Top: RFI mit off
Middle: SL Canceling
Bottom: Blanking

Detector:
Total power pulse
W = 8 ms
\( \beta = 10\sigma \) at PMF output

SL Canceling:
Projecting out estimated spatial signature of burst
Cancel 56 ms window
Start 16 ms before trigger
No data loss

Blanking:
Blank 56 ms window
Start 16 ms before trigger
~ 20% of data is blanked

PSD calculation:
\( \Delta \nu = 100 \text{ Hz} \)
\( \Delta t = 10 \text{ ms} \)
\( \tau = 58.3 \text{ s} \)

(compare2b.m)
Blanking vs. Sidelobe Canceling

N=1 (Spiral element)

Top: RFI mit off
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PSD calculation:
$\Delta \nu = 100 \text{ Hz}$
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Error in estimation of interferer steering vector limits effectiveness of sidelobe canceling to about 30 dB

(compare2b.m)
Concluding Remarks

- Details of Iridium downlink at 1624 MHz has been presented

- Outlook for effective mitigation:
  - Transients: Pretty good.
  - Spectroscopy: Pretty good for integration times < 1 min; otherwise TBD.

- Detection Techniques
  - Pulse detection: Simple
  - Rank detection: More complicated, but more sensitive
  - In practice (e.g., see [3]), this is usually the limiting factor

- Removal Techniques
  - Blanking; simple & effective; however data loss and gaps
  - Sidelobe canceling: A little more complicated and less effective, but no data loss or gaps
  - Best choice depends on application (e.g., spectroscopy vs. transients)

- References / More Information