Radar-Embedded Communications

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Backscatter Communications

- Radar illumination
- RF tag
- Embedded communication waveform
- Ambient scattering
**Backscatter Communications**

- Exploit RF tag/transponder technology.
- Enable Low Probability of Intercept (LPI) communications
  » prevent reception/exploitation by an adversary.
- Use the ambient radar scattering to mask the comm signal.
- How to bury a comm signal into the radar backscatter that is:
  » invisible to an eavesdropper, yet
  » can be extracted by the desired recipient.
“Inter-Pulse” Modulation

- Previous work applied Doppler-like phase-shift sequence over numerous pulses (100s)
  - e.g., Athena tag developed at Sandia National Labs.
- To be covert → very low data rate (“bits-per-CPI”) → bps
- Utilized to insert identifiers into SAR images.
“Intra-Pulse” Modulation

- Operate on each incident pulse independently.
- Incident radar waveform converted into one of $K$ possible communication waveforms; i.e., symbols.
- Potential for much higher data rate while still LPI
  » $K = 4$, PRF $\geq 1.2$ kHz $\rightarrow$ embed speech via MELP codec.
Exploiting Natural Scattering

• For $s(t)$ the incident radar waveform, $y_s(t)$ is the ambient scattered signal incident at a given receiver.

• The ambient scattered signal acts as a masking interference for one of $K$ communication waveforms, which are denoted $c_k(t)$ for $k = 1, 2, \ldots, K$.

• To remain covert, a communication waveform must maintain a sufficient degree of similarity with the ambient scattered signal.

• The goal is to determine both appropriate comm waveforms and receiver processing structures to recover the embedded signal.
Received Response

- At a receiver (desired or intercept), the incident signal over the interval of the embedded communication signal is
  \[ y_r(t) = c_k(t) + y_s(t) + \nu(t) \]
  where \( \nu(t) \) is noise.

- To optimally estimate the given embedded signal, the set of communications waveforms would ideally possess the following properties:

\[
\begin{align*}
  c_k(t) \ y_s^*(t) \ dt &= 0 \\
  c_j(t) \ c_k^*(t) \ dt &= 0 \quad \text{for} \quad j \neq k
\end{align*}
\]

\( \} \) does nothing to ensure LPI
Covert Waveform Design

• To ensure the communications waveforms possess a low probability of intercept (LPI)
  » Comm waveforms must remain partially correlated with the natural radar scattering.

• Prevents intercept receiver from simply suppressing the radar illumination \( s(t) \) in the received signal \( y_r(t) \) to recover the embedded signal.

• Need to exploit the scattering phenomenology and the knowledge of the incident radar waveform to design “good” comm waveforms.
Covert Waveform Design

• Difficult to use ambient scattering to design comm signals → but may easily employ the incident radar waveform.

• Design approaches based on presumed uniform scattering of radar illumination.

• Exploits “dirty spectrum” that radars generate
  » Allows comm signals to occupy “incremental” bandwidth surrounding the radar passband.
Receive Processing

• If the communication waveforms were designed according to “ideal” estimation criteria, coherent matched filtering as

\[
\hat{k} = \arg \max_k c_k(t) y_r^*(t) \, dt
\]

would enable optimal estimation of the embedded signal.

• However, some nominal correlation between the comm waveforms and the naturally scattered signal is required to maintain LPI

  » Necessitates coherent interference cancellation to effectively extract the embedded signal from the ambient scattering.
Results from Preliminary Work

• Initial efforts have yielded promising waveform design strategies that
  » are dependent on illuminating radar waveform,
  » provide low communication error probability,
  » enable data-rates on the order of (“bits-per-pulse”) \( \rightarrow \) kbps.

• An indirect metric for the probability of intercept for \textit{intra}-pulse embedded communications has been identified as well
  » Based on a normalized correlation metric presuming the intercept can suppress the ambient radar scattering.
Error-Rate Performance Example

- Using *Dominant-Projection* waveform design strategy.

- Good receiver error-rate performance is attained for low SIR values when using interference cancellation.

![Graph showing error-rate performance vs. SNR (dB) for different SIR values.]

- Matched filter
- Decorrelator
Measure of LPI

- Embed waveform 1 (of 4) and vary the rank of suppressed ambient scattering.
- Plot of correlation between suppressed residue and each of the 4 waveforms.
- Correlation-based LPI metric does not exceed 40%.
- Eavesdropper cannot obtain embedded waveform, yet intended receiver can discern among the known possibilities.
• Preliminary work indicates that *intra*-pulse radar-embedded communications can enable much higher data rates than previous *inter*-pulse methods while maintaining LPI.

• Necessitates the determination of appropriate comm waveforms and receive processing structures.

• Interference suppression receiver needed to maintain good estimation accuracy for LPI comm waveforms.

• Recently it has been found that comm waveform design can be made virtually immune to multipath effects.