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Satellite Navigation Anti-Spoofing Using Deep Learning on a Receiver Network

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Introduction

- Spoofers can generate false GNSS signals using publicly available pseudorandom number (PRN) codes to disrupt one or more receivers
- Multiple GNSS signals are structured using a public signal as the in-phase component and a restricted signal (with PRN codes unknown to civilians) as the quadrature component
- Our example: the Galileo E1 code (f_c = 1575.42 MHz)
  - In-phase: Open Service → spoofable
  - Quadrature: Public Restricted Service → not spoofable without
- We leverage the absence of a quadrature component in a spoofed signal by inputting the quadrature component into an artificial neural network (ANN) for classification

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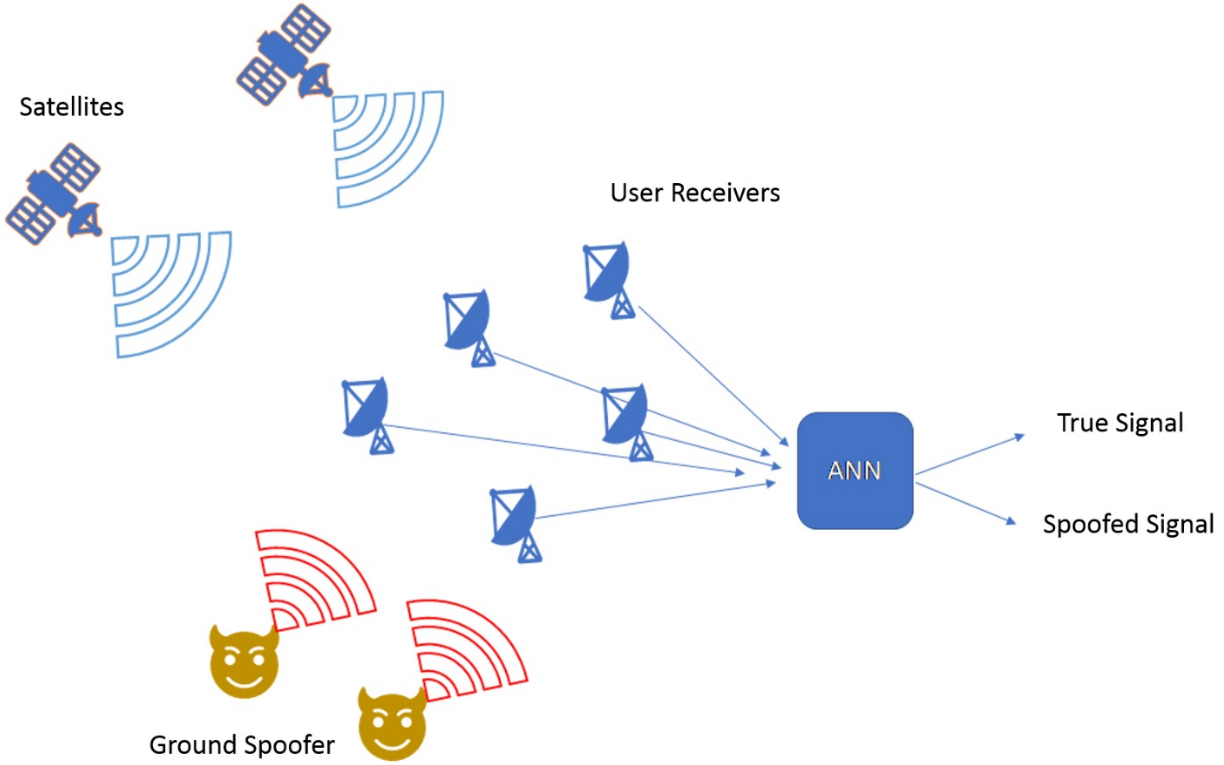
Problem Formulation



Signal Generation

- The baseband PRS signal is generated using an arbitrary navigation message spread using a PRN sequence similar to a PRS code
  - Chip rate – 2.5575 Mcps
  - Modulation – cosine binary offset carrier (BOC) with subcarrier frequency 15.345 MHz
  - Code length – unknown, periodicity assumed to be greater than collection time
  - Samples collected over 0.1 s → 255750 chips, BOC modulated

Signal Generation

- Rayleigh Fading Channel
  - Simulations done with and without fading
  - Applies multipath to signal, without a dominant line-of-sight path between satellite and receiver
  - Testing robustness of deep learning classification
  - Several weaker replicas with varying delays → impacts both cross-correlation and cyclostationarity of signals

Signal Generation

- Additive White Gaussian Noise (AWGN)
  - For a desired signal-to-noise ratio (SNR), a white Gaussian sequence is scaled and added to the normalized signal
  - SNR is selected according to a range of values of the ratio of an expected GNSS signal power to reasonable noise floor levels
    - 0 dB, -5 dB, -10 dB
  - Spoofed signals are simply the white Gaussian sequence

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Cross-Correlation

- Each receiver is given an arbitrary delay to represent varying pseudoranges to a satellite
- A reference receiver is selected and its PRS signal is cross-correlated with the other receivers in the network
- For a network of *N* receivers, each data point is the peak value of each of the *N-1* cross-correlation formulations

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Cyclic Profile

- The spectral correlation function (SCF) of each received signal is computed, and the cyclic profile is taken
- The cyclic profile represents the maximum spectral correlation at each cyclic frequency α (we select 2049 separate values)
- Calculated using the fast spectral correlation (FSC) function
- The *N* cyclic profiles are concatenated into an *N x* 2049 data point as an input to the ANN

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Cyclic Profile

Cyclic Auto-correlation function

$$R(\alpha, \tau) = \int_{-\infty}^{\infty} x\left(t - \frac{\tau}{2}\right) x^{*}\left(t + \frac{\tau}{2}\right) e^{-j2\pi\alpha t} \, \mathrm{d}t$$

Spectral Correlation function

$$S(\alpha, f) = \int_{-\infty}^{\infty} R(\alpha, \tau) e^{-j2\pi f\tau} \, \mathrm{d}\tau.$$

Cyclic Profile

$$C(\alpha) = \arg\max_{f} S(\alpha, f)$$

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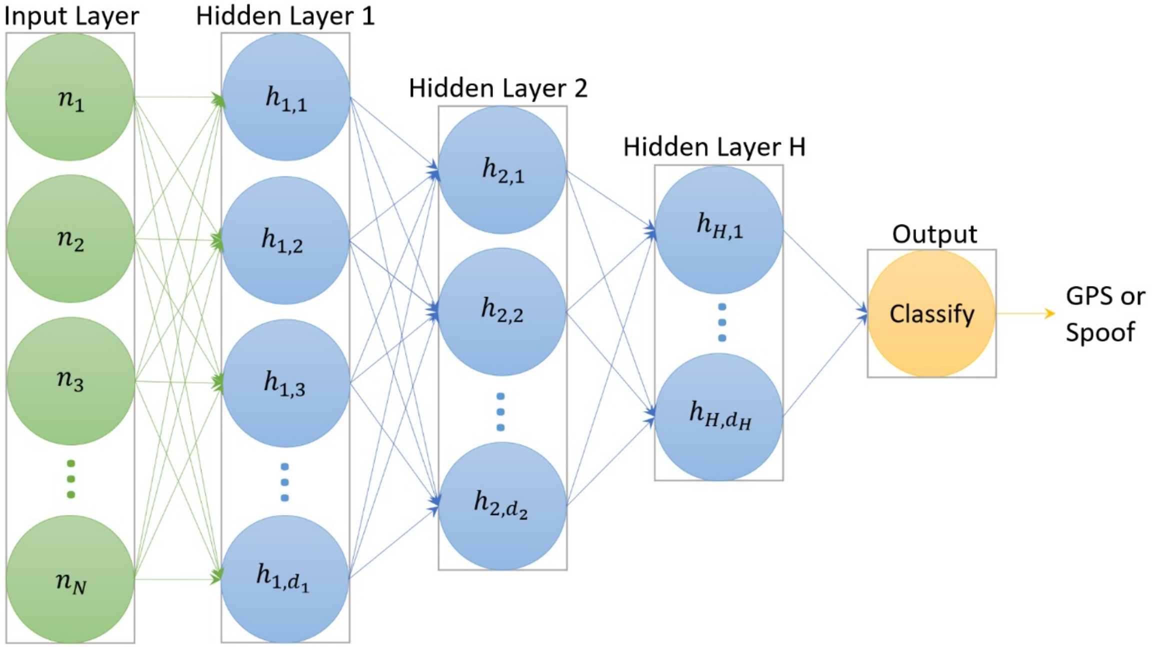
ANN Structures



- **Long Short Term Memory (LSTM) -** Includes feedback paths in order to establish long-term patterns as the training/validation process occurs
- **Convolutional Neural Network (CNN) –** Includes pooling layers between hidden layers which reduce the dimensionality of the data at each step

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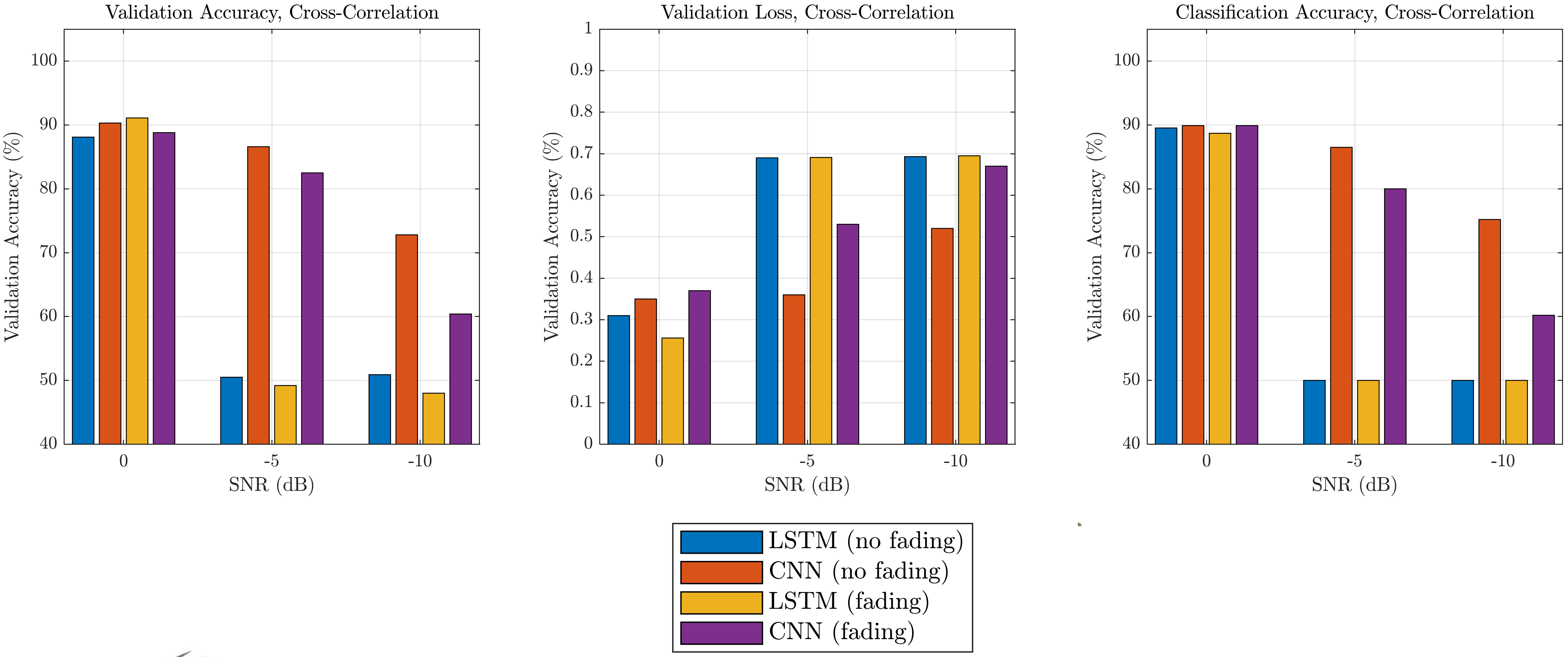
Simulation Results – Cross-correlation



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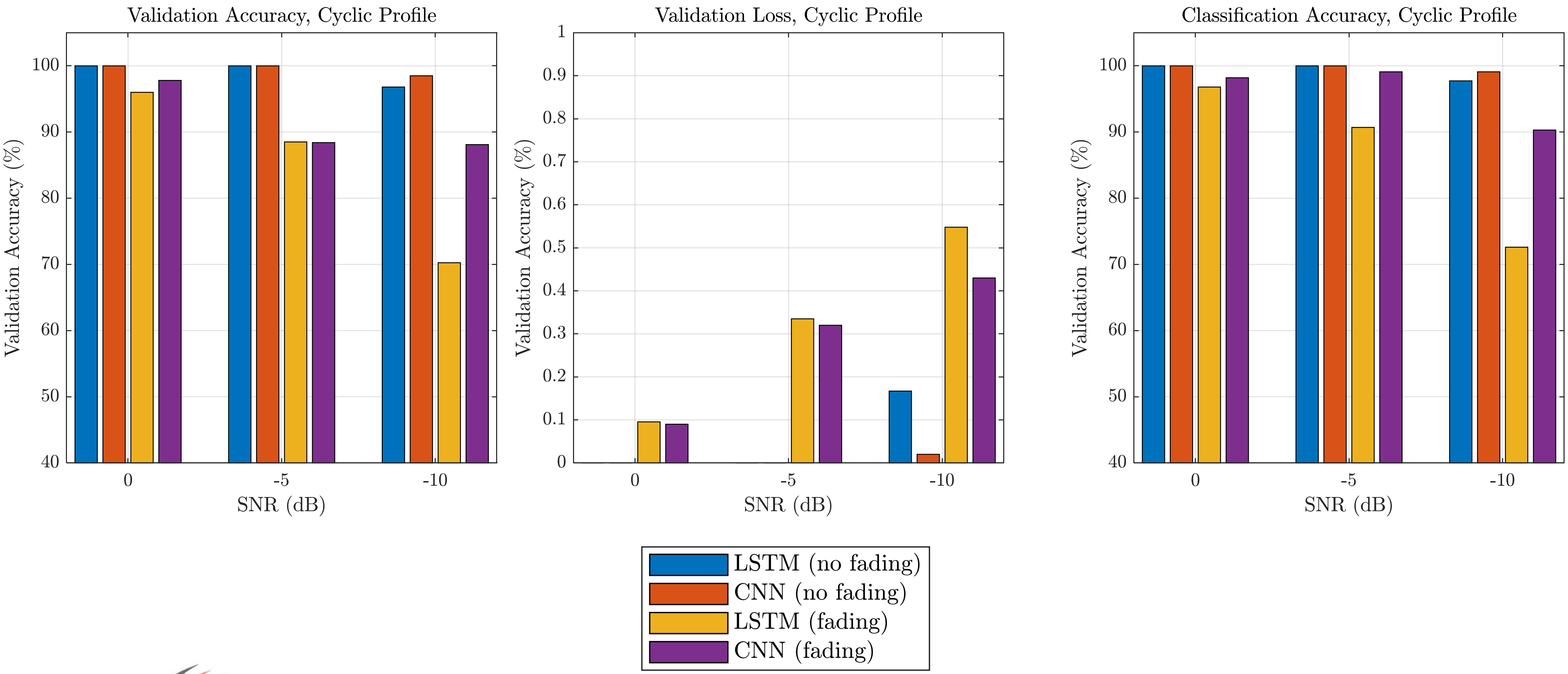
Simulation Results – Cyclic Profile



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Conclusions

- The CNN model is shown to be more robust than the LSTM model regarding decreasing SNR and Rayleigh fading
- The cyclic profile results in more accurate classification across the board, likely due to more information per data point
- Calculated using the fast spectral correlation (FSC) function
- The *N* cyclic profiles are concatenated into an *N x* 2049 data point as an input to the ANN