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SYSC 5804 – Term Project

Deep Learning m-MIMO Channel Estimation

Overview

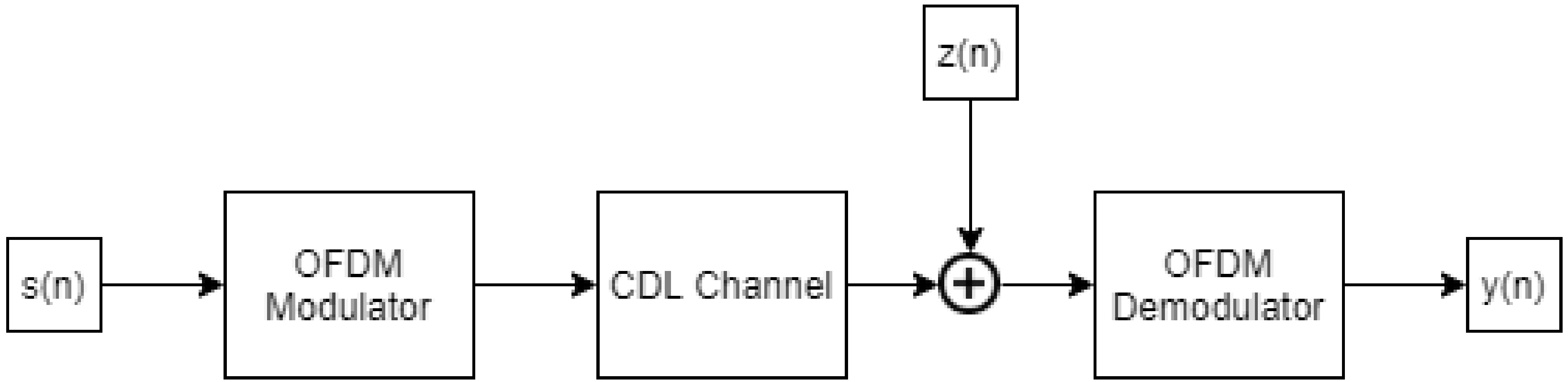
1. Definitions
2. Channel Model
3. Image Generation
4. YOLO
5. LASSO

Definitions

- m-MIMO
- Channel Estimation
- Pilot Signals

Simulated System

- Pilot symbols, s(n), are modulated
- Signal is sent through the CDL channel
- White gaussian noise is added, z(n)
- Received signal is demodulated to get received pilots, y(n)



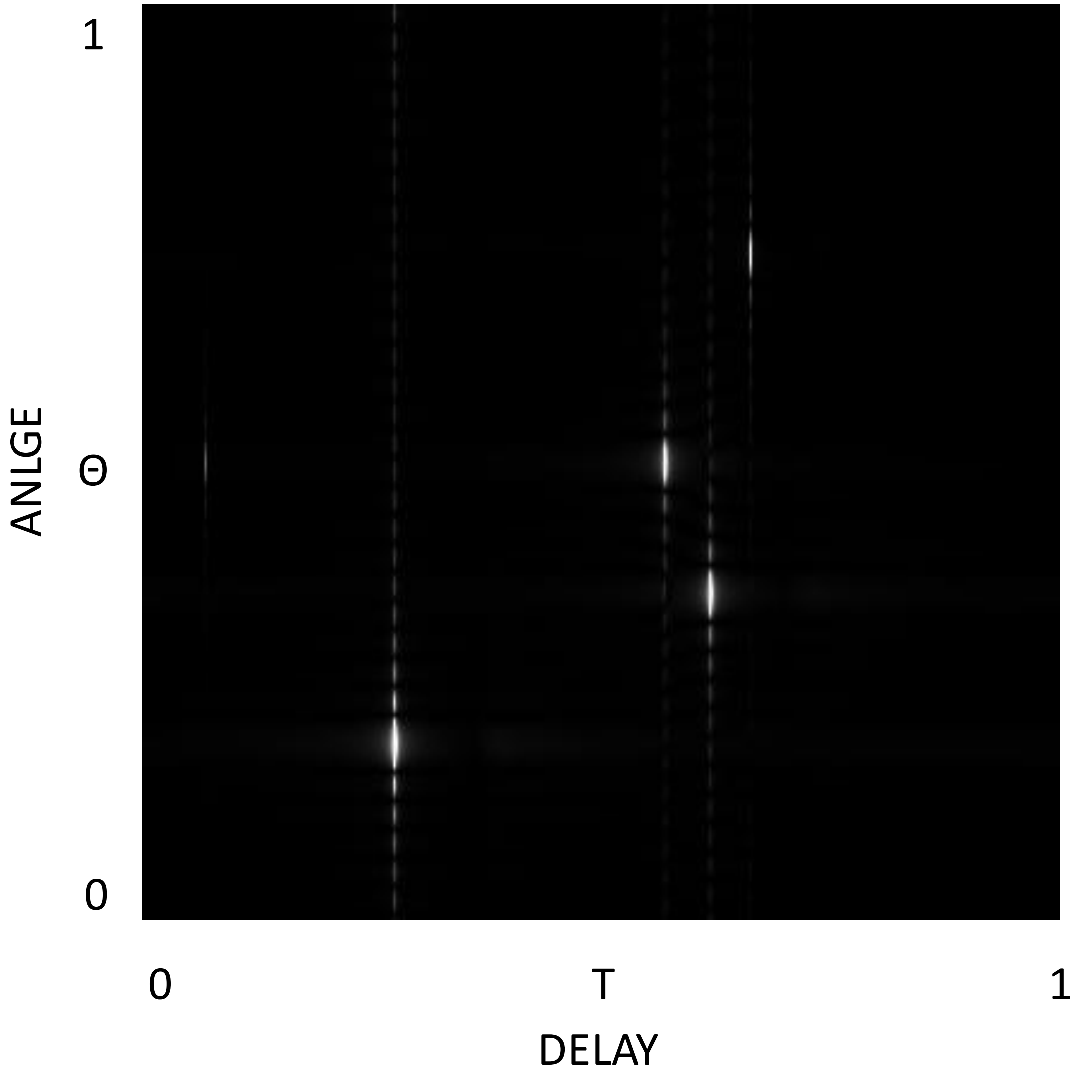
Simulated Channel Model: CDL

- Clustered Delay Line (CDL): Multipath channel defined by 3GPP in ETSI TR 138 900 V14.2.0
- Custom profile, allows for configurable
  - Path count
  - Average Path Gains
  - Path Delays
  - Path Angles (AoA, ZoA, AoD, ZoD)
- Script generating random CDL channel profiles

Delay-Angle Space Image Generation

- Received pilot: $y_m^{\mathrm{ul}}(n) = h_m^{\mathrm{ul}}(n)s(n) + z_m^{\mathrm{ul}}(n)$
  - For simplicity set $s(n) = 1$ ∀ n
  - Noise is variable in simulations
- Apply transform to get pilots in delay-angle space: $\overline{\mathbf{Y}} = \mathbf{U}_\Theta^T \mathbf{Y} \mathbf{U}_\mathrm{T}$
  - $\mathbf{U}_\Theta$ is a [M *x* αM] DFT matrix
  - $\mathbf{U}_\mathrm{T}$ is a [N *x* β N] DFT matrix
  - α , β are oversampling factors
- Normalize delay-angle matrix: $[\tilde{\mathbf{Y}}]_{m,n} = \frac{\delta}{\max\limits_{\substack{i=1,\ldots,\alpha M \\ j=1,\ldots,\beta N}} \left|[\overline{\mathbf{Y}}]_{i,j}\right|} \left|[\overline{\mathbf{Y}}]_{m,n}\right|$
  - δ is the normalized maximum value

Resulting Images



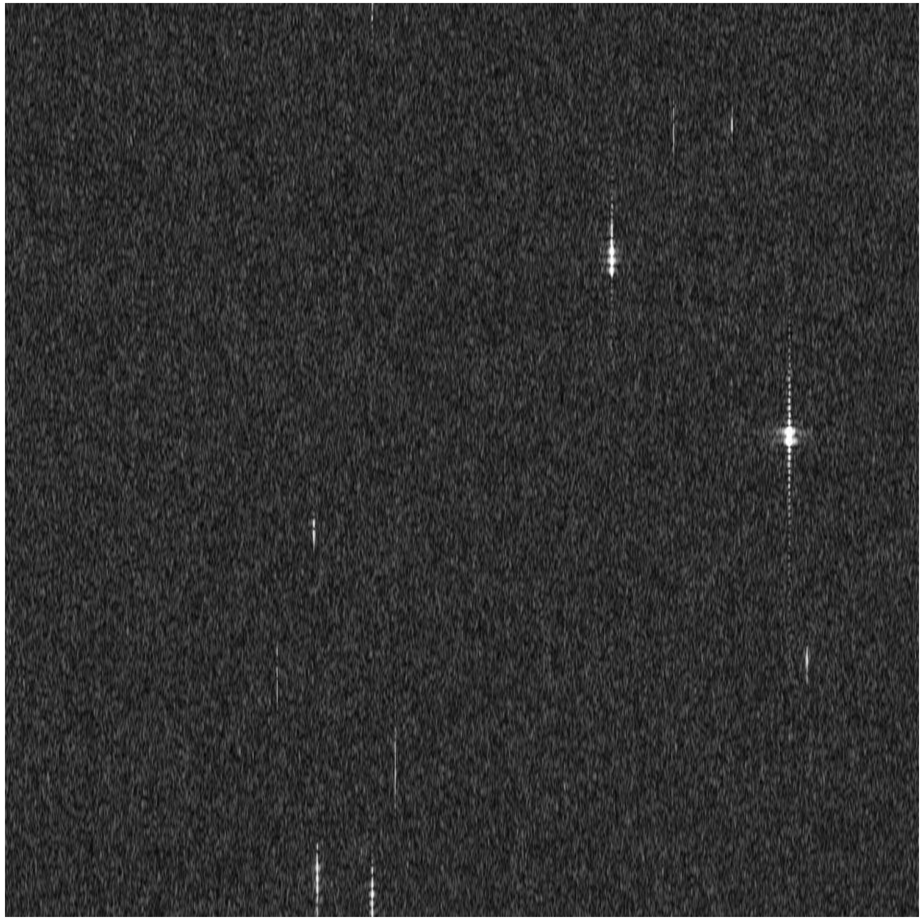


Image to Delay-Angles-Gains

- The path delays, angles, and gains are all encoded in the image
- Each bright spot is a unique path
- Delay is a function of the x coordinate of the center of the spot $\hat{\mathrm{T}}_l$
- Angle is a function of the y coordinate of the center of the spot $\hat{\Theta}_l$
- Gain is a function of the brightness of the spot
  - The gain is not extracted in the reference paper, so it is out of scope of this project

$$\Theta_l = \frac{d}{\lambda} \sin \theta_l \qquad \mathrm{T}_l = \Delta f \tau_l$$

Multipath Channel Reconstruction

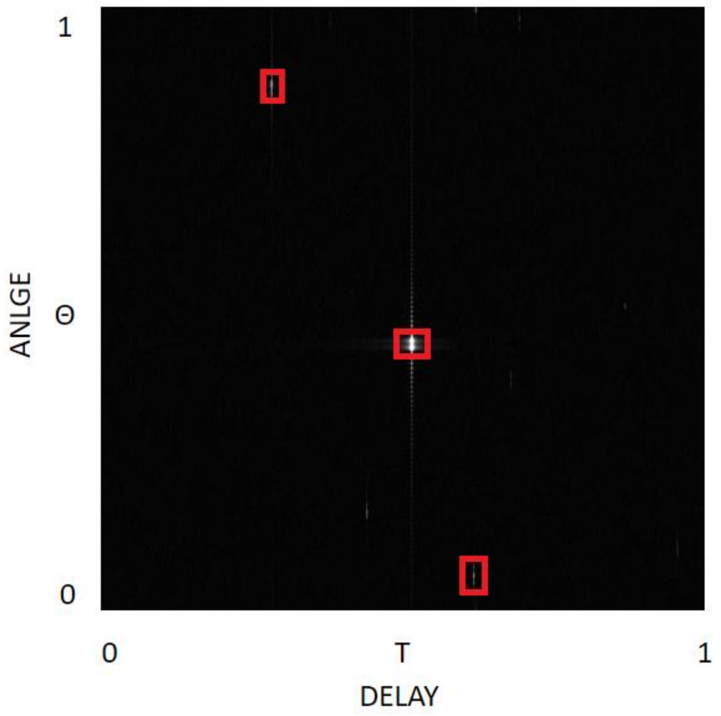
- Vector equation for multi-subcarrier, multi-antenna channel
  - $\mathbf{p}(\tau)$ = delay-related phase vector
  - $\mathbf{a}(\theta)$ = steering vector of ULA

$$\boxed{\mathbf{h}^{\mathrm{ul}} = \sum_{l=0}^{L^{\mathrm{ul}}-1} g_l^{\mathrm{ul}} \mathbf{p}(\tau_l^{\mathrm{ul}}) \otimes \mathbf{a}(\theta_l^{\mathrm{ul}}),}$$

$$\boxed{\mathbf{p}(\tau) = \left[e^{-j2\pi \lfloor \frac{N}{2} \rfloor \triangle f \tau}, \ldots, e^{j2\pi (\lceil \frac{N}{2} \rceil - 1) \triangle f \tau}\right]^H}$$

$$\boxed{\mathbf{a}(\theta) = \left[e^{-j2\pi \lfloor \frac{M}{2} \rfloor \frac{d}{\lambda} \sin\theta}, \ldots, e^{j2\pi (\lceil \frac{M}{2} \rceil - 1) \frac{d}{\lambda} \sin\theta}\right]^H}$$

- Channel Reciprocity: Certain path components are frequency independent
  - $L^{\mathrm{ul}} = L^{\mathrm{dl}} = L$, $\tau_l^{\mathrm{ul}} = \tau_l^{\mathrm{dl}} = \tau_l$, and $\theta_l^{\mathrm{ul}} = \theta_l^{\mathrm{dl}} = \theta_l$

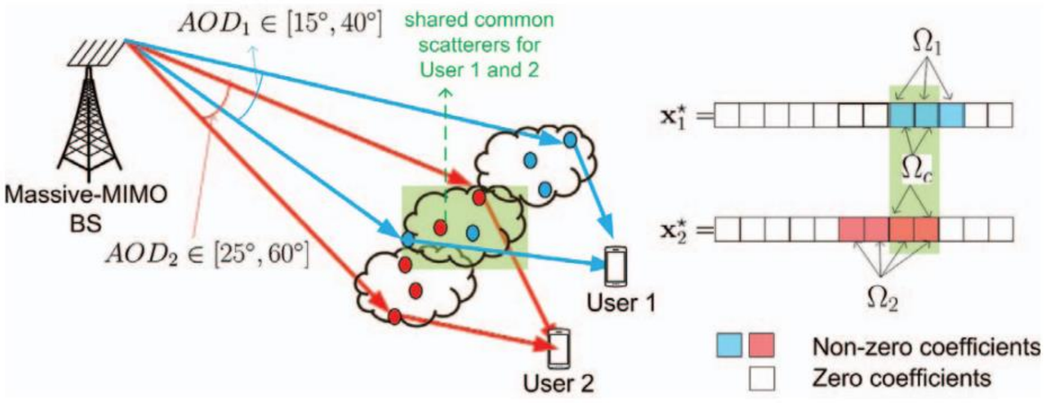


YOLO

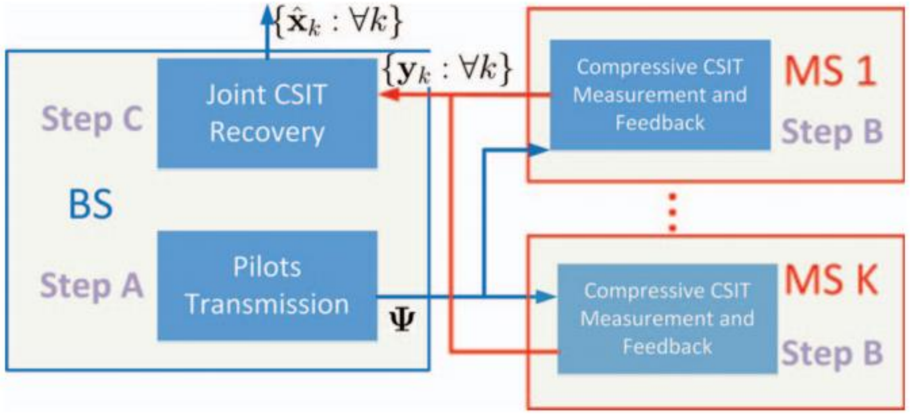
- Deep learning real-time object detection algorithm (Fast, image division -> gird cells)
- Uses the Darknet open-source neural network framework
- Uses 53 convolutional layers (1x1 and 3x3) and analyzes at 3 scale
- Objects are the dominate paths for a UE within the MIMO channel
- Modify YOLOv3 to only include one class and the loss function to improve accuracy and avoid capturing "star's" wings
- Transform received pilots into 2-D image for object detection and object locations back to their respective path representations

LASSO

- Several channel estimation techniques have been introduced to take advantage of the burst-sparsity and joint-sparsity due to scattering in m-MIMO
- One such technique uses the regression method Least Absolute Shrinkage and Selection Operator (LASSO)
- Compressed channel sensing measurements returned to BS for analysis
- Burst-sparse signal => Block-sparse signal through lifting transform (x = Lz)
- Used as a comparison against deep learning methods



$$\min_{\mathbf{x}} f(\mathbf{x}), \text{ s.t. } \|\mathbf{y} - \mathbf{\Phi x}\|^2 / M \leq (1+\epsilon)\sigma^2$$



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