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Deep Receiver for Multi-Layer Data Transmission with Superimposed Pilots

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Overview

- Research Motivation
- System Model
- Proposed Methods
- Numerical Results
- Summary

Research Motivation

- Comparison between **Orthogonal Pilot** Scheme and **Superimposed Pilot** Scheme.

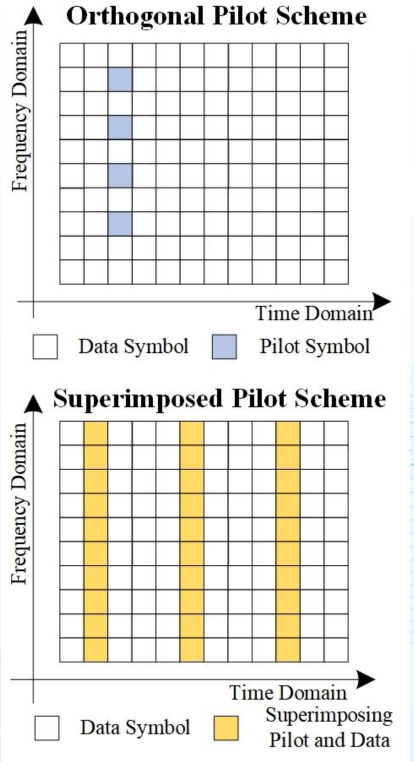
  Superimposed pilots offer **high spectral efficiency**.

- **Challenges in Multi-Layer Data Transmission**

  The channel environment is complex and dynamic, and interference between different users or antennas increases the difficulty of channel estimation and equalization.

- **End-to-End Learning**

  The deep receiver leverages deep learning techniques to directly extract features from the received signals and perform decoding, enabling automatic adaptation to channel variations and optimization of decoding strategies.



System Model

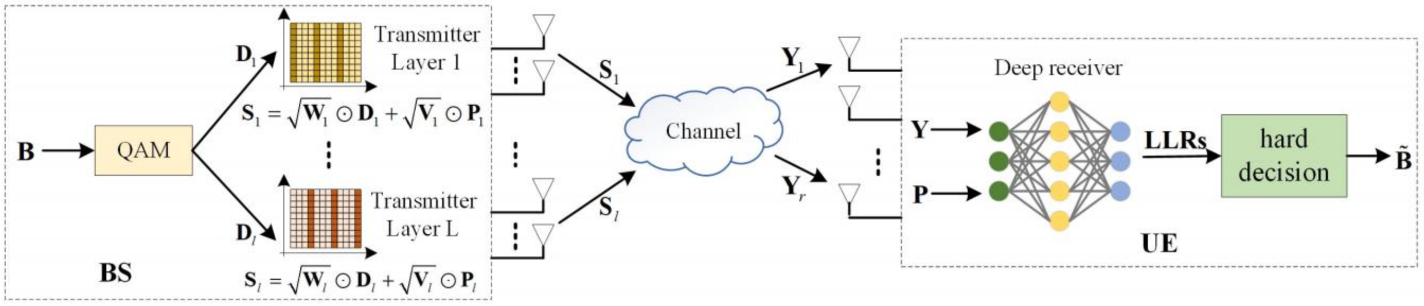


Fig. 1. A system for MIMO-OFDM multi-layer data transmission with SIP scheme.

The transmitter performs superposition of pilot $\mathbf{P}$ and data $\mathbf{D}$ to obtain superimposed symbols

$$\mathbf{S}_l = \sqrt{\mathbf{W}_l} \odot \mathbf{D}_l + \sqrt{\mathbf{V}_l} \odot \mathbf{P}_l \qquad (1)$$

The superimposed symbols are transmitted through the channel to the UE, resulting in the received signal

$$\mathbf{Y}_r = \sum_{l=1}^{L} \mathbf{H}_{r,l} \odot \mathbf{S}_l + \mathbf{Z}_r \qquad (2)$$

Proposed Method-Deep Receiver Based on Multi-Head Self-Attention Mechanism

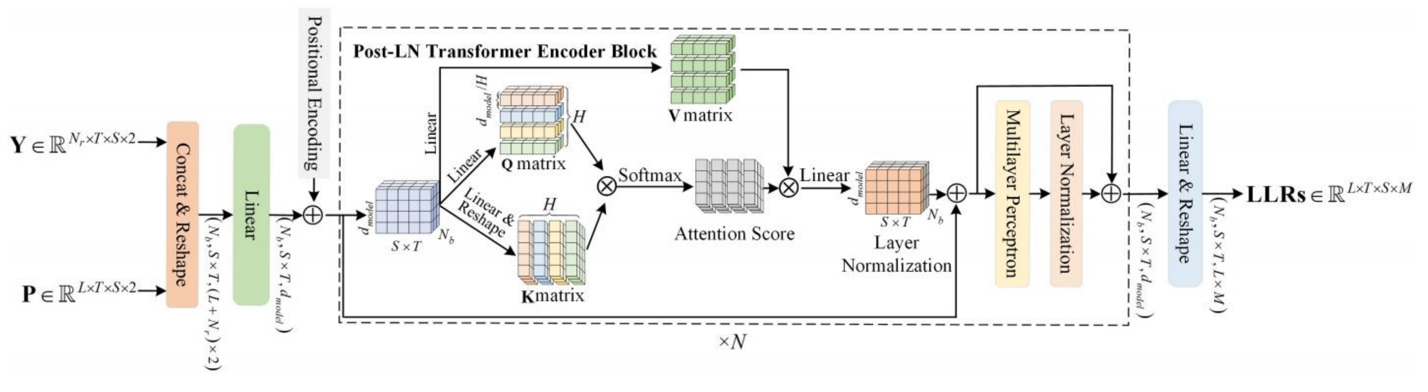


Fig. 2. Architecture design of the proposed SANet.

$$L = -\frac{1}{N_b KTSM} \sum_{i=0}^{N_b-1} \sum_{k=0}^{K-1} \sum_{t=0}^{T-1} \sum_{s=0}^{S-1} \sum_{m=0}^{M-1} \left[\mathbf{B}_{k,t,s,m}^{(i)} \log\left(\sigma\left(f\left((\mathbf{Y}^{(i)}, \mathbf{P}^{(i)}), \boldsymbol{\theta} \right) \right) \right) + \left(1 - \mathbf{B}_{k,t,s,m}^{(i)} \right) \log\left(1 - \sigma\left(f\left((\mathbf{Y}^{(i)}, \mathbf{P}^{(i)}), \boldsymbol{\theta} \right) \right) \right) \right] \quad (1)$$

(1) Common Subspace (2) Multi-Head Self-Attention

Proposed Method-A Flexible and Diverse Data Augmentation Strategy

- **Angle rotation**: Different small-angle rotations are applied to all symbols within an OFDM frame.

$$\mathbf{Y}_{\text{aug}} = \exp\left(j \bullet \boldsymbol{\alpha}_{\text{aug}} \right) \bullet \mathbf{Y} \quad (1)$$

- **Time-domain shuffling**: The received signal, pilot matrix, and bitstream are shuffled in the time domain according to the same rules.

$$\mathbf{Y}_{\text{aug}}[:, k, :, :, :] = \mathbf{Y}[:, \pi(k), :, :, :] \quad (2)$$

- **Data flipping**: Symmetric flipping is performed on the layer dimension of the pilot matrix and the bitstream matrix.

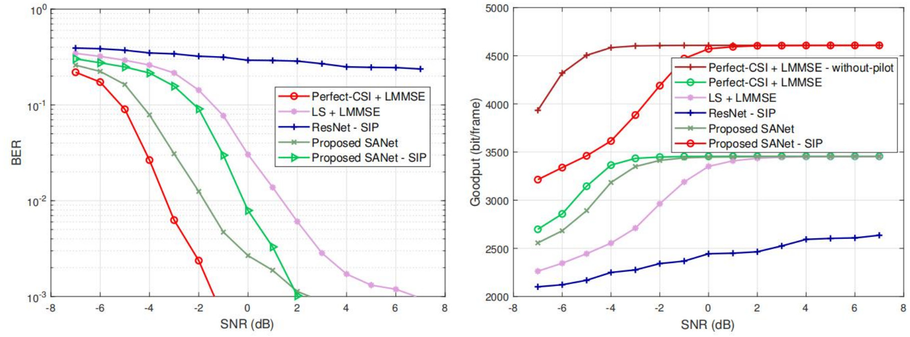
$$\begin{aligned} \mathbf{P}_{\text{aug}}\left[:, k, :, :, :\right] &= \mathbf{P}\left[:, K-k-1, :, :, :\right], \\ \mathbf{B}_{\text{aug}}\left[:, k, :, :, :\right] &= \mathbf{B}\left[:, K-k-1, :, :, :\right]. \end{aligned} \quad (3)$$

Numerical Results

We developed a MIMO-OFDM multi-layer transmission system based on the Sionna open source library.

TABLE II
AVERAGE BER PERFORMANCE OF DATA AUGMENTATION STRATEGIES

Data Augmentation Methods	Average BER
SANet ($d_{model} = 256$, $N = 16$)	0.02426
SANet + Angle rotation	0.02389 (- 0.00037)
SANet + Time-domain shuffle	0.02383 (- 0.00043)
SANet + Data flipping	0.02385 (- 0.00041)
SANet (augmented)	0.02320 (- 0.00106)



(a) BER *vs.* SNR (b) Goodput *vs.* SNR

Fig. 4. BER and Goodput performance of different receivers.

The goodput upper limit of the SIP scheme is approximately 35.91% higher compared to the orthogonal pilot scheme.

Compared to the “LS + LMMSE” scheme, the proposed SANet scheme based on orthogonal pilots and SIPs has a goodput improvement of approximately 7.01% and 37.15%, respectively.

Summary

- We have designed a MIMO-OFDM multi-layer data transmission system based on superimposed pilots.

- To address the interference issues in the aforementioned system, we propose a deep receiver based on a multi-head self-attention mechanism, which achieves feature extraction from the received signals and generates the corresponding log-likelihood ratios (LLRs) for the data symbols.

- In addition, we propose a flexible and diverse data augmentation strategy to enhance the robustness of the deep receiver, enabling it to better adapt to complex and dynamic communication environments.