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Deep Receiver for Multi-Layer Data Transmission with Superimposed Pilots

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Motivation

- **High Spectrum Efficiency**: By superimposing pilots onto data symbols, NOSIP reduces pilot overhead and improves spectral utilization.
- **Challenges in Multi-Layer Data Transmission**: Multi-layer data transmission systems improve throughput by transmitting multiple data streams simultaneously. However, superimposed pilots further complicate the detection process.
- **End-to-End Learning Capability**: Deep receivers leverage data-driven learning to extract complex channel characteristics and mitigate interference from superimposed pilots.
- **Enhancing Robustness with Data Augmentation**: Data augmentation techniques can improve the robustness of both conventional and deep receivers, making them more resilient to real-world uncertainties.

System Model

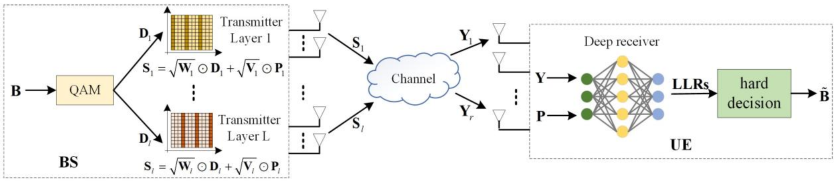


Fig. 1. A system for MIMO-OFDM multi-layer data transmission with SIP scheme.

We consider a MIMO-OFDM downlink system, where transmission resources are allocated across S subcarriers in the frequency domain and T symbols in the time domain, enabling parallel transmission of an L-layer bitstream.

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

$$\mathbf{S}_l = \sqrt{\mathbf{W}_l} \odot \mathbf{D}_l + \sqrt{\mathbf{V}_l} \odot \mathbf{P}_l.$$

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

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

Deep Receiver Based on Multi-Head Self-Attention Mechanism

- **Common Subspace**: Extracts shared features from intermediate results in the signal-to-LLR mapping process. By leveraging these shared features across tasks, it improves the receiver's robustness.
- **Multi-Head Self-Attention**: Allows parallel attention to different signal feature layers, enhancing the receiver's ability to extract key information and improving demodulation accuracy and interference resistance.

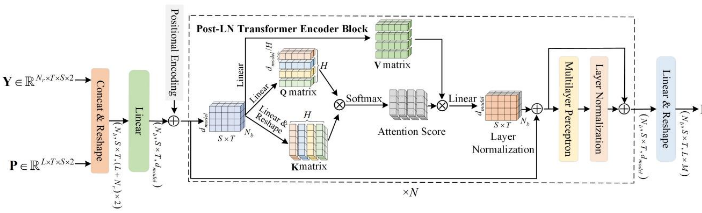


Fig. 2. Architecture design of the proposed SANet.

Data Augmentation Strategy

This strategy can be dynamically adjusted to meet the specific requirements of various scenarios.

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

$$\mathbf{Y}_{\text{aug}} = \exp\left(j \cdot \boldsymbol{\alpha}_{\text{aug}}\right) \cdot \mathbf{Y}.$$

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

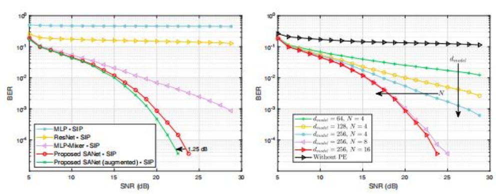
$$\mathbf{Y}_{\text{aug}}[:,k,:,:,:] = \mathbf{Y}[:,\pi(k),:,:,:].$$

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

$$\mathbf{P}_{\text{aug}}\left[:,k,:,:,:\right] = \mathbf{P}\left[:,K-k-1,:,:,:\right],$$
$$\mathbf{B}_{\text{aug}}\left[:,k,:,:,:\right] = \mathbf{B}\left[:,K-k-1,:,:,:\right].$$

TABLE II
AVERAGE BER PERFORMANCE OF DATA AUGMENTATION STRATEGIES

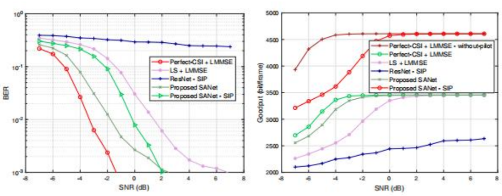
Data Augmentation Methods	Average BER
SANet ($d_{model} = 256$, $N = 16$)	0.02426
SANet + Angle rotation	0.02389 (- 0.00037)
SANet + Time-domain shuffle	0.02383 (- 0.00043)
SANet + Data flipping	0.02385 (- 0.00041)
SANet (augmented)	0.02320 (- 0.00106)



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

Fig. 3. BER performance of different receiver schemes and the proposed SANet under various parameter settings.

Experiments Results



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

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

✓ we developed a data augmentation strategy to further enhance the robustness capability of the receiver.

✓ 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.

That is all! ! !