電機資訊學院 2025 作 BRAIN PLUS HAND 實作專題競賽

AutoEncoder Applied to Radio-over-Fiber (RoF) Terahertz Wireless Communication Systems

應用於6G光纖前傳太赫茲無線通訊系統之自編碼器

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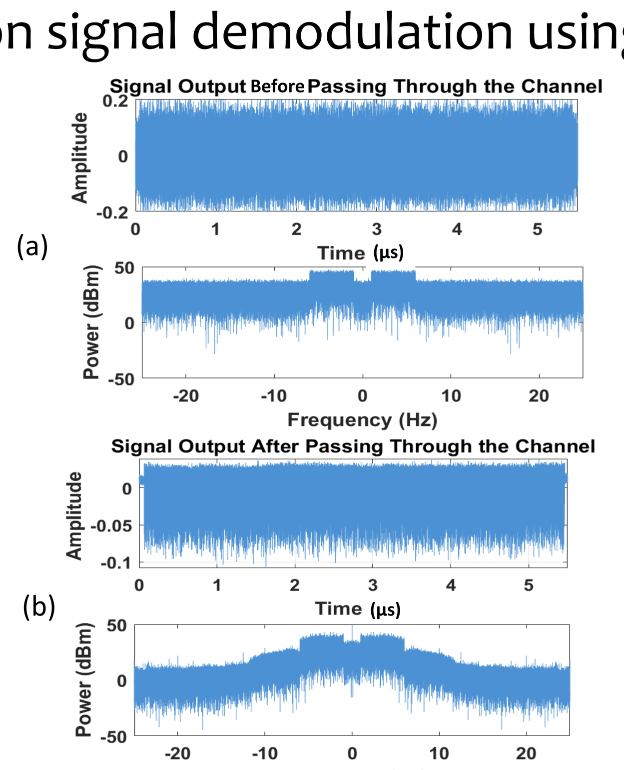
I. Abstract

With the advancement of 5G and emerging 6G standards, communication frequency bands are extending to millimeter-wave and terahertz ranges, offering ultra-high spectral efficiency and transmission rates. This project simulates and experiments in the 300 GHz terahertz band for 6G, employing an AutoEncoder model to mitigate nonlinear effects introduced by the experimental channel. This approach lowers Bit error rate (BER) of the OFDM system.

II. Introduction

In the experimental setup, the Mach-Zehnder Modulator (MZM), Uni-Traveling-Carrier Photodiode (UTC-PD), and Fermi-level Managed Barrier Diode (FMB) all introduce nonlinear effects to the signal. Severe nonlinear effects can result in waveform distortion and more pronounced inter-carrier interference (ICI), leading to increased demodulation error rates and reduced system reliability. Therefore, we aim to mitigate the impact of these effects on signal demodulation using machine learning.



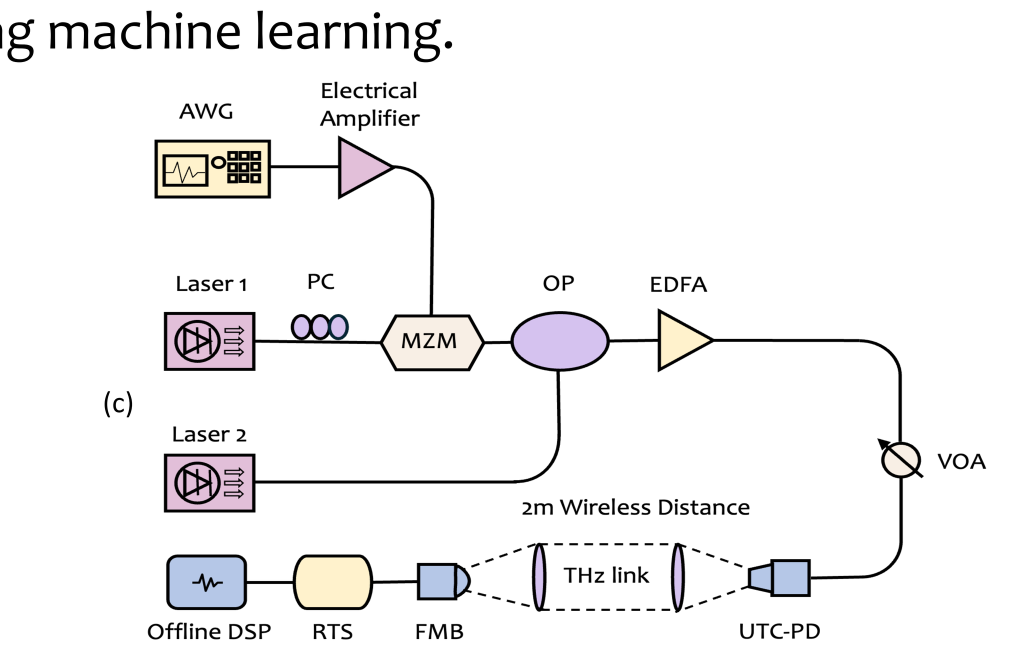


Fig. 1 (a) Signal of Transmitter (b) Signal of Receiver (with nonlinear effects) (c) Experimental Terahertz Fiber Optic Communication system setup

III. Research Methodology

a. AutoEncoder

AutoEncoder (AE) is an unsupervised learning model designed to compress and reconstruct data, enabling constellation points restoration without labeling data. By reducing two-dimensional signals to one dimension, data distribution accuracy improves.

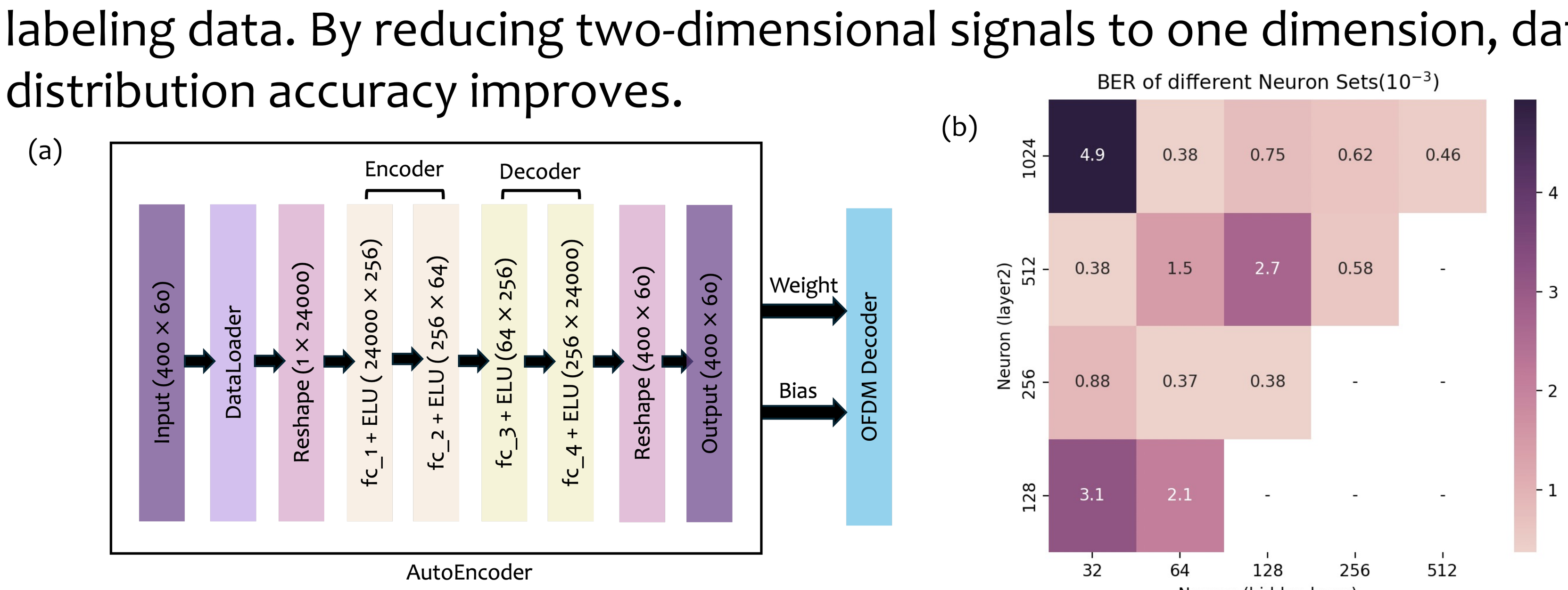


Fig. 2 (a) Structure of AutoEncoder, (b) Heat map of different neuron sets

The AE features a symmetrical Encoder and Decoder structure. The architecture includes two fully connected layers with ELU activation, chosen for its ability to handle negative inputs, avoid the "Dying ReLU" problem, and offer tunable saturation properties. The heat map (fig.2(b)) helps identify efficient neuron combinations to minimize BER while reducing computational cost, leading to the selection of (256, 64) for optimization.

b. OFDM

In OFDM systems, signal transmission faces performance degradation due to linear and non-linear effects. Zero-Forcing Equalizer (ZF Equalizer) addresses linear effects using an inverse channel matrix. While the AutoEncoder addresses non-linear effects, which cannot simply be compensated by ZF Equalizer.

IV. Results

a. Constellation Diagram

In the 4QAM experiment with 10dB SNR, the ZF Equalizer reduced BER by 94% by mitigating linear effects. Applying the AutoEncoder further reduced BER by 61.7%, addressing non-linear distortions.

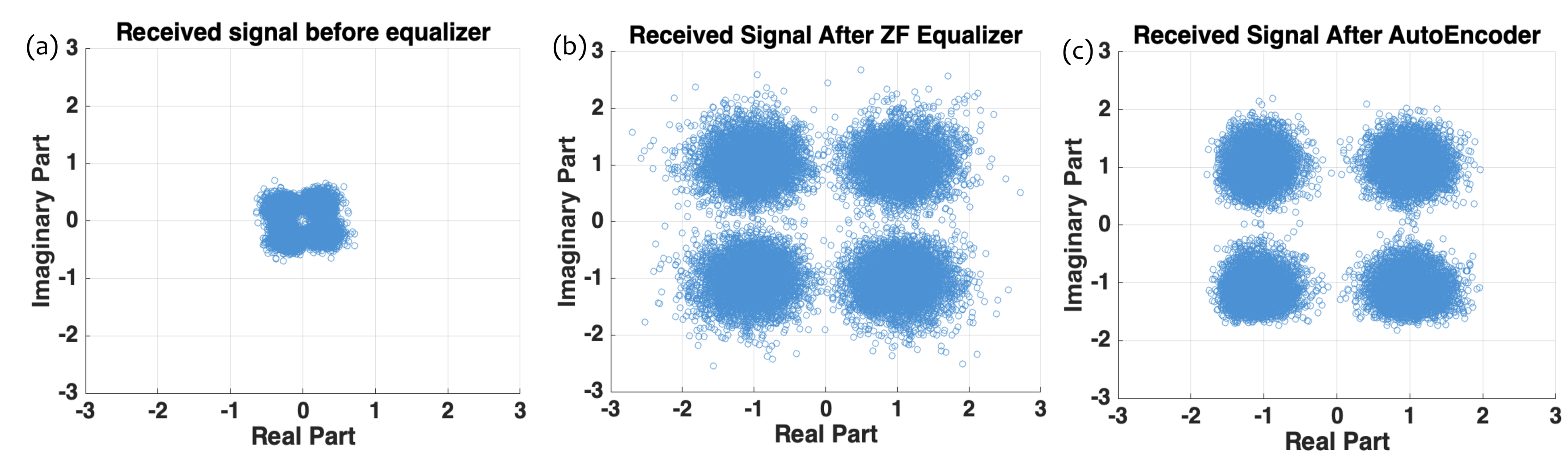


Fig. 4 (a) Before Equalization, BER: 1.8×10^{-2}, (b) After ZF Equalization, BER: 9.8×10^{-4}, (c) After AutoEncoder, BER: 3.75×10^{-4}

b. BER vs. SNR

After incorporating the trained AutoEncoder, exhibits a leftward shift in BER vs. SNR. This allows the system to meet the Forward Error Correction (FEC) threshold (BER of 3.8×10^{-3}) with an SNR reduced from 9dB to 8dB.

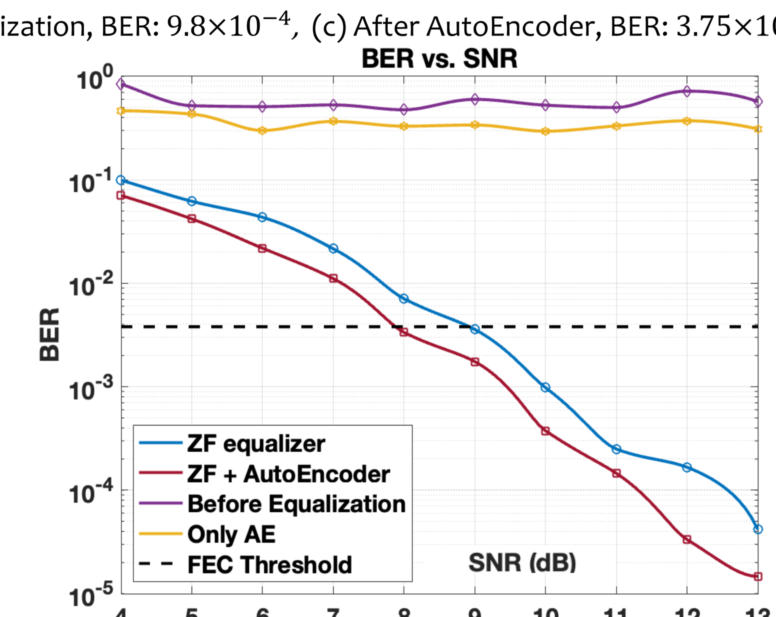


Fig. 5 BER vs. SNR with/without AE after ZF Equalizer

c. Gain

As SNR increases, both ZF Equalizer and AutoEncoder gains improve. Fig. 6(b) shows AutoEncoder alone cannot fully replace the Equalizer, primarily mitigating nonlinear effects while linear effects compensation still relies on the ZF Equalizer.

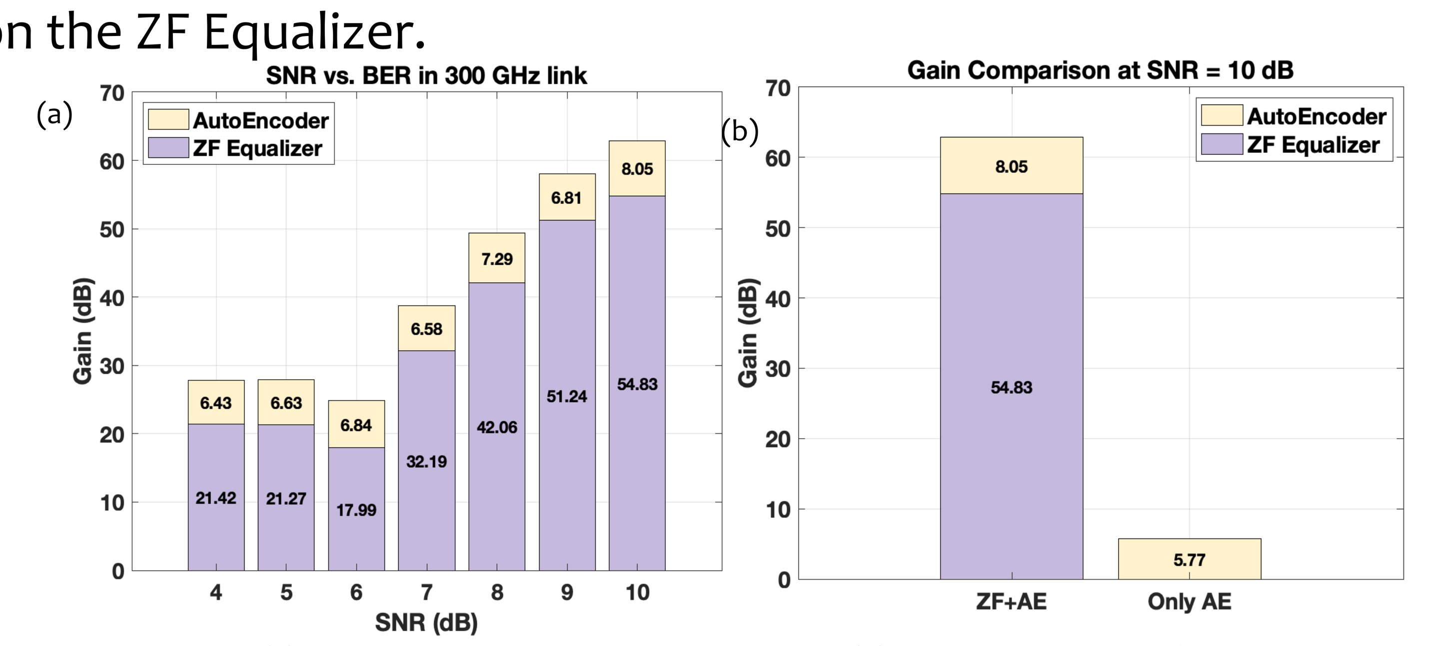


Fig. 6 (a) ZF Equalizer and AE gains at varying SNRs, (b) Gain comparison with/without AE

c. Application of AutoEncoder in OFDM

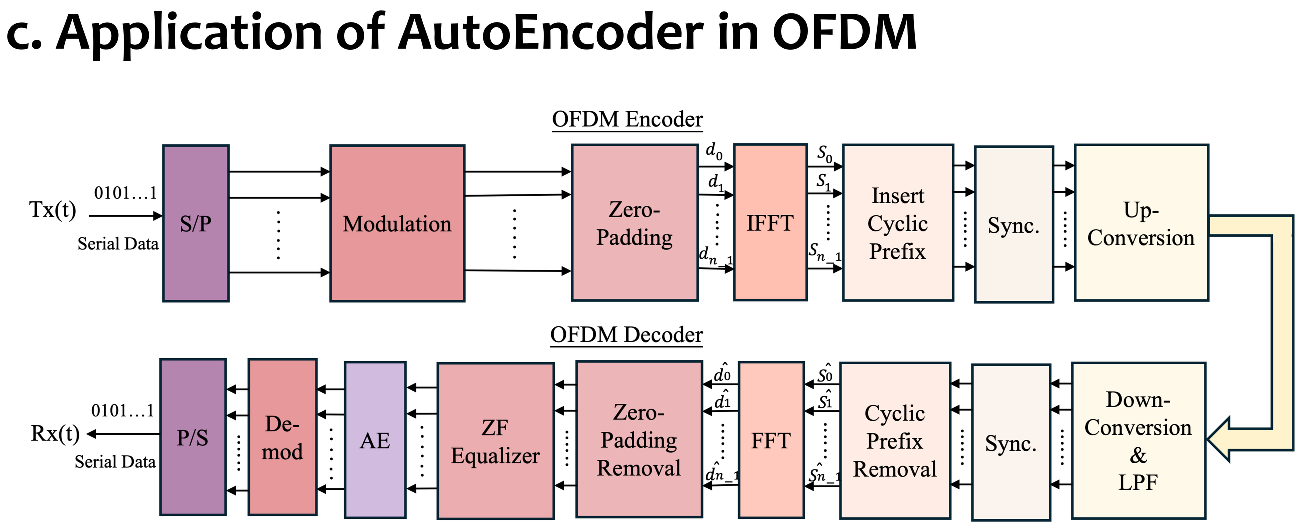


Fig. 3 Structure of OFDM combined with AutoEncoder

V. Conclusion

In this project, we integrated the AutoEncoder model into the lab's OFDM framework to address nonlinear effects beyond the ZF Equalizer's capabilities. Experiments at a 300 GHz carrier with 4QAM and SNR = 10 dB showed a 61.7% reduction in BER, significantly enhancing system performance and reliability. Moving forward, we plan to refine the AutoEncoder to handle more complex channels and higher-order modulation schemes, paving the way for practical applications in 6G communication systems.