FlexRx: an end-to-end Deep Learning-Based OFDM Receiver

By: Yuzheng He Supervisor: Rasheed Hussain

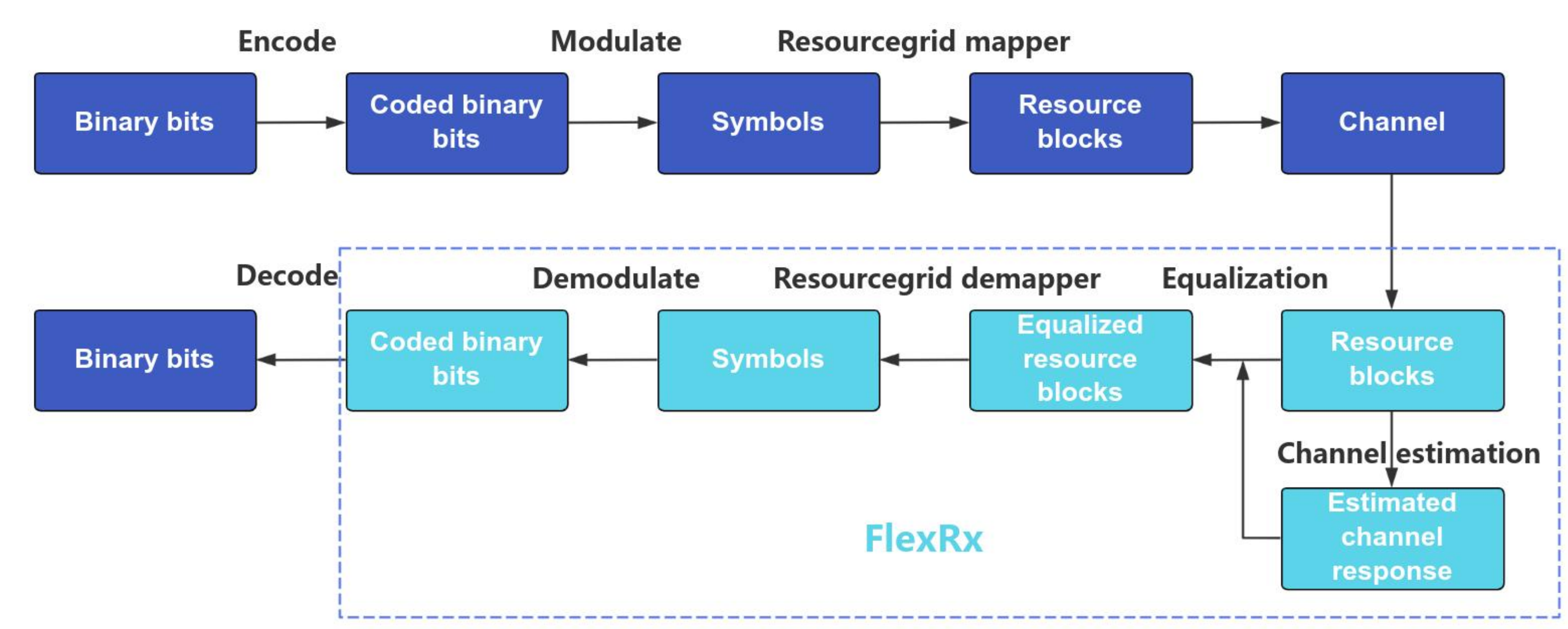
Introduction

- **Orthogonal Frequency Division Multiplexing (OFDM)** is widely used in modern wireless communication systems.
- **Traditional OFDM receivers** struggle with noise and channel estimation, as well as equalization, resulting in higher bit error rates (BER) .
- **Current deep learning-based OFDM receivers** can achieve lower BER but often have limited flexibility and higher computational complexity.

Objectives

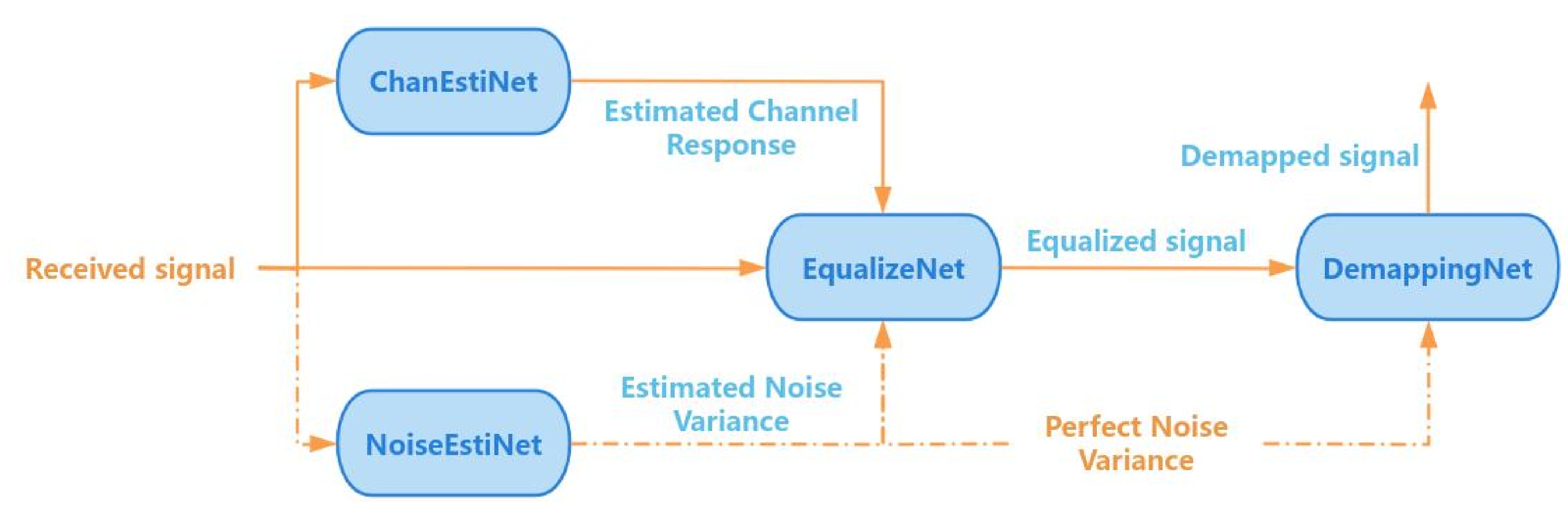
- Develop an **end-to-end deep learning-based OFDM receiver** covering channel estimation, noise estimation, equalization, and demapping.
- Enhance the receiver's **flexibility** to adapt to **diverse operating conditions**, while optimizing **complexity** such as **parameter size** and **processing time** for sustained efficient performance.
- Evaluate and compare the BER performance of the proposed network against traditional and existing deep learning-based receivers under various operating conditions.

Implementation



- The **overall OFDM system** includes end-to-end signal processing from transmission to reception, covering the full process from encoding to decoding.
- The **FlexRx** is designed to optimize the OFDM receiver by effectively extracting soft information of encoded bits from the received signal.

- **ChanEstiNet**: Estimates the channel response.
- **NoiseEstiNet**: Estimates the noise variance, with the option to bypass it for perfect noise variance.
- **EqualizeNet**: Produces the equalized signal.
- **DemappingNet**: Recovers the demapped signal.



FlexRx Network Overview: The tight integration of four modules forms an entire OFDM receiver, ensuring accurate and efficient signal recovery.

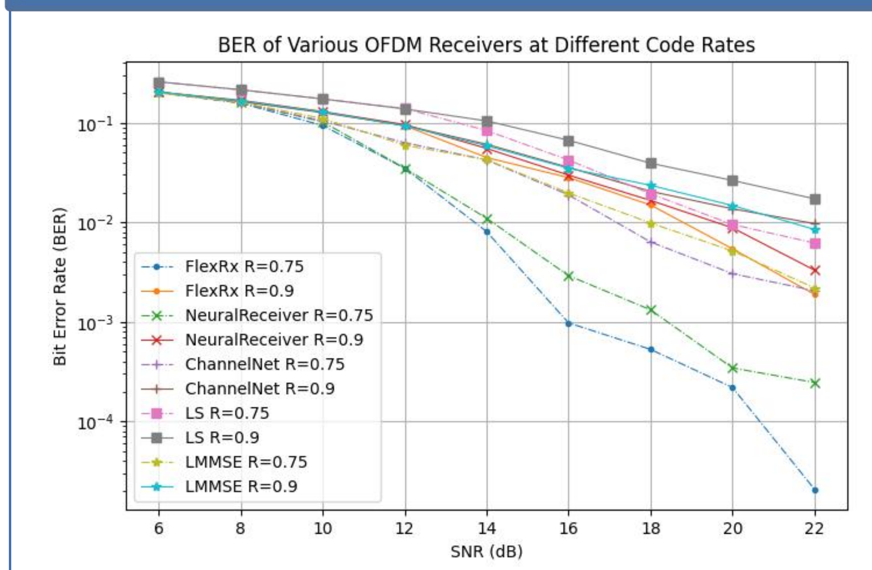
Experimental Design and Comparisons

Receiver Configurations	FlexRx	NeuralReceiver [1]	ChannelNet [2]	LS	LMMSE
			Zero Forcing	Zero Forcing	Zero Forcing
			Maximum Likelihood	Maximum Likelihood	Maximum Likelihood

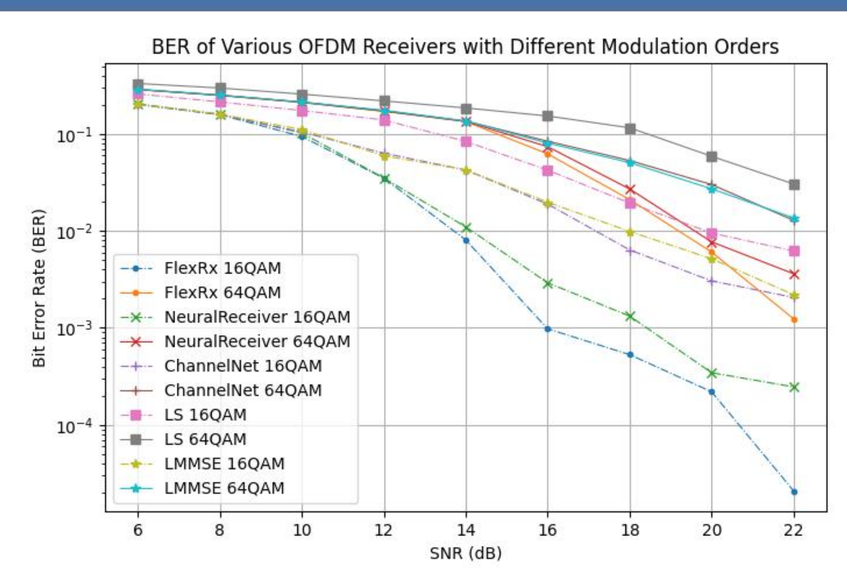
Test Conditions	Code Rate: 0.75 & 0.90	Modulation Order: 16 & 64QAM	Wireless Channel Type: umi & rma	User Speed: static & 120 km/h

- **FlexRx** and **NeuralReceiver** are complete OFDM receivers designed to directly recover soft bits from received signals.
- **ChannelNet**, **Least Squares (LS)**, and **Linear Minimum Mean Square Error (LMMSE)** are channel response estimators combined with Zero Forcing (ZF) equalizers and Maximum Likelihood (ML) demappers to form complete receivers.
- Test the BER performance under different **channel conditions** such as user speed and wireless channel type.
- Test the BER performance with different **transmission parameters**, such as modulation order and code rate.

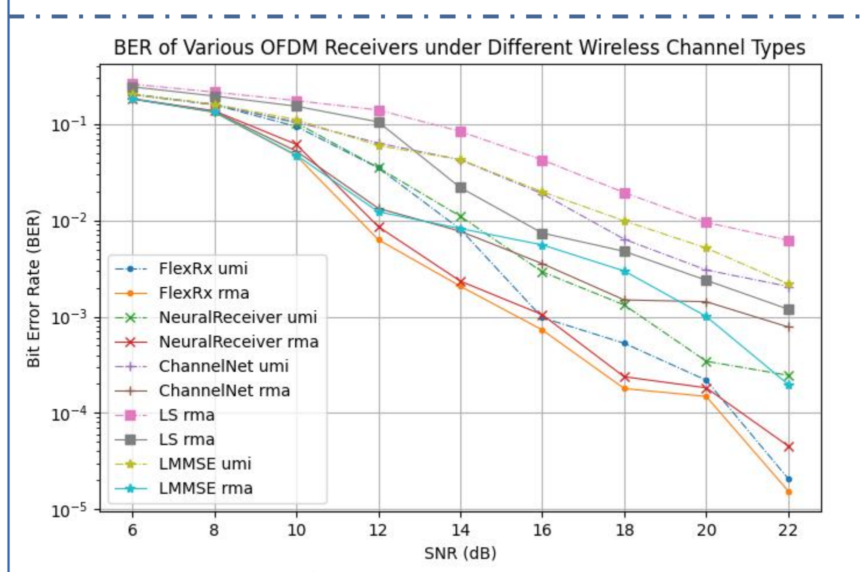
BER Results & Analysis



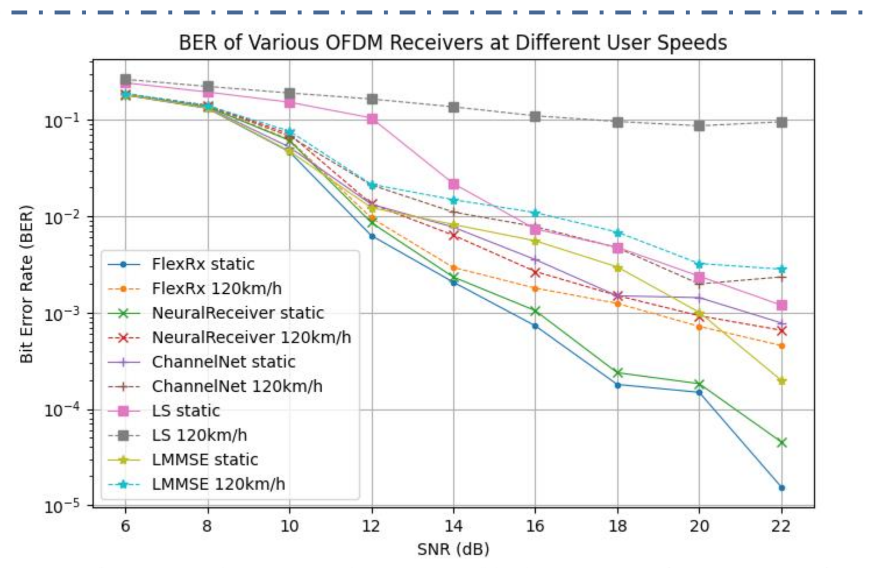
- **FlexRx at 0.75 code rate** achieves the best BER performance.
- **FlexRx at 0.9 code rate** needs **5 dB** more SNR than at 0.75 for the same BER of 10^{-2}.



- **FlexRx with 16QAM** achieves the best BER performance.
- **FlexRx with 64QAM** needs **5.5 dB** more SNR than 16QAM for the same BER of 10^{-2}.

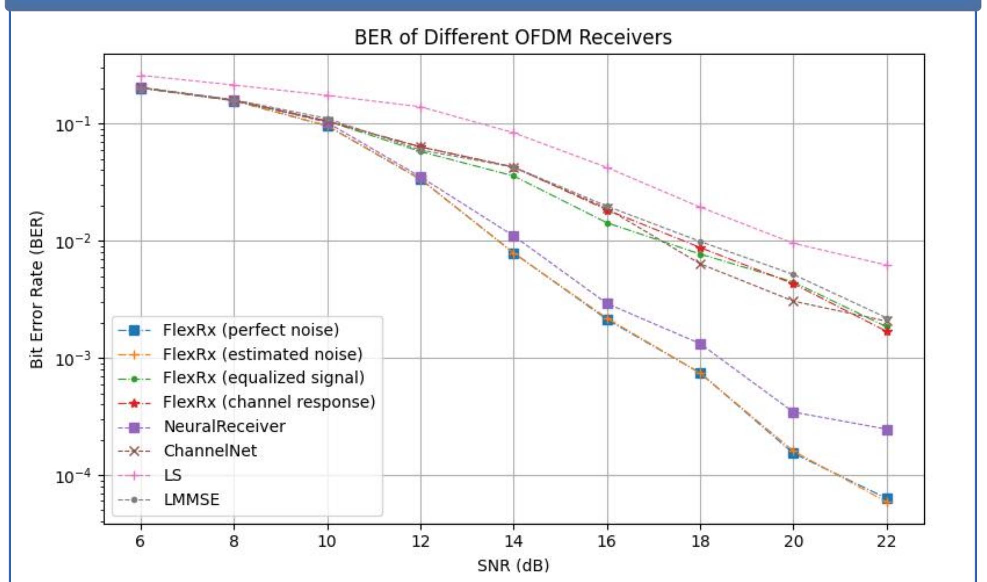


- **FlexRx under rma channel** achieves the best BER performance.
- **FlexRx under umi channel** needs **0.8 dB** more SNR than under rma channel for the same BER of 10^{-3}.

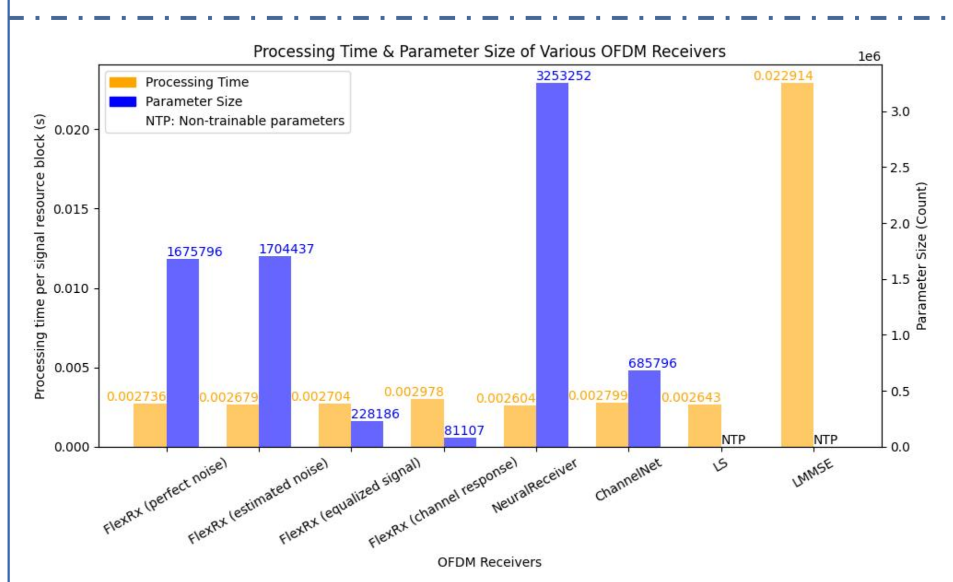


- **FlexRx in static conditions** achieves the best BER performance.
- **FlexRx at 120 km/h** needs **3.5 dB** more SNR than in static conditions for the same BER of 10^{-3}.

Flexibility Analysis



- **FlexRx with perfect or estimated noise variance** achieves the lowest BER, though at the cost of increased training time.
- Using **predicted equalized signal** or **channel response of FlexRx** increases BER, but remains within acceptable limits.



- FlexRx achieves a **balance** between **minimal parameter size** and **fast processing time**.

Conclusion

- **Development of FlexRx**: This end-to-end multi-module deep learning-based OFDM receiver is designed to effectively recover soft bits from the received signal.
- **Excellent BER Performance**: FlexRx demonstrates low BER across various operating conditions.
- **High Flexibility with Low Complexity**: FlexRx allows for different processing configurations, enabling efficient and adaptable processing across various scenarios.

Reference

[1] J. Hoydis, S. Cammerer, F. Ait Aoudia, et al., "Sionna: An Open-Source Library for Next-Generation Physical Layer Research," arXiv preprint, Mar. 2022.

[2] M. Soltani, V. Pourahmadi, A. Mirzaei, et al., "Deep Learning-Based Channel Estimation," arXiv preprint, 2019.