LoRa Digital Receiver Analysis and Implementation

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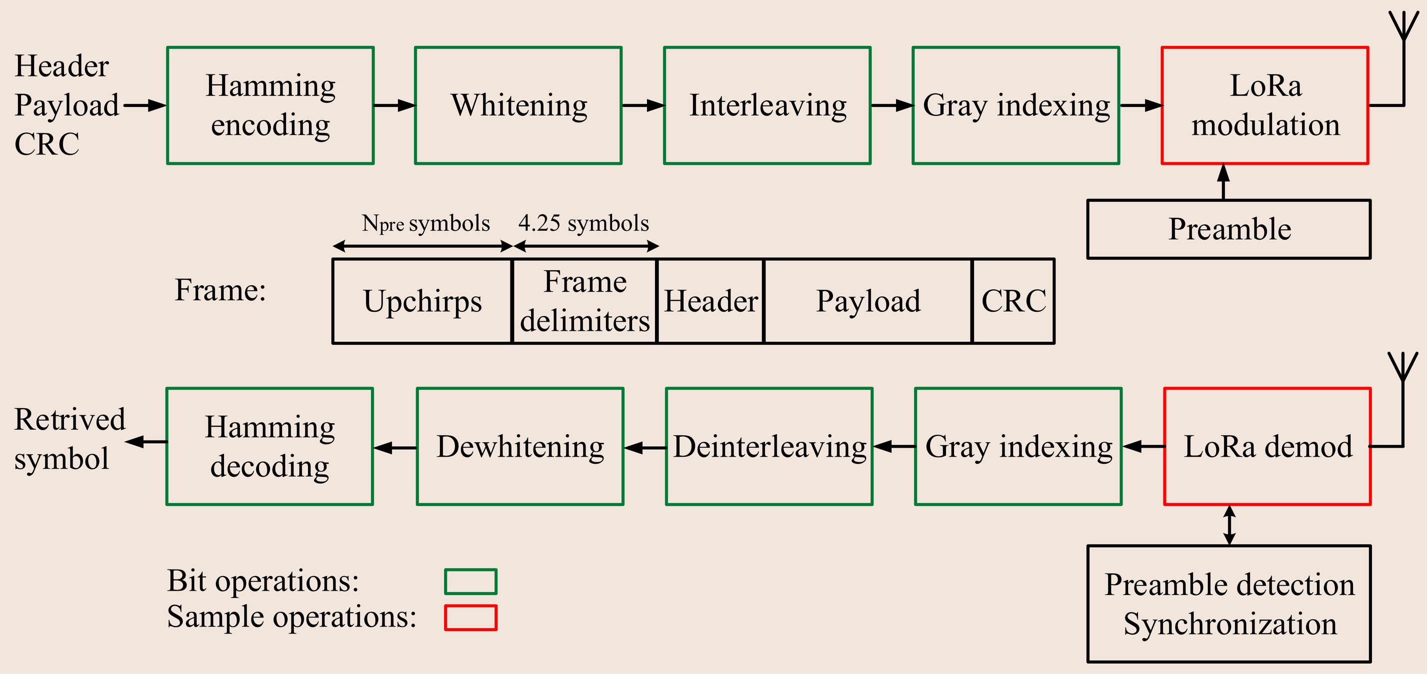
Introduction

- LoRa is a proprietary physical layer (PHY) standard for low power wide area networks

LoRa PHY block diagram and frame structure



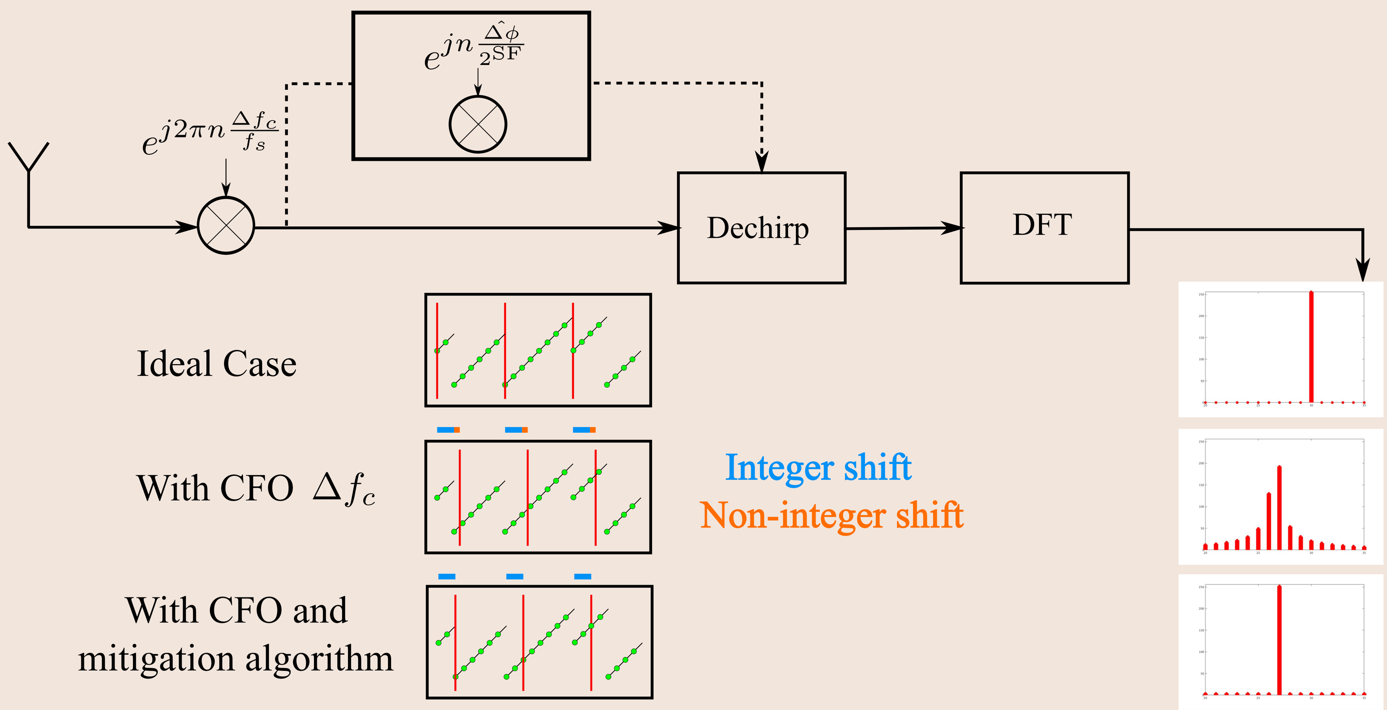
Carrier Frequency Offset (CFO) Analysis

Problem Formulation

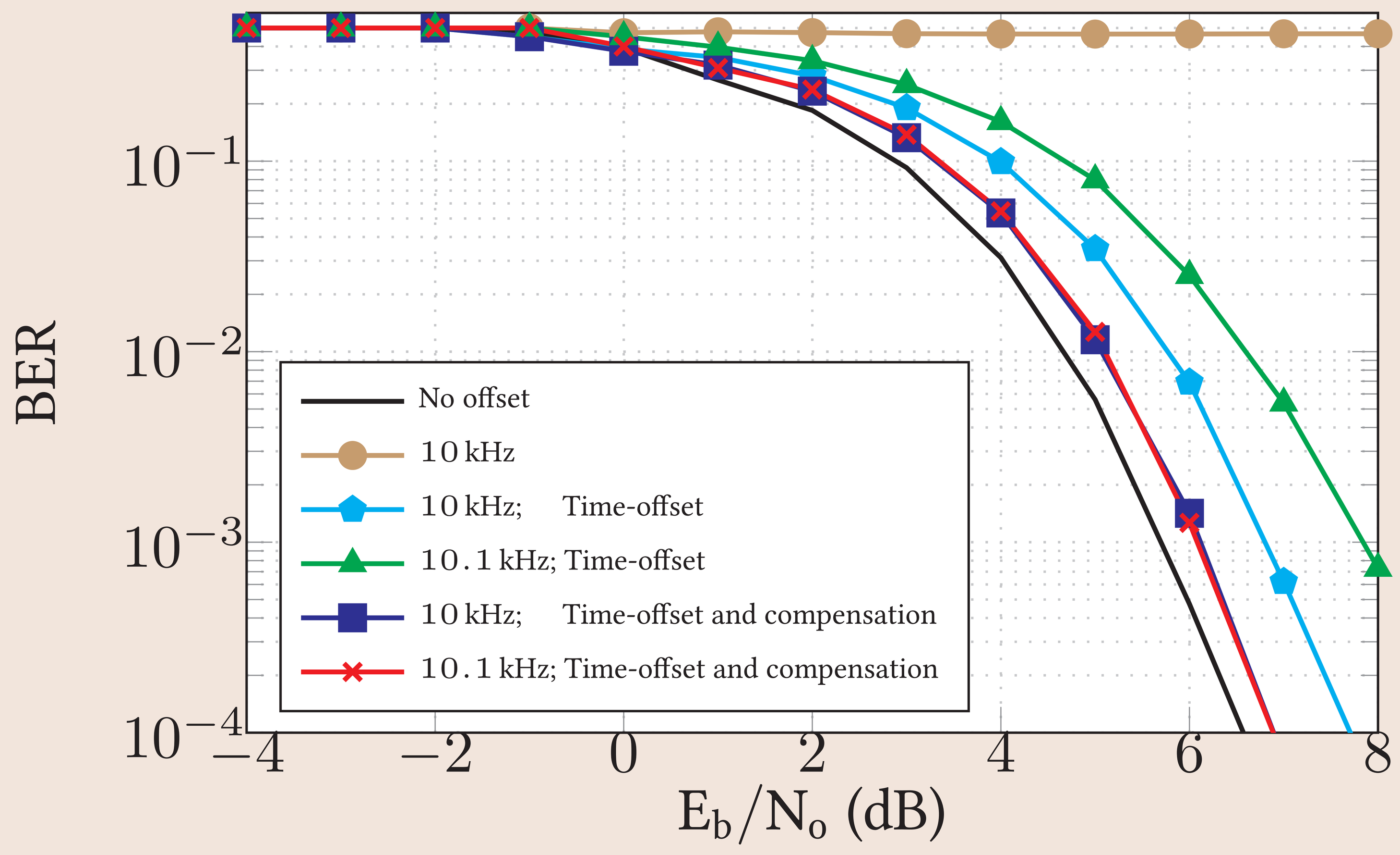
- Δf_c : Difference between carrier frequencies used for up- and down-conversion (CFO).
- CFO results in a frequency shift leading to a decision error.
- The frequency shift can be modeled as a time shift consisting of an integer shift of $L = \lfloor \frac{\Delta f_c}{f_s} \cdot 2^{SF} \rceil$ chips and a non-integer shift.

Estimation and Compensation of CFO

- **Integer shift:** The CFO leads to a time offset in synchronization by L samples, which partially compensates for the CFO.
- **Non-integer shift:** A residual CFO remains – an estimation of the phase offset $\hat{\Delta\phi}$ can be obtained using the phase difference of the samples with the same index along all preamble symbols.



- **Results:** system bit error rate before/after CFO compensation



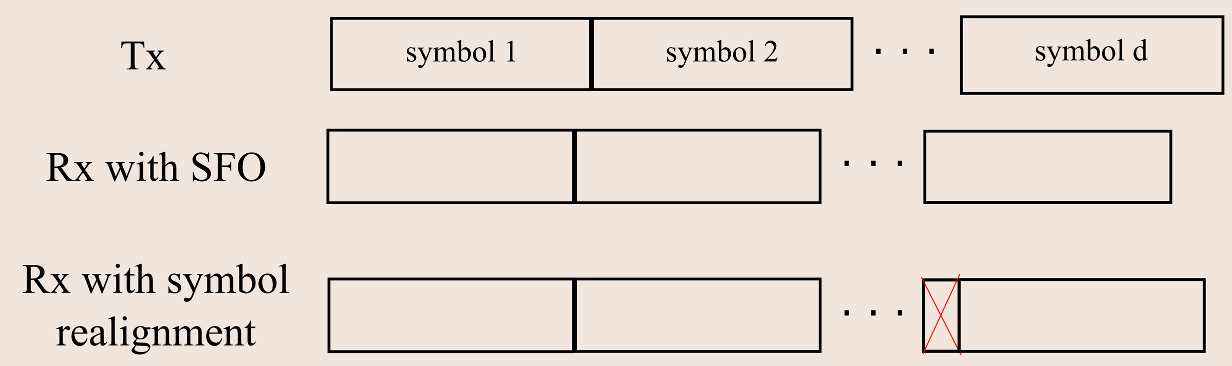
Sampling Frequency Offset (SFO) Analysis

Problem Formulation

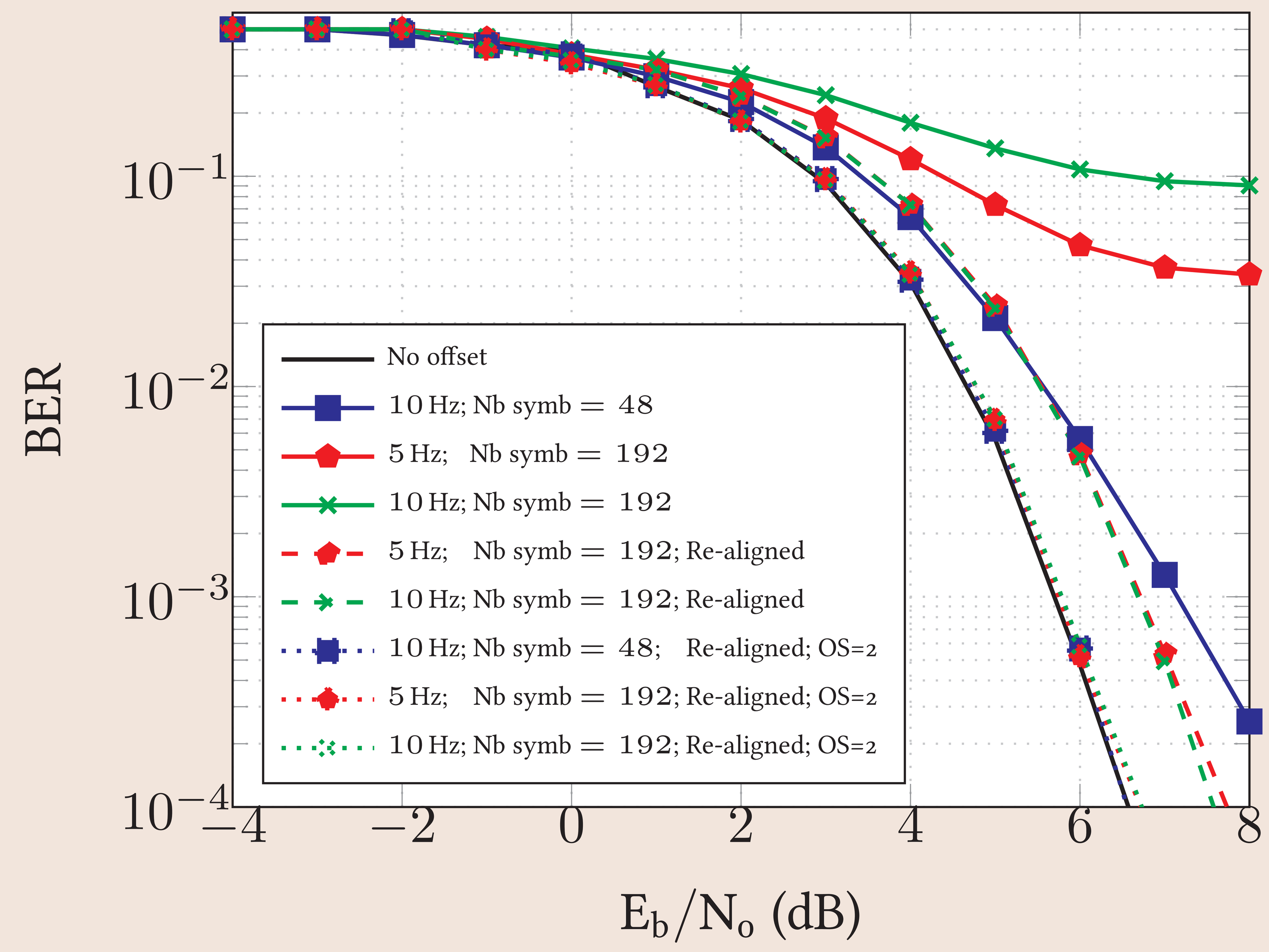
- $\Delta T_d = d\left(\frac{2^{SF}}{f_s'} - T_s\right)$: The progressing time offset of the d-th symbol due to sampling rate mismatch ($f_s' \neq BW$)
- Re-sampling of the signal required for a correct demodulation

Estimation and Compensation

- **Assumption:** The receiver is able to generate a reference signal that matches the transmitter BW. Then the SFO simplifies to a sample drift.
- **Solution:** discard (add) a sample when sample drift corresponds to more than half a sample is drifted $\frac{n+1/2+d2^{SF}}{f_s'} < \frac{n+d2^{SF}}{BW}$ (symbol realignment).

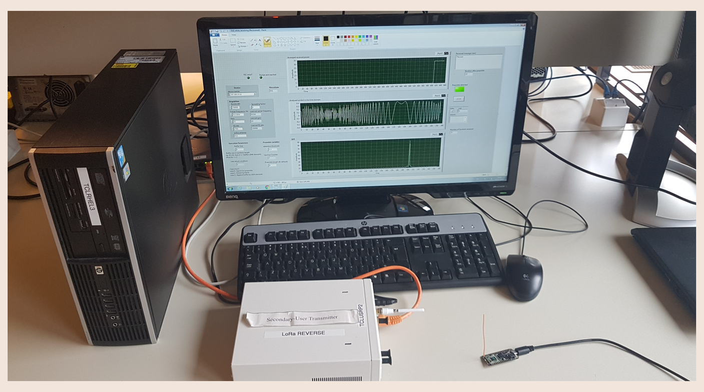


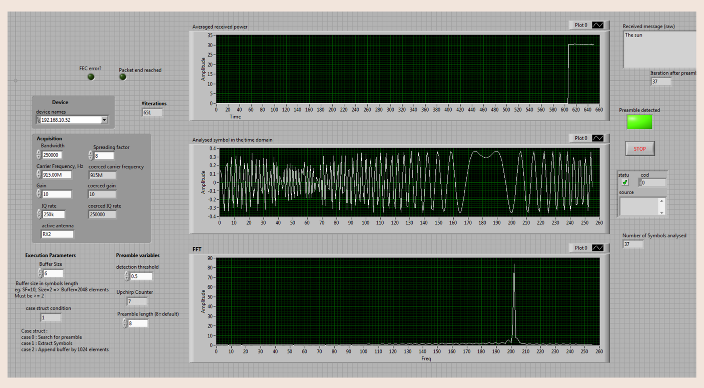
- **Results:** system bit error rate before/after SFO compensation



SDR Implementation

LoRa Transceiver Implementation on USRPs





Conclusion

- LoRa receiver is partially robust against CFO.
- SFO effect on LoRa demodulation can be compensated by symbol boundary realignment.
- LoRa transceiver is implemented on a USRP platform.

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