Physical Communication

Implementaion of OFDM Transceiver

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CONTENT

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2. Transmitter
3. Channel
4. Receiver
5. Results
6. Conclusions and Discussion

INTRODUCTION

1. **Goal of the project:** Make a transmit/receive simulation model for a generic OFDM simulation.
2. **Future work:** Compliant with the IEEE 802.11p standard.

MODEL STRUCTURE

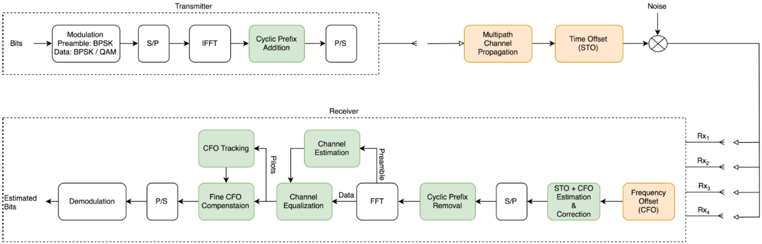

Figure: OFDM Model Structure.

TRANSMITER OVERVIEW

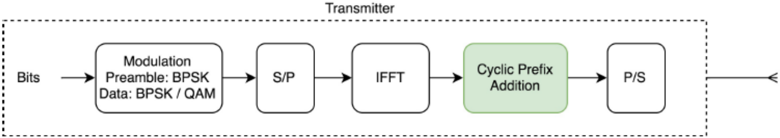

Figure: Transmitter Structure.

MODULATOR

QAM: amplitude modulation with two orthogonal carriers.
Gray Code: two successive values differ in only one bit.

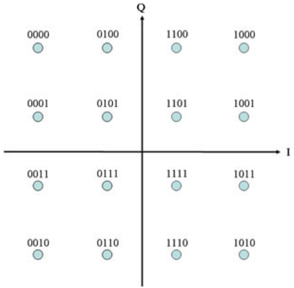

Figure: 16-QAM Signal Constellation with Gray Coding.

S-P/P-S CONVERTER

Serial to Parallel during modulation: The input data is formatted into 4 bits/symbol(16-QAM), 10 symbols/subcarrier and with 90 subcarriers. The goal is to perform IFFT calculation on each subcarrier at the same time.

Parallel to Serial after adding cyclic prefix and before transmission: Transmit the serial data with one antenna.

IFFT on transmitter: multi-carrier modulation.
FFT on receiver: multi-carrier demodulation.

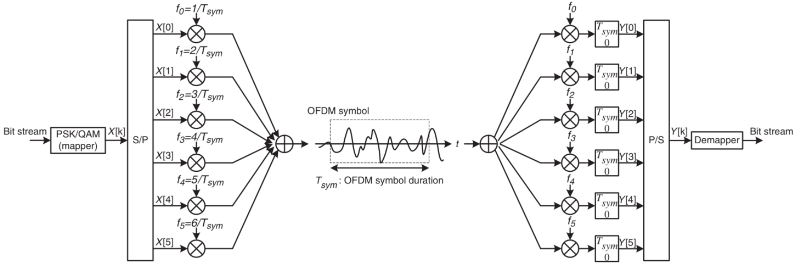

Figure: IFFT and FFT at transmitter and receiver side.

PILOT SYMBOLS

A pilot symbol is a complete OFDM symbol where the value of each subcarrier is predefined and known in transmitter and receiver. It is repeated with a certain rate that depends on how fast the channel changes. The received signal is correlated with the pilot symbol to detect the OFDM symbol start. It can also be used for channel estimation. In our experiment, the pilot frequency representation is $5 + 5i$ and there are 6 groups of pilot tones.

CYCLIC PREFIX

Cyclic Prefix: OFDM guard interval.

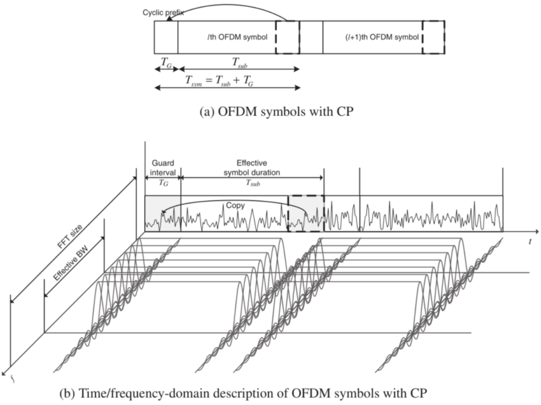

Figure: Cyclic Prefix Illustration.

Channel

Multipath fading

MULTIPATH FADING

THE SIGNAL ARRIVES FROM DIFFERENT PATHS WITH DIFERRENT DELAYS

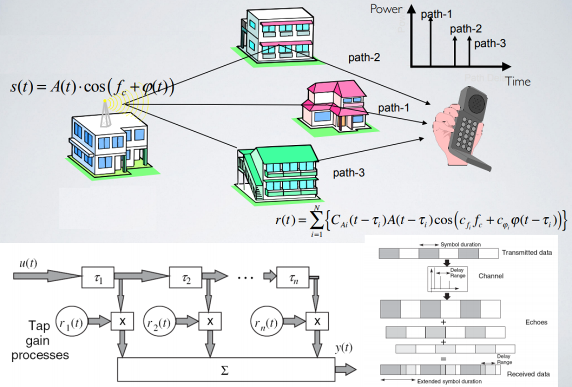

Figure: Multipath Transmission

Leads to:

- Signal Fading
- Signal dispersion and distortion

Channel

General Idea (Transfer function)

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TRANSFER FUNCTION

THE INTERPOLATED SIGNAL IS CALCULATED

- Based on the Channel estimate.
- Difference between estimators' theoretical values and true value estimated quantity.
- Use of Location of pilot sequence
- Calculation of Means square Error of Estimator

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SYNCHRONIZATION FOR OFDM

HOW CAN WE CORRELATE THE SIGNAL TO THE REAL ONE

1. OFDM: Orthogonal subcarriers for parallel transmission
2. Advantage only when orthogonality is maintained
3. If not orthogonal, the performance may be degraded
4. Interference (Inter-symbol interference,Inter-carrier interference)

Receiver

Symbol Time Offset (STO)

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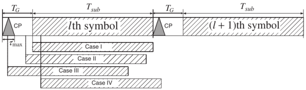
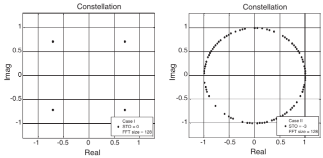
STO

THE SYMBOL HAS TO BE ALLIGNED

1. Symbol-timing synchronization detects the starting point per OFDM symbol
2. STO can be calculated in both domains
3. Time is simpler to calculate
4. Phase offset may be created



(a) Cases of STO



(b) Comparison of Signal with and without STO

STO ESTIMATION TECHNIQUES

SLIDING WINDOW IS A SIMPLE BUT EFFECTIVE TECHNIQUE

1. Two symbols with T_{sub} distance between the CP's
2. The CP has T_G duration
3. Consider two windows with distance equal to $N_{sub}(T_{sub})$
4. If the first symbol is in the CP, difference is minimized
5. This will be the optimal case

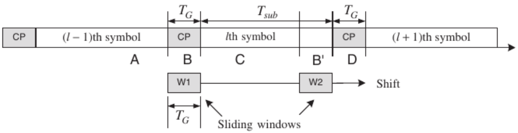


Figure: Sliding Window Estimation

STO ESTIMATION TECHNIQUES

MORE COMPLEX TECHNIQUES CAN LEAD TO BETTER ESTIMATION

Other Estimation techniques exist in the Time domain:

1. Previous technique can calculate the maximum likelihood instead
2. Training symbol can be used (Symbol division in two parts and correlation)
3. Minimum Squared Difference can be calculated for the maximum correlation
4. Cross-Correlation (Between Training Symbol and received signal)

STO can be calculated in the Frequeency domain as well estimating the phase difference.

Receiver
Carrier Frequency Offset (CFO)

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CFO

FREQUENCY SHIFT (ϵ) LEADS TO ICI

- f_c equals to transmitter carrier frequency
- f'_c equals to receiver carrier frequency
- δf equals to the subcarrier spacing
- $f_d = \frac{v \cdot f_c}{c}$
- $\epsilon = \frac{f_c - f'_c}{f_d}$

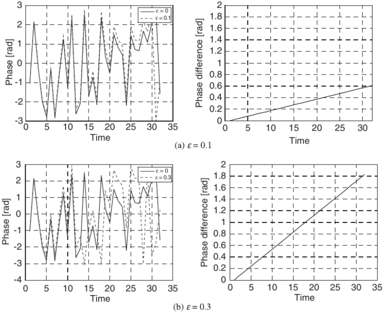

Figure: Comparison of Signal with different CFO’s

CFO ESTIMATION TECHNIQUES

CAN BE DONE ON TIME AND FREQUENCY DOMAIN

- The same techniques as in STO can be applied (CP, Training Symbol)
- Conversion of the phase rotation has to be made
- The frequency domain is simpler
- Pilot tones can be used to track CFO

Receiver
Channel estimation

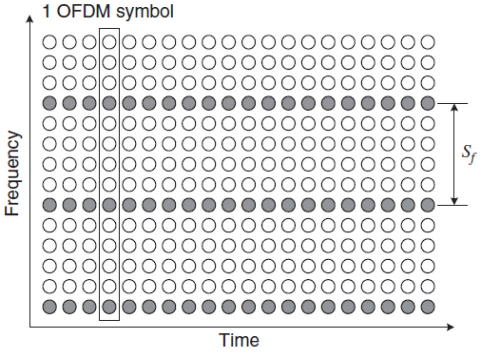

Figure: Comb-type pilot arrangement

- $S_f \leq \frac{1}{\sigma_{max}}$

- Suitable for fast-fading channels, but not for frequency-selective channels

- LS Channel Estimation

The least-square (LS) channel estimation method finds the channel estimate H in such a way that the following cost function is minimized:

$$\begin{aligned} J(\hat{\mathbf{H}}) &= \left\| \mathbf{Y} - \mathbf{X}\hat{\mathbf{H}} \right\|^2 \\ &= (\mathbf{Y} - \mathbf{X}\hat{\mathbf{H}})^H (\mathbf{Y} - \mathbf{X}\hat{\mathbf{H}}) \\ &= \mathbf{Y}^H\mathbf{Y} - \mathbf{Y}^H\mathbf{X}\hat{\mathbf{H}} - \hat{\mathbf{H}}^H\mathbf{X}^H\mathbf{Y} + \hat{\mathbf{H}}^H\mathbf{X}^H\mathbf{X}\hat{\mathbf{H}} \end{aligned}$$

$$\hat{\mathbf{H}}_{LS} = (\mathbf{X}^H\mathbf{X})^{-1}\mathbf{X}^H\mathbf{Y} = \mathbf{X}^{-1}\mathbf{Y}$$

RECEIVER

CHANNEL ESTIMATION

- Data interpolation

```
if pilot_loc(1)>1
slope = (H(2)-H_est(1))/(pilot_loc(2)-pilot_loc(1));
H = [H(1)-slope*(pilot_loc(1)-1) H];
pilot_loc = [1 pilot_loc];
end

if pilot_loc(end) <n_subcarriers
slope = (H(end)-H(end-1))/(pilot_loc(end)-pilot_loc(end-1));
H = [H H(end)+slope*(n_subcarriers-pilot_loc(end))];
pilot_loc = [pilot_loc n_subcarriers];
end
H_interpolated=interp1(pilot_loc,H,(1:n_subcarriers));
```

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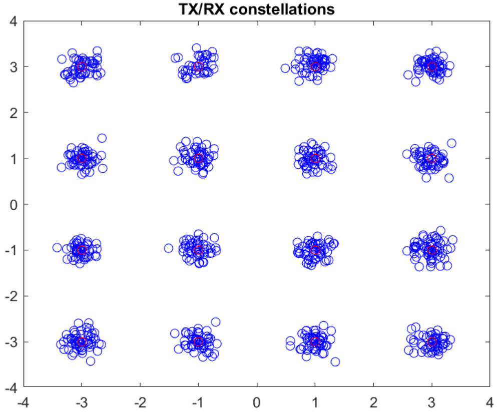
Results

Transmitter side

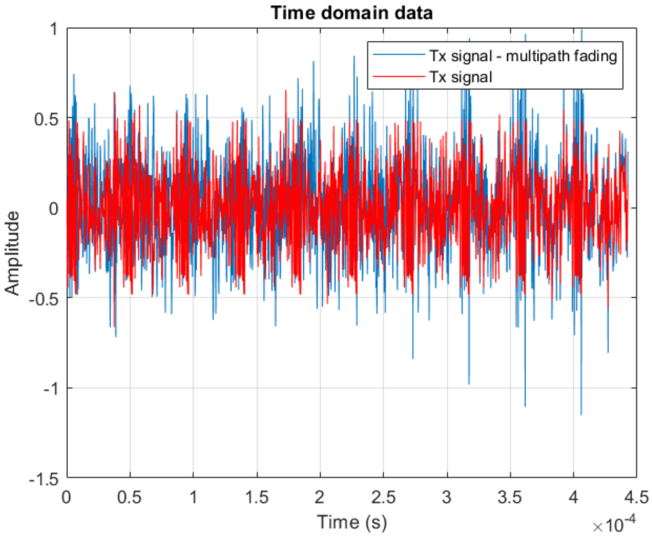
RESULTS

TRANSMITTER SIDE - TX CONSTELLATIONS



RESULTS

TRANSMITTER SIDE - TIME DOMAIN SIGNAL



Results

Channel transfer function

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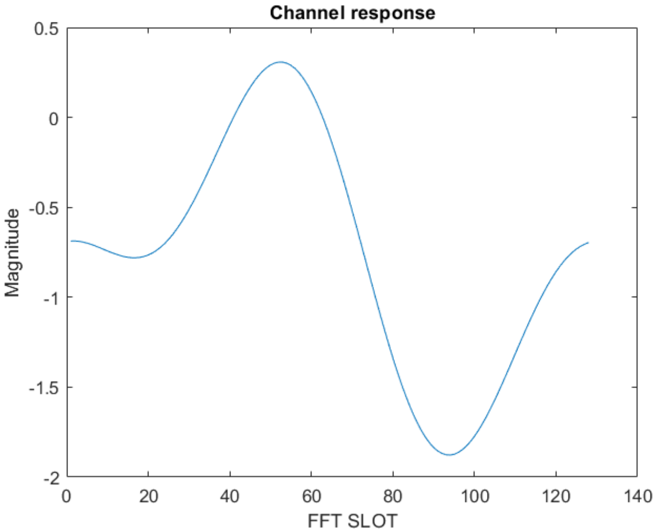
RESULTS

CHANNEL TRANSFER FUNCTION



Results

Compensation

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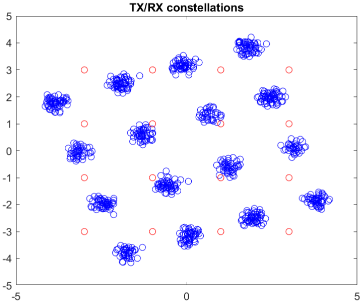
RESULTS

PHASE COMPENSATION

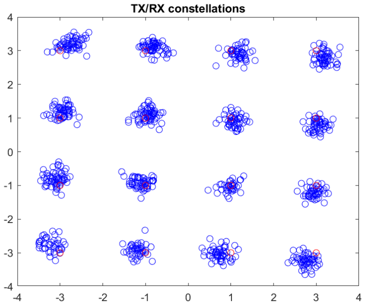
FREQUENCY OFFSET = 0; PHASE OFFSET = 20

WITHOUT PHASE TRACKING




```
tx data != rx data
>> main
```

WITH PHASE TRACKING




```
tx data = rx data
fx >>
```

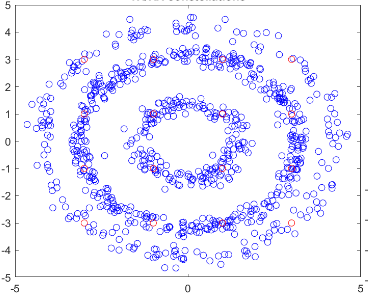
RESULTS

FREQUENCY COMPENSATION

FREQUENCY OFFSET = 7000; PHASE OFFSET = 0;

WITHOUT CFO ESTIMATION

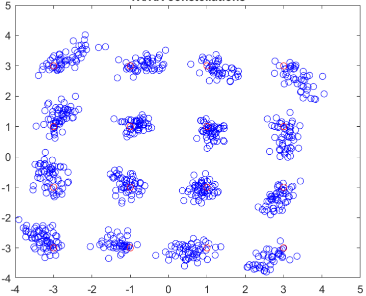
TX/RX constellations




```
tx data != rx data
>> main
```

WITH CFO ESTIMATION

TX/RX constellations



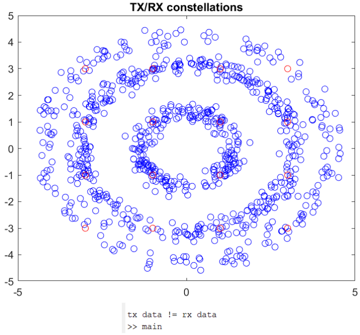

```
tx data = rx data
fx >>
```

RESULTS

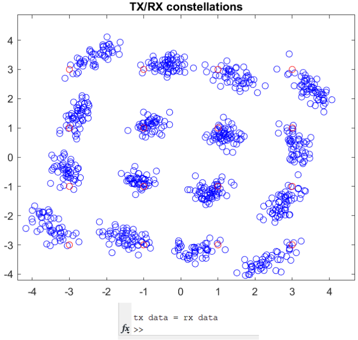
FREQUENCY AND PHASE COMPENSATION

FREQUENCY OFFSET = 7000, PHASE OFFSET = 20

NO PHASE AND CFO ESTIMATION



WITH PHASE AND CFO ESTIMATION



Results

Real world - TX signal

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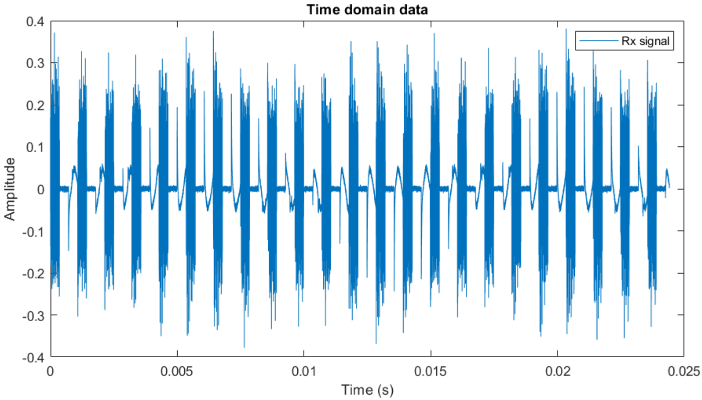
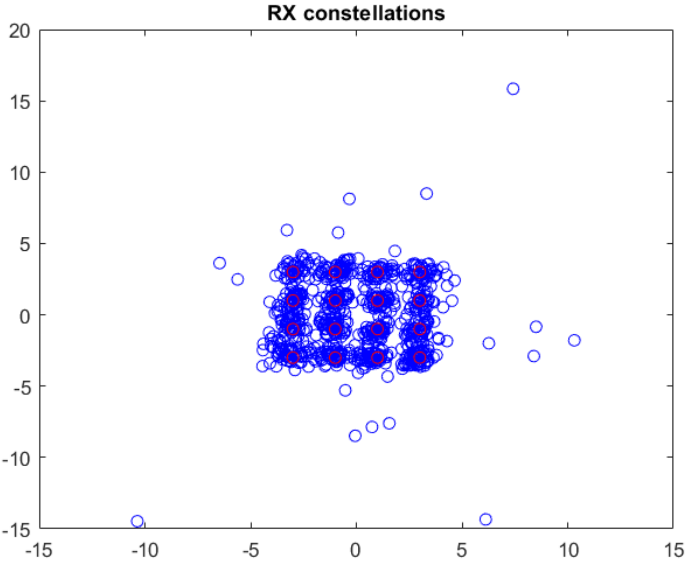
RESULTS

REAL WORLD - TX SIGNAL - SCENARIO 1



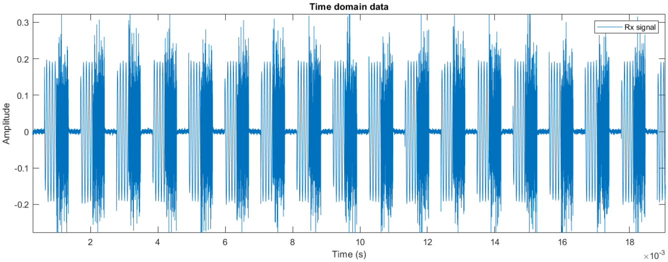
RESULTS

REAL WORLD - RX SIGNAL - SCENARIO 1



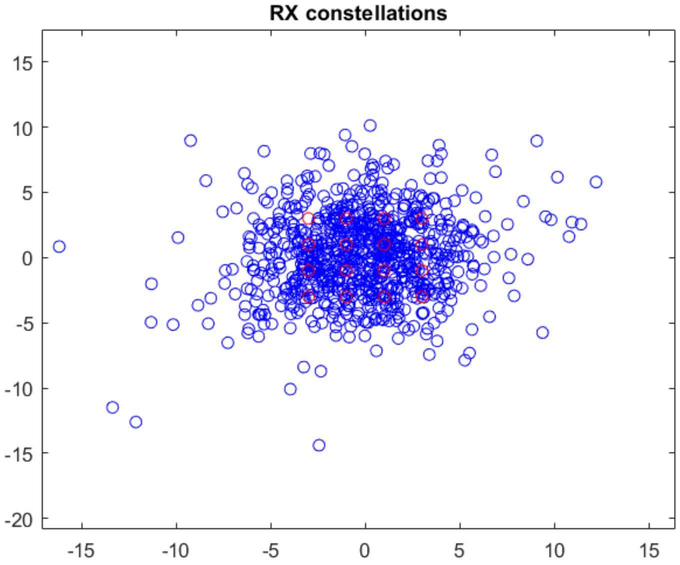
RESULTS

REAL WORLD - TX SIGNAL - SCENARIO 2



RESULTS

REAL WORLD - TRX SIGNAL - SCENARIO 2



Results

Intepretation

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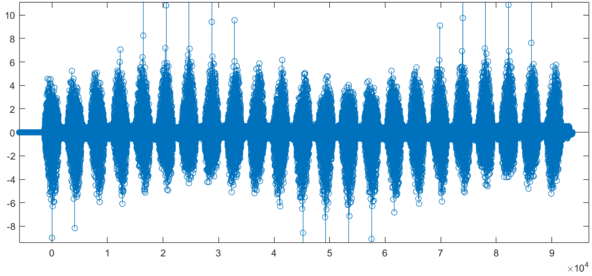
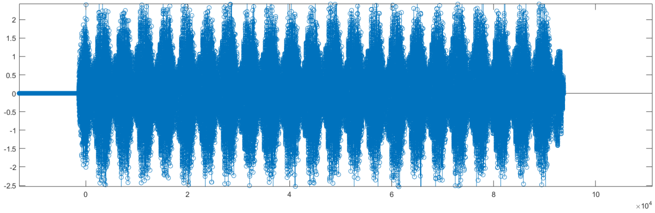
RESULTS

INTEPRETATION





Results

Tried but did not worked

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MORE

TRIED BUT NOT WORKED

- Data coding (only TX part implemented but not used)
- Use preamble for channel estimation (not used in real world scenario)
- Get the real channel transfer function
- Use MMSE for channel estimation

REPOSITORY LINK

https://github.com/vladBaciu/SW_2020_Matlab_OFDM_simulation