Designing and Implementing a MIMO-OFDM Transmission Link using USRPs

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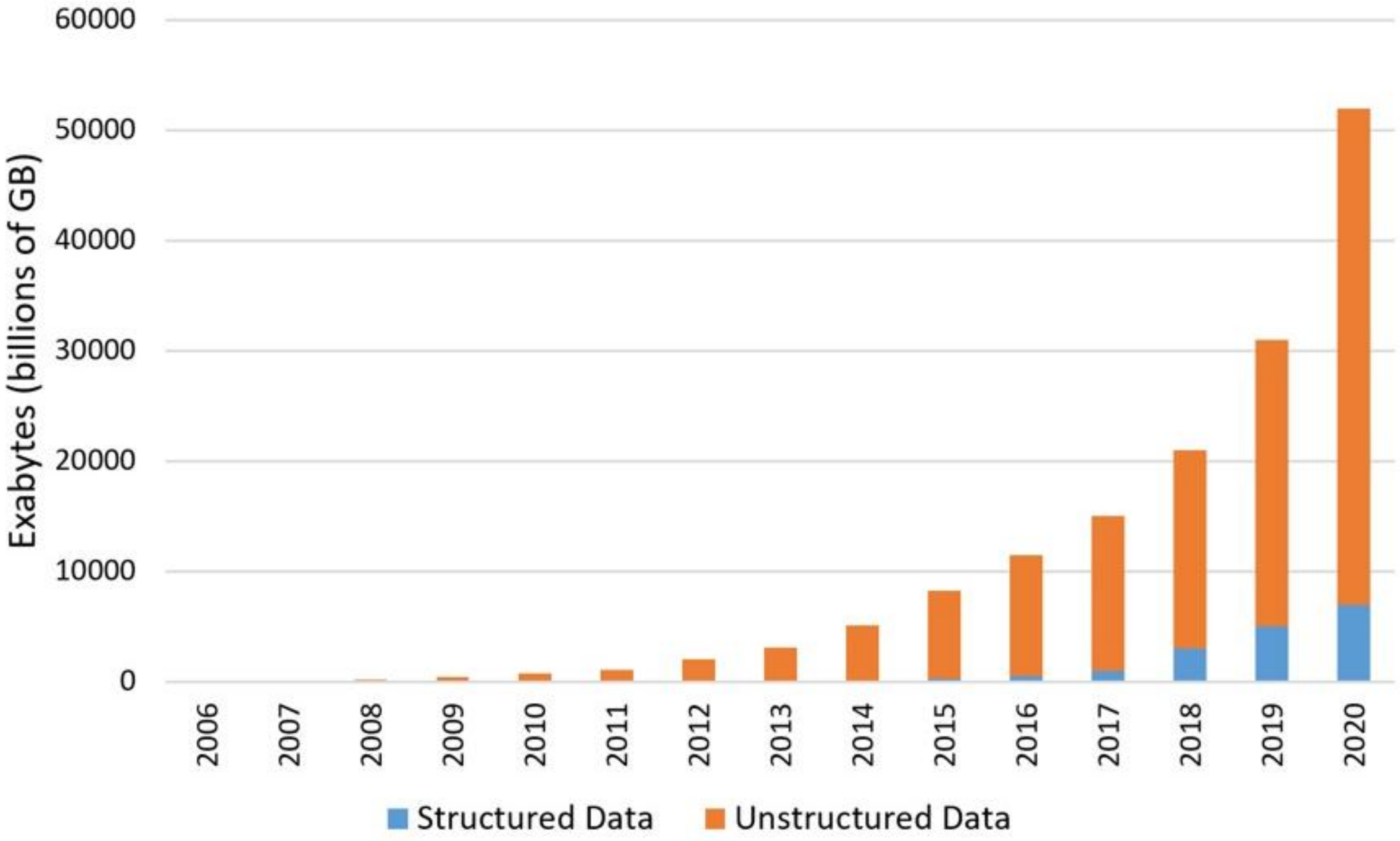
Introduction



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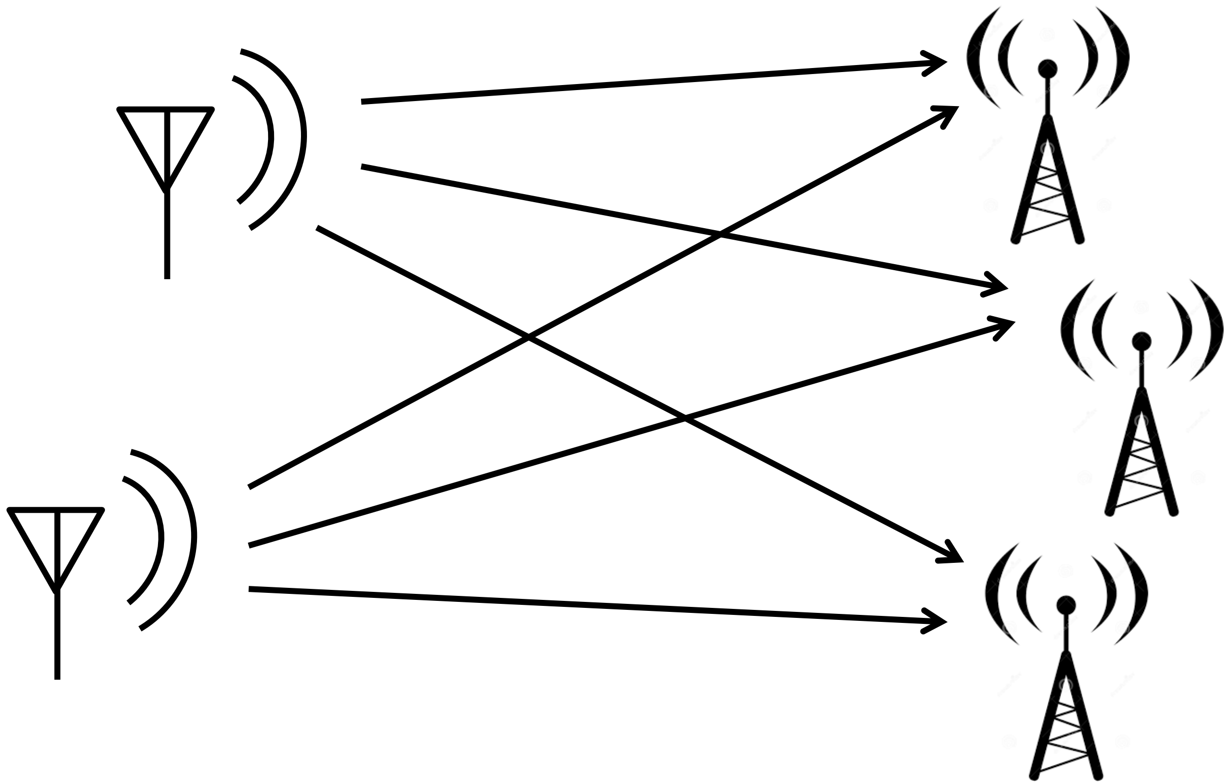
Introduction

- To increase the data rate, one of the following things can be done:
    - Increasing the bandwidth
    - Increasing the signal to noise ratio
    - Increasing the channel capacity using the multi-antenna technique

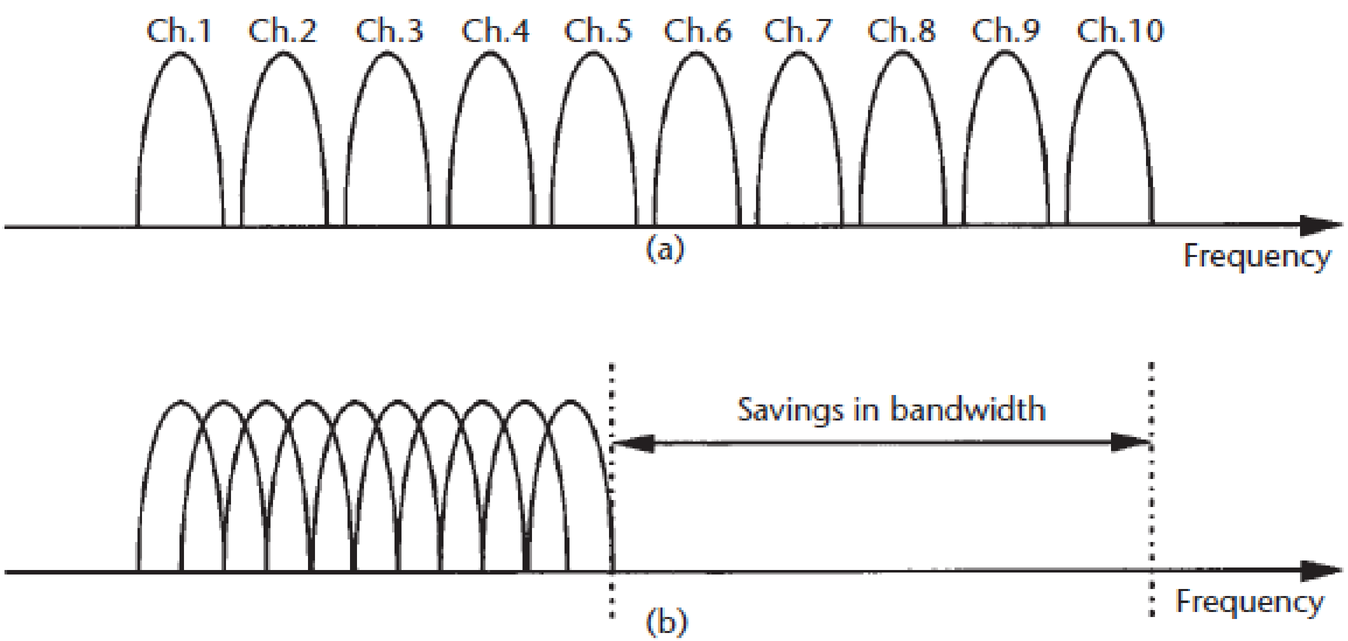
Multi-Antenna



$$C = \min\{N_T, N_R\} \cdot BW \cdot \log_2\left(1 + \frac{N_R}{\min\{N_T, N_R\}} \cdot SNR\right)$$

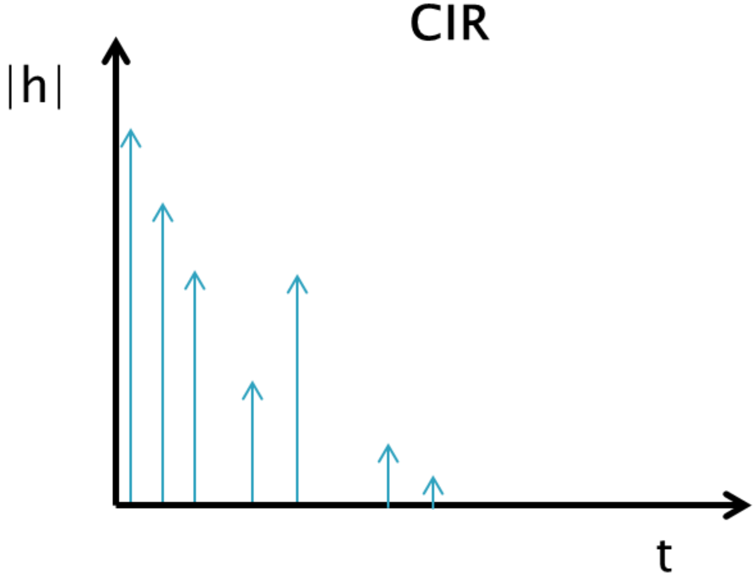
Reasons For OFDM

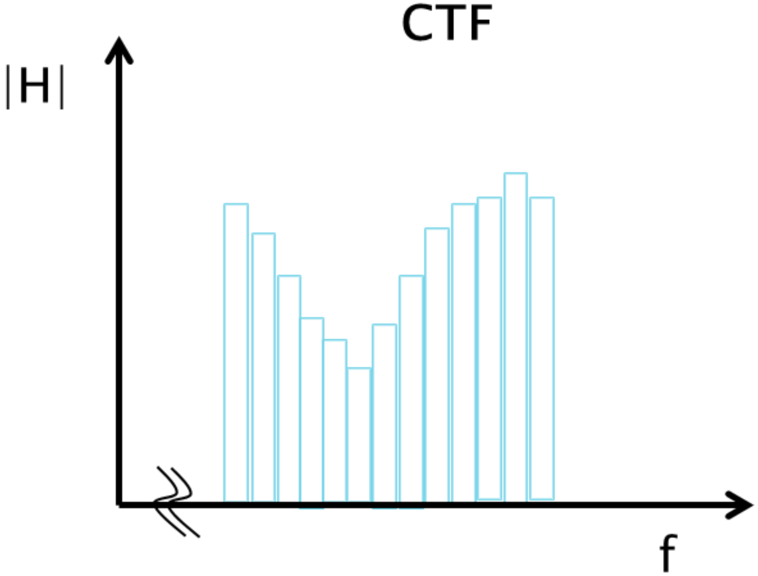
- In OFDM, sidebands of the individual carriers overlap and the signals are still received without adjacent carrier interference.



Reasons For OFDM

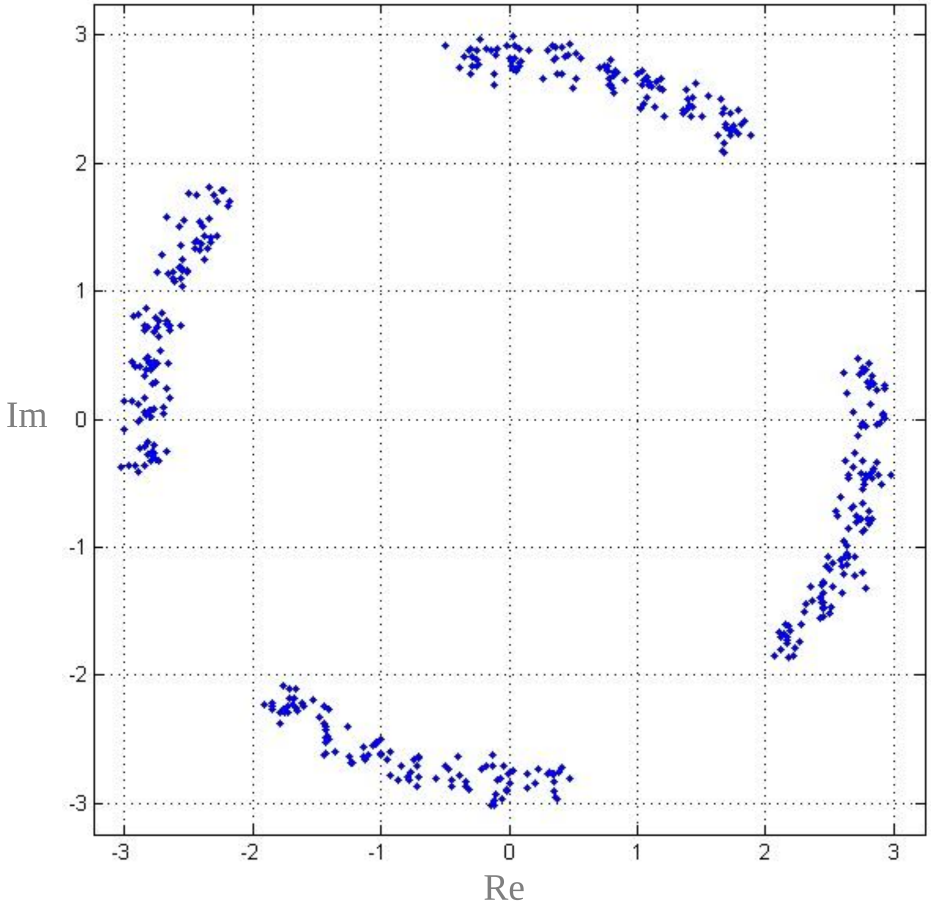
- OFDM is an efficient way to deal with multipath; for a given delay spread, the implementation complexity is significantly lower than that of a single-carrier system with an equalizer.





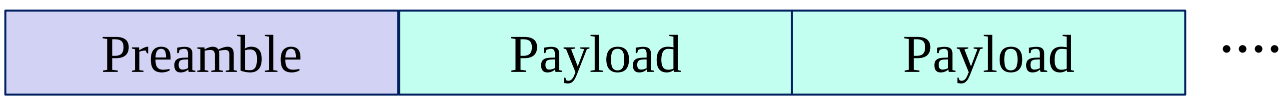
OFDM Synchronization

- Constant Carrier Frequency Offset (CFO)



OFDM Synchronization

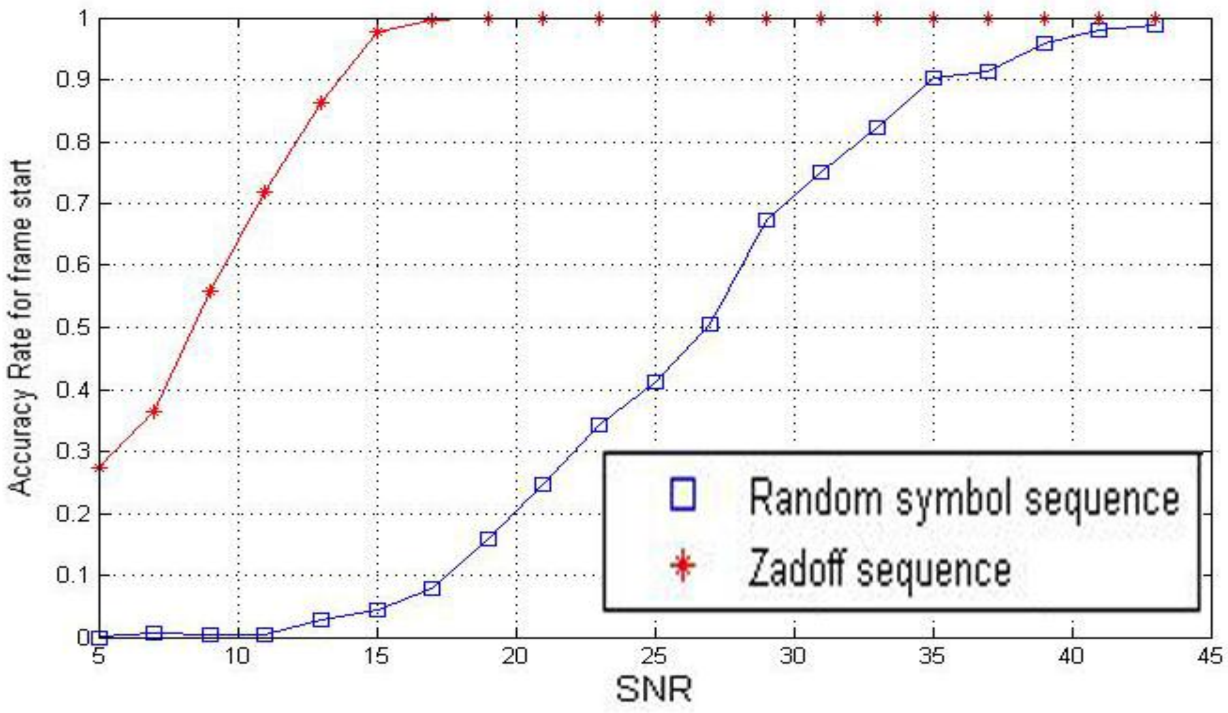
- Preamble
  - Synchronization
  - Channel Estimation



OFDM Synchronization

- Zadoff-Chu Sequence

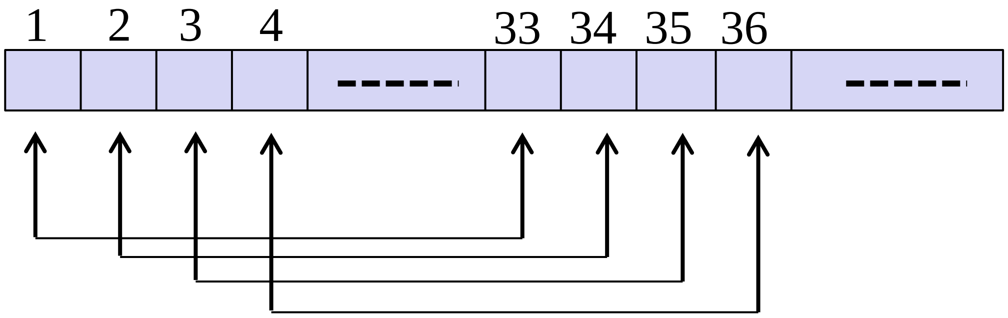
$$ZC_{N_{ZC},M}[k] = \begin{cases} \exp(-\mathrm{j}\frac{M\pi k^2}{N_{ZC}}) & \text{for even } N_{ZC} \\ \exp(-\mathrm{j}\frac{M\pi (k+1)^2}{N_{ZC}}) & \text{for odd } N_{ZC} \end{cases}$$



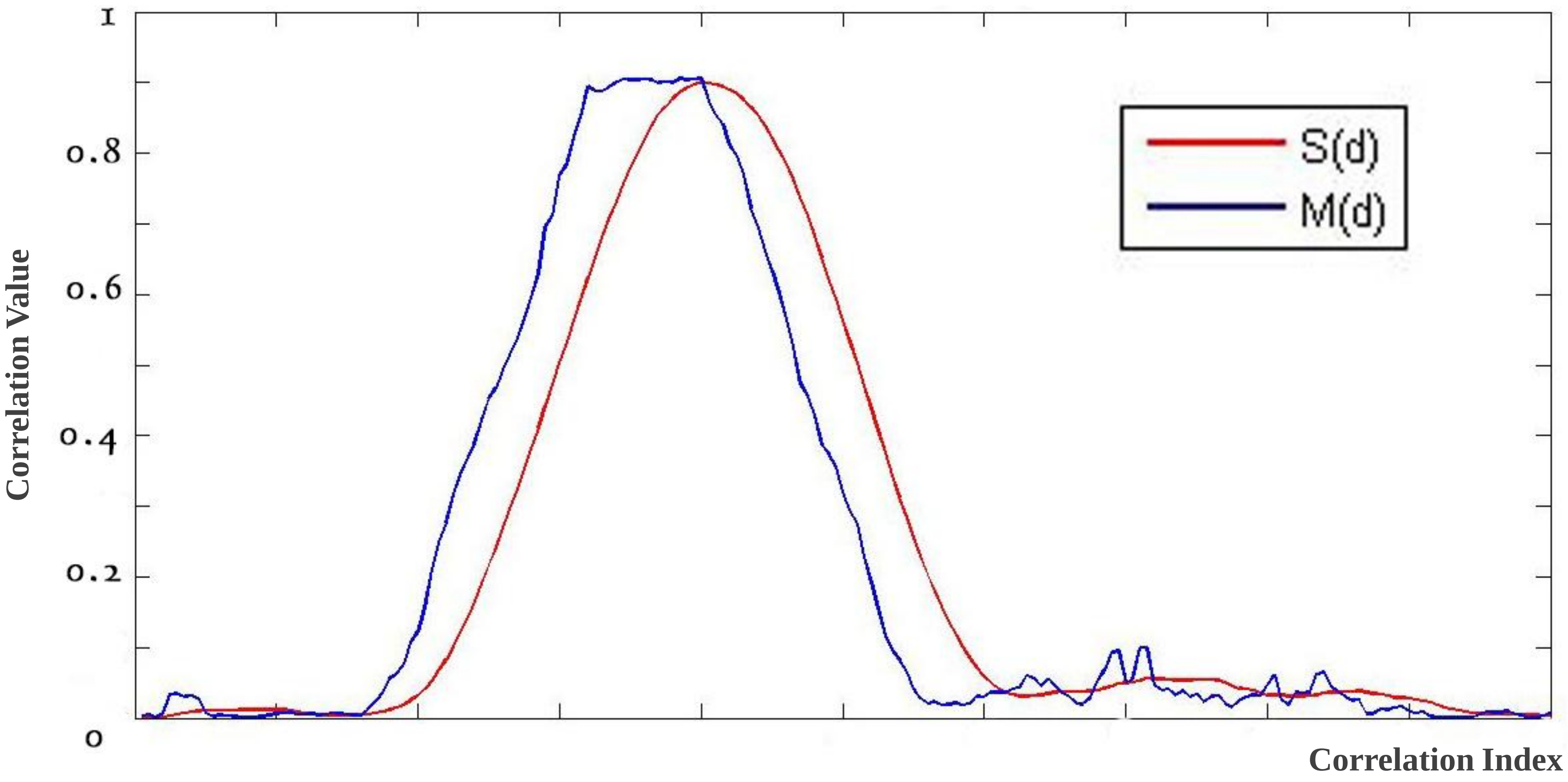
OFDM Synchronization

- Schmidle-Cox

$$M(d) = \frac{|P(d)|^2}{|R(d)|^2} \qquad S(d) = \frac{1}{N_{cp}+1} \sum_{n=-N_{cp}}^{0} M(d+n)$$



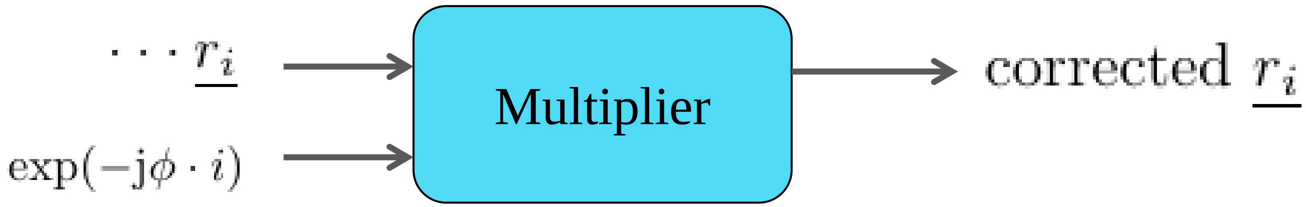
OFDM Synchronization



OFDM Synchronization

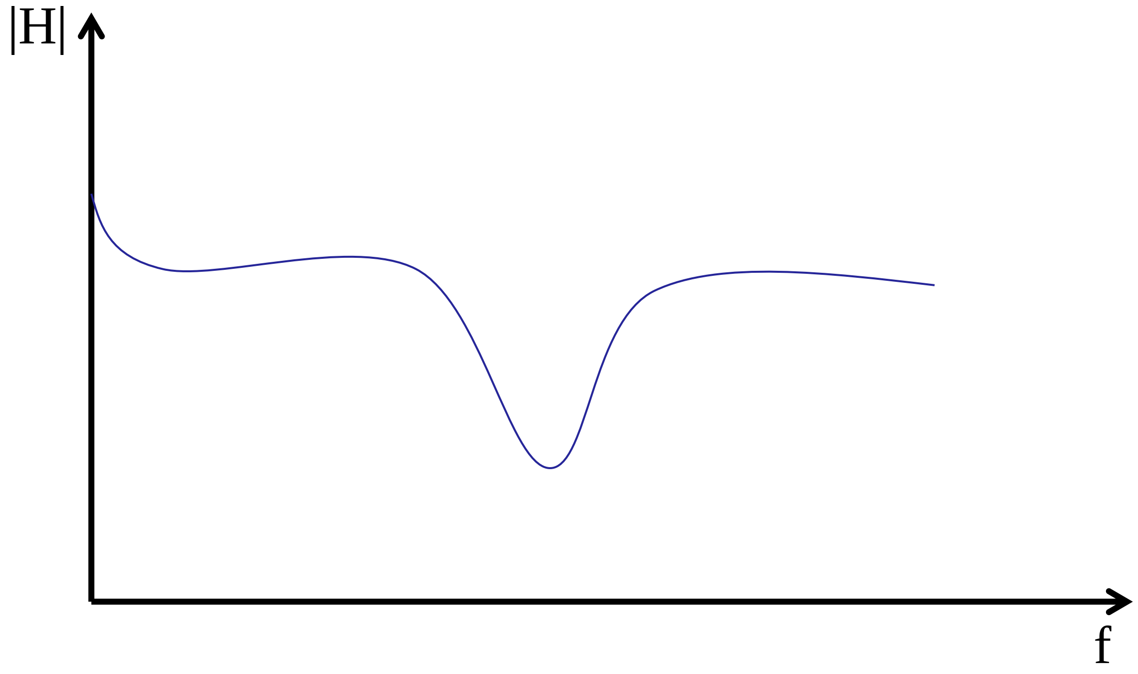
- Correcting The Frequency Offset

$$\phi = \frac{1}{32} \angle P_{Smax}(d)$$

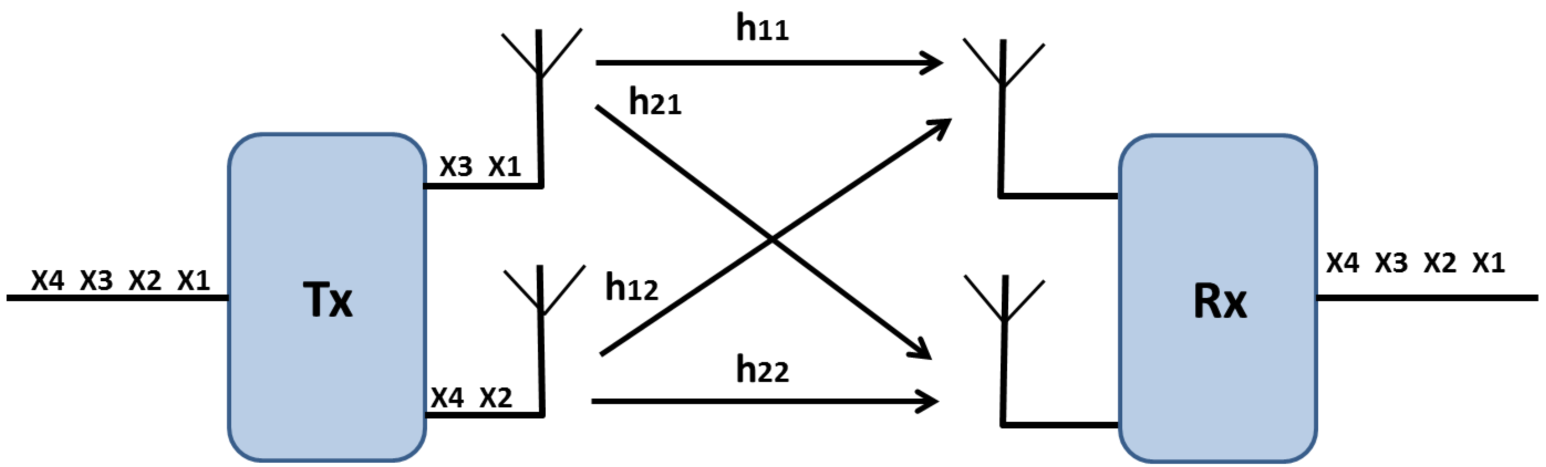


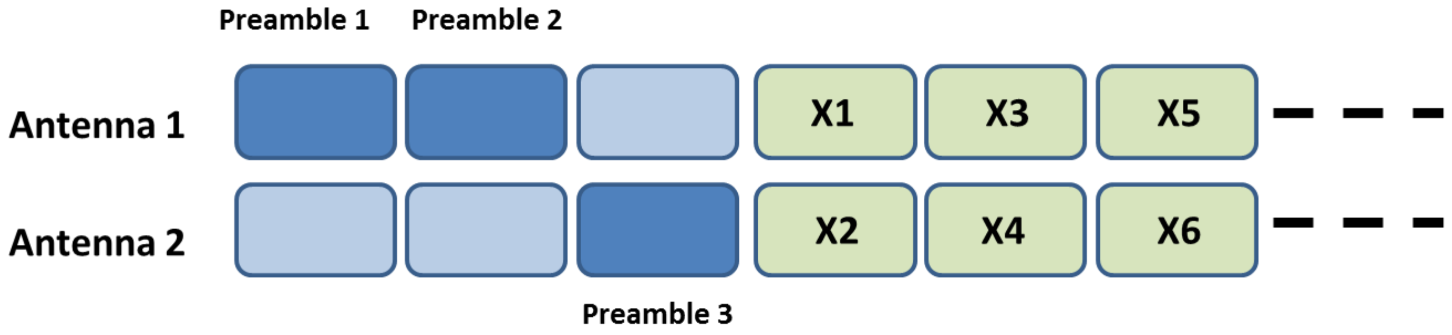
OFDM Synchronization

- Adding zeroes to weak subcarriers



MIMO Implementation





MIMO Implementation

- General system matrix for MxN MIMO-OFDM system:

$$\vec{y} = H \cdot \vec{x} + \vec{w}$$

$$\Updownarrow$$

$$\begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ y_M \end{pmatrix} = \begin{pmatrix} h_{11} & h_{12} & \cdots & h_{1N} \\ h_{21} & h_{22} & \cdots & h_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ h_{M1} & h_{M2} & \cdots & h_{MN} \end{pmatrix} \cdot \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_N \end{pmatrix} + \begin{pmatrix} w_1 \\ w_2 \\ \vdots \\ w_M \end{pmatrix}$$

MIMO Implementation

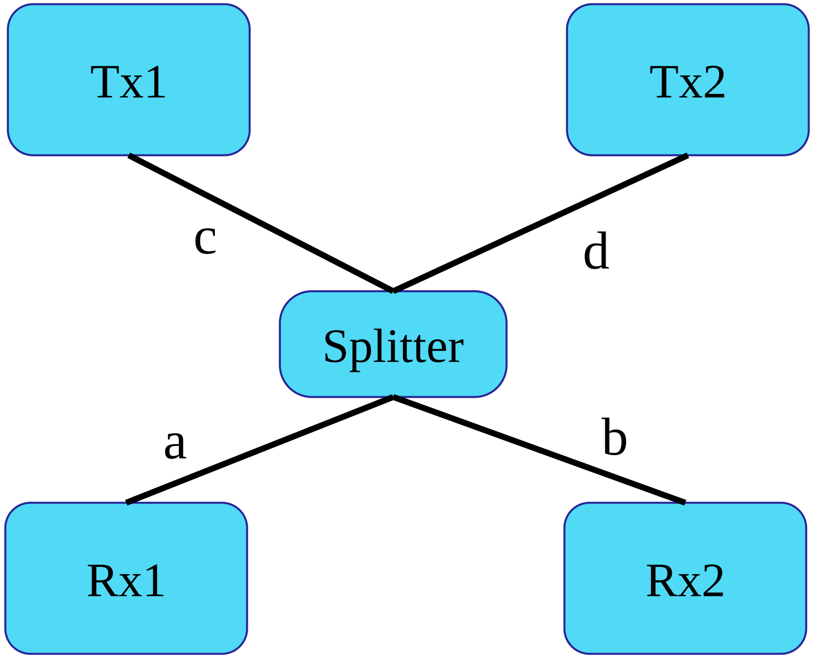
- Simplified equations for a 2x2 MIMO-OFDM system:

$$y_1 = h_{11} \cdot x_1 + h_{12} \cdot x_2 + w_1$$
$$y_2 = h_{21} \cdot x_1 + h_{22} \cdot x_2 + w_2$$

$$x_1 \approx \frac{h_{22} \cdot y_1 - h_{12} \cdot y_2}{h_{11} \cdot h_{22} - h_{12} \cdot h_{21}} \quad \text{and} \quad x_2 \approx \frac{h_{11} \cdot y_2 - h_{21} \cdot y_1}{h_{11} \cdot h_{22} - h_{12} \cdot h_{21}}$$

Measurements and Results

- Tow splitters instead of one were used in order to avoid a singular channel transfer matrix:



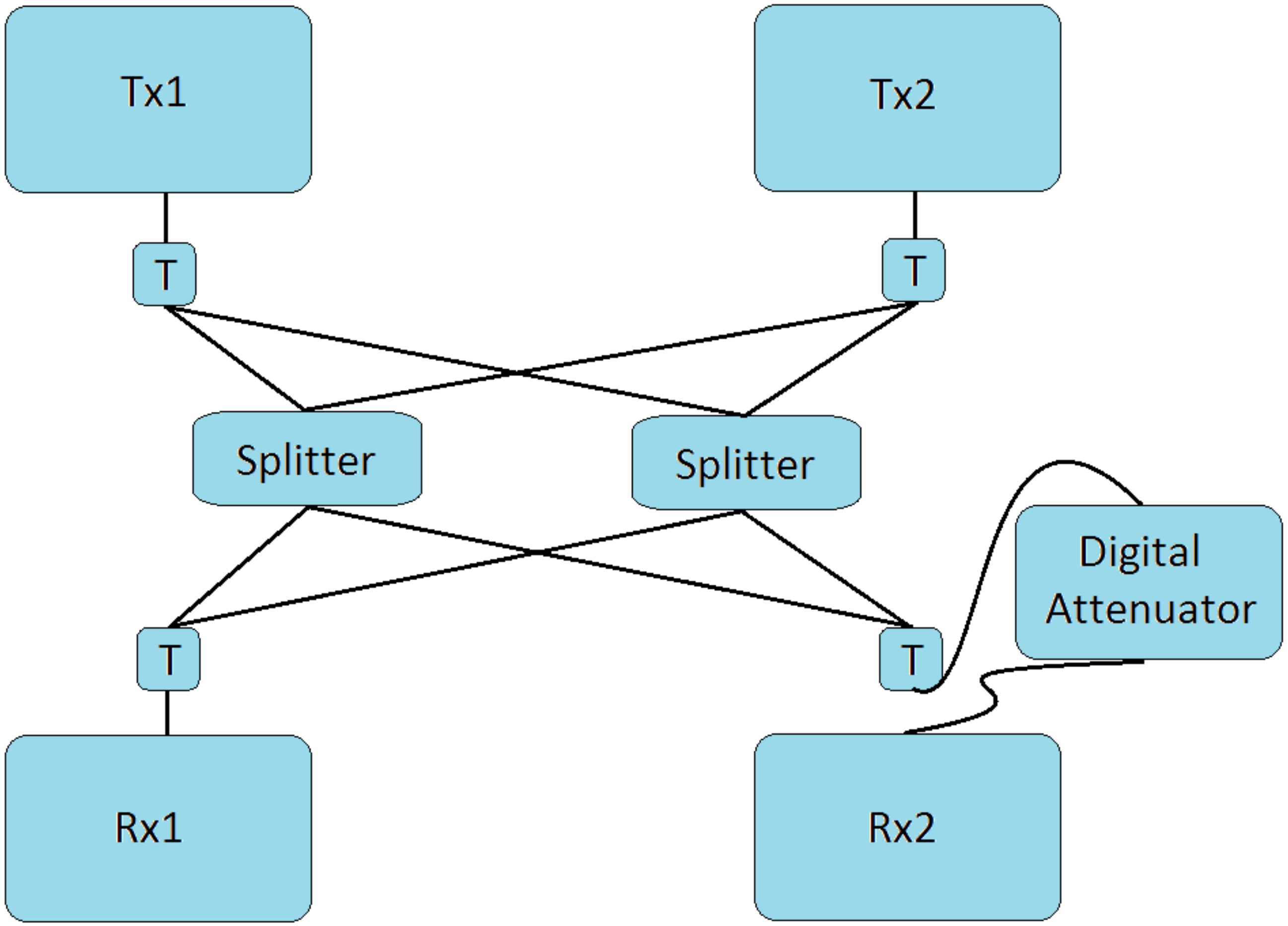
Measurements and Results

- The mathematical representation for the previous circuit:

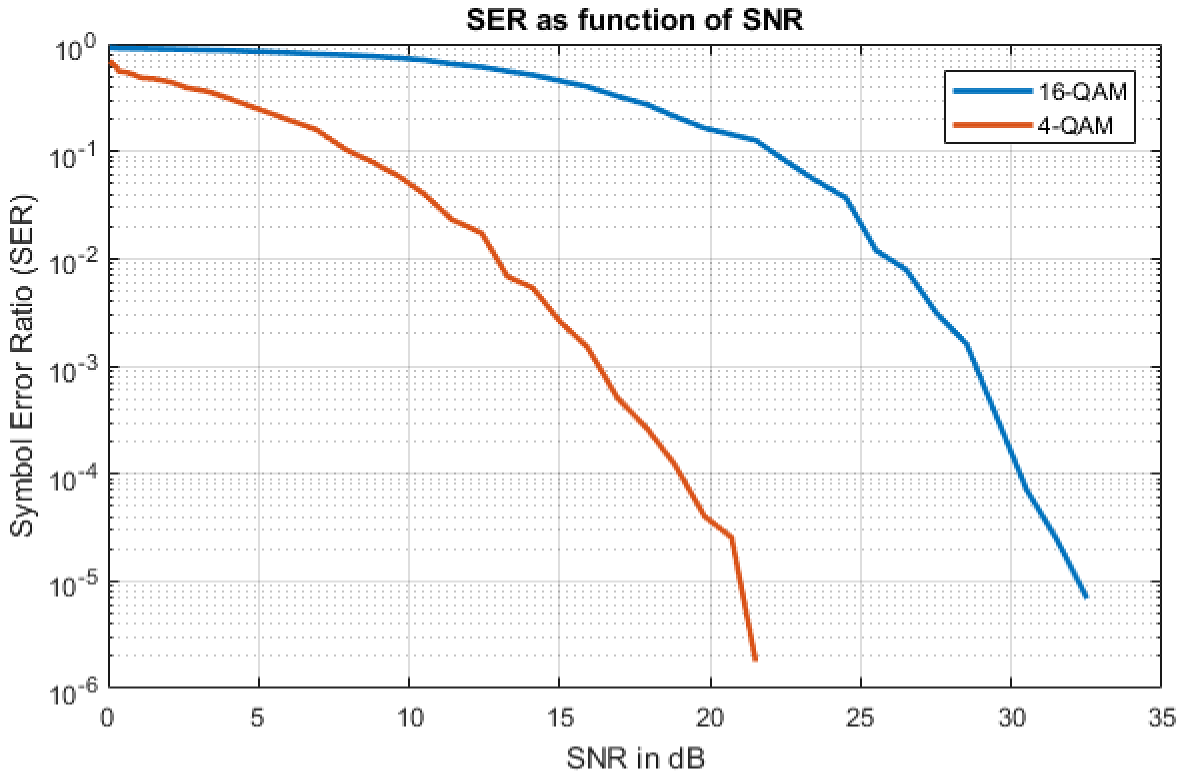
$$\vec{y} = \begin{pmatrix} a \\ b \end{pmatrix} \cdot \begin{pmatrix} c & d \end{pmatrix} \cdot \vec{s} = \begin{pmatrix} ac & ad \\ bc & bd \end{pmatrix} \cdot \vec{s}$$

$$\begin{vmatrix} ac & ad \\ bc & bd \end{vmatrix} = abcd - abcd = 0$$

Measurements and Results



Measurements and Results



Future work

- More antennas can be used in order to increase the maximal data rate of the developed system.
- Extending the system with a Forward Error Correction algorithm to improve the SER and make the system more reliable.
- Other modulation schemes like 64-QAM or 256-QAM can be used in order to increase the number of transmitted bits per symbol.
- Adding some Pilot subcarriers.

Thank you for your interest!