Synchronization and Channel Estimation in Experimental M-QAM OFDM Radio over Fiber Systems Using CAZAC Based Training Preamble

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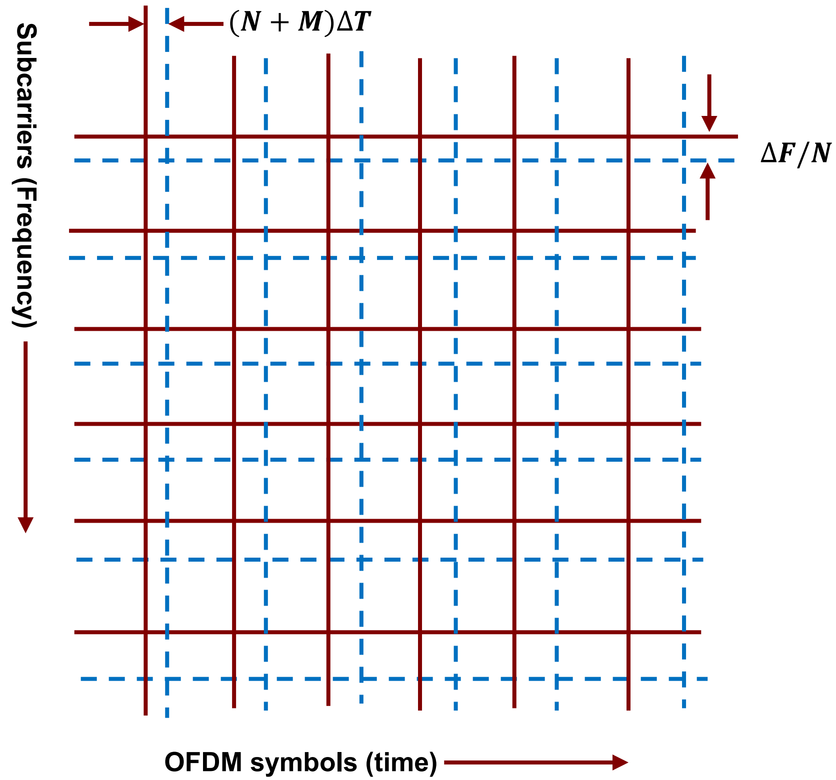
Introduction

- **mmWave RoF systems**
  - **60 GHz: (57-64 GHz)**
    - High attenuation, CD affects severly
    - Deployment of large number of small cells
      - Base station complexity should be reduced
        - Signal processing optimization problems : modulation, demodulation, power efficient coding, synchronization, channel estimation etc
  - **5G goal: 1-10 Gbps to end user**
  - **OFDM**
    - Tolerent to liner impairments
    - Highly spectral efficient
    - Well studied method, easy implemenation
    - Practical problem: *very sensitive to synchronization errors!*

Introduction

- **OFDM problem: Synchronization**
  - **Symbol time offset**
    - Rx never knows the precise arriving time of the symbol
    - Missalignment of Tx and Rx symbols
    - Problem statements
      - **Find the accurate downsampling point**
      - **Allign the Tx and Rx symbol correctly**
    - Causes imperfect further processing, leading to imperfect demodulation (ISI and ICI).



  - **Frequency offset**
    - Frequency errors between Tx and RX: carrier frequency and LO frequency difference, due to channel characterstic etc.
    - Causes missalignment of IFFT and FFT window affecting orthogonality which leads to ICI
    - Causes constellation rotation

Synchronization Methods

- **Symbol timing offset estimation**
  - **Training preamble**
    - **Cross correlation** of received signal with native training signal

$$R(d) = \left| \sum_{k=0}^{\frac{N}{2}-1} r\left(d + k + \frac{N}{2}\right) s(d + k) \right|$$

      - **Not good for low SNR : phase is badly destroyed in the received signal**
    - **Auto correlation** of received signal and delayed received signal

$$R(d) = \left| \sum_{k=0}^{\frac{N}{2}-1} r\left(d + k + \frac{N}{2}\right) r^{*}(d + k) \right|$$

      - **Better correlation, because channel is same**
    - Longer sequence, better correlation
    - Performance determined by preamble structure !

  - **Blind timing offset estimation**
    - Time locked loop : operates based on the error signal adaptation
    - **Delay and correlate** of the cyclic prefix.

Synchronization Methods

- **Different preamble structures**
  - **Schmidl** [1]
    - Preamble
      - Consist of two identical halfs: PN sequence on the even ferquencies and zeros on odd frequencies

$$Preamble_{Schmdl} = \left[A_{\frac{N}{2}} \quad A_{\frac{N}{2}}\right]$$

    - Correlation:

$$R(d) = \left|\sum_{k=0}^{\frac{N}{2}-1} r\left(d+k+\frac{N}{2}\right) r^*(d+k)\right|$$

    - Energy:

$$\mathrm{E}(d) = \sum_{k=0}^{\frac{N}{2}-1} \left|r\left(d+k+\frac{N}{2}\right)\right|^2$$

    - Timing metric:

$$M(d) = \frac{|R(d)|^2}{|\mathrm{E}(d)|^2}$$

Synchronization Methods

❑ Different preamble structures

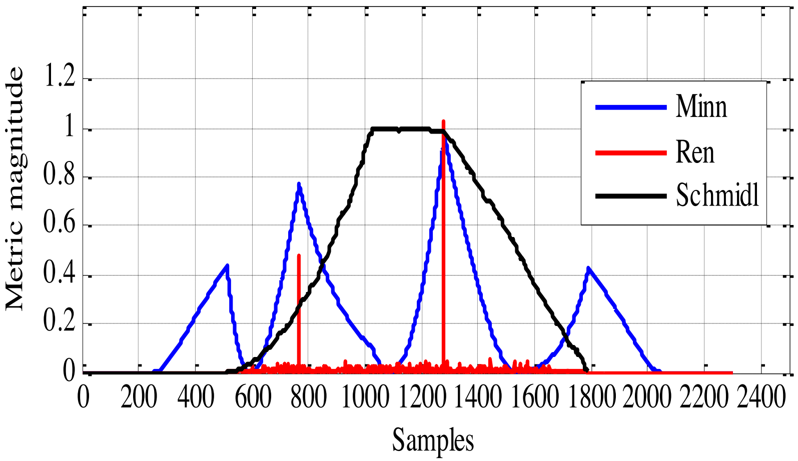
❑ Minn [2]

- Preamble
  - Consist of four identical halfs

$$Preamble_{Minn} = \left[A_{\frac{N}{4}} \quad A_{\frac{N}{4}} \quad -A_{\frac{N}{4}} \quad -A_{\frac{N}{4}}\right]$$

❑ Ren [3]

- Preamble
  - Consist of two constant amplitude zero auto correlation (CAZAC) sequences weighted by real valued PN sequences (values either +1 or -1).



$$Preamble_{Ren} = \left[(CAZAC)_{\frac{N}{2}} \quad (CAZAC)_{\frac{N}{2}}\right] \circ S_N$$

Synchronization Methods

- **Frequency offset estimation**
  - **Using training preamble**

$$\triangle f = \frac{1}{\pi} angle\ (R(\epsilon))$$

$$\epsilon = \text{position of starting symbol}$$

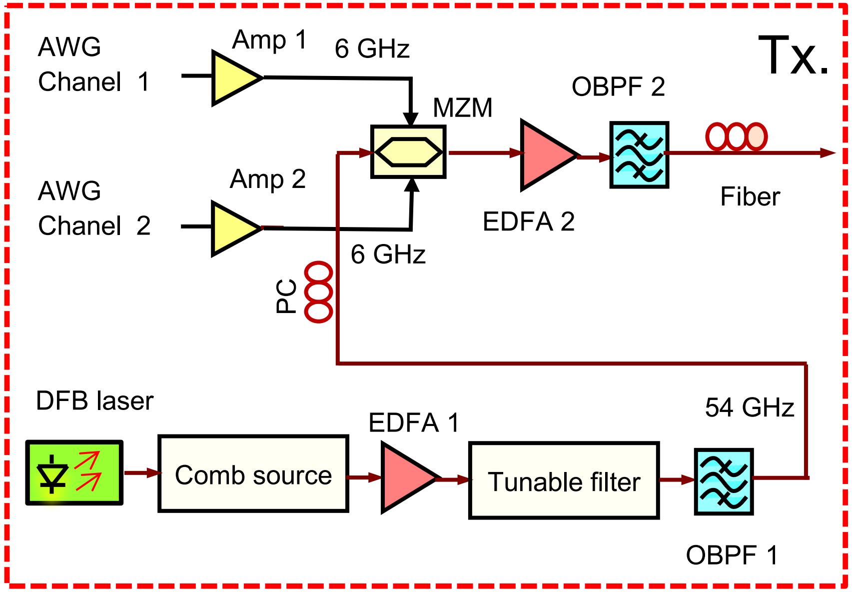
- **Chanel estimation**
  - **Using pilots:** least square (LS) estimation and interpolation
    - For channel response $H(k)$, transmitted signal response $X(k)$ and noise response $W(k)$, received signal response $Y(k)$

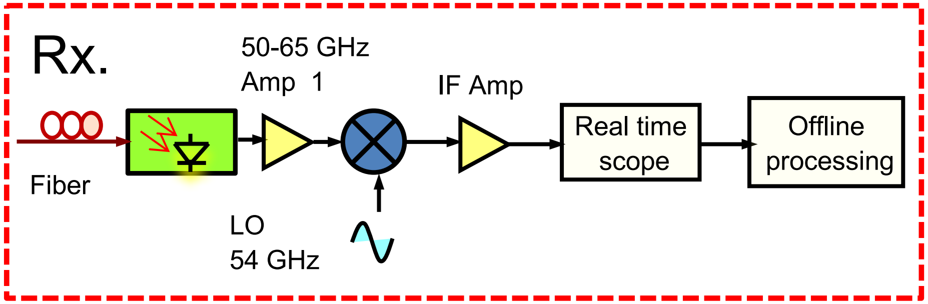
$$\widehat{H}_{pilot}(k) = \frac{Y_{pilot}(k)}{X_{pilot}(k)}$$

  - **Using traning preamble**: interpolation not possible.
    - We use the averaging technique

Experimental setup

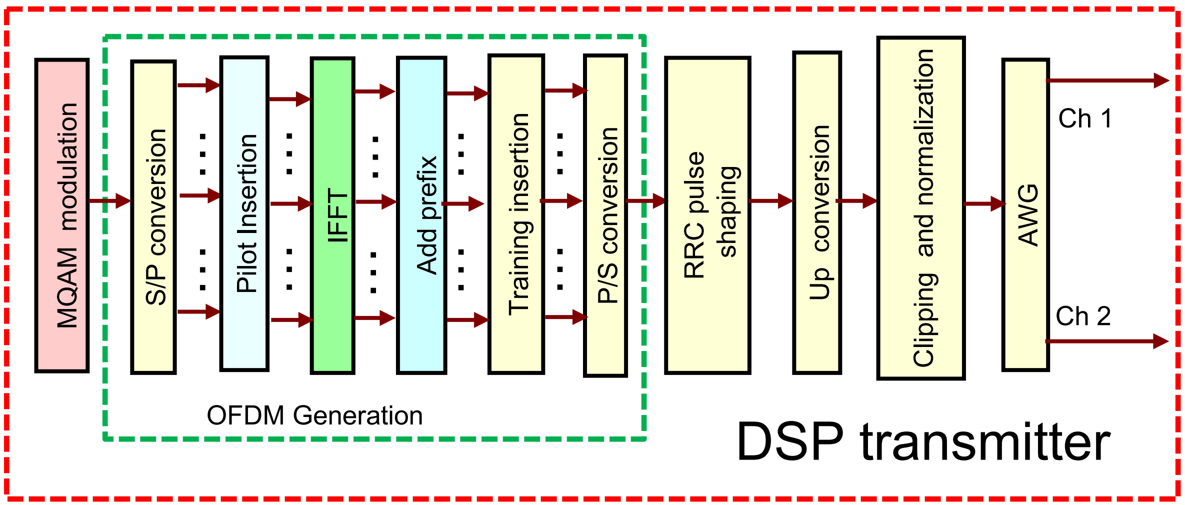
❑ Transmission system





Experimental setup

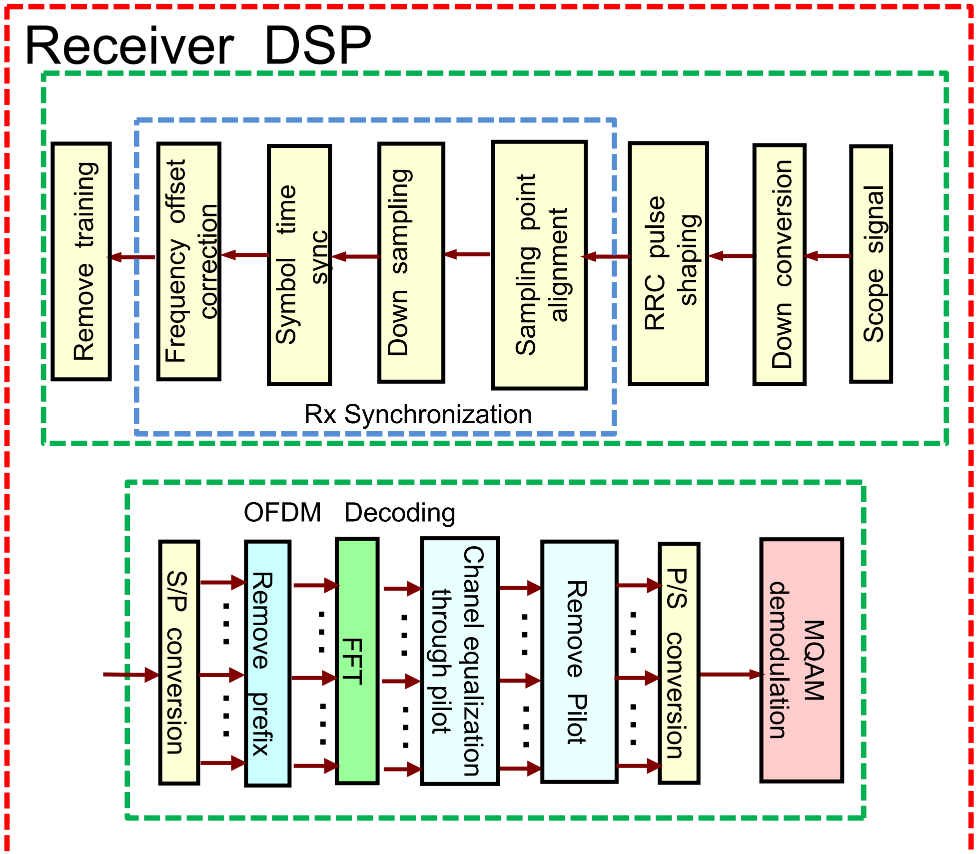
❑ Transmission system

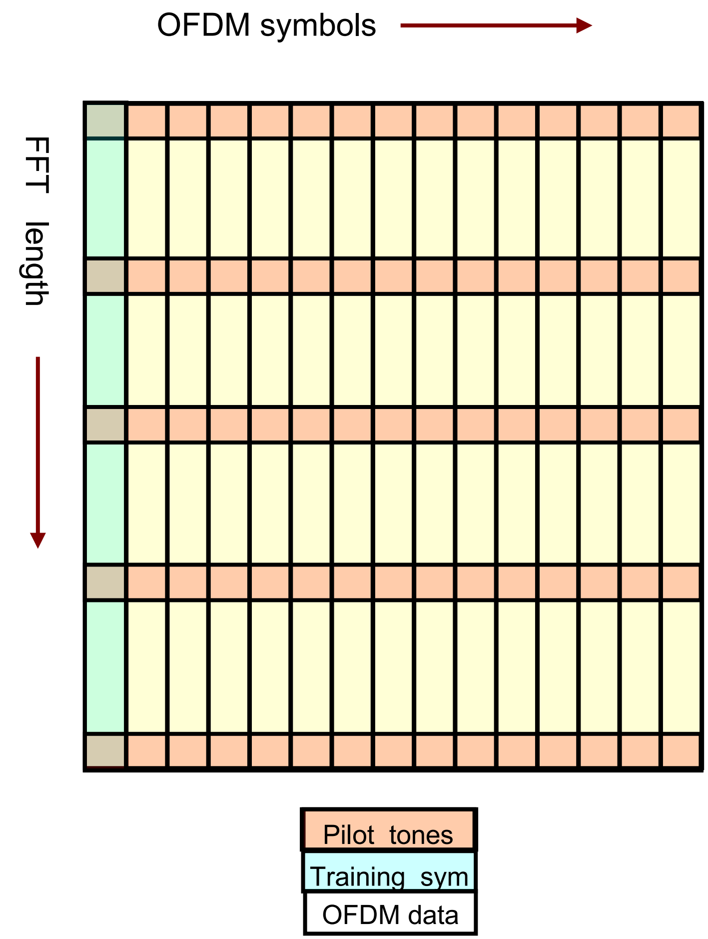


parameters	values
No. of bits	57344
Baud rate	5 Gbaud
QAM order	16
CP	25 %
NFFT	1024
RRC roll off	0.4
Training symbol	1
Pilots	5

Experimental setup

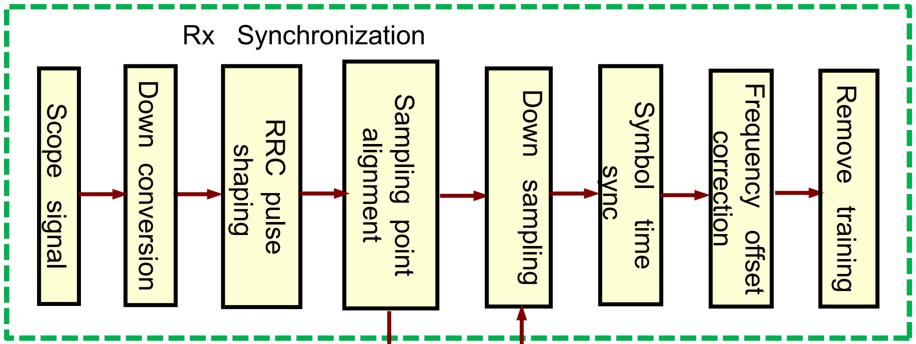
❑ Receiver DSP



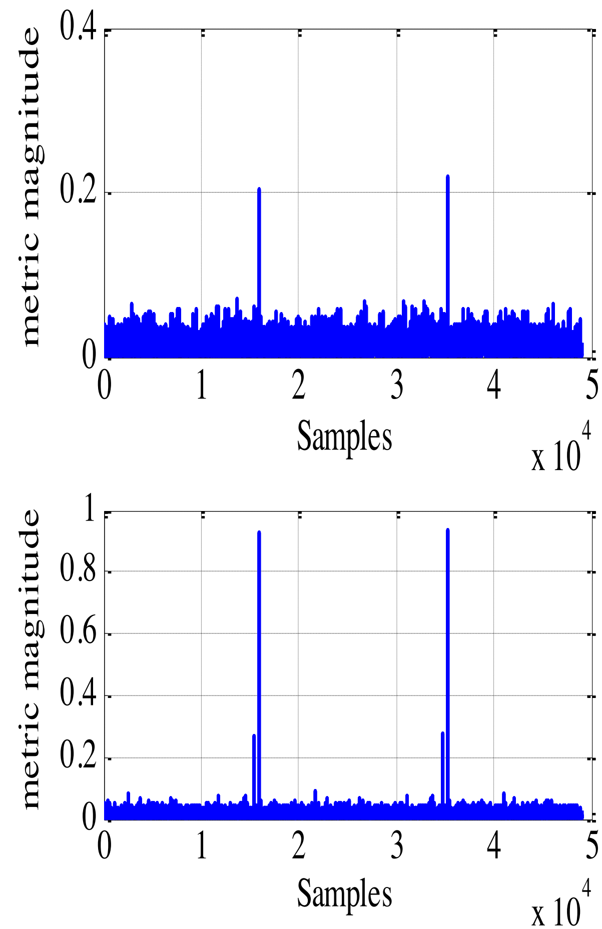


Results

❑ Downsampling offset correction

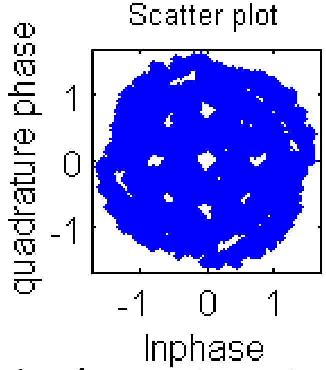


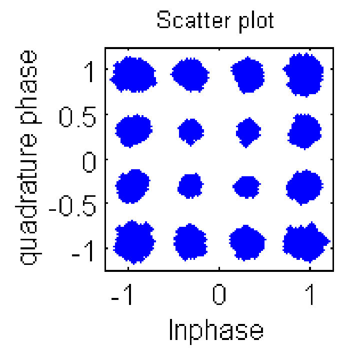

```
Step 1: Initializations
            iteration = ADC sampling rate/QAM symbol rate
            factor= iteration
            buffer =0;

Step 2:  Down sample and iterative search for  peak values
            for  i= 1: iteration-1
                  offset =i;
                  signal= downsample(signal, factor, offset);
      % calculate the Ren metric and find  the position  of peak(i)
      % store the peak(i) in buffer as
                  buffer(i)=[ buffer(i-1)  peak (i)] ;
            end
Step 3: Calculate the downsample position
             downsample position = arg max[buffer (i)];
```



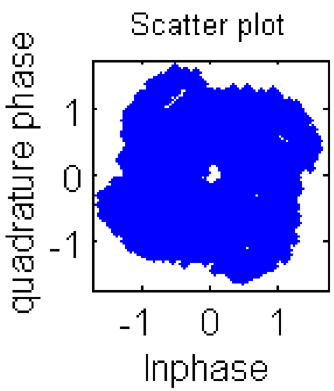
Results

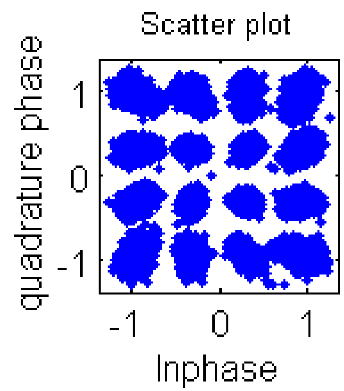
- **Downsampling offset correction**
  - **For Back to back** (w/o and with downsampling point correction)





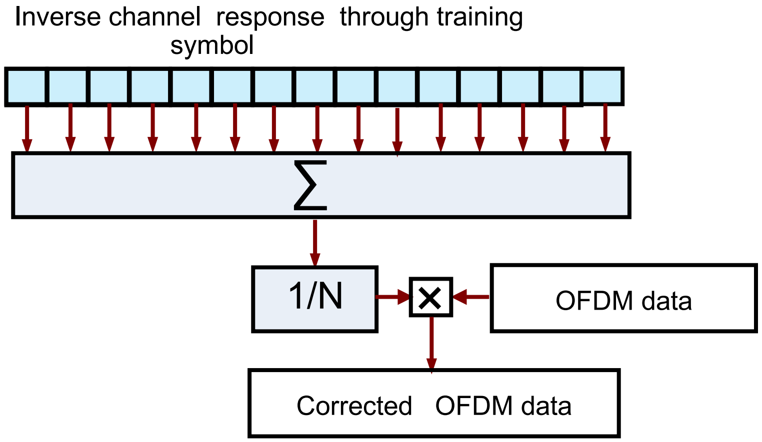
  - **With Optical channel** (w/o and with downsampling point correction)



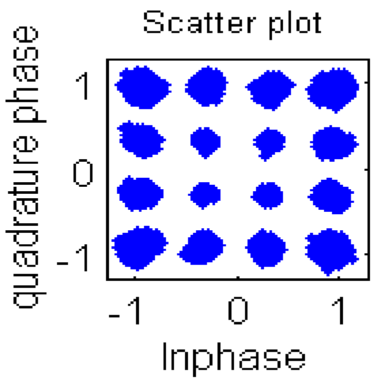


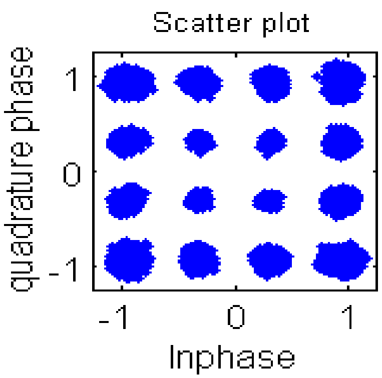
Results

- **Chanel estimation:** using training preamble



- **Pilot with interpolation method and training signal with averaging technique: comparision**





Conclusions

- CAZAC based training preamble can be used effectively in experimental M-QAM OFDM RoF systems for synchronization and channel estimation. Can be applied to any order (M) in M-QAM OFDM.

- For effective time synchronization, optimum downsampling point has to be identified, which can be obtained with proposed iterative method.

- Same training preamble can be used for all the purposes: symbol time offset estimation, frequency offset estimation and channel estimation
  - Bandwidth efficiency increases !
  - Lower signal processing tasks: reduces complexity.

References

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Thank you for your attention !!!