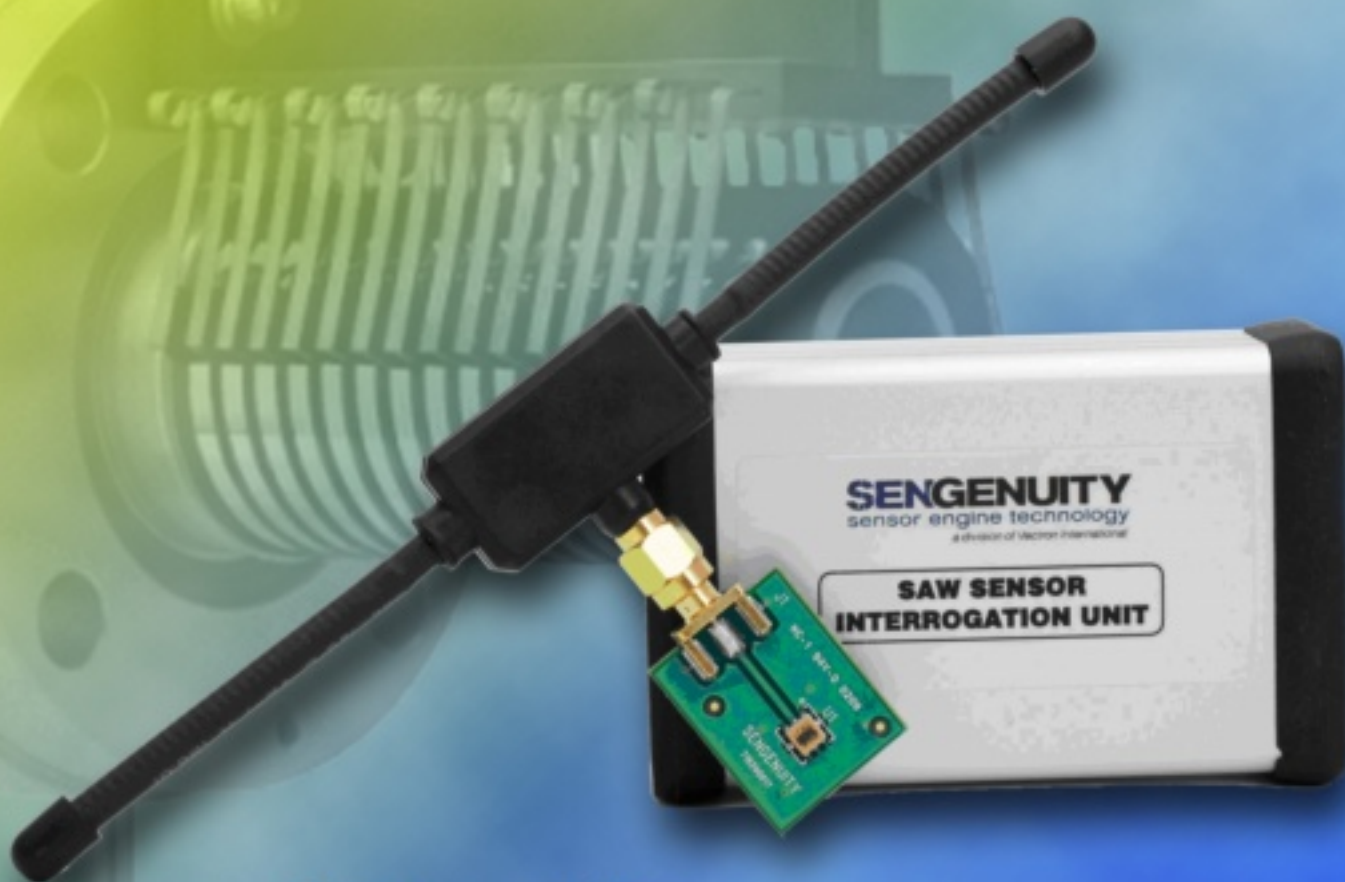


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Simulation Study of OFDM, COFDM and MIMO-OFDM System

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Abstract: Orthogonal frequency division Multiplexing (OFDM) is a popular method for high data-rate wireless transmission. It converts a frequency selective channel into a set of parallel flat fading sub-channels, which makes the receiver simpler. Thereby, the bandwidth of the sub-carriers becomes small compared with the coherence bandwidth of the channel, which allows simple equalization. The BER curve of OFDM is compared with the single carrier 16-QAM systems. The BER curve for COFDM using differential encoding method is also discussed. OFDM may be combined with multiple antennas at both Transmitter and Receiver, resulting a MIMO-OFDM system. In this paper, various channel estimation methods of MIMO-OFDM system using MMSE and LS are discussed. Also, in this, the effect of various Doppler frequencies on the normalized channel estimation is discussed. Finally, the normalized channel estimation versus no. of iteration by using multiple antennas (same or different) at both the access points is discussed. *Copyright © 2009 IFSA.*

Keywords: OFDM, COFDM, MIMO-OFDM, Channel estimation, MMSE and LS, Normalized estimation error comparison, Spatial Multiplexing, STBC, SVD

1. Introduction

Orthogonal frequency division multiplexing (OFDM) is a parallel transmission scheme, where a high-rate serial data stream is split up into a set of low-rate sub-streams, each of which is modulated on a separate sub-carrier (frequency division multiplexing). Thereby, the bandwidth of the sub-carriers becomes small compared with the coherence bandwidth of the channel i.e. the individual sub-carriers experience flat fading, which allows for simple equalization [1]. This implies that the symbol period of

the sub-streams is made long compared to the delay spread of the time-dispersive radio channel. By selecting a special set of orthogonal carrier frequencies, high spectral efficiency is obtained, because the signal spectra corresponding to the different sub-carriers overlap in frequency domain, while mutual influence among the sub-carriers can be avoided [2].

The main principles incorporated are:

- The IFFT (Inverse Fast Fourier Transform) and the FFT (Fast Fourier transform) are basically used for modulating and de-modulating the data constellations on the orthogonal sub-carriers. These signal-processing algorithms replace the banks of I/Q modulators and de-modulators that would otherwise be required.
- These constellations can then be taken as per any signaling technique such as: PSK (phase shift Keying) or QAM (Quadrature amplitude modulation). In this paper, 16-QAM signaling set has been considered, which plays the role for symbol mapping.
- The second key principle is the concept of guard interval (or cyclic Pre-fixing), whose length should exceed the maximum excess delay of the multipath propagation channel. Due to the cyclic pre-fixing, the transmitted signal becomes periodic and the effect of the time-dispersive multipath channel becomes equivalent to a cyclic convolution, discarding the guard interval at the receiver.
- The equalization (symbol de-mapping) required for detecting the data constellation by the inverse of the estimated channel transfer function (channel estimation).
- Synchronization is another important issue in the OFDM transceiver design. Time and frequency synchronization are very important to identify the start of the OFDM symbol and to align the modulator and de-modulator local oscillator frequencies respectively. If not, then there is a high chance of losing the orthogonality of the sub-carriers, by the virtue of which ISI and ICI will be introduced [3, 4].

2. OFDM System

2.1. OFDM System Block Diagram

The block diagram of an OFDM transceiver is shown in Fig. 1.

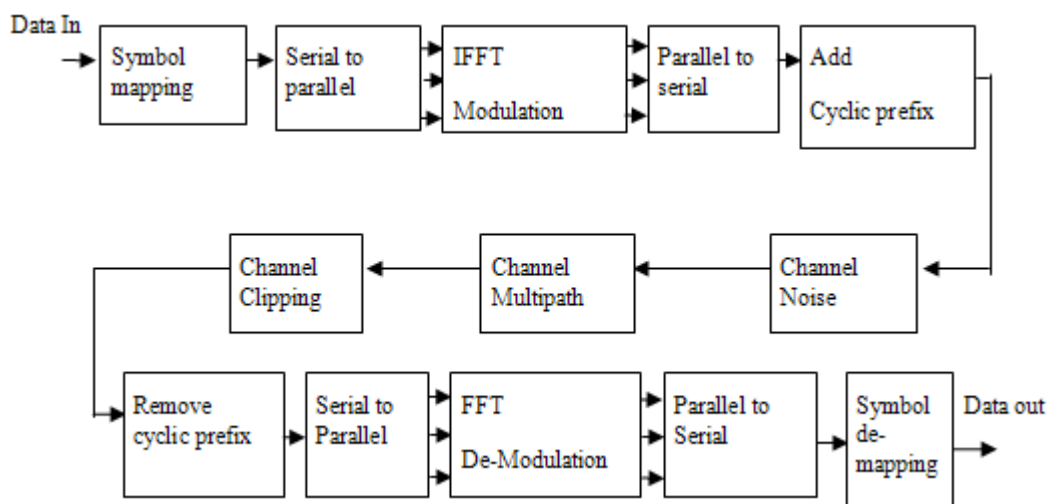


Fig. 1. Block Diagram of an OFDM Transceiver.

Description of Block Diagram

The serial data stream is mapped to data symbols with a symbol rate of $1/T_s$, employing a general phase and amplitude modulation scheme and the resulting symbol stream is demultiplexed into a vector of N data symbols X_0 to X_{N-1} . The parallel data symbol rate is $\frac{1}{NT_s}$, i.e. the parallel symbol

duration is N times longer than the serial symbol duration T_s . The IFFT of the data symbol vector is computed and the coefficients x_0, x_1, \dots, x_{N-1} constitutes an OFDM symbol. The x_n are the time domain samples of the OFDM symbol and are transmitted sequentially over the channel at a symbol rate of $1/T_s$. At the receiver, a spectral decomposition of the received time domain samples d_n is computed employing an N -tap FFT and the recovered data samples d_k are restored in serial order and demultiplexed.

Cyclic Prefixing

The introduction of a cyclic prefix as a guard Interval, whose length should exceed the maximum excess delay of the multipath radio channel,. Due to the cyclic prefix, the transmitted signal becomes periodic and the effect of the time-dispersive multipath channel becomes equivalent to a cyclic convolution, discarding the guard interval at the receiver. Due to the properties of the cyclic convolution, the effect of the multipath channel is limited to a point wise multiplication of the transfer function, the Fourier transform of the channel impulse response i.e. The sub carriers remain orthogonal [5,6].

As mentioned above, the guard interval, a cyclic prefix, is a copy of the last part of the OFDM symbol, which is transmitted before the so-called “effective” part of the symbol.

Windowing

A rectangular pulse has a very large bandwidth due to the side lobes of its Fourier transform being a sinc function. Windowing is a well-known method to reduce the levels of these side lobes and thereby reduce the signal power transmitted out of band. In an OFDM system, the applied window must not influence the signal during its effective period.

Due to this, the efficiency is further reduced, as the receiver also discards the window part. The orthogonality of the sub-carriers of the OFDM signal is restored by the rectangular receiver filter implementation by the FFT, requiring the correct estimation of the FFT start time $k \cdot T$, where T is the OFDM symbol period.

2.2. OFDM Signal Generation

Transmission:

A $M = \frac{N}{2}$ carrier OFDM signal for the QAM mapped symbol sequence, $\{d_0, d_1, d_2 \dots\}$ is given by,

$$X(t) = \text{Re} \sum_{k=0}^{\frac{N}{2}-1} d_k \exp(j2\pi kt/T), \text{ for } 0 \leq t \leq T \quad (1)$$

$$= \sum_{k=0}^{N-1} d_k \exp(j2\pi kt/T), \text{ when } d_{N-k} = d_k^* \quad (2)$$

When this OFDM signal is sampled at $t = nT_s$, the discrete time OFDM symbol becomes,

$$x(n) = \frac{1}{N} \sum_{k=0}^{N-1} d_k \exp(j2\pi kt/T), \text{ for } 0 \leq n \leq N-1 \quad (3)$$

⇒ N-point IDFT of $\{d_0, d_1, \dots, d_{N-1}\}$

Reception:

An N carrier OFDM signal yields the detection statistic for the QAM mapped symbol sequences as,

$$d_k = \int_0^T X(t) \exp(-j2\pi kt/T) dt, \text{ for } 0 \leq k \leq N-1 \quad (4)$$

⇒ The QAM mapped symbols can be obtained by comparing $\{d_0, d_1, \dots, d_{N-1}\}$ against the appropriate thresholds.

When the OFDM signal is sampled at $t = nT_s$

$$d_k = \sum_{n=0}^{N-1} x(n) \exp(-j2\pi kn/N), \text{ For } 0 \leq k \leq N-1 \quad (5)$$

⇒ N-point DFT of $\{x(0), x(1), \dots, x(N-1)\}$.

2.3. Advantages of OFDM Systems

- High spectral efficiency
- Simple implementation by FFT and IFFT
- Low receiver complexity
- Suitability for high data rate transmission over a multipath fading channel.

2.4. Disadvantages of OFDM Systems

- Higher PAPR (peak to average power ratio) compared to single carrier (16-QAM) modulation
- Sensitive to time and frequency synchronization errors
- There is a slightly loss of effective transmit power, as the redundant GI must be transmitted.

Usually, the GI is selected to have a length of one tenth to a quarter of the symbol period, leading to an SNR loss of 0.5-1 dB.

2.5. Application areas of OFDM Systems

- Due to their receiver complexity, OFDM applications have been scarce until quite recently. Recently, however, OFDM has been adopted as the new European digital audio broadcasting

- (DAB) standard as well as for the terrestrial digital video broadcasting (DVB) system [3, 7].
- Wideband communication over mobile radio: Mobile Radio-FM, Digital cellular telephony, WLAN, WMAN, and UWB...
- Optical communications.

3. Coded OFDM

Coded orthogonal frequency division multiplexing (COFDM) is the same modulation technique as that of OFDM one, except that, in this forward error correction is applied to the signal before transmission. This is to overcome the errors in the transmission due to lost carriers from frequency selective fading, channel noise and other propagation effects. More details about this can be obtained from [8, 9].

4. MIMO-OFDM (Multi-input Multi-output OFDM)

Multiple antennas can be used at the transmitter and the receiver, to term a MIMO system. MIMO is known to boost the capacity. For high data rate transmission, the multipath characteristic of the environment causes the MIMO channel to be frequency selective. OFDM can transform such a frequency selective MIMO channel into a set of parallel frequency-flat MIMO channels, and therefore decreases the receiver complexity. The combination of the two powerful techniques, MIMO and OFDM, is very attractive, and has a most promising broadband wireless access scheme.

One of the important issues of the MIMO-OFDM systems is the estimation of the channel. The computational complexity increases rapidly by increasing the number of antennas at the transmitter and receiver, and the performance substantially degrades with the estimation error. The several channel estimation techniques that have been proposed will improve the estimation and reduce the computational complexity by exploring the certain characteristics of the channel.

A MIMO system takes the advantage of the spatial diversity obtained by spatially separated antennas in a dense multipath scattering environment. MIMO system may be implemented in a number of ways to obtain either a diversity gain to combat signal fading or to obtain a capacity gain. The details can be found in [10].

4.1. Types of MIMO

There are three categories of MIMO technique present. They are:

- ▶ The first one to improve the power efficiency by maximizing the spatial diversity. These include:
 - Delay diversity, STBC (Space time block code) and STTC (space time Trellis code).
- ▶ The second type uses a layered approach to increase the capacity. One example is:
 - V-BLAST (vertical-Bell laboratories layered space time) architecture, where the independent data signals are transmitted over antennas to increase the data rate, but full spatial diversity is usually not achieved.
- ▶ The third one exploits the knowledge of the channel at the transmitter. It decomposes the channel matrix using singular value de-composition (SVD) and uses these decomposed Unitary matrices as pre- and post-filters at the transmitter and the receiver to achieve capacity gains [11].

4.2. Block Diagram of MIMO-OFDM Transmitter and Receiver

Transmitter:

As shown in Fig. 2, in the transmitter, the source bit stream is mapped to a constellation by the digital modulator, and then encoded by a MIMO encoder. Then, each of the parallel output symbol streams corresponding to a certain transmit antenna follows the same transmission process.

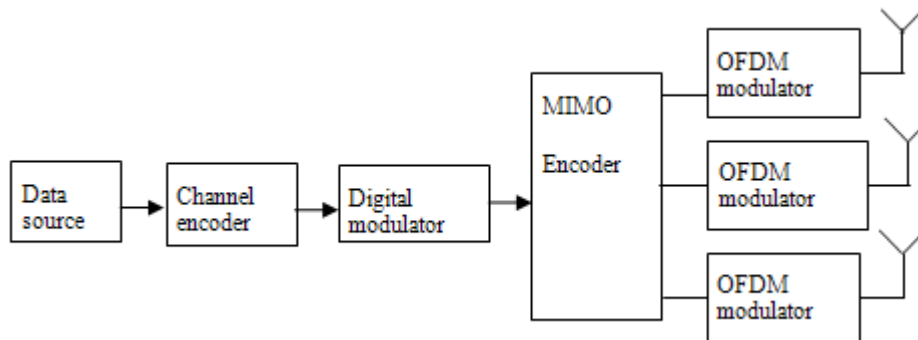


Fig. 2. Block Diagram of MIMO-OFDM transmitter.

Receiver:

The received symbol stream from IF/RF components over the receive antennas are first synchronized, including the coarse frequency synchronization and timing aided by the preamble. After OFDM demodulation is over, the refined frequency pilots from all the receive antennas are used for channel estimation. The estimated channel matrix aids the MIMO decoder in decoding the refined OFDM symbols. The estimated transmit symbols are then demodulated and decoded. At last, the decoded source bit streams are transmitted to the data sink. The block diagram of MIMO-OFDM receiver is shown in Fig. 3.

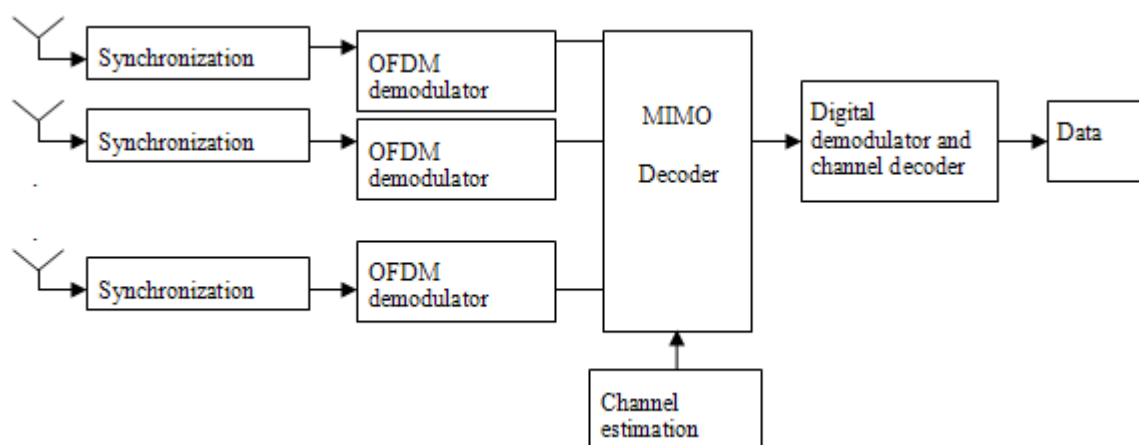


Fig. 3. Block Diagram of MIMO-OFDM Receiver.

4.4. MIMO-OFDM Channel Estimations

In this, with M_T transmitter and M_R receivers, there are $M_T \times M_R$ channels to be estimated. As all Transmitters send their signals simultaneously, the received signal at each receiver is a superposition of all the transmitted signals that are distorted by the channel. Hence, in the estimation process of the channel between i^{th} . Transmitter to the j^{th} . Receivers, the signals transmitted by the other transmitter are interference. So, in the MIMO channel estimation, whenever a pilot tone is inserted in a sub carrier, all other transmitters don't send anything in that sub carrier. This is the proposed method for cases that the time interval between two consecutive symbols is larger than channel coherence time, or the case that we have no information about the temporal correlation of the channel.

In some cases, the channel estimation is based on this assumption that the delay profile of the channel is known and it doesn't change much between two consecutive symbols. If the interval between two consecutive symbols is less than the channel coherence time, it is possible to use this correlation to improve the channel estimation.

Assume (k, n) is the estimate of the channel at time k and n th. Pilot tone frequency. Also, assume $(k+1, n)$ is the Least square (LS) estimate of the channel at time $k+1$, and pilot tone frequency n .

The best linear Mean Square Estimation (MSE) of $H(k+1, n)$, for given $H(k+1, n)$ and $H(k, n)$ is:

$$H(k+1, n) = a \times H(k, n) + b \times H(k+1, n),$$

where,

$$a = \frac{(R_{hh}^2(0) - R_{hh}^2(1))}{(R_{hh}^2(0) - R_{hh}^2(1) + r^2 R_{hh}^2(0))} \quad \text{and} \quad b = \frac{\sigma^2 R_{hh}^2(1)}{(R_{hh}^2(0) - R_{hh}^2(1) + \sigma^2 R_{hh}^2(0))} \quad (6)$$

More detail description about the channel estimation schemes can be obtained from [12].

5. Results and Discussion

5.1. Simulation of an Un-coded OFDM System

The BER (bit error rate) of the OFDM system and the 16-QAM systems is shown below as to compare the multi-carrier and single carrier communication system respectively. It is very clear from the BER curve obtained in Fig. 4 and Fig. 5 that OFDM is a good choice in comparison to 16-QAM for high data rate communications. All the Simulation results shown in this paper are done on MATLAB-6.5 platform with IBM PC, Pentium-IV, and 2.4 GHz, 40 GB HDD M/c.

5.2. Simulation of a Coded OFDM using AWGN

Three carrier modulation methods were tested to compare their performances. In this simulation, differential encoding technique is used which allows the use of Differential modulation methods, such as DBPSK, DQPSK and D16PSK. These were basically to show a trade off between system capacity and system robustness.

As shown in Fig. 6, DBPSK is the most durable method for spectral efficiency. However, in the DQPSK and D16PSK method, the system capacity can be enhanced at the cost of a higher BER.

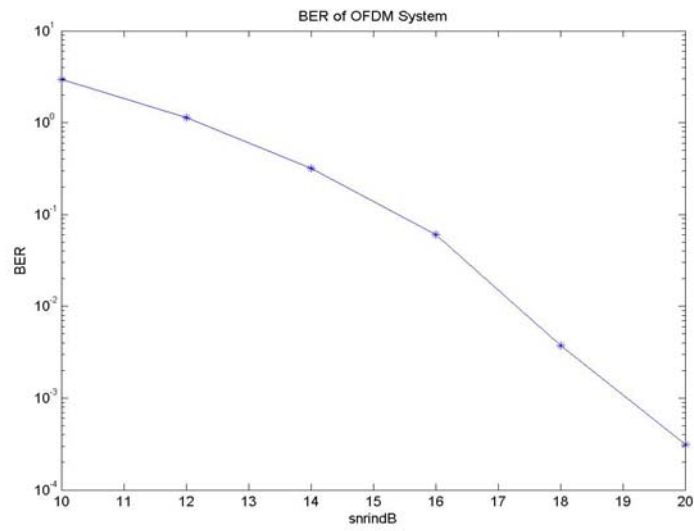


Fig. 4. Bit error rate curve for an OFDM system.

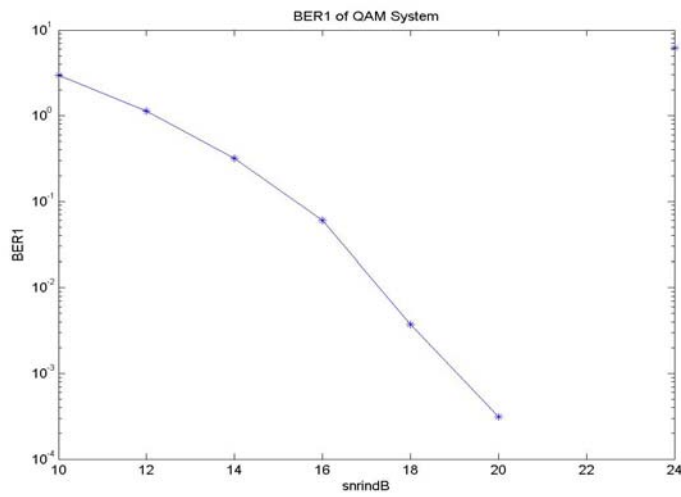


Fig. 5. Bit error rate curve for a 16-QAM system.

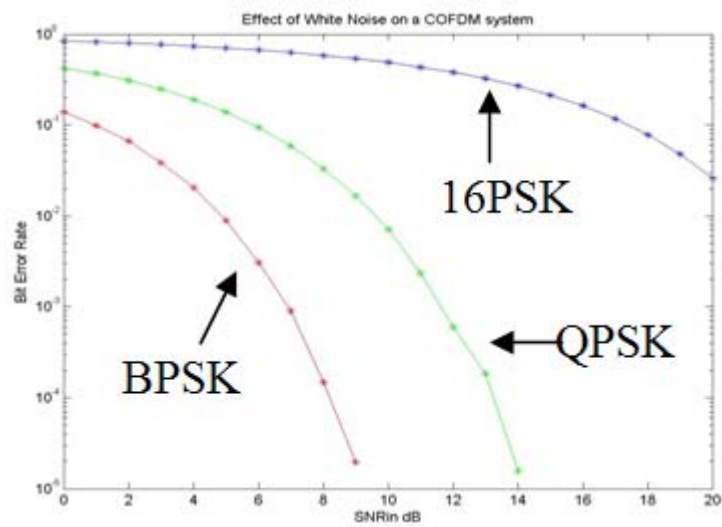


Fig. 6. Bit error rate comparison for coded OFDM.

5.3. Simulation of a MIMO-OFDM System

The figure, which is shown below, is to see the performance of the MIMO system for several Doppler frequencies. In all the cases, the bandwidth of each sub channel is 20 kHz, the total no. of sub carriers (SC) is 64 and the number of pilots is 32.

Increasing the maximum Doppler frequency decreases the coherence time of the channel. So, it is expected that the performance of the MMSE system degrade by increasing the maximum Doppler Frequency.

It can be noted from Fig. 7 that, although MMSE shows a better performance over LS, the computational complexity of this is the main problem of using that for this simulation. In this case, simulation has been done by taking Doppler frequency (f_m) =100 Hz. However, the difference will be more significant by using Doppler frequency (f_m) at 10 Hz. To compare these results, MIMO systems with varying antenna numbers at Transmitter and Receiver taken in a Rayleigh fading channel is simulated as shown in Fig. 8 and Fig. 9. All channel impulse responses are RF channels with the Bessel auto correlation function (Jakes Model). The comparison of MMSE channel estimation using various Doppler frequencies (f_m) is shown in Fig. 10.

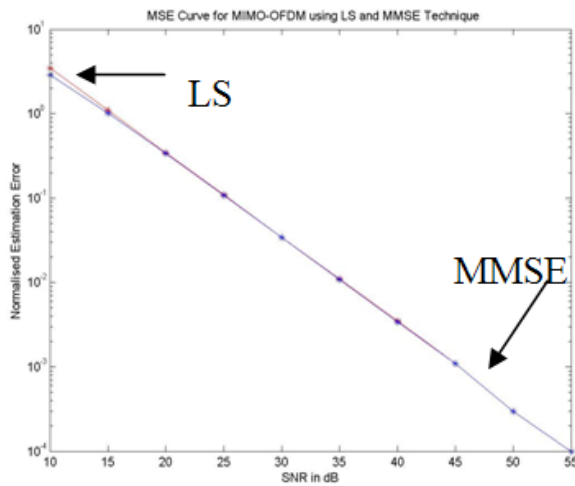


Fig. 7. Comparison of LS over MMSE channel estimation technique.

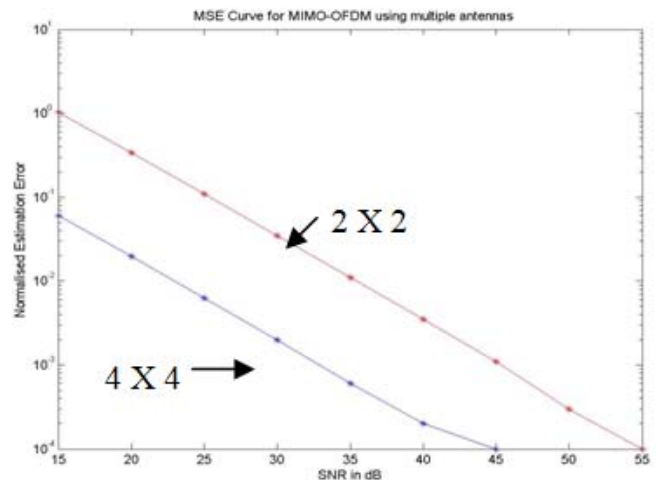


Fig. 8. Comparison on multiple antennas at transmitter and receiver station.

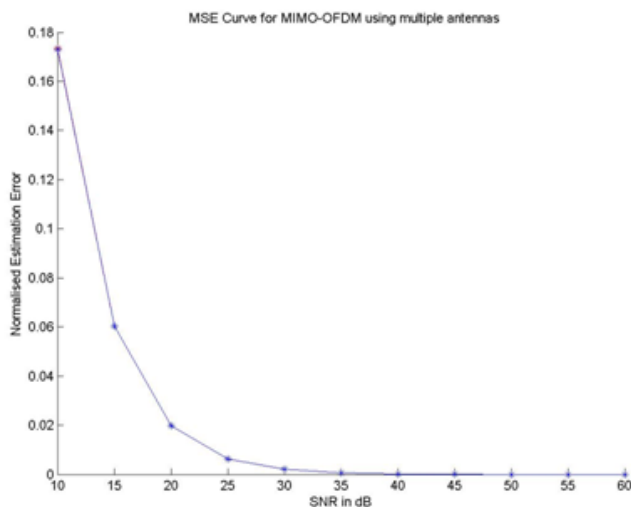


Fig. 9. MSE curve for 4X3 MIMO-OFDM system.

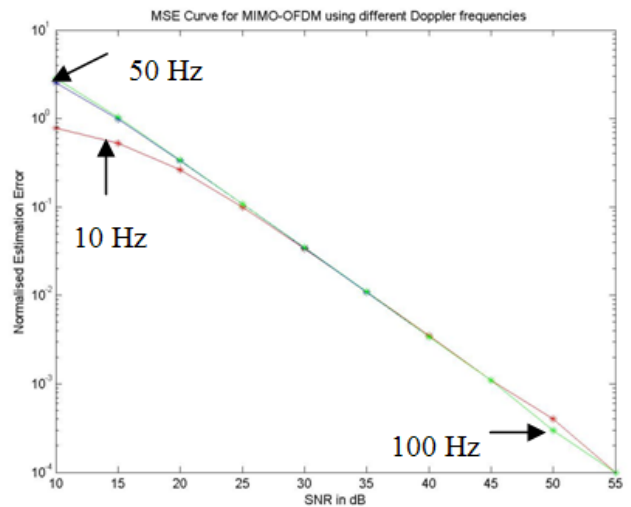


Fig. 10. Performance analysis of MIMO- OFDM system at various Doppler frequencies.

6. Comparison with Spatial Multiplexing, STBC and SVD Techniques Used for MIMO-OFDM Systems

In this paper, the spatial multiplexing with V-BLAST technique is used. This uses MIMO channels to send parallel symbols streams from the Transmitter. The main disadvantage with this is that the channel estimation needs to be good, which requires high SNR. Classical V-BLAST requires flat fading channel which leads to narrow band channel assumptions and use of multiple transmit and receive antennas in order to achieve high throughput rates. This makes it impracticable for portable WLAN applications. The problem with the STBC (Space Time Block Coding) technique is that, there are no full rate codes when there are more than two transmit antennas. Also, like the V-BLAST technique, the performance degrades, when the channel is not flat fading. A very useful property, mainly due to the SVD (Singular Value De-composition) approach is that it is relatively easy to handle cases, where the numbers of Tx and Rx antennas are not the same. A big assumption made in this is that, the channel is reciprocal and hence, the same channel estimation done at the receiver can be used for the transmitter. While this is a valid assumption for the channel for se, the problem comes when the transmitter and receiver chain hardware are included. Another issue is that SVD is computationally intensive. Once SVD is done, the additional computation required to compute the best possible rate is small and can easily be implemented.

7. Conclusions

In this article, OFDM transceiver design is introduced. We have simulated the BER for OFDM (Multi-carrier) and 16-QAM (single carrier) communication systems and found that, OFDM is a better choice for high data rate systems. Here, Differential encoding technique is used which is required for Coded OFDM systems for error free transmission. However, Coherent detection scheme can be used for the purpose using 16-QAM systems for achieving better spectral efficiency. In this, we have discussed with some basic features of MIMO-OFDM techniques. Apart from this, we have concentrated on the various channel estimation techniques, which are needed for design of such a very power technique. Finally, we have compared through the computer simulation various cases of MIMO-OFDM using same number of antennas at the TX and Rx side and also, with the Rx antennas \leq TX antennas (Spatial multiplexing). At last, how MIMO-OFDM system behaves for various Doppler frequencies considered (10, 50, and 100Hz) for MMSE receiver is also being simulated. These overall results and discussion shows that MIMO-OFDM is a potential candidate for the future Broadband wireless access.

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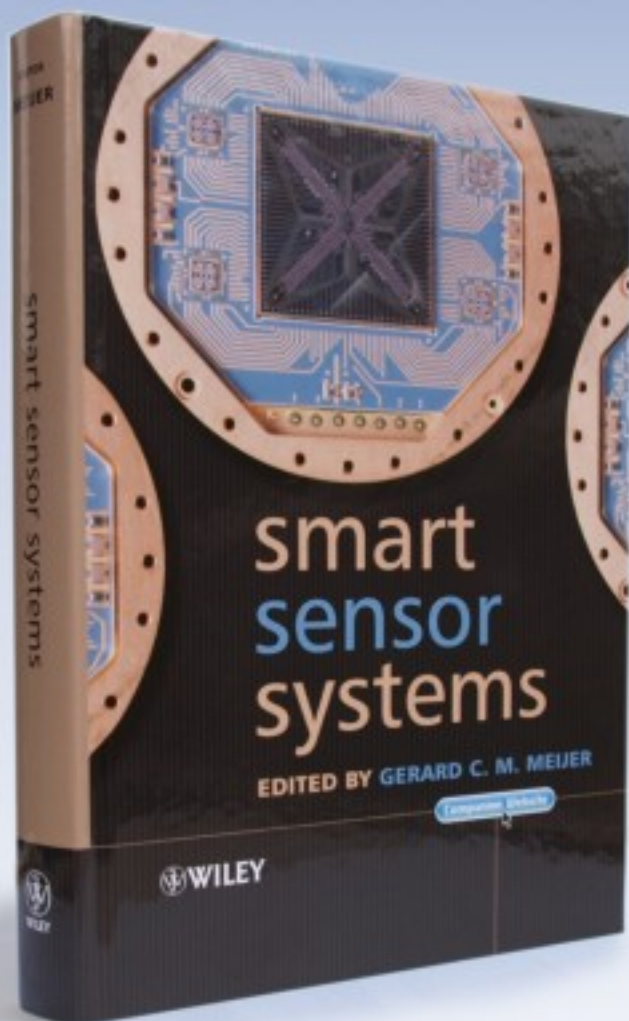
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