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Wireless Signal Quality Analysis, Enhancement and Estimation for 2x2 MIMO using OFDM

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ABSTRACT

Background: The wireless channel is both frequency- and time selective, and also the space-selective with multiple antennas. Increasing demand with time for high data rates with the evolution of the Very Large Scale Integration (VLSI) had been forcing effective utilization of available limited spectrum.. Objective: The multiple inputs multiple output-orthogonal frequency division multiplexing (MIMO-OFDM), an air-interface solution with its inherent high spectral efficiency, data rate, increased coverage area, and resistance towards multipath propagation can satisfy the multiplying demands of wireless mobile applications without additional bandwidth (BW) or power. Results: If propagating channel properties, that is, Channel State Information (CSI) are known priori wireless link, signal degradation by fading and scattering can be reduced considerably. In the perspective of MIMO-OFDM, link abstraction models are desirable to squeeze the wideband channel quality measurements performed Channel Quality Indicators (CQI) or CSI. The models are based on mutual information and are trained to obtain the relevant link parameters, then tested on scenarios with different antenna correlation conditions. Conclusion: The results show that MMSE abstraction model with 2x2 MIMO systems produces a set of parameters useful to predict the better BER with cyclic delay diversity and high antenna correlation.

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INTRODUCTION

Channel Estimation:

The strength, quality, and characteristics of a wireless signal decays with Doppler effects as signal propagates from link to link. The data link, network, and physical layers have a crucial role in establishing communication link. To achieve reliable link, especially in MIMO systems prior transmission, knowledge of channel state helps in calculating/estimating link budget. Since the receiver has to know the packet synchronization before being processed, CSI's at the transmitter (CSIT) and receiver (CSIR) needs anticipate channel characteristics at the receiver. Therefore, the transmitter and receiver can have different CSI (P. Venkateswarlu, R. Nagendra, 2014).

Instantaneous:

Instantaneous CSI is reasonably possible for slow fading systems.

Statistical:

Statistical evaluation of signal propagation circumvents multipath fading distribution, the average SNR, the line-of-sight path, spatial modulation-and-multiplexing optimization. Always, estimation accuracy relates to random propagation variations. Practical channel characterization is validated to instantaneous and statistical approximations. As shown in the Fig.1.

Training Based:

Trained or known symbols called pilot tones can be used as Block type pilots or Comb type pilots, which are known to the receiver are encapsulated along with data streams.

Block type pilot estimation:

A block of OFDM symbols which contains data and pilot subcarriers is transmitted along with data blocks periodically, in coherence with the Doppler effects. This coherency is in proportion to the pilot spaces spaced for reliable transmission of symbols,

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knowing the delay spread of MIMO channel fading effects. It is suitable for slow fading channels. Here, one specific symbol full of pilot subcarriers is transmitted periodically as in fig.2 below.

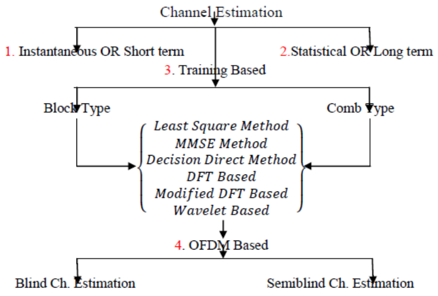


Fig. 1: Different classes/Types of channel estimation.

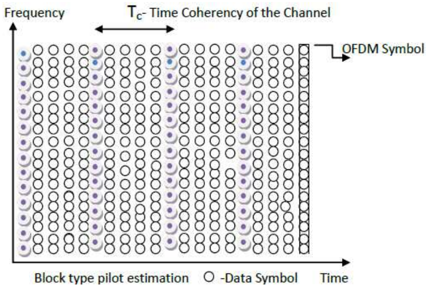


Fig. 2: Block type pilot estimation.

***Comb type pilot estimation*:**

It is suitable for fast fading channels where obviously symbol density is more. In this arrangement, pilot tones/symbols are inserted into each OFDM symbol with a specific period of frequency bins as shown in fig.3. Multiplexing of pilot symbols continuously over specific pilot sub-channels in all OFDM symbols according to the following equation:

$$X_m = \begin{cases} pilot, & m = kP \\ data, & otherwise \end{cases}$$

Where P denotes the pilot repetition or spaces rate in OFDM symbol which can be calculated by $P = N/N_c$; N_c = the pilot number

MIMO:

The information to be transmitted is divided into number of time slots depending on the number of transmit (TX) and receive (RX) antennas of MIMO structure, and multiple copies of the same slot are transmitted with different time delays in different frequencies. Since signal traverses in multiple paths and multiple times proportional to the number of TX antenna times, gets distracted due to reflection, diffraction, and scattering through propagation to reach the destination, resulting in random variations of amplitude, phase and frequency of the received signal. Amplitude variation fades the signal strength; change in phase enhances the signal strength adding amplitude constructively to another same copy or interferes or nullifies destructively when not in phase, and differences in symbol arrival times at the receiver causes overlap leading to intersymbol interference (Geert Leus and Alle-Jan Van Der Veen, Ali Asadi and Behzad Mozaffari Tazehkand,& Waheed U. Bajwa, Jarvis Haupt, Akbar M. Sayeed, and Robert Nowak,2013).

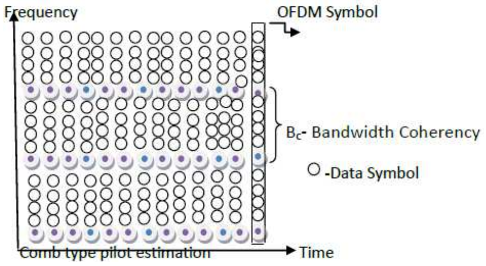


Fig. 3: Comb type pilot estimation.

Since signals are transmitted in multiple copies in multiple paths, they are to be independent without interaction in specific time intervals of packet data traffic. This can be achieved only through orthogonal frequency division multiplexing (OFDM), a combination of modulation and multiplexing. Spatial multiplexing gain and antenna diversity gain of MIMO with link reliability of OFDM, increases spectral efficiency considerably. Capacity increases linearly in MIMO and logarithmically in SIMO/MISO [1, 3, 8]. The impulse response of MIMO is a summation of random variations of phase, Doppler shift, and delay which is characterized by

$$h_{nk} = lim_{n\to\infty} \frac{1}{\sqrt{N}} \sum_{i=1}^{N} exp^{j(} \emptyset_i + 2\pi f_D T_s k - 2\pi \tau_i F_s n) \quad (1)$$

Where n and k are the frequency and time indices of the channel/link, N is the number of channels in MIMO system. T_s is the spacing between symbols $and\ F_s$ is the spacing between carriers.

Benefits Of Mimo Systems:

Interference reduction and avoidance: Exploits spatial dimension sharing time and frequency resources to improve the coverage and range of a wireless n/w.

Spatial multiplexing: Increases the transmission rate (or capacity) linearly for the same bandwidth and with no additional power expenditure.

Array gain:

The average increase in the SNR at the receiver that arises from the coherent combining effect of multiple antennas at the receiver or transmitter or both.

Modulation:

Signals from the transmitting channel are modulated to a waveform to be compatible with the communication channel 'according to the information in the message signal with the carrier signal'. Quadrature Amplitude Modulation (QAM) achieves high spectral efficiency/channel capacity because of its inherent nature, uses both amplitude(using Amplitude Shift Keying) as well as phase (Phase Shift Keying) modulation to generate two carriers (usually sinusoids) of $(90)^0$ out of phase (in quadrature) of the same frequency. Orthogonality of the carrier signals detects the modulating signals independently. The resulting signal's amplitude and phase will be the sum of I & Q signals as per (Ragam.Gouthami, K.Ragini, Ch. Ganapathy Reddy, 2013).

$$M = \{s_i(t) = \underbrace{A_i}_{\text{Amplitude}} p(t) cos(2\pi \underbrace{f_c}_{\text{Frequency}} t + \underbrace{\varphi_i}_{\text{Phase}})1\}_{i=1}^{m} \quad 0 \le t \le T_s, \tag{2}$$

Where,

$$S_i(t) = (A_i cos\varphi_i)p(t)\cos(2\pi f_c t) + (A_i sin\varphi_i)p(t)\sin(2\pi f_c t) \tag{3}$$

Where, A_i is the amplitude, f_c is the carrier-frequency and $\varphi_i$is the phase of the ith signal in the M-ary QAM signal set. With these $\cos(2\pi f_c t)$ and $\sin(2\pi f_c t)$ quadrature carriers, QAM is able to modulate, add, and then transmit two separate signals I & Q independently with the same carrier frequency, as shown in Fig.4 & 5. Therefore, the received signal is,

$$r(t) = s(t)\cos(2\pi f_0 t)$$

$$= I(t)\cos(2\pi f_0 t)\cos(2\pi f_0 t) - Q(t)\sin(2\pi f_0 t)\cos(2\pi f_0 t) \tag{4}$$

Where, QAM is combination of ASK and PSK. That is,

I = A cos (Ψ) = $(A_i cos\varphi_i)p(t)\cos(2\pi f_c t)$ and

Q = A sin (Ψ) =$(A_i sin\varphi_i)p(t)\sin(2\pi f_c t)$. (5)

By their phase difference of 90°, the signal can be expressed as:

Cos (α + β) = cos (α) cos (β) - sin (α) sin (β) (6)

Using the expression A cos (2πft + Ψ) for the carrier signal.

A cos ($2\pi f_c$t + Ψ) = I cos ($2\pi f_c$t) - Q sin ($2\pi f_c$t) (7)

The M-ary square QAM signals can be denoted as,

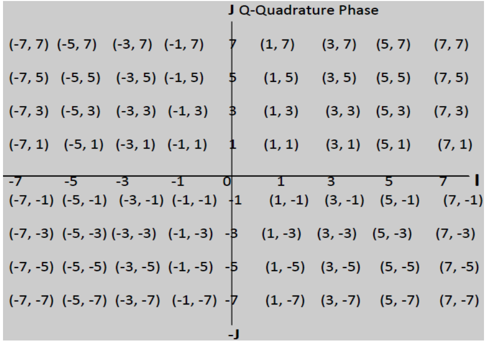
$$S_i(t) = A_k cos\theta_k(t)\cos(2\pi f_c t) - A_k sin\theta_k(t)\sin(2\pi f_c t) \tag{8}$$

As a linear combination of two orthogonal functions,

$$S_i(t) = a_i\sqrt{\frac{2E_0}{T_S}}\cos(2\pi f_c t) + b_i\sqrt{\frac{2E_0}{T_S}}\sin(2\pi f_c t) \tag{9}$$

Accordingly the coordinates of the ith signal points derived from the elemental energy and power are represented in rectangular co-ordinate by $(a_i\sqrt{E_0}, b_i\sqrt{E_0})$ where (a_i, b_i) are symbols of the 64-QAM matrix represented as,

$$\{a_i, b_i\} = [I\&Q\ elements of\ 64\ QAM\ Constellations]$$



(-7, 7)	(-5, 7)	(-3, 7)	(-1, 7)	7	(1, 7)	(3, 7)	(5, 7)	(7, 7)	
(-7, 5)	(-5, 5)	(-3, 5)	(-1, 5)	5	(1, 5)	(3, 5)	(5, 5)	(7, 5)	
(-7, 3)	(-5, 3)	(-3, 3)	(-1, 3)	3	(1, 3)	(3, 3)	(5, 3)	(7, 3)	
(-7, 1)	(-5, 1)	(-3, 1)	(-1, 1)	1	(1, 1)	(3, 1)	(5, 1)	(7, 1)	
-7	-5	-3	-1	0	1	3	5	7	I
(-7, -1)	(-5, -1)	(-3, -1)	(-1, -1)	-1	(1, -1)	(3, -1)	(5, -1)	(7, -1)	
(-7, -3)	(-5, -3)	(-3, -3)	(-1, -3)	-3	(1, -3)	(3, -3)	(5, -3)	(7, -3)	
(-7, -5)	(-5, -5)	(-3, -5)	(-1, -5)	-5	(1, -5)	(3, -5)	(5, -5)	(7, -5)	
(-7, -7)	(-5, -7)	(-3, -7)	(-1, -7)	-7	(1, -7)	(3, -7)	(5, -7)	(7, -7)	

Fig. 4: 64 QAM Constellation diagram in the matrix form.

Unique 16 symbols of 64-QAM are the result of 16 I and 16 Q values with each symbol representing six bits (2^6 =64). I and Q are amplitude and phase modulated (encoded) by the 6 bits per clock before being modulated to radio frequency (RF). As the order of modulation increases; number of bits per symbol increases, the link between bits in the symbol becomes more susceptible to noise and linearity of the communications channel (Tara.Saikumar R. Nirmala Devi & Dr. K. Kishna Rao ,2012 & Aida Zaier and Ridha Bouallègue,2012).

Let us visualize the collection of bits transmitted (symbols) over the QAM signal as falling into a grid of buckets. Bucket collects one symbol for each clock cycle. Since I and Q are supposed to be discrete amplitudes (4I and 4Q levels in QAM-64), the first clock cycle would plot the reception as shown in Fig.5 and the same continues .

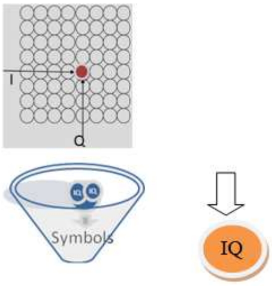


Fig. 5: QAM signal formation with the clock.

The table I gives a summary of the bit rates of different forms of QAM.

Table I: Summary of modulation types with data capacities.

Modulation	Bits per symbol	Symbol Rate	Error Margin
2QAM (BPSK)	1	1 x bit rate	1
4QAM (QPSK)	2	1/2 bit rate	1/√2 = 0.71
16QAM	4	1/4 bit rate	√2/6 = 0.23
64QAM	6	1/6 bit rate	√2 /14 = 0.1

Orthogonal Frequency Division Multiplexing (OFDM):

Orthogonal Frequency Division Multiplexing, a combination of modulation and multiplexing in which signals are independent and also they'll never interact with each other in specific time intervals of packet data traffic. OFDM offers different modulation schemes for different subcarriers and even for different users, so that multiple symbols can be transmitted in parallel.

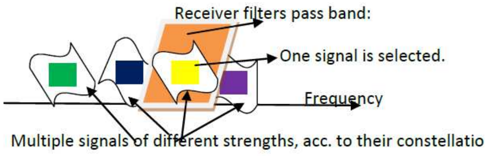


Fig. 6: Signals at the receiver carrying modulation.

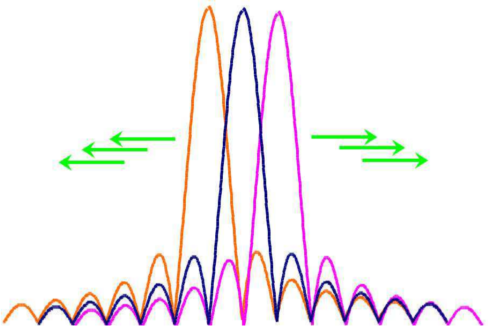


Fig. 7: OFDM Spectrum of 3 carriers, contributions from other un-correlated signals cancel.

In a propagating signal/symbol sequence according to the QAM constellation, each symbol is having different strength. The cyclic prefix (CP) or guard interval is a copy of the last part of the OFDM symbol, turns a linear convolution into a cyclic convolution for the use of an IFFT at the transmitter and an FFT at the receiver for precise control.

As shown in the Fig.6 & 7.

OFDM with its inherent ability of modulation and multiplexing, simplifies equalization, and with MIMO enhances data rate, link reliability and spectral efficiency due to their parallel transmission technologies in the frequency and space domains, respectively(Mr. S. Lenin, Dr .S. Malarkkan,2014 & Hadimani H.C., Dr. Mrityunjaya V.Latte ,2015).

OFDM Signal Model:

OFDM has a defined and articulated mathematical relationship between the frequencies I & Q of the carriers in the QAM system. In an OFDM, an l-th symbol X is framed by K complex QAM symbols, that is, $X_{l,k}$ where each symbol modulates a sub-carrier symbol T_{sc} of period T by an N-point ($N \geq K$) IFFT with a sampling period of $T = T_{sc}/N$ with frequency $f_k = k/T_{sc}$. Sampled signal is then passed through pulse-shaping filter g (t) which is then encapsulated with a guard-band of length $T_g = N_g T$ for transmission with the complex base band signal described by,

$$x(t) = \frac{1}{\sqrt{T_{sc}}} \sum_{l=-\infty}^{\infty} \sum_{k=-\frac{K}{2}}^{\frac{K}{2}-1} X_{l,k}\, e^{j2\pi} f_k(t - T_g - lT_0)\; g(t - lT_0) \qquad (10)$$

Where T_0 is the generated OFDM symbol corresponding to $N_0 = N_g + N$ samples. This complex base band signal is transmitted over MIMO channel to yield at the receiver, (Helmut Bölcskei, eth Zurich, 2006)

$$y(nT) = \sum_{m=0}^{M-1} h_m(nT)\, x(nT\tau_m) + n(nT) \qquad (11)$$

Where, $T_g \gg y(nT)$.

This is the total received information of the m-th channel symbols of mxn MIMO. The signal to noise ratio (SNR) per sub-carrier is the reciprocal of the square of the total m-th channel symbol variance, i.e.

$$SNR = 1/\sigma_{\bar{m}}^{2} \qquad (12)$$

Defining parameters for channel estimation:

Let us consider the following defining parameters:

N : Number of pilots in one OFDM symbol,

A : Diagonal matrix of pilots = diag$\{A_0, A_1, A_2, \dots \dots A_{N-1}\}$,

$\hat{h}$: The impulse response of the pilots of one OFDM symbol,

B : The vector of output signal after (OFDM) demodulation = $[B_0, B_1, B_2, \dots \dots, B_{N-1}]^T$,

$\hat{H}$: The channel matrix,

$S_{HB} = E\{HB^H\} = S_{HH}A^H$ = The cross-co-variance matrix between H and B,

S_{HH} = Auto co-variance matrix of H,

S_{BB} = Auto co-variance matrix of B = $E\{BB^H\} = AS_{HH}A^H + I_N\sigma_z^{\,2}$,

$\sigma_z^{\,2}$ = The noise variance,

I_N = The identity matrix of pilot distribution,

Z = The AWGN channel noise.

Least Square (LS) Algorithm:

$\hat{H}_{LS} = A^{-1}$B ; obviously simple but suffers from mean square error (MSE). (13)

Minimum Mean Square Error:

$$\hat{H}_{MMSE} = S_{HB}S_{BB}^{-1}B = S_{HH}A^H(AS_{HH}A^H + \qquad (14)$$

At lower BER MMSE does 10-15 dB more better performance than LS.

The design of MMSE estimator for 2x2 MIMO-OFDM is shown in Fig.8 below; and the parameters considered for concluding results are shown in table II.

Effect of Channel Estimation Error on the BER performance of ZF receiver with QAM:

BER performance of any channel is characterized by the number of transmit (N_t) and receive (N_r) antennas and their differences (D), presence or absence of channel estimation error. Since in this channel estimation QAM is used, related BER can be approximated by,

$$BER_{MQAM} \cong \frac{2(\sqrt{M}-1)}{\sqrt{M}\log_2\sqrt{M}}\left[\frac{1}{2}(1-\mu_0)\right]^{D+1}\sum_{j=0}^{D}\binom{D+j}{j}\left[\frac{1}{2}(1+\mu_0)\right]^{j} + \frac{2(\sqrt{M}-2)}{\sqrt{M}\log_2\sqrt{M}}\left[\frac{1}{2}(1-\mu_1)\right]^{D+1}\sum_{j=0}^{D}\binom{D+j}{j}\left[\frac{1}{2}(1+\mu_1)\right]^{j} \quad (15)$$

Where,

$D = N_r - N_t$. **M is the order of modulation (4, 8, 16, 32, 64…)**

Here, from the theoretical analysis of MIMO and QAM we know that, as the number of transmit antenna increases BER increases due to multipath fading and destructive signal overlapping, and as the constellation size of QAM increases the symbol spacing decreases which leads to fusion of constructive/destructive overlapping depending on the phase of the symbols.(Hadimani.H.C, Dr. Mrityunjaya.V. Latte, 2014).As shown in the Fig.8 to 19).

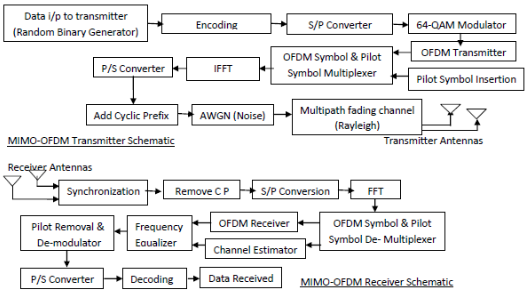


Fig. 8: Design/Block diagram of MMSE Estimator for 2x2 MIMO-OFDM.

Table II: Simulation Parameters.

Parameters	Type
Antenna Configuration	2x2, N_t= N_r
Channel Condition	NLOS (No HAPs), LOS (With HAPs)
Channel BW	1.75 MHz – 20 MHz
HAPs Height	20km
Modulation	64-QAM
Fading	Rayleigh
Noise Channel	AWGN
Average Tx Power	1 dB
Frame length	100
Maximum No. of packets	3000
Carrier frequency	900 MHz
Signal BW (BWs)	200 kHz
Symbol Period	1/BWs
Time delay	$(0.1-0.2)^{-4}$
Filter	Low-Pass-Filter, Cosine Filter
Roll off factor	25%
SNR	0:2:28 dB
OFDM Sub-carriers	1-56 (IEEE802.11n WLAN Std.)
CP Length	1/4
CP Duration, T_{cp}	0.8 µsec
Data symbol Duration, T_{ds}	3.2 µsec
Total Symbol Duration, T_{sd}	4 µsec
Channel estimator/Detection	MMSE
Coding	Convolutional Coding (CC), Cyclic Redundancy Check (CRC)
Code Rate	CC (1/2), CRC (2/3)
K-factor	3
Constraint Length	7
FFT Size	64
FFT sampling frequency	20 MHz
Maximum Doppler Shift	100/40Hz
User Mobility	Low - High

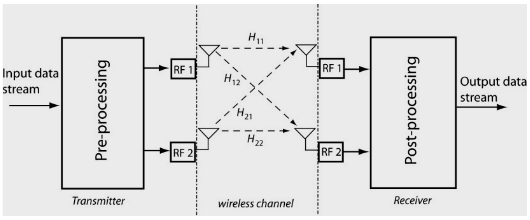


Fig. 9: 2x2 MIMO (multipath) connections.

H_{11} is the channel propagation from the transmitting antenna 1 to receiving antenna 1.

H_{12} is the channel propagation from the transmitting antenna 1 to receiving antenna 2.

H_{21} is the channel propagation from the transmitting antenna 2 to receiving antenna 1.

H_{22} is the channel propagation from the transmitting antenna 2 to receiving antenna 2.

Simulation Results:

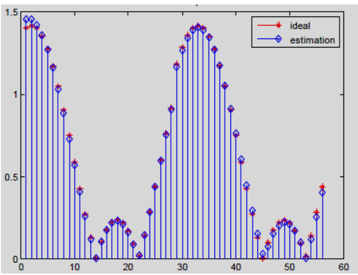


Fig. 10: H11-Real Part of 2x2 MIMO-OFDM.

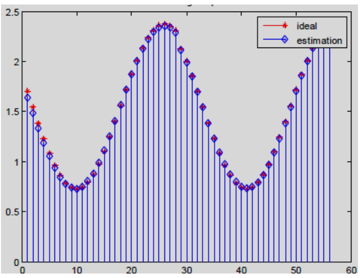


Fig. 11: H11-Imaginary part of 2x2 MIMO-OFDM.

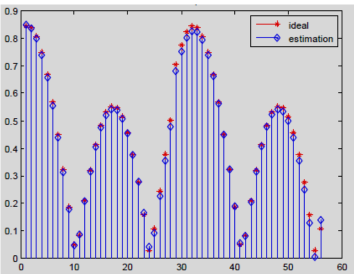


Fig. 12: H1 2- Real part of 2x2 MIMO-OFDM.

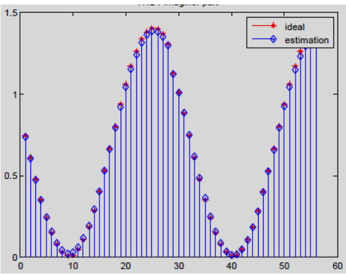


Fig. 13: H1 2- Imaginary part of 2x2 MIMO-OFDM.

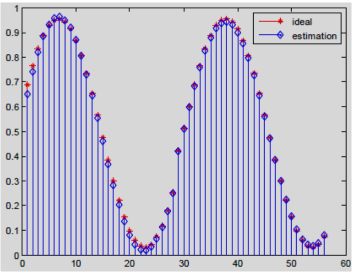


Fig. 14: H21- Real part of 2x2 MIMO-OFDM.

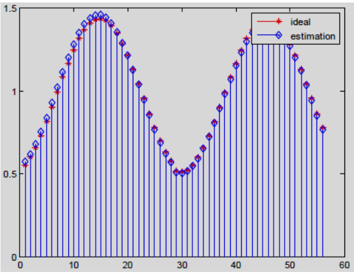


Fig. 15: H21- Imaginary part of 2x2 MIMO-OFDM.

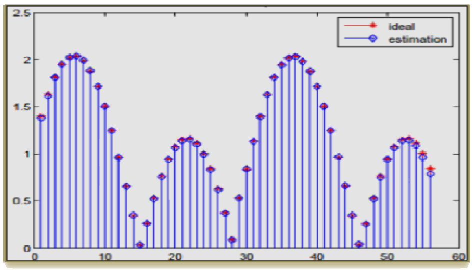


Fig. 16: H22- Real part of 2x2 MIMO-OFDM.

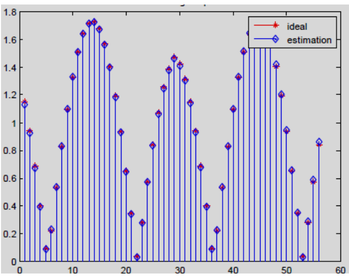


Fig. 17: H22- Imaginary part of 2x2 MIMO-OFDM.

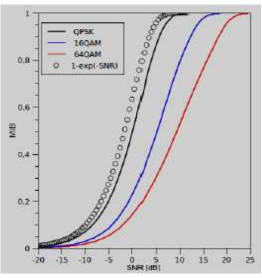


Fig.18: SNR vs BER of different modulations.

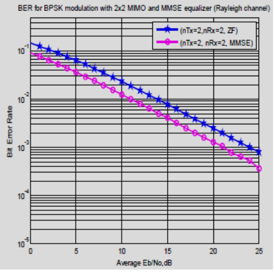


Fig. 19: SNR vs BER of ZF and MMSE.

Conclusion:

For mobile communication and data transmission, mobile integrated multimedia digital service network needs essentially high quality audio, video and internet applications for which high bit rate of approximately 500 Mbps to 1 Gbps is needed. This is possible only through MIMO where many symbol periods overlap due to extension of channel impulse responses, which leads to Intersymbol interference. From the plots 1-8 and 9 - 10 the following observations can be made:

The channel estimator ZF removes ISI for noiseless channels and MMSE algorithm estimates the channel much better than ZF at the cost of increasing complexity. Moreover it is observed that QAM data symbols results in less number of errors as compared to QPSK. One Tx antenna is favoured to one Rx antenna in Line Of Sight propagation. Spatial multiplexing and reception qualities are balanced for 2x2 (2 Tx and 2 Rx) antenna configuration. MMSE detector for the 2x2 configuration exploiting cross polarization, achieves 28-30 dB SINR variations even in unfavorable channel propagation scenarios.2x2 mimo transceivers excel in better performance with 64-QAM and MMSE resulting high antenna correlation, link abstraction and cyclic symbol synchronization with better directional channel diversity.

REFERENCES

Venkateswarlu, P., R. Nagendra, 2014. “Channel Estimation Techniques in MIMO-OFDM LTE Systems”, Int. Journal of Engineering Research and Applications, ISSN: 2248-9622, 4-7 (Version 1), 157-161.

Geert Leus and Alle-Jan Van Der Veen, Delft University of Technology, Dept. EEMCS, Mekelweg 4, 2628 CD Delft, the Netherlands.

Ali Asadi and Behzad Mozaffari Tazehkand, 2013. “A New Method to Channel Estimation in OFDM Systems Based on Wavelet Transform”, International Journal of Digital Information and Wireless Communications (IJDIWC) 3(1): 1-9, the Society of Digital Information and Wireless Communications, (ISSN: 2225-658X).

Waheed, U., Bajwa, Jarvis Haupt, Akbar M. Sayeed and Robert Nowak, “Compressed Channel Sensing: A New Approach to Estimating Sparse Multipath Channels”, Program in Applied and Computational Mathematics, Princeton University, Princeton, NJ 08544. JH is with the Department of Electrical and Computer Engineering, Rice University, Houston, TX 77005.

Ragam, Gouthami, K. Ragini, Ch. Ganapathy Reddy, 2013. “Iterative Channel Estimation and ICI Cancellation Techniques in MIMO-OFDM Wireless Communication Systems”, International Journal of Engineering and Advanced Technology (IJEAT) ISSN: 2249 – 8958, 2-6.

Tara, Saikumar, R. Nirmala Devi & Dr. K. Kishna Rao, 2012. “Adaptive MMSE Equalizer for Blind Fractional Spaced CMA Channel Equalization through LMS Algorithm”, International Journal of Ad hoc, Sensor & Ubiquitous Computing (IJASUC), 3-1.

Aida Zaier and Ridha Bouallègue, 2012. “Blind channel estimation enhancement for MIMO- OFDM systems under high Mobility conditions”, International Journal of Wireless & Mobile Networks (IJWMN), 4-1.

Mr. S. Lenin, Dr .S. Malarkkan, 2014. “An extensive review of significant researches on channel estimation in MIMO-OFDM”, ISSN: 1992-8645, E-ISSN: 1817-3195, 64-2. www.jatit.org

Hadimani H.C., Dr. Mrityunjaya, V. Latte, 2015. “Wireless Signal Qualitative Analysis of Improving SNR for MIMO Channels Using 64 QAM”, IJSRE, 3(1): 2321-7545. Website: http://ijsae.in

Helmut Bölcskei, eth Zurich, 2006. “MIMO-OFDM wireless systems: Basics, perspectives, and challenges”, IEEE wireless communications.

Hadimani, H.C., Dr. Mrityunjaya, V. Latte, 2014. “Performance Analysis of Fading and Interference over MIMO Systems in Wireless Networks”, International Journal of Recent Development in Engineering and Technology [Online], (ISSN 2347 – 6435, 2-2, www.ijrdet.com