AL-MUKHTAR JOURNAL OF ENGINEERING RESEARCH ISSN online: 2519-6839 // ISSN Print 2519-6820
Vol. 6, No. (1): 50-57 Available at mjer.omu.edu.ly
Received July 7, 2022, Accepted October 15, 2022, Published December, 2022 DOI: https://doi.org/10.54172/97aj4r07

High Channel Capacity MIMO-OFDM System Using V-BLAST Architecture

Mohammed Abdul Rahim Elshaery(1), Ibrahim Mohamed(2), Wafa Saleh Shuaieb(3)

(1), (2), (3) Electrical and Electronics Department, Faculty of Engineering, Omar Al Mukhtar University, Libya
E-mails: mohammed.elshaery@omu.edu.ly, ibrahim.zalitny@omu.edu.ly, wafa.shuaieb@omu.edu.ly

Abstract

Wireless systems with high data rate and short code durations typically encounter unacceptable inter-symbol interference (ISI) due to multipath propagation and its inherent delay propagation. Orthogonal Frequency Division Multiplexing (OFDM) is a multi-carrier-based ISI mitigation technology that increases the power of a wireless system through spectral efficiency. In this paper, the OFDM system has been studied and combined with the multiple input multiple output (MIMO) technology that doubles the transmission speed and then improves the new system called MIMO-OFDM using Vertical-Bell Laboratories Layered Space-Time (V-BLAST), which works to reduce the error rate of the bits, which in turn contributed greatly to the increase in channel capacity.

الملخص العربي

عادةً ما تواجه الأنظمة اللاسلكية ذات معدل البيانات المرتفع ذات فترات الرموز القصيرة تداخلًا غير مقبول بين الرموز **(ISI)** بسبب الانتشار متعدد المسارات وانتشار التأخير المتأصل فيه. تعد تقنية تعدد الإرسال بتقسيم التردد المتعامد **(OFDM)** إحدى تقنيات التخفيف **ISI** القائمة على الموجات الحاملة المتعددة والتي تزيد من قدرة النظام اللاسلكي من خلال الكفاءة الطيفية. في هذه الورقة تم دراسة نظام **OFDM** ودمجه مع تقنية تعدد المدخلات والمخرجات **(MIMO)** التي تعمل على مضاعفة سرعة الارسال ثم تحسين النظام الجديد المسمى **MIMO-OFDM** باستخدام تقنية مختبر بيل في الترميز الزماني والمكاني العامودي **(V-BLAST)** التي نعمل على تقليل معدل الخطأ في البتات والتي بدورها ساهمت كثيرا في زيادة سعة القناة.

Keywords: Orthogonal Frequency Division Multiplexing (OFDM), Multiple-input Multiple-output (MIMO), Inter-symbol interference (ISI), Bet Error Rate (BER). Vertical-Bell Laboratories Layered Space-Time (V-BLAST), Data Rate, Channel capacity

Introduction

We are now living in the age of wireless technology, and the use of wireless technology is increasing at a tremendous rate every day. Multi-input multi-output (MIMO) refers to radio transmit antenna configuration technique that uses multiple antennas on both the transmitter and receiver sides. By combining antennas at both ends of the communication circuit, the error is reduced and data speed is optimized [1-2]. MIMO technology has gotten a lot of attention because both the sender and the receiver use multiple antennas to send and receive multiple signals at the same time. It offers the potential for higher data rates compared to single antenna systems [3]. Point-to-point MIMO (single-user) communication systems promise significant improvements in both data transmission speed and reliability. These are achieved by using spatiotemporal code (diversity gain oriented) [4]. This technique provides high channel capacity for wireless systems and can linearly increase channel capacity using multiple antennas and link distances without the need for additional bandwidth or power. The transmitter said it would use multiple components and multiple antennas to transmit data, double the transmission speed, increase the channel capacity, and transmit more data. The range is on track [5]. Symbols with high transmission rates are small, resulting in overlapping inter-symbol interference (ISI) symbols. Inter-carrier interference (ICI) and its surroundings also occur at high transmission rates due to the multipath phenomenon caused by simultaneous transmission at the same frequency. This problem was solved using Orthogonal Frequency Division Multiplexing (OFDM). This multi-carrier technology eliminates code interference, increases the efficiency of transmission system by increasing spectral efficiency, and divides high-speed transmission speeds into slow paths. This improves the overall transmission throughput [6]. The data transmission rate is the main requirement in modern communication systems and according to studies, the MIMO-OFDM system provides a significant increase in data transfer rate, as it makes optimal use of bandwidth using OFDM system and MIMO technology that allows the possibility of using the frequency more than once on several antennas. These advantages made it the primary core in 4G cellular systems and beyond, as well as in wireless networks in general. This research aims to increase the data transmission rate without increasing the transmission power and without increasing the bandwidth.

Literature Review

M. D. Batariere et al. [7] have performed channel measurements for a 2 x 2 MIMO-OFDM system at 3.65 GHz and 20 MHz bandwidth in an indoor laboratory environment. They provided plots of MIMO sub channel frequency responses illustrating line-of-sight (Los) and non-Los differences (NLos). The authors attributed the presence of a full-rank channel matrix throughout the entire 20MHz band, including for the Los path, which the authors attributed to the presence of numerous reflectors within the laboratory.

R. Piechocki et al. [8] measured 8 x 8 MIMO-OFDM channels at 5.2 GHz with 120 MHz of bandwidth were at 20 locations in an open-plan office. Even though the measured channels were used in packet error rate simulations to test how well different modulation and coding schemes worked, there was no analysis of the channels' fading properties or MIMO sub-channel correlation properties.

M. Bengtsson et al. [9] reported A wideband 8 x 8 MIMO channel measurement was undertaken involving the analysis of five NLos paths to develop a wideband MIMO channel model. Even though full 8x8 MIMO channels were collected, only their subsets (2x2 and 3x3) were used by the authors to build the channel model.

Ben Zarling A. Gupta et al. [10] reported measurement results for a 2 x 2 MIMO-OFDM channel at 2.4GHz and 16MHz bandwidth. In the NLOS office, graphs of the frequency of responses in a short amount of time (200 milliseconds) were shown.

R. M. Rao et al. [11] measured 2 x 2 MIMO-OFDM channels at 5.25 GHz with a bandwidth of 25 MHz at 200 indoor locations along traveling paths, using wavelength-sized steps to obtain independent channel realizations. The condition number, which is the ratio of the smallest singular value to the largest singular value of the MIMO channel matrix, did not differ significantly between LOS and NLOS channels in a laboratory environment. The authors think that this fits with the idea that when there are a lot of reflectors in a laboratory, each channel is tuned to a different frequency.

Ali Farzamnia et al. [12] proposed and is applied a hybrid algorithm of Water Filling and Nash algorithm to revise the power allocations to the channels. The proposed method has considered Rayleigh, Rician and Nakagami fading channels in the simulations. The results have shown that the channel capacity is increased significantly in different fading channels by using the proposed method compared to the existing water filling algorithm. In the future, researchers may focus on the improvement of the channel capacity in terms of power allocation method.

Orthogonal Frequency Division Multiplexing (OFDM)

OFDM is one of the multi-carrier modulation (MCM) techniques used in the fourth generation (4G) wireless communications. This technology is very useful for high-speed data transmission used in mobile communications, digital terrestrial mobile communications, Digital Video Broadcasting (DVB), Mobile Worldwide Interoperability for Microwave Access (Mobile WiMAX), and 3GPP Long Term Evolution (LTE) [13]. In simple communication systems, data is modulated onto a single carrier frequency. The available bandwidth is then fully occupied by each symbol. In the case of frequency-selective channels, this type of system causes inter-symbol interference (ISI). Wideband channels are sensitive to frequency-selective fading, which requires complex equalizers in the receiver to restore the original signal. The basic idea of OFDM is to divide the available transmission bandwidth into several orthogonal sub-carriers for simultaneous transmission so that each narrow-band sub-carrier experiences almost flat fading. With OFDM, subcarriers can be overlapped in a frequency range, thereby increasing the transmission rate. The appeal of OFDM lies primarily in the way it handles multipath interference at the receiver. Multipath has two effects: (a) frequency selective fading and (b) inter-symbol interference (ISI) [14].

OFDM System Model

In OFDM systems, information bit sequences are modulated using various modulation schemes such as quadrature amplitude modulation (MQAM) and phase-shift keying (MPSK), passing through a serial-to-parallel converter to size N. Form a complex vector. Mathematically, the data is modulated by N subcarriers, the transmitter requires N oscillators to generate, and the receiver requires another N oscillator, which complicates the hardware. It becomes difficult to control the frequency of the oscillator. In other words, it is difficult to make N subcarriers orthogonal to each other, in 1971, Weinstein and Ebert [15] introduced the idea of using the Discrete Fourier Transform (DFT) to implement the generation and reception of OFDM signals, eliminating the need for banks of analog subcarrier oscillators. This provided easy implementation of OFDM, especially using the Fast Fourier Transform (FFT), which **is** an efficient implementation of DFT. Figure (1) shows the symbol sequence is divided into N different parallel routes an N point IFFT and FFT operation is used to modulate and demodulate the data. The complex vector is written as $X = [X_0, X_1, X_2, X_{N-1}]$. Complex vector X is passed through the IFFT block. After IFFT transform the signal can be written as:

$$x(n) = \frac{1}{N}\sum_{K=0}^{N-1} m\, X(k)\, e^{j2\pi Kn/(LN)} \quad , \quad 0 \leq n \leq L_{N-1} \qquad (1)$$

Where $x(n)$ represent the transmitted OFDM signal in time domain, N is the number block size, k and n are the frequency and time indices respectively the oversampling factor L in a practical OFDM system is sufficient for captures the peaks [16]. From Eq. (1), the L-time oversampled samples can be obtained by performing LN-point inverse fast Fourier transform (IFFT) on the data block X with $(L-1)\,N$ zeros padding.

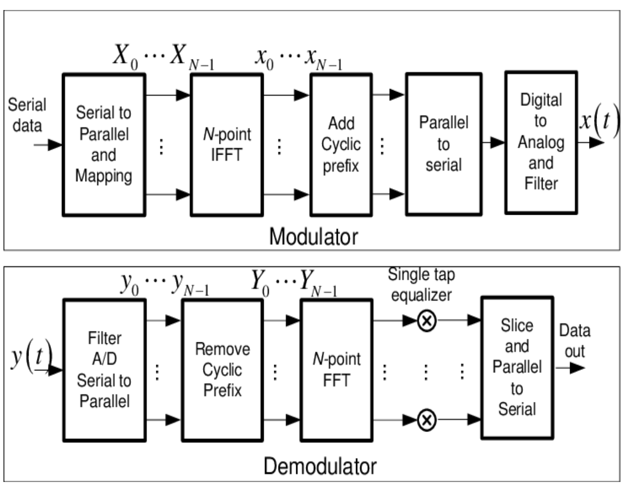

Fig. 1 OFDM System Model

OFDM System Advantages

- ❖ OFDM is an effective way of dealing with multipath fading channels.
- ❖ In OFDM systems equalization is very simpler and reduces complexity at the receiver.
- ❖ OFDM technique provides high spectral efficiency due to orthogonality amongst the subcarriers.
- ❖ OFDM is attractive for broadcasting applications using a single frequency.
- ❖ It is possible in OFDM that subcarrier spacing could be adjustable according to the requirements and data rates.
- ❖ Simple implementation of FFT and low receiver complexity [14].

OFDM System Disadvantages

- ❖ There exists a higher peak-to-average-power ratio (PAPR) as compared to single-carrier modulation which reduces the power efficiency of radio frequency (RF) amplifier.
- ❖ OFDM is much sensitive to frequency offset and phase noise.
- ❖ High sensitivity inter-carrier interference (ICI) [14].

Multiple Input Multiple Output (MIMO)

MIMO is a wireless communication technology that uses multiple antennas at the transmitter and receiver (Multiple Input Multiple Output). These strategies are often thought to improve a system's range and performance. As a result, using several antennae allows you to broadcast and receive data simultaneously while avoiding the multipath effect. Higher throughput, diversity gain, and interference reduction are all possible with MIMO. It also meets the criteria by providing a high data rate and better link reliability thanks to antenna diversity gain [17].

Page numbers

MIMO System Model

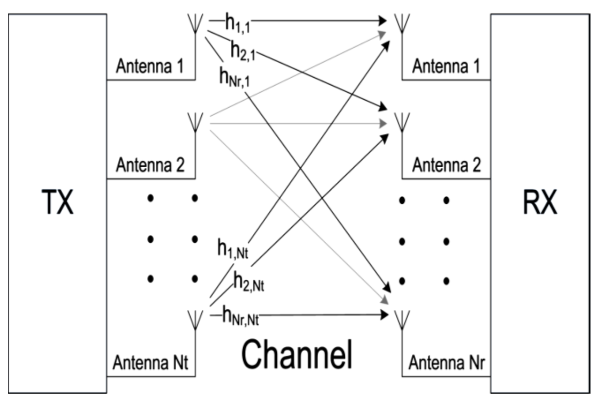

Fig. 2 MIMO System Model

Consider a 2×2 MIMO channel, the received signal on the first receive antenna is,

$$y_1 = h_{1,1}x_1 + h_{1,2}x_2 + n_1 = [h_{1,1}h_{1,2}]\begin{bmatrix}x_1\\x_2\end{bmatrix} + n_1$$

(2)

The received signal on the second receive antenna is,

$$y_2 = h_{2,1}x_1 + h_{2,2}x_2 + n_2 = [h_{2,1}h_{1,2}]\begin{bmatrix}x_1\\x_2\end{bmatrix} + n_2$$

(3)

Where,

y_1, y_2 are the received symbol on the first and second antenna respectively,

$h_{1,1}$ is the channel where 1 is the both 1st sending antenna and 1st receive antenna,

$h_{1,2}$ is the channel where 2 is the 2nd sending antenna and 1 is the 1st receive antenna,

$h_{2,1}$ is the channel where 1 is the 1st sending antenna and 2 is the 2nd receive antenna,

$h_{2,2}$ is the channel where 2 is the both 2nd transmit antenna and 2nd receive antenna,

x_1, x_2 are the sending symbols, and

n_1, n_2 is the noise on 1st, 2nd receive antennas.

Equivalently,

$$Y = HX + N \quad (4)$$

Where,

Y = Received Symbol Matrix, H = Channel matrix, X = Transmitted symbol Matrix, and N = Noise Matrix.

MIMO Technology Advantages

MIMO advantages can be achieved without any expansion in required bandwidth or increases in transmit power.

- **Array gain**: Array gain results in an increase in average receive SNR and hence enhances the coverage area and range of the network.
- **Diversity gain**: MIMO opens a new dimension space to offer an advantage of diversity. With multiple numbers of independent copies transmitted, there are fewer chances of losing the information.
- **Multiplexing gain**: The MIMO system significantly increases the channel capacity which immediately translates to a higher data rate through spatial multiplexing.
- **Interference reduction**: Interference is minimized in the MIMO system by exploiting the spatial dimension to increase the distance between users [19].

MIMO-OFDM System

In frequency selective fading conditions, MIMO combined with orthogonal frequency division multiplexing (OFDM) is a promising technology for achieving high data rates and huge system capacity for wireless communication systems. Next-generation wireless LANs such as 4G and 5G are the most likely uses of MIMO (WLAN). The WLAN standards used in 3G, such as IEEE 802.11a and IEEE 802.11g, are based on OFDM. However, MIMO is used to obtain higher data rates [20]. A wireless link's quality is determined by three factors: transmission rate, transmission range, and transmission dependability. The foregoing factors can be enhanced simultaneously with the advent of MIMO aided OFDM systems [21]. The main advantage of wireless LAN is indoor use. All the individual properties of OFDM such as IFFT, FFT, and CP make it MIMO-OFDM when applied to each individual transmit and receive antenna (MIMO).

MIMO-OFDM System Model

Consider a MIMO OFDM system implementing MIMO space-time processing techniques. Encoding can be performed jointly by multiple transmit antennas or on a single antenna. The encoding performed on a single antenna is called per-antenna encoding (PAC) [22].

MIMO-OFDM System Advantages

- Less interference.
- Diversity Gain.
- Increase data capacity.
- Power efficiency.
- Bandwidth gain [23].

V-BLAST Processing Algorithm

It has been shown in [24-27] that if a wireless channel is rich in multipath scattering it is capable of producing large capacities with a relatively low number of bit errors. Various techniques have been developed to take advantage of this property including BLAST. This architecture takes advantage of Space Division Multiplexing (SDM) or Space Division Multiple Access (SDMA). SDM is inherent to a MIMO system because multiple antennas are being used to transmit data across the wireless channel at the same frequency. To ensure error-free decoding is possible multiple receive antennas are required, again, an inherent property of a MIMO system. There are two common encoding methods for MIMO spatial multiplexing, horizontal and vertical encoding. In horizontal encoding, each data stream is independently encoded and transmitted by direct antennas. The vertical encoding uses a single encoder to spread information across all antennas. V-BLAST utilizes the horizontal encoding method. The term vertical", as mentioned, does not refer to the encoding method used but refers to the method in which the detection at the receiver is performed. The V-BLAST transmission mechanism is shown in Figure 4.

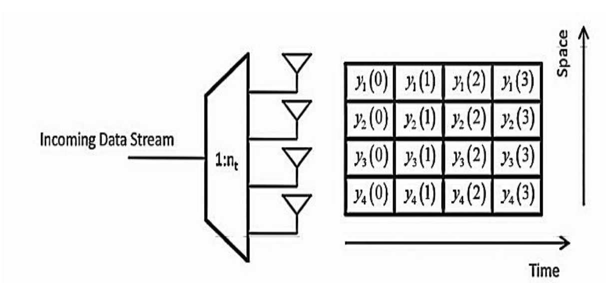

Fig. 3 VBLAST Transmission Mechanism

As seen in Figure 3, when the transmitted data stream is received, the initially received vector will consist of Yi(0) where i = 1; 2; 3; 4, thus being vertically received. The receivers, due to the effect of multipath, will receive the signals radiated from all Nt transmit antennas. In comparison to other multiple access techniques, such as Time Division Multiple Access (TDMA), Frequency Division Multiple Access (FDMA), and Code Division Multiple Access (CDMA), V-BLAST ensures that the entire bandwidth of the system is used all the time by all transmitting antennas, each transmitted signal occupies the entire bandwidth, and the total bandwidth utilized is only a small fraction in excess of the symbol rate [28]. To achieve a sufficient level of de-correlation at the receiver, V-BLAST requires its operation to be conducted in a multipath environment. These conditions allow the receiver to distinguish signals occupying the same channel space. V-BLAST and OFDM can be combined in frequency selective fading channels to achieve a high rate of data transmission.

Working Principle of V-BLAST Processing Algorithm

The V-BLAST algorithm arranges the received signals according to their relative strengths. Once the signal with the greatest strength has been identified, it is decoded, its samples are extracted and deleted from the total received signals to lessen the likelihood of interference, and the process is then repeated [28].

Simulation Results and Discussions

To analyze the studied system and obtain the results of the study; MATLAB has been used for its many advantages and useful results in the study, analysis, and testing of the OFDM system and MIMO technology. In the simulation part, we will assume the following: The use of the communication channels is the Rayleigh fading channel. The modification used is BPSK with a number of carriers and The channel bandwidth appropriate a BPSK modulation. The signal-to-noise ratio ranges from -10 to 20dB. Will choose a case study represented by two antennas at the transmitter end and two antennas at the receiver.

Channels Models (AWGN Channel)

Additive White Gaussian Noise is the fundamental noise model for thermal noise in communication channels. It contains fundamental ideas:

Additive: the noise is additive, meaning that the received signal is equal to the transmit signal when some noise is added, where the noise is linearly independent of the channel signal.

White: the noise is white, meaning that the ability spectral density is flat, and thus the autocorrelation of the noise in the time domain is zero for any non-zero time offset.

Gaussian: the noise samples have a normal distribution, and the average value in the time domain is zero. AWGN is typically utilized in channel models that are able to transmit a linear addition of wideband or white noise with a constant spectral density (expressed in watts per hertz of bandwidth) and therefore the amplitude has a Gaussian distribution. The model does not take into account fading, frequency selectivity, interference, or dispersion. Fading is the time-dependent variation of the received signal due to a variety of factors. However, it generates some straightforward and compliant mathematical models that are useful for a number of satellites and deep space communication links. Wideband noise has several natural noise sources, including thermal variations of atoms in conductors (termed thermal noise), short noise, and divine sources such as the sun [29].

Channels Models (Rayleigh Channel)

Modeling the multipath propagation and scattering of a MIMO system using a Rayleigh fading channel. When the number of multipath components is sufficiently large, the propagation can be modeled as a radial component of two independent Gaussian random distributions, according to the central limit theorem. It is a statistical model that assumes uniform scattering in all directions and no Line Of Sight (LOS) between the transmitter and receiver. As seen in equation 5 [29], the pdf of such a statistical model follows a Rayleigh distribution.

$$p(n)=\frac{1}{\sqrt{2\pi}} e_2^{u^2} \qquad (5)$$

Binary Phase Shift Keying (BPSK)

The simplest form of PSK, BPSK is a single-phase modulation technique that consists of two phases. This is known as 2-PSK. These two phases are represented by 0^0 and 180^0, which are separated by 180^0.
Where = 0^0 indicates binary message 1, and = 180^0 indicates binary message 0.
The general form of BPSK modulation is represented by the equation:

$$S_n(t) = \sqrt{\frac{2E_b}{T_b}} \cos\left(2\pi f t + \pi(1-n)\right), n = 0,1 \qquad (6)$$

The two phases are 0^0, and 180^0. These two phase represents two carrier signals and this are given below

$$S_0(t) = \sqrt{\frac{2E_b}{T_b}} \cos\left(2\pi f t + \pi(1-n)\right)$$

$$= -\sqrt{\frac{2E_b}{T_b}} \cos(2\pi/t) \text{ for binary “0”} \qquad (7)$$

$$S_1(t) = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi/t) \text{ for binary “1”} \qquad (8)$$

Where, f is the frequency of the base band, E_b is the energy per bit, and T_b is the bit duration.

BER is theoretically relative to BPSK modulation over a Rayleigh fading channel with AWGN noise given by

$$P_b = \frac{1}{2}\left(1 - \sqrt{\frac{E_b/N_0}{1+E_b/N_0}}\right) \quad (9)$$

Performance Analysis

BER comparison for BPSK modulation in Rayleigh channel and AWGN channel

The simulation model used to include BPSK over the 1x1 Rayleigh fading channel and compare it to the AWGN channel is outlined below, figure 4 shown a BER comparison for BPSK modulation in Rayleigh channel and AWGN channel**.**

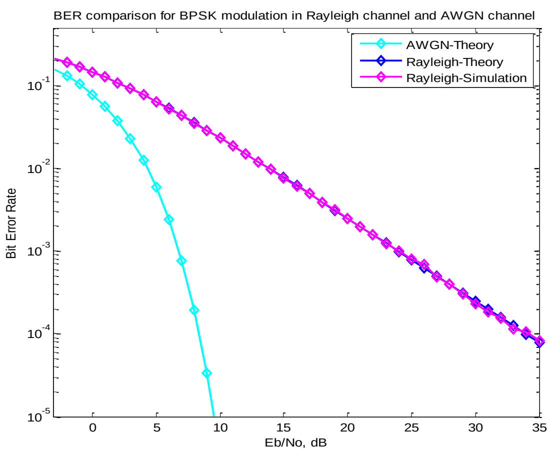

Fig. 4 BER comparison for BPSK modulation in Rayleigh channel and AWGN channel

When compared to the AWGN case, there is around a 25dB degradation due to the multipath channel (at the point). This is both good and bad: bad because we need to spend so much energy to get a reliable wireless link up (in this era of global warming), and good because we signal processing engineers are trying to figure out ways to improve the performance.

Channel Capacity Analysis in OFDM System

Started by studying the OFDM system with one transmitter antenna and one receiver at a signal-to-noise ratio of 20dB, In the Rayleigh fading channel has a channel capacity of up to 6bps/Hz in figure 5.

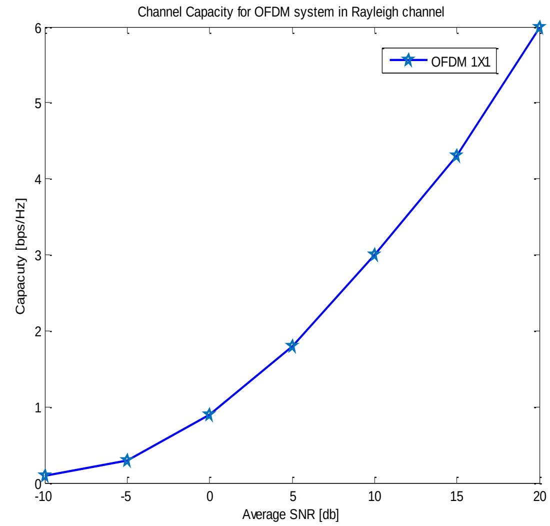

Fig. 5 channel capacity of the OFDM system in the Rayleigh fading channel

MIMO-OFDM System Configuration

The subsequent step is to examine the system capacity in the MIMO-OFDM system after integrating the two technologies into one system and the improvements that resulted from this merger. In this case of system will be examined two antennas at the transmitting and receiving ends. Figure 6 depicts the capacity of the MIMO-OFDM system in the Rayleigh damping channel in two antennas at both ends of the transmitting and receiving, and a capacity increase to 13bps/Hz at a signal-to-noise ratio of 20dB.

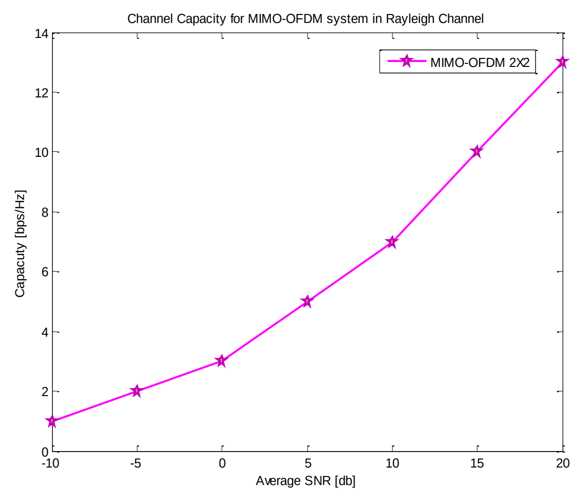

Fig. 6 Channel capacity of a MIMO-OFDM system in the Rayleigh fading channel

Channel Capacity optimization for MIMO-OFDM System Using V-BLAST

The use of the V-BLAST algorithm at the receiving end of the MIMO-OFDM system significantly improves the performance of the system and increases the channel capacity. We have studied a case of antennas with two antennas at the transmitting and receiving end.

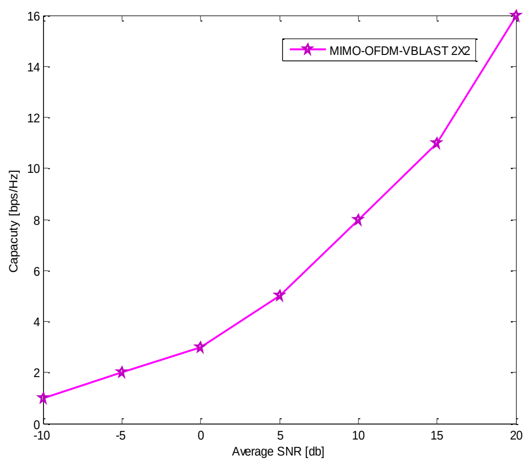

Fig. 7 Channel Capacity for MIMO-OFDM System Using V-BLAST in Rayleigh Channel

At the Rayleigh fading channel, the channel capacity is 16bps/Hz for two antennas transmitting and receiving. As shown in figure 7.

Conclusions

This paper has thoroughly analyzed the performance of the proposed MIMO OFDM V-BLAST system for different antenna configurations and propagation conditions. It has found that V-BLAST can get potentially higher spectral efficiency because no orthogonal transmitted signals and received co-channel signals are separated by decorrelation (processing algorithm) due to multipath. This study has shown that MIMO OFDM V-BLAST systems are capable of optimization a channel capacity with V-BLAST processing at the receiver as an efficiency cancellation technique, got the following:

1. . Configuration a MIMO-OFDM system on 13bps/Hz that has a higher channel capacity than that of OFDM by adding more than one antenna when transmitting and receiving
2. Optimization the channel capacity of the MIMO-OFDM system using V-BLAST algorithm to 16bps/Hz.

References

[1] David Gesbert, Mansoor Shafi, Danshan Shiv, and Smith, P.J. (2003). "From theory to practice: An over View of MIMO space time coded wireless system," IEEE Journal on selected areas in Communication, 21(3), pp. 281- 301, https://doi.org/10.1109/JSAC.2003.809458

[2] Zhang, X. and Kung, S., (2003). "Capacity analysis for parallel and sequential MIMO equalizers," IEEE Transactions on Signal Processing, 51, pp.29893002,https://doi.org/10.1109/TSP.2003.818151

[3] Telatar I. E., (1999). "Capacity of multiantennaGaussian channels," Eur. Trans. Telecommun., 10(6), pp. 585-595.https://doi.org/10.1002/ett.4460100604

[4] Ju, Meiyan, et al. (2013). "Comparison of multiuser MIMO systems with MF, ZF and MMSE receivers." IEEE Third International Conference on Information Science and Technology (ICIST). IEEE, 2013.

[5] Trimeche, Abdessalem, et al. (2012). "Performance analysis of ZF and MMSE equalizers for MIMO systems." 7th International Conference on Design & Technology of Integrated Systems in the Nanoscale Era. IEEE, 2012.

[6] Vipin Kumar,Parveen Dhyani, Performance Analysis of MIMO-OFDM System Using BPSK Modulation Scheme, International Journal of Emerging Trends in Engineering and Development Issue 5, Vol.4 (June -2015).

[7] M. D. Batariere, J. F. Kepler, T. P. Krauss, S. Mukthavaram, J. W. Porter, and F. W. Vook, "An experimental OFDM system for broadband mobile communications," in Proceedings of 54th IEEE Vehicular Technology Conference (VTC '01), vol. 4, pp. 1947–1951, Atlantic City, NJ, USA, October 2001.

[8] R. Piechocki, P. Fletcher, A. Nix, N. Canagarajah, and J. McGeehan, "A measurement based feasibility study of spacefrequency MIMO detection and decoding techniques for next generation wireless LANs," IEEE Transactions on Consumer Electronics, vol. 48, no. 3, pp. 732–737, 2002.

[9] K. Yu, M. Bengtsson, B. Ottersten, D. McNamara, P. Karlsson, andM. Beach, "Modeling of wide-band MIMO radio channels based on NLoS indoor measurements," IEEE Transactions on Vehicular Technology, vol. 53, no. 3, pp. 655–665, 2004.

[10] A. Gupta, A. Forenza, and R. W. Heath Jr., "Rapid MIMOOFDM software defined radio system prototyping," in Proceedings of IEEE Workshop on Signal Processing Systems Design and

Implementation, pp. 182–187, Austin, Tex, USA, October 2004.
[11] R. M. Rao, S. Lang, and B. Daneshrad, "Indoor field measurements with a configurable multi-antenna testbed," in Proceedings of IEEE Global Telecommunications Conference (GLOBECOM' 04), vol. 6, pp. 3952–3956, Dallas, Tex,USA,November- December 2004.
[12] Ali Farzamnia, Eng Soo Yew, Md. Nazrul Islam " Investigation on channel capacity enhancement for MIMO-OFDM in fading channels using hybrid water filling and nash algorithm", 2017 IEEE 13th International Colloquium on Signal Processing & its Applications (CSPA)
[13] T. Jiang, W. Xiang, H. H. Chen, and Q. Ni, "Multicast broadcasting services support in OFDMA-based WiMAX systems," IEEE Communi- cations Magazine, vol. 45, no. 8, pp. 7886, Aug. 2007.
[14] D.Jagadeesh,"Simulation Of Wireless Communication System Using OFDM Principle",(2005 - 2007).
[15] S. Weinstein and P. Ebert,"Data Transmission by Frequency Division Multiplexing Using the Discrete Fourier Transform IEEE Trans". vol.19.
[16] Dr. Amandeep Singh Sappal, Parneet Kaur,"Oversampling Technique For Peak To Average Power Ratio Measurement Of Discrete Time Ofdm Signal",Volume 1, Issue 3 (May-June 2012).
[17] L. M. Cortes-Pena. (2009). *MIMO Space-Time Block Coding: Simulations and Results* [Online]. Available FTP: users.ece.gatech.edu Directory: ~cortes/projects.html#stbc File: CORTES_MIMO_STBC_MATLAB.pdf
[18] G. Tsoulos, "Theory and Practice of MIMO Wireless Communication Systems," in *MIMO System Technology for wireless Communications*, USA: CRC press, 2006, pp. 30-33.
[19] E. Biglieri, R. Calderbank and A. Constantinides, "Introduction," in *MIMO Wireless Communications*, New York, USA: Cambridge Univ. press, 2007, pp. 2-3.
[20] V. Zelst and T. C. W. Schenk, "Implementation of a MIMO OFDM-Based Wireless LAN System," in IEEE Trans. Signal Process., vol. 52, no. 2, pp. 483-494, Feb. 2004.
[21] M. J. Jiang and L. Hanzo, "Multiuser MIMO-OFDM for Next-Generation Wireless Systems," in Proc. IEEE., vol. 95, no. 7, pp. 1436-1438, Jul. 2007.
[22] S. J. Vaughan-Nichols, "Mobile WiMAX: The Next Wireless Battleground,"in IEEE Comp. Soc. Mag. vol. 41, pp. 16-18, Jun. 2008.
[23] U. D. Dalal and Y. P. Kosta, "The Role of WiMAX Technology of Broadband Access Networks: Economic Model" in WiMAX, New Developments, Vukovar, Croatia: In-Tech, 2009, pp. 17-18.
[24] G. J. Foschini, \Layered Space-Time Architecture for Wireless Communication in a Fading Environment When Using Multiple Antennas", Bell Laboratories Technical Journal, Vol. 1, No. Autumn, 1996, pp. 41-59.
[25] P. W. Wolniansky, G. J. Foschini, G. D. Golden, and R. A. Valenzuela, \V BLAST:An Architecture for Realizing Very High Data Rates Over the Rich-Scattering Wire-less Channel," Proc. ISSSE Conference, Pisa, Italy, Sept. 1998.
[26] G. J. Foschnini and M. J. Gans, \On the Limits of Wireless Communications in a Fading Environment when using Multiple Antennas," Wireless Personal Communi-cations, vol. 6, no.3, pp.311-335, 1998.
[27] E. Telatar, \Capacity of multi-antenna Gaussian Channels," European Trans On Telecommun., vol. 6, no. 3, pp. 311-335, 1998.
[28] R. Zhang and J. M. Cio_, \Approaching MIMO-OFDM Capacity With Zero-Forcing V-BLAST Decoding and Optimized Power, Rate, and Antenna-Mapping Feedback," IEEE Trans. Signal Process., vol. 56, pp. 5191-5203, Oct. 2008.
[29] SAMARENDRA, N. S; DEBJYOTI, G. Channel Capacity and BER Performance Analysis of MIMO System with Linear Receiver in Nakagami Channel, Sikkim Manipal University, Sikkim, India, 2013.