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Performance Analysis of MIMO-OFDM LTE Communication and LTE Multicast Systems in Jamming Environment

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Abstract: LTE is a 4G wireless communications standard, mature, proven reliable and robust, easily deployable, and scalable. However, reliable communications in the COTS-based LTE system are critical in defense applications and the ability to protect jamming signal is key to the tactical communication systems. The objective of this paper is to analyze the performance of the MIMO-OFDM for LTE communication systems and LTE Multicast systems in jamming environment. In this research, the average Bit Error Rate (BER) under the asynchronous off-tones (AOTJ) jamming environment with different dynamic ranges of the colored noise jamming is analyzed. Moreover, examine the influence of the colored noise jamming on the performance of the LTE multicast systems in term of the average throughput. MATLAB simulations are used to evaluate the performance of this research.

Keywords:Performance, MIMO-OFDM, LTE, Multicast, Jamming.

I. INTRODUCTION

The LTE and LTE-A are referred to as System Architecture Evolution (SAE). The main goal of SAE is to provide seamless Internet Protocol (IP) connectivity between the User Equipment (UE) and the Packet Data Network (PDN) with reduced latencies and improved performance using fully optimized for packet-based networks [1].

The high-level architecture of LTE comprised of three main components, namely the UE, the Evolved UMTS Terrestrial Radio Access Network (E-UTRAN) and the Evolved Packet Core (EPC). The E-UTRAN corresponds to the air interface of the network between the UE and the EPC. The Evolved Node B (eNodeB) is the base station for LTE radio without any separate control node and using an X2 interface to communicate with other eNBs, and an S1 interface to communicate with the EPC. This has more flexibility and speed in access during handovers [1].

On the network side, the eNodeB is responsible for the Radio Resource Management (RRM), each of which can be responsible for managing multiple cells. Unlike some of the previous second- and third-generation technologies, LTE integrates radio controller function utilities into eNode B. This minimizes the latency and improving the efficiency between the different protocol layers of the radio access network (RAN). The LTE physical layer is highly efficient in conveying both data and control data between eNode B and mobile user equipment (UE). The simplified block diagram of the LTE downlink physical layer is shown in Fig. 1,.

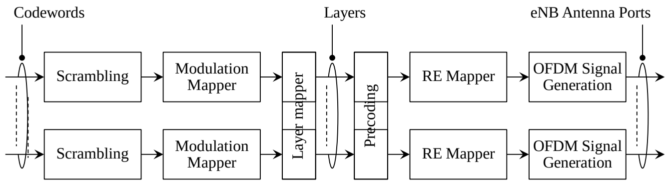

Fig. 1. LTE downlink physical layer block diagram [2]

The downlink frame contains the information being sent to the UE that are currently connected to the base station. The scrambling task is performed using a Gold code. The attractive feature of Gold codes is that they can be generated with very low implementation complexity by a simple shift register. Following the scrambling process, the information bits are coded and mapped to complex valued modulation symbols. Once physical channel's codewords have been scrambled and modulated, a layer mapping is applied to the modulated codewords. Next, the layers are precoded using a precoding matrix in 3GPP TS 36.211 which consists of applying coding to the layers of modulated symbols prior to mapping onto Resource Element (RE). After RE mapper operation, the OFDMA mapper combines the precoded values from physical-layer channels. It is the transformation of the complex modulated symbols at the output of RE mapper into a complex valued OFDM signal by means of an Inverse Fast Fourier Transform (IFFT).

In the LTE PHY layer, the Orthogonal frequency division multiplexing (OFDM) and multiple input multiple output (MIMO) are employed to enhance the performance in the LTE network with higher data rates and higher capacity. In addition, the LTE PHY uses Orthogonal Frequency Division Multiple Access (OFDMA) on the downlink (DL) and Single Carrier – Frequency Division Multiple Access (SC-FDMA) on the uplink (UL) [3].

The MIMO-OFDM systems provide high data rates and are robust to multi-path delay in wireless communications. However, channel parameters are required for diversity combining, coherent detection and decoding [4]. While MIMO-OFDM systems are robust to multipath fading and severe interference, they are not perfect for intentionally jam environments. [5].

In many researches [6], [7], [8], [9], [10], [11], the LTE vulnerabilities by jamming signals is under consideration for military application fields. This drawback is serious concern since it is possible to completely shut down the tactical communication systems running by LTE network with jamming signals. More sophisticated attacks have been discovered as a

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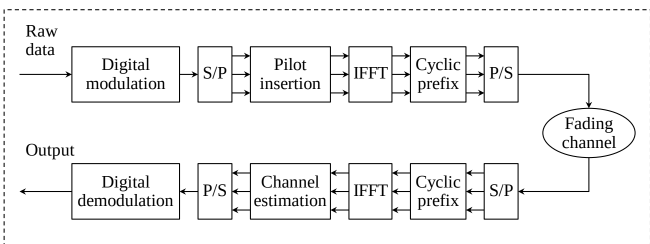
potentially more effective way to jam LTE networks [12], [13]. Hence, this paper aims to analyze the performance of the MIMO-OFDM for LTE communication systems and LTE multicast systems in jamming environment.

This paper is organized as follows. Section II provides a description of the MIMO-OFDM system model. The Section III presents the proposed model of jamming environment in MIMO-OFDM communication systems. Section IV describes the Bit Error Rate in the LTE MIMO systems. Section V proposed model of LTE multicast in jamming environment is presented. Section VI covers the simulations results. Finally, the conclusion is specified in the last section.

II. MIMO-OFDM Communication Systems

MIMO systems use the feature of spatial diversity by using spatially separated antennas in a dense multipath fading environment to obtain diversity gain or capacity gain. Advanced techniques in MIMO make a significant increase in performance for OFDM systems with bandwidth efficiencies on the order of 10 b/s/Hz.



(a) An OFDM transceiver

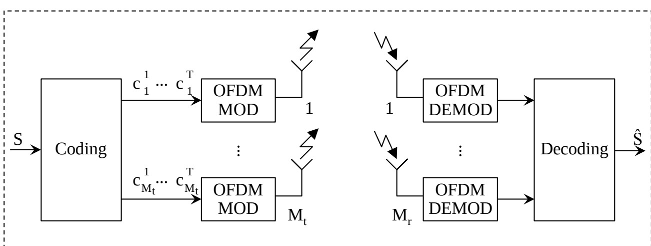


Fig. 2. A simplified block diagram of MIMO-OFDM system, where $S=\left[s1,s2,\cdots,sN_S\right]$ denotes a block of Ns data symbols [14].

(b) A MIMO-OFDM transceiver

Fig. 2(a), shows a simplified block diagram of an N-tone OFDM system. First, the incoming data stream is mapped into some modulation scheme such as QPSK or QAM. [15]. After going through all processes, the data symbols are detected with the estimated channel information and the transmitted bit stream is recovered.

A general MIMO-OFDM system is shown in Fig. 2(b), where Mt transmit antennas, Mr receive antennas, and N-tone OFDM are used [15]. First, the incoming bit stream is mapped into a number of data symbols via some modulation type such as QAM. Then a block of Ns data symbols $S=\left[s1,s2,\cdots,sN_S\right]$ are encoded into a codeword matrix C of size $NT\times Mt$, which will then be sent through Mt antennas in T OFDM blocks, each block consisting of N subchannels. Specifically, $cj^1,cj^2,\cdots,cj^T$ will be transmitted from the jth transmit antenna in OFDM blocks $1,2,\cdots,T$, respectively, where c_j^n denotes a vector of length N, for all $j=1,2,\cdots,M_t$ and $n=1,2,\cdots,T$. The codeword matrix C can be expressed as

$$C=\begin{pmatrix} c_1^1 & \cdots & c_{M_t}^1 \\ \vdots & \ddots & \vdots \\ c_1^T & \cdots & c_{M_t}^T \end{pmatrix} \quad (1)$$

After appending the cyclic prefix on each OFDM block, c_j^n will be transmitted from the jth transmit antenna in the nth OFDM block and passed through the MIMO channels. Then, the received signals will be sent to the reverse OFDM block and sent to the decoder.

In LTE, transmit diversity is an effective technique for combating fading by using Space Frequency Block Coding (SFBC). SFBC provides both spatial and frequency diversity and improves cell coverage and/or improves cell-edge throughput. SFBC is a frequency domain adaptation of renowned Space-time Block Coding (STBC). STBC is also recognized as Alamouti coding [16].

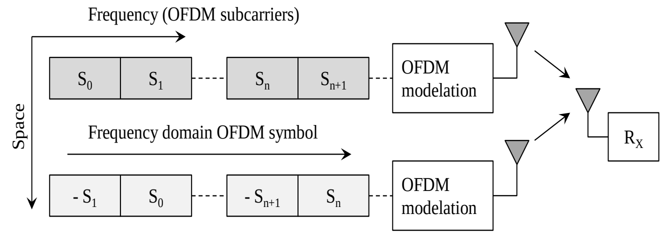


Fig. 3. Space Frequency Block Coding SFBC assuming two antennas [17]

The advantage of SFBC over STBC is that in SFBC coding is done across the sub- carriers within the interval of OFDM symbol while STBC applies coding across the number of OFDM symbols equivalent to number of transmit antennas [16]. Fig. 3, illustrates the SFBC operation for the particular two-antenna configuration. The transmitters send the same underlying user data, but in different parts of the RF frequency space.

III. LTE MIMO-OFDM System in Jamming Environment

As any kind of wireless network systems, LTE is also vulnerable to radio jamming attacks especially in the case of next-generation COTS tactical communication systems. A simple method for radio jamming is the transmission of radio signals to disrupt communications by decreasing the Signal-to-Noise ratio (SNR) of the received signal. This jamming transmits a high-power signal over the entire target bandwidth of the victim system [18].

Jamming is different from network interferences because it describes the tactical use of electromagnetic signals in an intent to disrupt communications but interference is unintentional forms of disruptions. Intentional interference or jamming is usually operated by an attacker who intends to interrupt communications within or between wireless networks. Different techniques of jamming attacks can be conducted, from hindering transmission to distorting packets in legitimate wireless communications.

Tactical LTE communication systems should be able to operate in spectral environments fraught with interference and jamming. The wireless channels are subject to attack from jamming signals. This causes the performance of the network to degrade. In this paper, the Asynchronous Off-Tone Jamming (AOTJ) is focused.

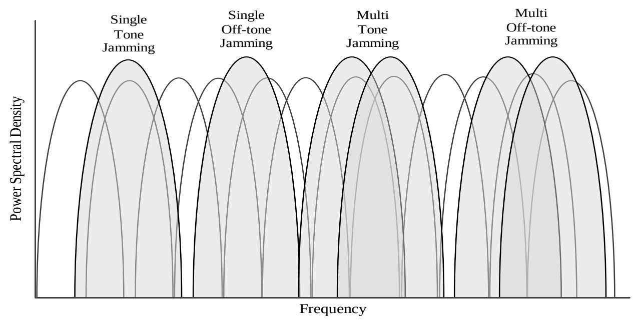


Fig. 4. Different jamming attacks on LTE downlink [19]

There are two types of Asynchronous Off-Tone Jamming (AOTJ). The first type is called single off-tone jamming and the second type is multiple off-tone jamming attack. The operational concept of this technique is to transmit asynchronous off-tones which generates inter channel interference (ICI) of the OFDM signal at the receiver [19]. Also the side-lobes of the signal not aligned with the orthogonal OFDM subcarriers due to frequency offset will create non-zero components at the sampling period that can be a source of ICI. AOTJ is efficient and practical for attackers because the jamming signal does not need frequency matching with target signal. The example of the two types of AOTJ can be seen in Fig. 4,.

IV. BER ANALYSIS OF LTE MIMO SYSTEM

In a MIMO system with N_r receive antennas and N_t transmit antennas, the relation between the received and the transmitted signals on OFDM subcarrier frequency k ($k \in 1, ..., N$), at sampling instant time n is given by

$$y_{k,n} = H_{k,n}x_{k,n} + n_{k,n} \tag{2}$$

where $y_{k,n} \in C_{N_r \times 1}$ is the received output vector, $H_{k,n} \in C_{N_r \times N_t}$ represents the channel matrix on subcarrier k at instant time n, $x_{k,n} \in C_{N_t \times 1}$ is the transmit symbol vector and $n_{k,n} \sim CN\left(0, \sigma_n^2.I\right)$ is a white, complex valued Gaussian noise vector with variance σ_n^2 and I is an $N_r \times N_r$ identity matrix. Assuming perfect channel estimation, the channel matrix and noise variance are considered to be known at the receiver. A linear equalizer filter given by a matrix $F_{k,n} \in C_{N_r \times N_r}$ is applied on the received symbol vector $y_{k,n}$ to determine the post-equalization symbol vector $r_{k,n}$ as follows [20]

$$r_{k,n} = F_{k,n}y_{k,n} = F_{k,n}H_{k,n}x_{k,n} + F_{k,n}n_{k,n}. \tag{3}$$

The Zero Forcing (ZF) or Minimum Mean Square Error (MMSE) design criterion is typically used for the linear receiver and the input signal vector is normalized to unit power [21]. In MIMO-OFDM systems, the key factor of link error prediction and performances is the signal to noise ratio (SNR) which represents the measurement for the channel quality information. In this study, the SNR is defined as follows [22]:

$$\gamma_{k,n} = \frac{H_{k,n}x_{k,n}{}_F^{2}}{N_t\sigma_n^2} \tag{4}$$

where $x_{k,n}$ is the transmitted symbol vector, $._F^2$ is the squared Frobenius norm of a matrix.

A. Average BER Performance analysis for several M-QAM Schemes

In this section, a Bit Error Rate (BER) analysis is presented for Multiple-Input Multiple Output (MIMO) schemes in the 3GPP Long Term Evolution (LTE) system. The average BER of the system is analyzed over flat Rayleigh fading channels by applying M-ary quadrature amplitude modulation (M-QAM) schemes. The analysis is based on the probability density function of the instantaneous Signal to Noise Ratio and the Moment generating function.

B. Analysis for 2 × 1 SFBC-OFDM Scheme

When two eNodeB antennas are available for transmit diversity operation, the Space Frequency Block Code (SFBC) is used [23]. SFBC is based on the well known Space Time Block Code (STBC), derived by Alamouti for two transmit antennas [24]. In LTE, for SFBC transmission, the symbols are transmitted from two eNodeB antenna ports on each pair of adjacent subcarriers as follows [23]:

$$\begin{bmatrix} y^{(0)}(1) & y^{(0)}(2) \\ y^{(1)}(1) & y^{(1)}(2) \end{bmatrix} = \begin{bmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{bmatrix} \tag{5}$$

where $y^{(p)}(k)$ denotes the symbols transmitted on the k^{th} subcarrier from antenna port p. An important characteristic of such codes is that the transmitted signal streams are orthogonal and a simple linear receiver is required for optimal performance.

This paper applied the BER expressions over flat Rayleigh fading channels, given by $P_b(E)$. from the reference [2]. Then, the overall average BER over N subcarriers, in each case can be calculated from

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$$BER = \frac{1}{N}\sum_{k=1}^{N} P_{b,k}(E) \quad (6)$$

where the index k. is the subcarrier index.

For the 2×1 SFBC MIMO scheme, the probability density function of the SNR for each subcarrier is $f(\gamma)$.

$$f(\gamma) = \frac{2}{\bar{\gamma}^2}\gamma e^{-\frac{2}{\bar{\gamma}}\gamma} \quad (7)$$

To derive the BER, we follow the unified approach to the performance analysis of digital communication systems over generalized fading channel [25]. To this end, we first derive the expression of Moment Generating Function (MGF) of the derived probability density function of the instantaneous SNR as [26]:

$$M_{\bar{\gamma}}(s) = \int_0^{\infty} e^{-s\gamma} f(\gamma)\, d\gamma. \quad (8)$$

The average BER expression for M-QAM modulation scheme can be obtained from [26] as:

$$P_b(E) \cong B \sum_{i=1}^{\sqrt{M}/2} \frac{1}{\pi} \int_0^{\pi/2} M_{\bar{\gamma}}(A_{i,\theta})\, d\theta \quad (9)$$

As described in Section III, the AOTJ Jamming type is considered in this research. In this scenario, this paper used the jamming model from [27].

To describe the concept of the jamming signal model we restate the derivation of the model from the reference [28] in this section.

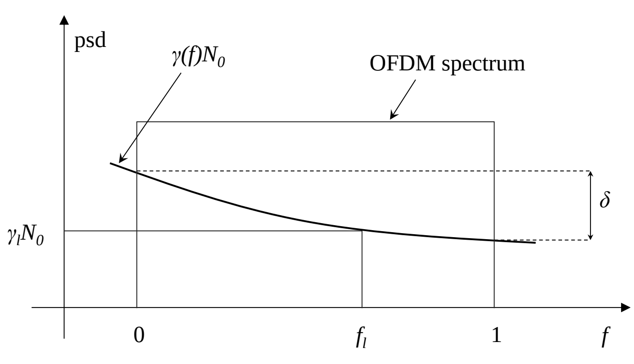

Fig. 5. An OFDM user spectrum and the psd of the colored noise process over the normalized frequency.

In our jamming signal model, we adopt the concept of the colored noise process over the normalized frequency in [28]. Fig. 5, shows the illustration of an OFDM user spectrum and the psd of the jamming signal over the normalized frequency. δ. is the dynamic range, defined as:

$$\delta = \frac{\gamma_{max}}{\gamma_{min}}. \quad (10)$$

It is the power ratio between the highest and lowest value of γ.

To model the shape of its psd, we define a frequency dependent power weighting factor $\gamma \in \mathrm{R}^+$. So the noise psd at frequency f_l is $\gamma_l N_0$ with $\gamma_l = \gamma(f_l)$. For convenience, we normalize the frequency so that $f = 0$ represents the left edge and $f = 1$ represents the right edge of the OFDM bandwidth. A symbol that is transmitted at frequency f_l, is then distorted by AWGN with noise power spectral density $\gamma_l N_0$.

Based on the reference [29], the frequency interleaver maps every complex symbol x_i to a certain frequency f_i. So if we assume ideal interleaveing, this frequency can be regarded as random variable, that is uniformly distributed over the interval (0, 1).

This leads to our proposed discrete channel model in Fig. 6,. The sequence $\boldsymbol{x}$ of K complex data symbols is distorted by additive noise $\boldsymbol{n} = (n_1,\ldots,n_K)^T$ .This noise vector $\boldsymbol{n}$ results from the multiplication of white Gaussian noise $\boldsymbol{w} = (w_1,\ldots,w_K)^T$ with variance $\boldsymbol{E}\{w_i^2\} = \sigma^2 = N_0/2$ and the matrix of weighting factors $\boldsymbol{L} = diag(\sqrt{\gamma_1},\ldots,\sqrt{\gamma_K})$. The factors $\sqrt{\gamma_i}$ can be found via the transformation of the uniformly distributed random variable f through $\gamma_i = \gamma(f_i)$. The input to the receiver is

$$y = x + Lw \quad (11)$$

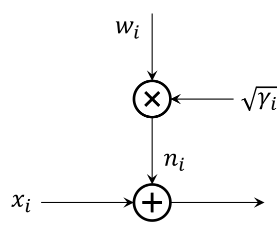

Fig. 6. Proposed channel model for additive colored Gaussian noise

V. LTE MULTICAST AND ITS PERFORMANCE

LTE multicast is when a base station (BS) broadcasts to a multiple group of users, namely the multicast group. For the signal reception to be good and for each user, a method is adopted where adapting data transmission rate to the worst channel among all users in the multicast group. However, data transmission speed decreases if the number of multicast users increases. “In a system with fixed number of channels (e.g., subcarrier in OFDM systems) and fixed user population, the bandwidth resource allocated to a group is proportional to the number of users in the group” [30].

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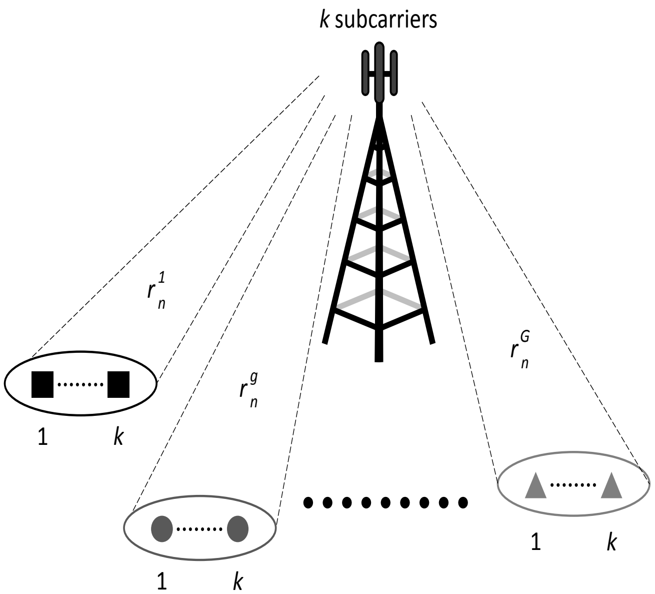

Fig. 7. LTE Multicast system: a base station (BS) broadcasts data to multicast groups

Fig. 7 illustrates multicast group with k users are allocated k fixed subcarriers in a wireless OFDM system. The BS transmits data to the users on subcarrier at a transmission r_n^g rate for the g-th multicast group [31].

Consider a wireless OFDM multicast system with J subcarriers and K users requiring the same desirable program from the BS. The users are equally divided into G multicast groups. Assuming that K is divisible by G and J is an integer multiple of K, each multicast group is associated with $k = K/G$ users and jk subcarriers, where $j = J/K$. For simplification, we assume $J = K$ in the rest of the paper, as shown in Fig.1. Our results, however, easily extends to the case with $j > 1$. We further assume that equal power is transmitted on all subcarriers.

"All subcarriers of an OFDM signal are radiated with the same power. Therefore its power spectral density is constant or "white" over its whole bandwidth. It is also a common assumption that the distribution of the amplitudes of an OFDM signal is Gaussian" [32].

To achieve the objective of this paper, we evaluate the performance of the LTE multicast per one user. We use the procedure in [30], [33] to obtain the user's average throughput as a function of the size of a multicast group.

In the LTE multicast transmission of this research, we transmit the BPSK symbols over the channel model. At the transmitter, data bits are mapped to complex symbols and, following the OFDM principle, N_c symbols are radiated simultaneously over orthogonal subcarriers within the bandwidth $B = N_c T_s^{-1}$.

Based on [34], the results of the derivation of the psd of the colored noise process are used in this paper. We also adopt the average throughput of one user in [30]. By assuming each user perceives i.i.d. Rayleigh fading channels, the average throughput of one user is given by:

$$C = k \int_\gamma B \log_2 \left(1 + \frac{PT_s}{N_0 N_c}\gamma\right) p(\gamma) d\gamma \quad (12)$$

As psd of the colored noise process shown in Fig.5, we choose the function

$$\gamma(f) = \frac{a}{f+b} \quad (13)$$

with $a, b \in \mathbb{R}^+$ free but constant parameters.

The uniformly distributed random variable f is transformed to the random variable γ by Eqn.(13). The probability density function (pdf) $p(\gamma)$ of this transformed random variable is defined by $p(\gamma)d\gamma = -df$, where the minus sign is used because $\gamma(f)$ is monotonically decreasing, Hence

$$p(\gamma) = \frac{a}{\gamma^2}. \quad (14)$$

VI. Simulation Results and Discussions

a) Performance of MIMO-OFDM LTE in Jamming Environment

The aim of this sub-section is to analyze the average Bit Error Rate (BER) for the $2x1$ SFBC 16-QAM and 64-QAM modulation schemes in the asynchronous off-tones (AOTJ) jamming environment with different dynamic ranges of the colored noise jamming. In our study, jamming signal is transmitted asynchronous off-tones which are not perfectly periodic or have an offset at the sampling frequencies. Thus, it creates interchannel interference (ICI) of the OFDM signal at the receiver. Table I shows essential parameters for the simulations.

TABLE I. Simulation Parameter Setting

Parameter	Setting
Transmission Schemes	2×1 SFBC
Bandwidth	5MHz
Simulation length	5000 subframes
Channel Type	Flat Rayleigh
Channel knowledge	Perfect
CQI	9(16-QAM) and 16(64-QAM)
Dynamic range (δ)	$\delta = 2$dB, 10dB

The average BER performance as a function of E_s / N_0 for 2×1 SFBC with different modulation modes has been analyzed.

Fig. 8, and Fig. 9, show the simulation results for 16-QAM and 64-QAM modulations respectively.

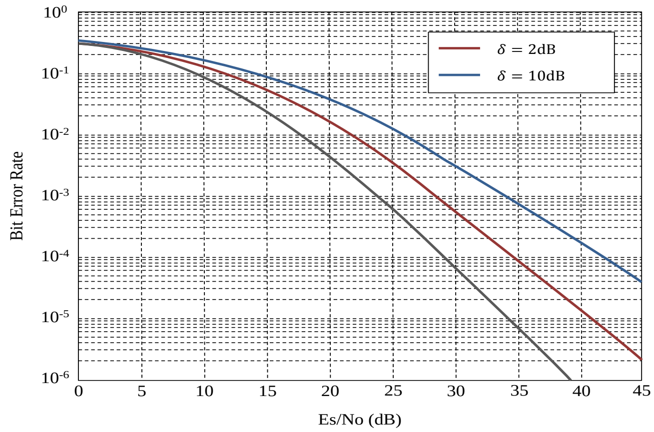

Fig. 8. Monte-Carlo Simulation of the average BER for 16-QAM modulation

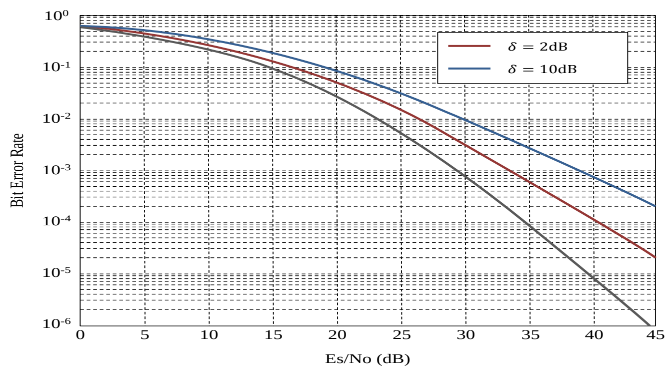

Fig. 9. Monte-Carlo Simulation of the average BER for 64-QAM modulation

Fig. 8, and Fig. 9, show the average BER for different dynamic ranges versus E_s / N_0 that is simulated by MATLAB. This result is indicated that when increases the dynamic ranges of the colored noise jamming, the effect on the reducing E_s / N_0 exhibits increasing average BER. Equivalently, the increasing in the noise jamming in this study will create higher interchannel interference (ICI) of the OFDM signal at the receiver.

b) Performance of LTE Multicast in Jamming Environment

In this sub-section, we analyze the average throughput under the different dynamic ranges δ of the colored noise jamming for the multicast group size $k = 100$. We also simulate in the case of increasing the multicast group size (k) to observe the performance of the systems.

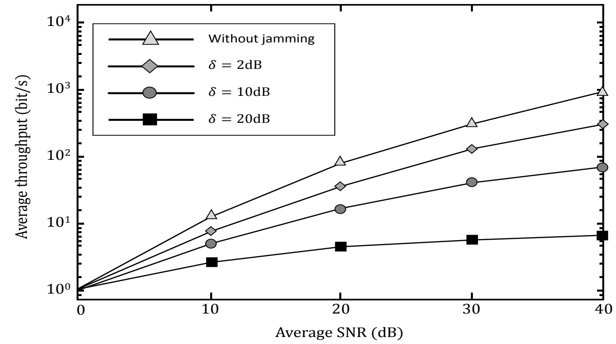

Fig. 10. Average throughput comparison

Fig.10 shows the average throughput for different dynamic ranges versus average SNR that is simulated by MATLAB. The simulation results can be explained that, for noise jamming with $\delta = 2\text{dB}$, most of all subcarriers are received correctly. For $\delta = 10\text{dB}$, there are some subcarriers that are corrupted by very intense jamming signal therefore the average throughput is degraded. For $\delta = 20\text{dB}$, most of all subcarriers are corrupted by very intense jamming signal. So, the performance of the systems is unacceptable.

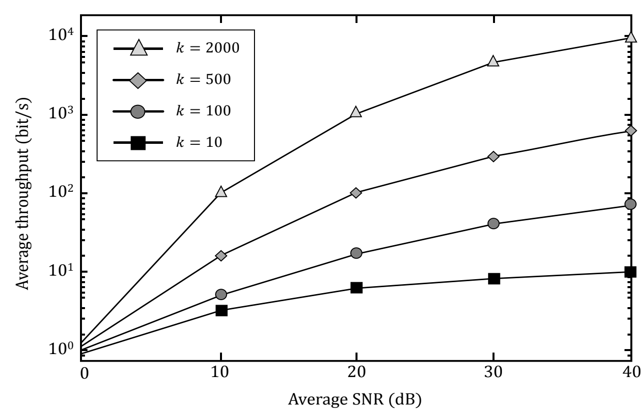

Fig. 11. Throughput comparison for different group size with $\delta = 10\text{dB}$

In Fig.11, we can observe that when the multicast group size increases, the average throughput also increases even though under the jamming condition. It has been also proved in [30] that despite the decreasing data rate on each subcarrier with the increasing group size, the analysis shows that the expected throughput received by each user increases with the number of users in a group.

CONCLUSION

In this paper we analyzed the performance of LTE for the $2x1$ SFBC 16-QAM and 64-QAM modulation schemes in the asynchronous off-tones (AOTJ) jamming environment. Monte-Carlo simulation is used to demonstrate the performance of the LTE in term of Bit Error Rate. Furthermore, we investigated the performance of LTE multicast systems when the bandwidth resource allocated to a multicast group is jammed by the colored noise jamming signal. We observe that when the dynamic range of the colored noise jamming signal increases, the average throughput decrease with a specific multicast group size. However, we also observe that when we increase a multicast group size, the average throughput received by each user increases. The simulation results in this research are indicated that LTE is extremely vulnerable to adversarial jamming. This is not surprising results, considering LTE was not designed to be a military communication system.

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