Performance Improvement on *64*-QAM Multicarrier with Closed-Loop Rotate Modulation

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***Abstract*— To improve performance in the *64*-QAM multicarrier communication system, we propose a new method, closed-loop rotate modulation. The closed-loop process requires feedback channel information in the form of complex quantities that contain information on the gain and delay of the channel. Based on the purpose of distortionless transmission, we can get the equation in the closed-loop rotate modulation method on the multi-carrier system at the transmitter side. From the simulation results, with the application of closed-loop rotate modulation, the output signal of the multicarrier demodulator is exactly the same as the transmission signal. On the probability of error curve generated, the application of closed-loop rotate modulation can coincide with the system performance if only disturbed by the AWGN channel. Terms so that the algorithm can work optimally, the speed of updating feedback must be faster than changes in channel fluctuations and channel feedback works perfectly. The simulation results also show that although channel information feedback is not perfect, but still can produce a good performance, the more accurate channel feedback will result in a better probability of error. Another advantage of the scheme that we propose is that the transmission process of a multi-carrier system does not use guard intervals, so the efficiency of the data is maximized.**

Keywords*— *rotate modulation, closed-loop, 64QAM, multicarrier

I. INTRODUCTION

At present there are rapidly developing various mobile communication applications, so that high-speed data transmission is needed. A suitable modulation type is a high-level modulation, including the modulation of *64*-QAM (Quadrature Amplitude Modulation). This modulation can provide efficiency bandwidth of 6 times [1].

The main problem in high-speed data communication is that the receiving signal will experience frequency selective fading [2]. This problem is overcome by multicarrier modulation. Multicarrier modulator implementation is using IFFT which produces 2^N subcarriers [3]. With the multicarrier signal which initially experienced frequency selective fading, each subcarrier can experience flat fading. However, the multicarrier system cannot anticipate channels that change due to high user mobility. This channel fluctuation will cause decrease the signal quality. Based on this, to handle high user mobility, we propose the application of rotated modulation.

In [4], the optimum angle shift was derived for the *M*-PSK and *M*-QAM modulation constellations. The research on rotated modulations that aims to minimize outage probability has been discussed in [5]. The application of rotate modulation on multicarrier systems has been studied by [6] and [7]. However all of these studies are only in the process of phase shifting, there has not been a combination of phase shifts with power settings and is still open-loop. The closed-loop multicarrier system has been investigated in the study [8] and [9] by utilizing feedback channel conditions which are complex quantities. But at [8] and [9], the feedback is only used as a basis for the clustering process of several subcarriers into one chunk. In [10], we have also conducted research on rotate modulation but have not focused on modulation *64*-QAM.

In this paper, we propose a closed-loop rotate modulation on *64*-QAM multi-carrier modulation to improve system performance. The rotation process combines phase shifts with power settings that utilize feedback channel response information in the form of complex quantities. The model that we propose without the need to add the guard interval so that it can maximize the efficiency of transmitting data

The structure of this paper consists of the following parts: chapter 1 explain the summary of previous research on rotate modulation, chapter 2 explain the *64*-QAM modulation, wireless channel, and multicarrier systems, chapter 3 explain the formula derivation and model simulation, in chapter 4 we discussed the simulation results, while conclusions and discussions presented in chapter 5.

II. *M*-ARY QAM, WIRELESS CHANNEL, MULTICARRIER SYSTEMS

A. M-Ary QAM

M-Ary QAM is a 2-dimensional form of *M*-Ary pulse amplitude modulation (PAM). Especially for *64*-QAM formed from 2 dimensions *8*-PAM which are orthogonal to each other. The equations of the symbols produced in *M*-Ary PAM are as follows [1]:

$$S_i^{PAM}(t) = a_i\sqrt{\frac{2}{T}}\cos(\omega_c t) \tag{1}$$

Where T is the duration of the symbol, a_i is the amplitude of the i^{th}-symbol, $i = 1, 2, 3, ..., M^{\text{PAM}}$. While the orthonormal base function is:

$$\psi_1(t) = \sqrt{\frac{2}{T}}\cos(\omega_c t) \tag{2}$$

Thus for *M*-Ary QAM modulation is [1]:

$$S_i^{QAM}(t) = a_{i1}\sqrt{\frac{2}{T}}\cos(\omega_c t) + a_{i2}\sqrt{\frac{2}{T}}\sin(\omega_c t) \quad (3)$$

Where the i^{th}-symbol for M-QAM is i = 1, 2, 3, ..., $(M^{PAM})^2$ and has 2 orthonormal base functions, namely:

$$\psi_1(t) = \sqrt{\frac{2}{T}}\cos(\omega_c t) \qquad \psi_2(t) = \sqrt{\frac{2}{T}}\sin(\omega_c t) \quad (4)$$

The pattern of M-Ary QAM signal constellations has the same mathematical pattern as follows [1]:

$$(a_{i1}, a_{i2}) = \begin{bmatrix} (-\sqrt{M}+1, \sqrt{M}-1) & (-\sqrt{M}+3, \sqrt{M}-1) & \cdots & (\sqrt{M}-1, \sqrt{M}-1) \\ (-\sqrt{M}+1, \sqrt{M}-3) & (-\sqrt{M}+3, \sqrt{M}-3) & \cdots & (\sqrt{M}-1, \sqrt{M}-3) \\ \vdots & \vdots & \vdots & \vdots \\ (-\sqrt{M}+1, -\sqrt{M}+1) & (-\sqrt{M}+3, -\sqrt{M}+1) & \cdots & (\sqrt{M}-1, -\sqrt{M}+1) \end{bmatrix} \quad (5)$$

B. Wireless Channel

The signal *s(t)* transmitted over the multipath fading channel will be the received signal *r(t)*, namely [2]:

$$r(t) = \sum_l \alpha_l(t).s(t\text{-}\tau_l(t))$$
$$= \text{Re}\left\{\left[\sum_l \alpha_l(t).u(t\text{-}\tau_l)e^{-j\omega_c\tau_l}\right]e^{j\omega_c t}\right\} \quad (6)$$

with $\alpha_l(t)$ and $\tau_l(t)$ are attenuation factors and delay times that occur in the l^{th}-signal propagation path. The signal received at the baseband can be expressed as:

$$r(t) = \sum_l \alpha_l(t).u(t\text{-}\tau_l)e^{-j\omega_c\tau_l t} \quad (7)$$

Equation (7) can be seen that the received signal is a convolution between signal *u(t)* with the time varying impulse response for a linear filter base band *h(τ;t)* which represents the multipath fading channel model, namely:

$$h(\tau; t) = \sum_l \alpha_l(t).\delta(t\text{-}\tau_l(t))e^{-j\omega_c\tau_l t} \quad (8)$$

By performing the Fourier transformation *h(τ;t)* to *τ*, the transfer function at the baseband is [2]:

$$H(f,t) = \int_{-\infty}^{+\infty} h(\tau;t)e^{-j2\pi f\tau}d\tau \quad (9)$$

The fading channel has the properties of Wide Sense Stationary (WSS) and uncorrelated scattering (US). B_c parameter called coherence bandwidth is a statistical measure of a frequency range in channel response that can be considered 'flat' or the bandwidth between two frequencies that has a strong potential in the correlation of amplitude.

If a signal is transmitted with a frequency band less than B_c, then all components of the signal will experience the same fading, so the signals are called experiencing flat fading. If the signal is transmitted with a frequency band more than B_c, then the signal components outside the B_c will experience a different fading, so that it is called frequency selective fading. Broadband signals for 4G and 5G can be ascertained to experience frequency selective fading. To overcome the problem of frequency selective fading in the downlink path, multicarrier modulation is used, while the uplink direction is still using a single carrier because of the limited power supply on the user device.

In addition to multipath the fading channel, transmitting a sinusoidal wave on the time-varying fading channel will cause the received signal with a spectrum that widens around the frequency f_c, which is equal to f_D. The doppler shift width is associated with each signal component related to the carrier frequency (f_c), the speed of movement (v), and the angle of arrival of the signal to the receiver (θ), namely [2]:

$$f_D = \frac{v}{c}.f_c.cos\theta \quad (10)$$

The amount of f_D will be the maximum (f_m) if $\theta = 0^0$. Doppler spread has a reciprocal relationship with coherence time, T_c, which is an interval in which the channel is not changed in the time domain (time-invariant). The amount of T_c can be approached by the equation [2]:

$$T_C = \sqrt{\frac{9}{16.\pi.f_m^2}} = \frac{0.423}{f_m} \quad (11)$$

If the symbol speed is greater than $1/T_c$, the signal does not experience channel distortion caused by the movement of the receiver so that it is classified as a slow fading. Conversely, if the symbol speed is smaller than $1/T_c$, then the signal has a channel distortion caused by the movement of the receiver so that it is included in the classification of fast fading. For high-speed data communication on 4G and 5G, with the speed of movement of users below 100 km/h, at an operating frequency of around 3 GHz, it is still in the classification of slow fading.

C. Multicarrier Modulation

Basically, multicarrier modulation can be implemented using many oscillators or with the help of digital signal processing. But for ease of implementation, the multicarrier modulator is using digital signal processing. The process used as a multicarrier modulator is Inverse Fast Fourier Transform (IFFT). The advantage of this process is that guaranteed orthogonality between subcarriers and frequency spectrum can be made overlapping so that it can save bandwidth.

The IFFT process equation as a multicarrier baseband modulator is as follows [11]:

$$s_m = \frac{1}{N}\sum_{n=0}^{N-1} S_n e^{j\frac{2\pi mn}{N}}, \quad 0 \le m \le N-1 \quad (12)$$

Where:

N = number of point IFFT (subcarrier total) used

S_n = the symbol data transmitted or received on the n^{th} subcarrier

s_m = Multicarrier symbol output with IFFT process or input FFT Proces

While the FFT process equation as a multicarrier baseband demodulator is as follows [11]:

$$S_n = \sum_{n=0}^{N-1} s_m e^{-j\frac{2\pi mn}{N}}, \quad 0 \le n \le N-1 \quad (13)$$

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IFFT Process: $$\begin{bmatrix} s_0 \\ s_1 \\ s_2 \\ \vdots \\ s_{N-1} \end{bmatrix} = \frac{1}{N} \text{ x } \begin{bmatrix} 1 & 1 & 1 & \cdots & 1 \\ 1 & e^{j\frac{2\pi.1.1}{N}} & e^{j\frac{2\pi.1.2}{N}} & \cdots & e^{j\frac{2\pi.1.(N-1)}{N}} \\ 1 & e^{j\frac{2\pi.2.1}{N}} & e^{j\frac{2\pi.2.2}{N}} & \cdots & e^{j\frac{2\pi.2.(N-1)}{N}} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 1 & e^{j\frac{2\pi.(N-1).1}{N}} & e^{j\frac{2\pi.(N-1).2}{N}} & \cdots & e^{j\frac{2\pi.(N-1).(N-1)}{N}} \end{bmatrix} \text{ x } \begin{bmatrix} S_0 \\ S_1 \\ S_2 \\ \vdots \\ S_{N-1} \end{bmatrix}$$

FFT Process: $$\begin{bmatrix} S_0 \\ S_1 \\ S_2 \\ \vdots \\ S_{N-1} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & \cdots & 1 \\ 1 & e^{-j\frac{2\pi.1.1}{N}} & e^{-j\frac{2\pi.1.2}{N}} & \cdots & e^{-j\frac{2\pi.1.(N-1)}{N}} \\ 1 & e^{-j\frac{2\pi.2.1}{N}} & e^{-j\frac{2\pi.2.2}{N}} & \cdots & e^{-j\frac{2\pi.2.(N-1)}{N}} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 1 & e^{-j\frac{2\pi.(N-1).1}{N}} & e^{-j\frac{2\pi.(N-1).2}{N}} & \cdots & e^{-j\frac{2\pi.(N-1).(N-1)}{N}} \end{bmatrix} x \begin{bmatrix} s_0 \\ s_1 \\ s_2 \\ \vdots \\ s_{N-1} \end{bmatrix}$$

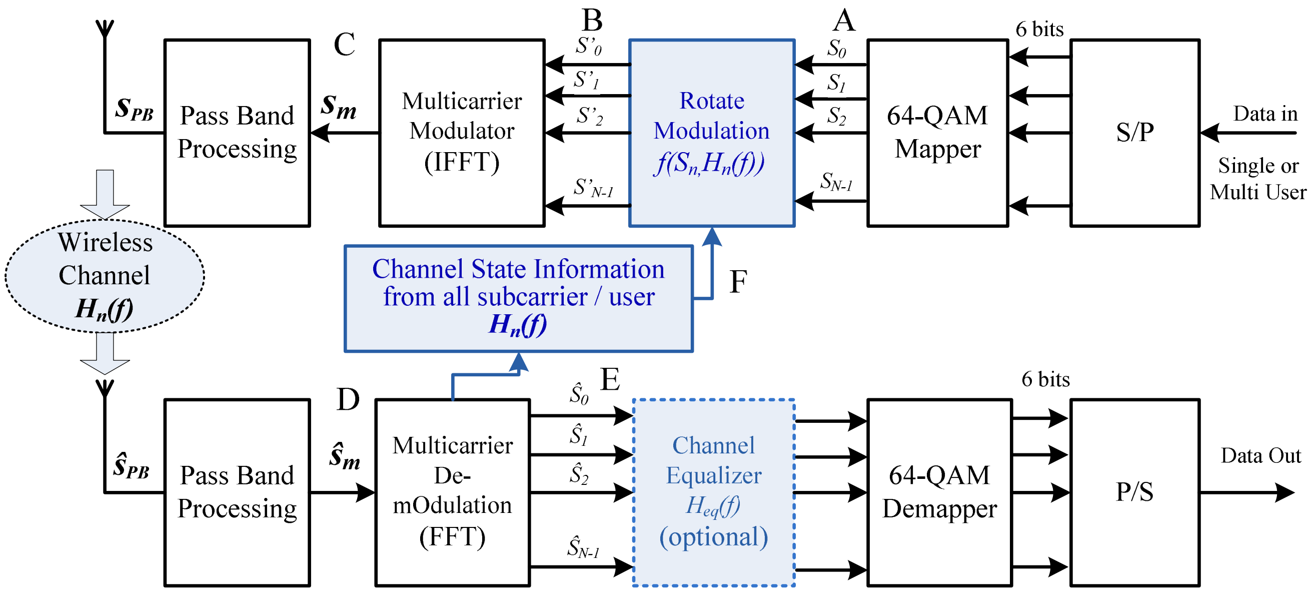


Figure 1. The proposed closed-loop rotate modulation model

III. CLOSED-LOOP ROTATE MODULATION MODEL

The closed-loop rotate modulation system model that we propose as in figure 1 above, consists of a transmitter, wireless channel, receiver, and channel feedback. Our proposed model does not use a guard intervals namely cyclic prefix.

A. Formula Derivation

The initial assumption that we use is the pass band processing on the transmitter and receiver works perfectly, then FFT output signal in Figure 1 has the following equation:

$$\hat{S}_n = \text{FFT}(\hat{s}_m) = \text{FFT}\left(s_m \; x \; H_n(f)\right)$$

$$= \text{FFT}\left(\text{IFFT}(S'_n) \text{ x } H_n(f)\right)$$

$$= \text{FFT}\left(\text{IFFT}\left(f\left(H_n(f),\, S_n\right)\right) \text{ x } H_n(f)\right) \qquad (14)$$

Where:

$H_n(f)$ = the frequency response of each n^{th}-subcarrier.

S'_n = the output of the closed-loop rotate modulation process on the n^{th}-subcarrier which is a function of S_n and $H_n(f)$ or $f\left(S_n, H_n(f)\right)$.

S_n = is a modulator output symbol

$\hat{s}_m$= the input symbol of the FFT process on the receiver

As a result of the $H_n(f)$ wireless channel, so S_n is distorted. To overcome this distortion, the channel equalization is usually done on the receiver, but our research we did, it on the transmitter. In order to distortionless transmission, $\hat{S}_n$ must be the same as S_n.

$$\hat{S}_n = S_n$$

$$\text{FFT}\left(\text{IFFT}\left(f\left(H_n(f),\, S_n\right)\right) \text{ x } H_n(f)\right) = S_n \qquad (15)$$

The equation $f\left(S_n, H_n(f)\right)$ is obtained by doing invers the transformation of equation (15), the first step on the right and left side of the equation (15) we do the IFFT- process so we get the equation:

$$\text{IFFT}\left(f\left(H_n(f),\, S_n\right)\right) \text{ x } H_n(f) = \text{IFFT}(S_n) \quad (16)$$

The second step, we move $H_n(f)$ at equation (16) from the left side to the right side, so we get the equation:

$$\text{IFFT}\left(f\left(H_n(f),\, S_n\right)\right) = \frac{\text{IFFT}(S_n)}{H_n(f)} \quad (17)$$

The third step, on the right and left side of the equation (17), we do the FFT- process so we get the equation:

$$\left(\left(H_n(f),\, S_n\right)\right) = FFT\left(\frac{IFFT(S_n)}{H_n(f)}\right) = S_n' \quad (18)$$

Equation (18) is the equation of the closed-loop rotate modulation process which rotates S_n to S_n' on the transmitter side by knowing $H_n(f)$, with the aim to get the received symbol equal to the send symbol.

B. Wireless Channel Model

In the Rayleigh distribution of wireless channel model simulations, we use a Jakes two-ray model, or a two-tap model often called a two-ray multipath Rayleigh fading. This model is a simplification of the tapped delay line model because it only uses 2-tap [12]. The figure of the wireless channel simulation model is as follows:

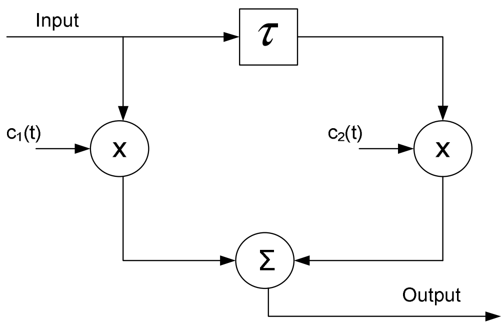


Figure 2. Channel simulation model

Two-ray multipath Rayleigh fading models use two mutually independent fading coefficients, namely:

$$c_1(t) = \alpha_1 e^{j\varphi_1} \qquad c_2(t) = \alpha_2 e^{j\varphi_2}$$

The values of α_1 and α_2 are Gaussian distributed, while φ_1 and φ_2 are uniformly distributed at 0 - 2π. While τ is the maximum tolerance for delay spread.

IV. SIMULATION RESULTS

In this section, we will show the simulation results according to figure 1 above, in the form of an illustration of the signal shape and system performance curve. The simulation is intended to show the signal in each process, by passing the Rayleigh channel and being slow fading. The updating rate on feedback channel conditions is much faster when compared to the fading rate.

A. Signal Shape without Rotate Modulation

The following is a picture of the signal shape at each point if there is no rotate modulation, the image is in the form of scatter/constellations and in the form of signal magnitude.

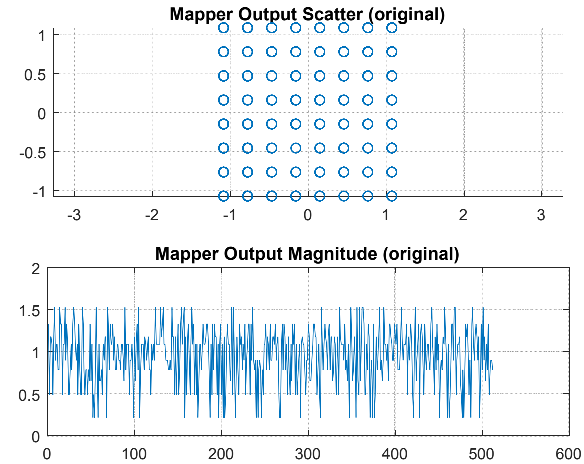


Figure 3. Scatter/constellations and magnitude of 64-QAM (point A or B)

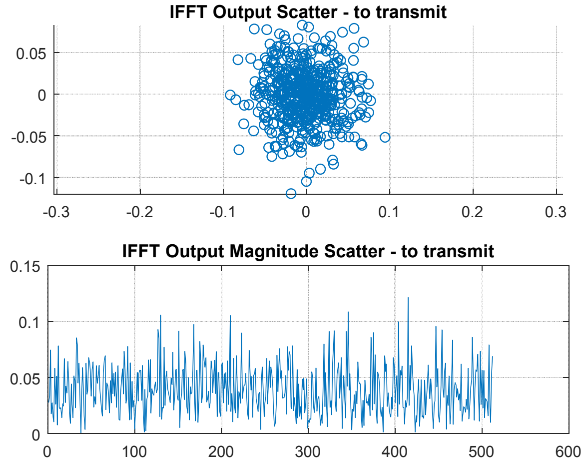


Figure 4. Scatter/constellations and magnitude IFFT output (point C)

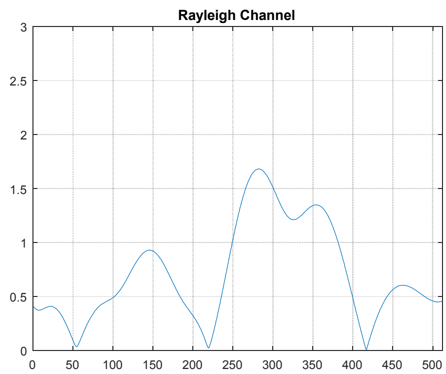


Figure 5. The magnitude of the wireless channel (point F)

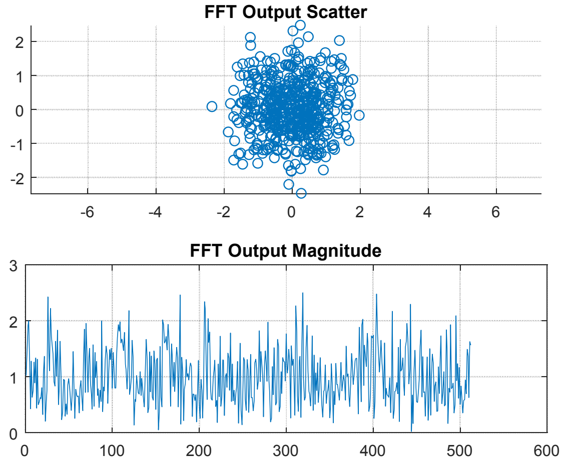


Figure 6. Scatter/constellations and magnitude FFT output (point E)

In Figure 3 and 4, we show the form of a single carrier *64*-QAM modulator output signal (original / without rotate modulation), and the Modulator multicarrier (IFFT) output, in the form of signal constellations and magnitude signal. After passing the Rayleigh channel as shown in Figure 5, the multicarrier demodulator (FFT) output in the signal receiver is distorted. Distortion is shown in the form of a constellated signal at point E becomes a mess, in figure 6.

B. Signal Shape with Rotate Modulation

The following is a signal shape figure at each point if, with the application of the rotate modulation process, the image is in the form of scatter/constellations and in the form of signal magnitude.

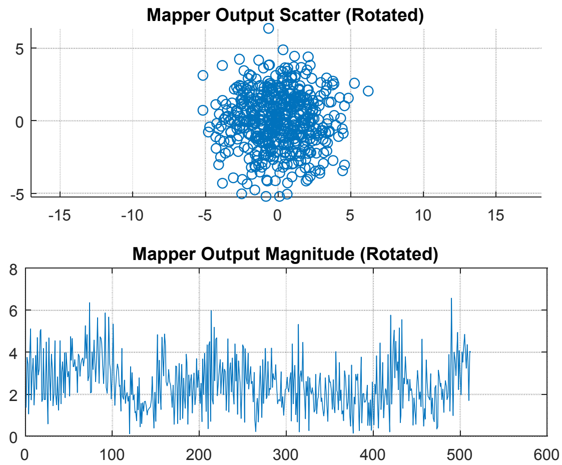


Figure 7. Scatter/constellations and magnitude of rotate *64*-QAM (point B)

In Figure 7 we show the form of a *64*-QAM modulator output signal after a rotate modulation single carrier, and in Figure 8 we show the modulator multicarrier (IFFT) output, in the form of signal constellations and magnitude signal. After passing through the Rayleigh channel as in figure 5, the multicarrier demodulator (FFT) output in the receiver will be an undistorted signal, indicated by the shape of the figure at point E is the same signal as the transmit signal, figure 9.

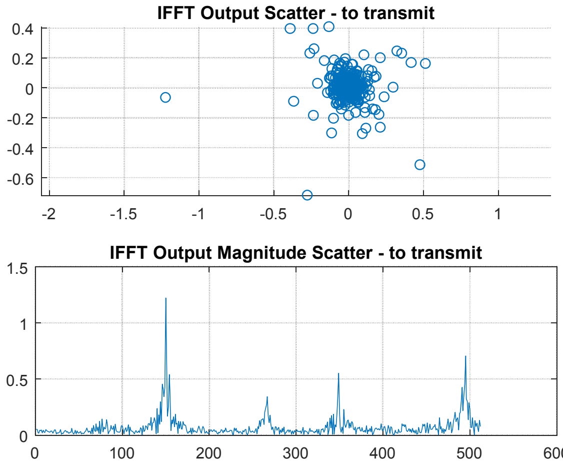


Figure 8. Scatter/constellations and magnitude of IFFT outout (point C)

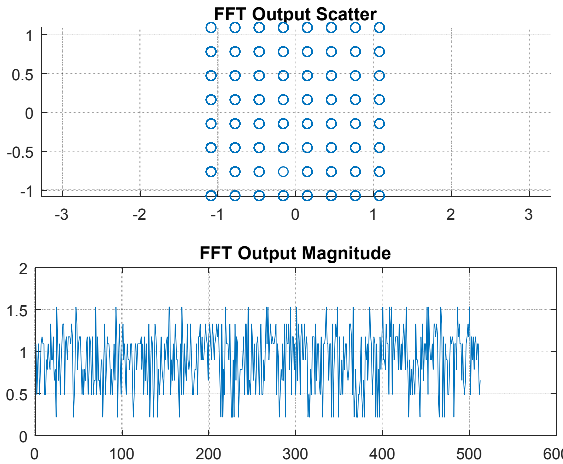
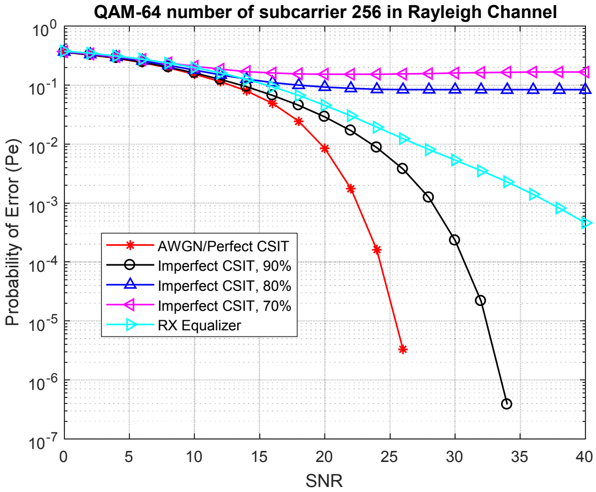
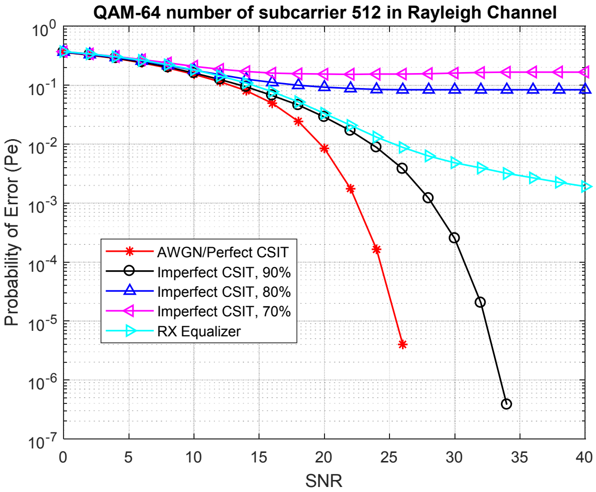


Figure 9. Scatter/constellations and magnitude of FFT output (point E)

C. Performance curve



(a)



(b)

Figure 10. Probability of error 64-QAM with closed-loop rotate modulation, in Rayleigh fading, number of subcarrier (a) 256, (b) 512.

In Figure 10 we plot the probability of error (P_e) as an SNR function on 64QAM with (a) 256 and (b) 512 subcarriers. We see that in the number of subcarriers 256 and 512, with the closed-loop rotate modulation process can improve performance, even if CSIT is perfect so the P_e becomes the same as the AWGN channel. If CSIT is not perfect, there is a decrease in quality. The worse the accuracy of CSIT, the worse the quality of communication that occurs. At P_e 10^{-5}, increasing CSIT accuracy from 90% to 100% gets a coding gain of 12 dB, which means a power saving of 16 times.

V. CONCLUSIONS

In this paper, we have presented a new method of closed-loop rotate modulation on a 64-QAM multicarrier. Our proposed model without using the guard interval insertion process. In slow fading simulations with the updating rate faster than the fading rate, the results show that our proposed method can improve the quality of the system, the received signal is the same as the transmit signal. On the probability of error curve also shows if the channel state information at the transmitter (CSIT) is perfect, then the P_e curve will coincide with the P_e curve if the system only has additional AWGN channels. Even though CSIT is not perfect, the system can still work, on CSIT 90% accuracy the system still works well.

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