International Journal on Advanced Science Engineering Information Technology

Vol.8 (2018) No. 5
ISSN: 2088-5334

Joint Power Loading and Phase Shifting on Signal Constellation for Transmit Power Saving on OFDM/OFDMA Systems

Budi Prasetya[#*], Adit Kurniawan[#], Iskandar[#], Arfianto Fahmi[*]

[#] *School of Electrical Engineering and Informatics, Institut Teknologi Bandung, Jl. Ganeca 10, Bandung 40132, Indonesia*
E-mail: budiprast_bpy@students.itb.ac.id, adit@stei.itb.ac.id, iskandar@stei.itb.ac.id

* *School of Electrical Engineering, Telkom University, Jl. Telekomunikasi, Bandung, 40257, Indonesia*
E-mail: arfiantof@telkomuniversity.ac.id

Abstract— **Power loading and phase shifting are generally applied separately to improve the performance of OFDM / OFDMA digital communication systems. In this paper, we propose a new method by combining the two to save transmit power. The channel information feedback used on prior power loading is just a channel gain, so in our method, channel state information at the transmitter (CSIT) feedback is a complex quantity. The magnitude of the channel is used to adjust the power allocation of each subcarrier, while the information on the channel phase is used to adjust the phase shifting. Our proposed method uses the principle of channel equalization but we apply in the transmitter. The first step in our research, we derive mathematical equations in the system model to obtain the ideal quality of communication. Next, to get curves that state the quality of the system, we do simulations with the help of computing software. From the simulation results, when the CSIT works perfectly, the resulting performance in terms of the probability of error is equal to the system passing through the AWGN channel, which means the maximum power savings. Although CSIT is not perfect but can still get power savings on the transmitter side. The more accurate CSIT, the greater the power saving is obtained. For low level modulation, 70% accuracy can get maximum pawer savings. The simulation results also show that the application of the propose method has a much better performance compared to the application of channel equalization on the receiver.**

Keywords— **Power loading, Phase Shifting, OFDM/OFDMA, CSIT, power saving.**

I. INTRODUCTION

Power loading is a process to improve performance on Orthogonal Frequency Division Multiplexing (OFDM) and Orthogonal Frequency Division Multiple Access (OFDMA) systems by providing optimal allocation of power to each subcarrier if it passes through the wireless channel. Without knowing the channel conditions on each subcarrier on the transmitter side, a simple strategy is to use equal power loading on each subcarrier to achieve a high signal to noise ratio (SNR). However, at the low SNR, the equal power loading strategy should still be applied to the adaptive power allocation process. Reference [1] implemented a water filling strategy for the power allocation of each subcarrier on a parallel Gaussian channel. Reference [2] and [3] use channel condition feedback for power loading which is still a channel gain information only.

The transmission channel conditions passed by signals due to propagation, shadowing, multipath and user movements, are in fact complex systems [4]. The channel condition can be represented as a complex quantity, the magnitude represents the channel gain, while the phase represents the delay experienced by the signal [5]. By utilizing feedback channel conditions which are complex quantity, research [6] and [7] have clustered several subcarriers into one chunk on OFDMA system but has not utilized this feedback for power loading process.

Another development in digital communication systems, to improve system performance is applied Rotate Modulation by performing phase shift in the constellation of the digitally modulated signal. The application of rotate modulation in the signal constellation also can improve mutual information in Rayleigh fading [8]. Rotate modulation applied to OFDM systems have been explored by [9] and [10]. Reference [9] has discussed the application of Coding Rotate Modulation for enhanced performance of OFDM and CDMA combined systems. The result of the application of Coded Constellation Rotated Vector OFDM with Almost Linear Interleaver can improve OFDM system performance [10]. However, all of these studies are only on phase shift process, it is still very interesting if this phase shift study is combined with power loading process.

Currently, power or energy efficient is becoming a very interesting issue in OFDM/OFDMA system research.

Reference [11] has been studied about the energy efficient resource allocation for downlink MIMO(multiple inputs multiple outputs)-OFDMA systems. Reference [12] has been studied about subcarrier allocation and precoder design for energy efficient MIMO-OFDMA downlink systems.

To get better performance and power saving, in this paper, we combine power loading and phase shift. This process is done by utilizing channel response information which is a complex quantity. The channel gain information is the basis of the power loading process, while the channel phase is used to adjust the amount of phase shift/rotation in the signal constellation. The observed performance is the probability of error of our proposed system. Based on the probability of error curve, obtained the amount of power savings. Power savings here are similar to coding gain, i.e. the amount of SNR savings after the application of our proposed method to the same probability error target.

II. MATERIAL AND METHOD

The basic idea of OFDM is to transmit data using FDM (frequency division multiplexing), while the basic concept of OFDM is to divide high-speed serial data into low-speed parallel data transmitted by multiple subcarriers. Each subcarrier is created orthogonally with appropriate frequency spacing, so spectral overlap between adjacent subcarriers can be performed without inter-carrier interference (ICI) effect.

A. FFT-based OFDM/OFDMA Systems

The use of Discrete Fourier Transform (DFT) on OFDM system will reduce the level of complexity of transmitting and receiving systems. DFT is used to generate an orthogonal subcarrier, to shorten computing time, it can be implemented Fast Fourier Transform (FFT) algorithm. FFT and Inverse FFT (IFFT)-based OFDM/OFDMA systems can be illustrated in Figure 1.

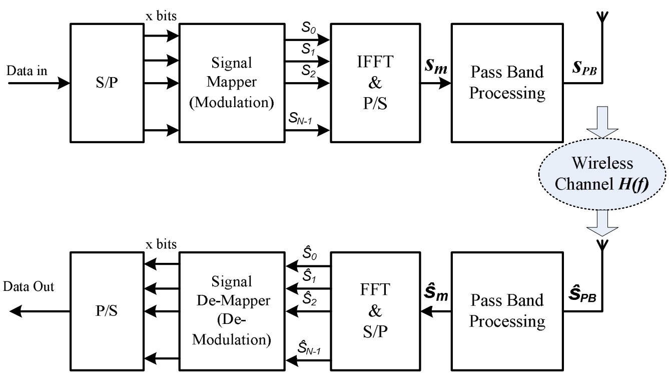


Fig. 1 FFT and Inverse FFT (IFFT)-based OFDM/OFDMA systems

To generate baseband OFDM symbols, serial data sequences are converted to parallel data to a number of subcarriers, N. Furthermore, parallel data is modulated using modulation schemes such as Phase Shift Keying (PSK) or Quadrature Amplitude Modulation (QAM). Inverse DFT (IDFT) is used as an OFDM modulator [6] and [7], OFDM symbol is generated from the equation:

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

Where N is the number of IDFT points or subcarrier total used, S_n is the transmitted data symbol on the n^{th} subcarrier and s_m is OFDM symbol output at IDFT/IFFT process. While DFT is used as an OFDM demodulator, OFDM demodulator output symbol is obtained from the equation:

$$\hat{S}_n = \sum_{n=0}^{N-1} \hat{s}_m \exp\left\{ -j\frac{2\pi mn}{N}\right\}, \quad 0 \le n \le N-1 \quad (2)$$

Where $\hat{S}_n$ is demodulator OFDM symbol output on the n^{th} subcarrier and $\hat{s}_m$ is demodulator OFDM symbol input at DFT/FFT process.

B. QPSK and M-QAM Modulation

The OFDM signal consists of the sum of subcarriers that are modulated with PSK or QAM. The serial data will be formed into the symbols of the data in accordance with the selection signal mapping. The transmitted M ary-QAM signal for m^{th} symbol and n^{th} subcarrier can be expressed as:

$$S_n(t) = \sqrt{\frac{2E_g}{T}}.a_y.\cos(2\pi f_c t) - \sqrt{\frac{2E_g}{T}}.b_y.\sin(2\pi f_c t) \quad (3)$$

Where T is the duration of the symbol, E_g or a^2 is the energy of the signal with the lowest amplitude, and the value of a_y or b_y is $\pm a$, $\pm 3a$, $\pm(\log_2 \text{M}-1)a$. The illustration of original M-QAM symbols can be seen in figure 6.

C. Wireless Channel Model

The process of transmitting a signal that reaches the receiver does not only pass one path but comes from multiple paths (multipath). Superposition received signal due to the multipath will experience attenuation (channel gain) and the phase shift or delay that fluctuates and is often called multipath fading. Some multipath channel parameters obtained from the power delay profile that represents the relative received power plot as a function of excess delay corresponding to the time delay of reference. Power delay profile is obtained from the average measurement of instantaneous power delay profile in a local area [4] and illustrates in figure 2.

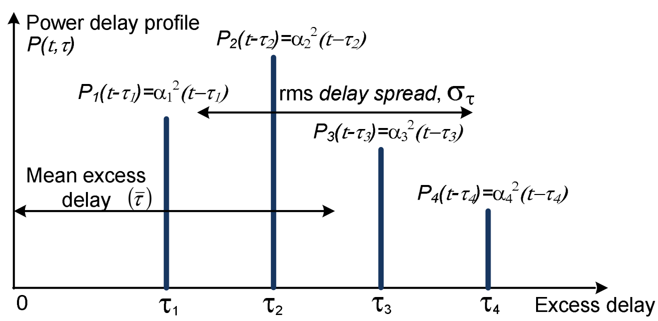


Fig. 2 The power delay profile as an excess delay function (eg. 4 paths)

Based on figure 2, the transmitted power delivered at time *t (t=0)*, then the received power equation as a function of time *t* and delay τ_l is:

$$P(t, \tau) = \sum_l P_l(t\text{-}\tau_l) \tag{4}$$

If each of the l^{th} paths has amplitude α_l so the equation becomes:

$$P(t, \tau) = \sum_l \alpha_l^2(t\text{-}\tau_l) \tag{5}$$

The amplitude equation of the received signal becomes:

$$\alpha(t, \tau) = \sum_l \alpha_l(t\text{-}\tau_l) \tag{6}$$

If the transmit signal amplitude for the n^{th} subcarrier is $\delta(t)$, so the channel impulse response equation becomes:

$$h_n(t, \tau) = \sum_l \alpha_{l,n}(t\text{-}\tau_{ln}) \tag{7}$$

Where $\alpha_{l,n}(t)$ is the amplitude gain of the l^{th} path for the n^{th} subcarrier or user, and $\tau_{l,n}$ is the delay of the l^{th} path for the n^{th} subcarrier or user. The $\alpha_{l,n}(t)$'s are assumed to be wide-sense stationary, narrow band, complex Gaussian process, which are independent for different paths or subcarrier.

At the frequency domain, the frequency response of the channel impulse response can be expressed as [8]:

$$H_n(f) = \int_{-\infty}^{+\infty} h_n(t,\tau)e^{-j2\pi f\tau}d\tau$$
$$= \sum_l \alpha_{l,n}(f)e^{-j2\pi f\tau_{l,n}} \tag{8}$$

D. Channel Equalization at the Receiver

The channel equalization model at the receiver can be shown in figure 3.

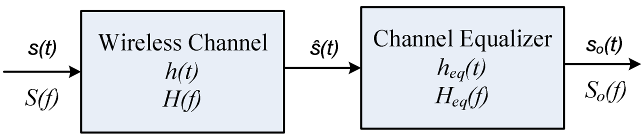


Fig. 3 The Basic Diagram of Channel Equalizer

The transmitted signal *s(t)* after passing the wireless channel *h(t)*, the received signal $\hat{s}(t)$ experiences negative gain (attenuation) and delay at the receiver. In order for distortionless transmission at the output of the receiver, the receiver added equalization channel. The received signal in the frequency domain becomes:

$$S_o(f) = S(f).H(f).H_{eq}(f) = S(f) \tag{9}$$

From equation (9), we can obtain the frequency response equation of channel equalization:

$$H_{eq}(f) = \frac{1}{H(f)} \tag{10}$$

Where *H(f)* is the frequency response of the wireless channel, that can be represented as a complex quantity. *H(f)* have magnitude response $|H(f)|$ and phase response $\angle\Phi(f)$. If *H(f)* is known in the receiver (CSIR or channel state information at the receiver), then the frequency response of the $H_{eq}(f)$ can also be obtained

E. Proposed Solution at the OFDM/OFDMA Transmitter

By analogy similar to the process of Channel Equalizer in the receiver, the transmitter can also do a wireless channel compensation process after the transmitter knows the channel conditions (CSIT). We propose the combined solution between power loading and phase shifting as in figure 4.

By assuming that the passband processing at the transmitter and the receiver works perfectly, the FFT & S/P input signal in Figure 4 has the equation:

$$\hat{s}_m = IFFT(S_n').H_n(f) \tag{12}$$

Where $H_n(f)$ is the channel frequency response passed by n^{th} subcarrier or user. If $\hat{s}_m$ passes through distortionless transmission with $H_n(f) = 1$, the equation (12) without $f(S_n, H_n(f))$ process becomes:

$$\hat{s}_m = IFFT(S_n) \tag{13}$$

In order to obtain the output of power loading and phase shifting S_n', we must substitute the equation (12) to the equation (13), so the equation becomes:

$$IFFT(S_n').H_n(f) = IFFT(S_n)$$
$$IFFT(S_n') = \frac{IFFT(S_n)}{H_n(f)} \tag{14}$$

$$S_n' = FFT\left(\frac{IFFT(S_n)}{H_n(f)}\right) = f\big(S_n, H_n(f)\big) \tag{15}$$

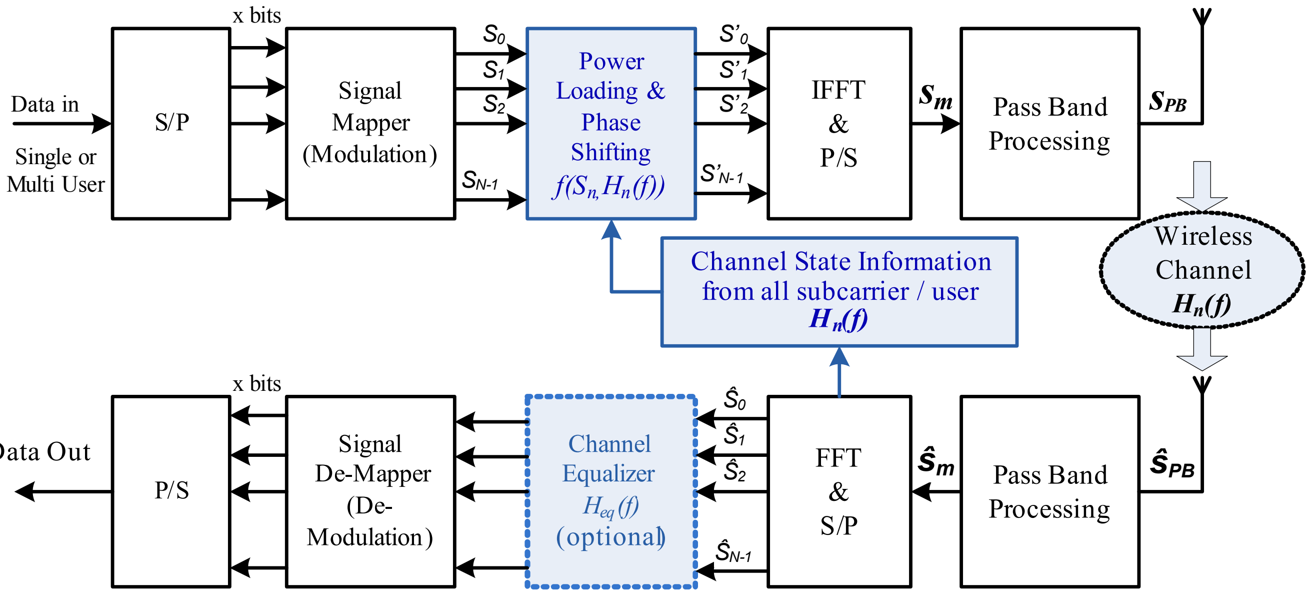


Fig. 4 Joint Power Loading and Phase Shifting OFDM/OFDMA Systems

The process of shifting the symbol S_n to S'_n based on knowledge of channel condition (CSIT) is called as the joint power loading and phase shift. The process of power loading is when shifting the signal constellation point of each subcarrier close to or away from the coordinate axis. While the phase shift is the shift of the signal constellation of each subcarrier in the same direction or counter clockwise, at the same time as the power loading process. The illustrations are in figure 5.

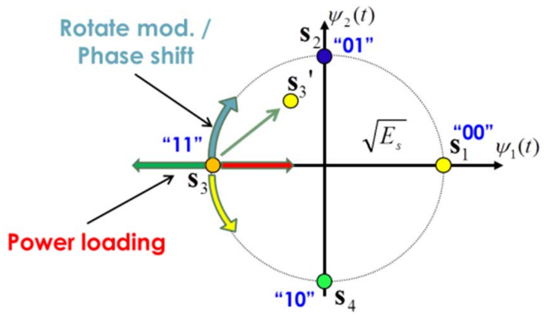
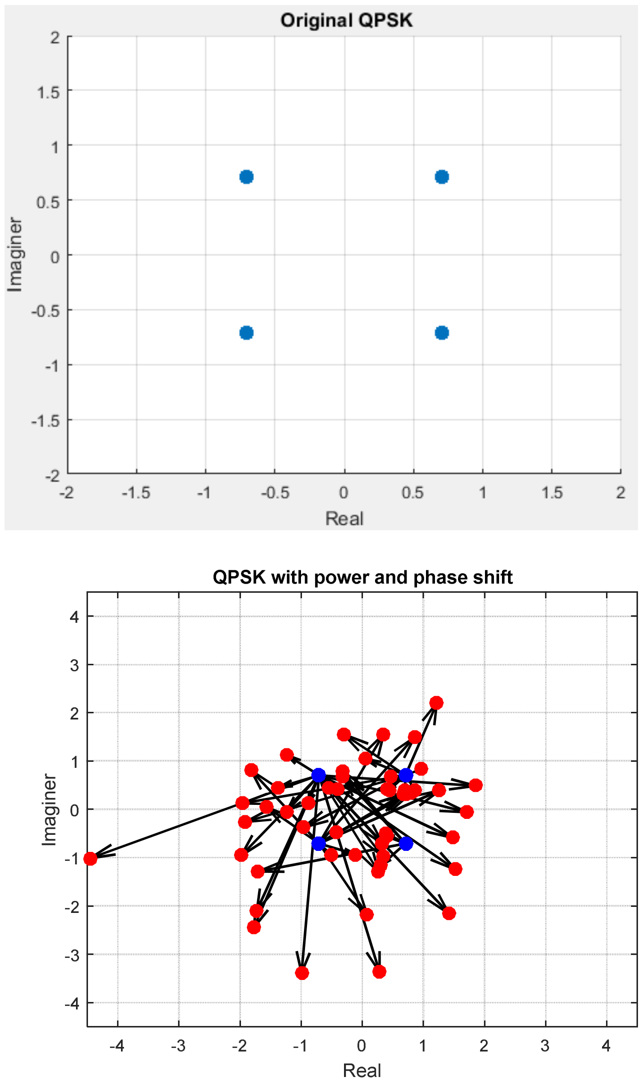


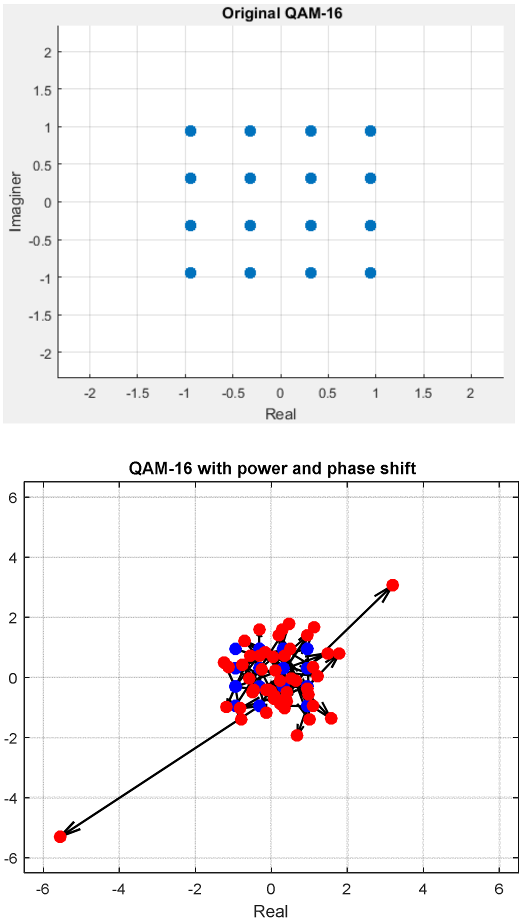
Fig. 5 Joint Power Loading and Phase Shifting on QPSK or 4QAM symbol (the shifting process of the symbol S_n to S'_n)

III. Result And Discussion

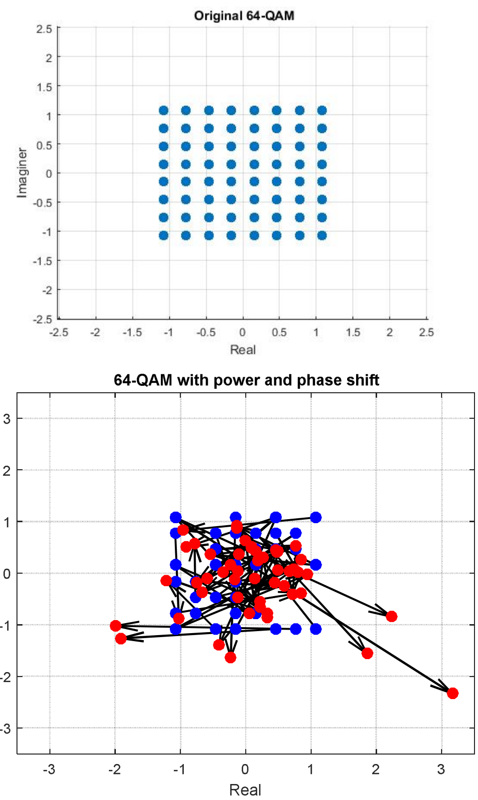
In this section, we evaluate the performance of the proposed solution by Matlab simulation. The simulation was done by using a variety of modulation type of M-QAM i.e. QPSK or 4QAM, 16QAM and 64 QAM. Variations in the number of subcarriers used are 256 and 512.



(a)



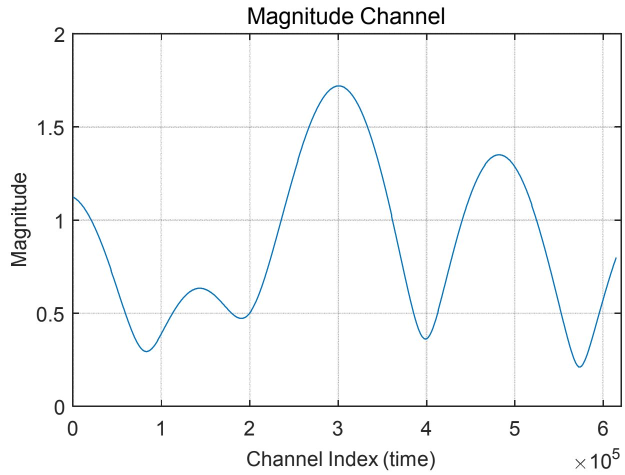
(b)



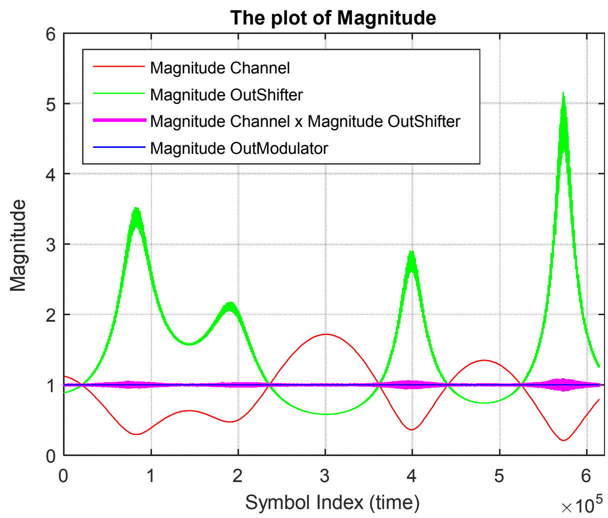
(c)

Fig. 6 The Illustration of Original M-QAM and Power-Phase Shifting on M-QAM, (a) QPSK or 4QAM, (b) 16QAM and (c) 64QAM.

In Figure 6, we illustrate the original point of the M ary-QAM signal constellation, and the point after the shift process with respect to CSIT, (a) QPSK or 4-QAM, (b) 16-QAM and (c) 64-QAM. The original point of the signal constellation has a regular form according to equation (3), whereas after the shifting process, the constellation point changes with the aim of compensating the channel conditions through which the information passes. In this case, the channel is assumed time-invariant at intervals between training signals to know the channel condition until the symbol information is completed.



(a)



(b)

Fig. 7 (a) Magnitude Channel, (b) The Comparison of Magnitude: magnitude channel, magnitude output shifter and magnitude output modulation.

In figure 7, we plot (a) Magnitude Channel, (b) The Comparison of Magnitude: magnitude channel, magnitude output shifter, and magnitude output mapper/modulation. Figure 7 (a) shows that the simulated channel response is different for each different symbol. Figure 7 (b) shows that the process of shifting the signal constellation from S_n to S_n' will eliminate the channel fluctuation effect. It is also seen if the channel has a small response, then the magnitude output of the shifter will have a high magnitude. If the channel has a high response, then the output shifter will have a low magnitude. In other words, the multiplication of the magnitude channel and the magnitude of the output shifter are the constants of the number one.

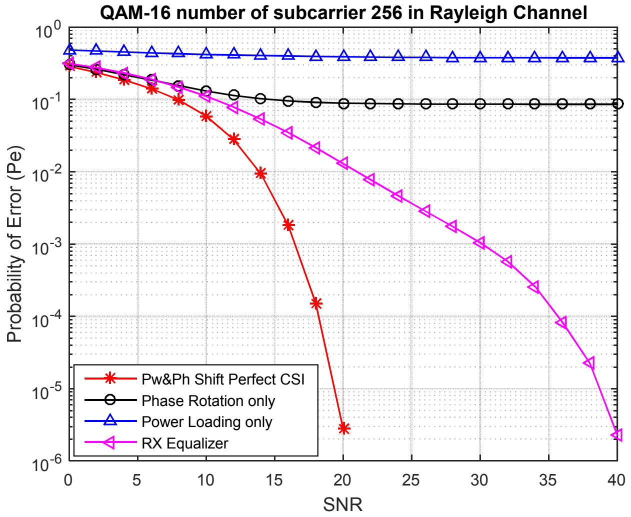
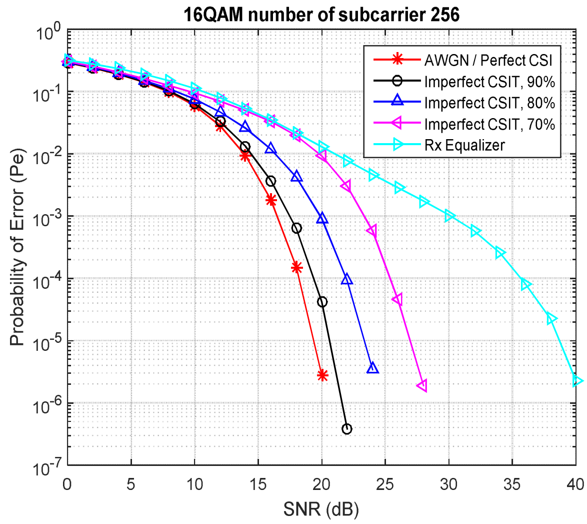


Fig. 8 The comparison of Probability of error over SNRs on power loading only, phase shift only, and combined power loading and phase shifting, also the equalizer application at the recipient

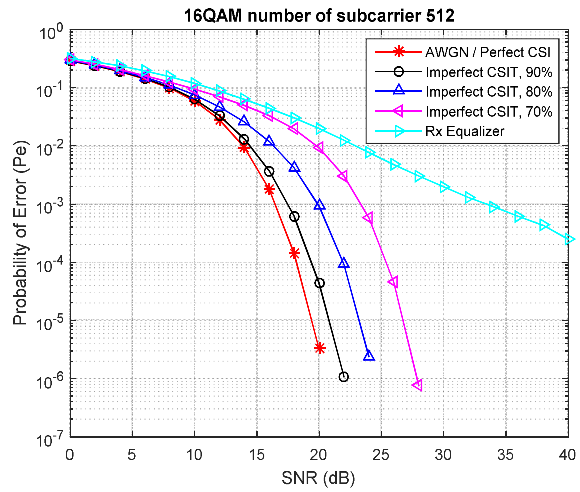
The simulation results that we show are based on the proposed system model in Figure 4. Figure 8 shows that the combined application of power loading and phase shifting provides a significant improvement of the probability of error when compared to the probability of error in the application of power loading only or phase shifting only. Previous research was still applied power loading only and phase shifting only.

On the Probability of error curve, the performance of digital communication system will be better if the resulting curve is on the left side. At a certain probability of error values, there is a value of SNR difference between SNRs without encoding on the system and SNR on the system with proposed coding. The difference of SNR value is called coding gain, can be expressed in numerical or decibel (dB). If the noise at the receiver is considered equal, then the SNR difference can be replaced by the receive power difference. If the transmission attenuation of the two comparable systems is considered equal, then the receive power difference can be replaced by the transmit power difference. The transmit power difference between these two comparable systems, we refer to as power savings.

In Figure 9, we plotted the Probability of error over SNRs on 16QAM with 256 (a) and 512 subcarriers (b). We see that on the number of subcarriers 256 and 512, the presence of a joint Power loading and phase shift can improve performance, even if CSIT is perfect then P_e becomes the same as the AWGN (additive white Gaussian noise) channel only. At P_e 10^{-5}, CSIT accuracy increase from 70% to 80% obtained a coding gain of 4 dB which means power savings of 2.5 times. Accuracy increased from 80% to 90% will get a coding gain of 3 dB which means power savings of 2 times. Accuracy increased from 90% to 100% will get a coding gain of 2 dB which means power savings of 1.6 times.



(a)

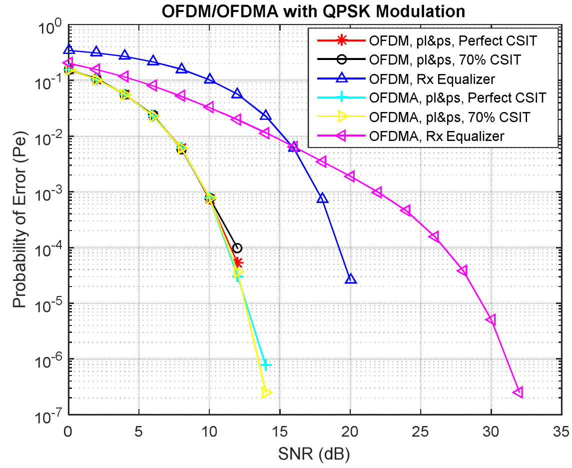


(b)

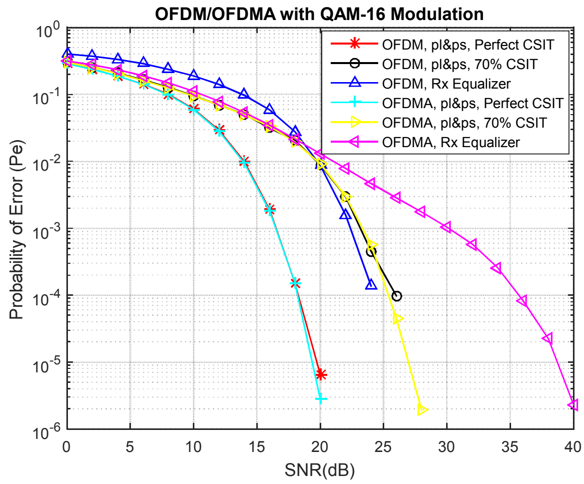
Fig. 9. The Probability of error over SNRs on 16QAM with 256 (a) and 512 subcarriers (b)

In Figure 10, we plotted Probability of error over SNRs on OFDM/OFDMA with (a) QPSK/4QAM and (b) 16QAM Modulation. Figure 10 (a) shows that in low-level modulation such as QPSK/4QAM, the performance of P_e OFDM and OFDMA is the same, also for perfect CSIT and imperfect CSIT up to 70% have the same P_e. The figure also shows that the implementation of joint power loading and phase shift on the transmitter side provides much better performance when compared to the channel equalization implementation at the receiver. At the P_e = 10^{-6}, in the OFDM system, the difference of 7 dB or power savings of 5 times, while the OFDMA system can reach 17 dB.

If the modulation used is a high-level modulation such as 16QAM (Fig. 10 (b)), a good channel estimation accuracy is required to obtain the best probability of error (equal to the probability of error in the AWGN channel). If the accuracy of channel estimation is 70%, then the probability of error in OFDM system will be less good that is similar to the application of Rx Equalizer. While the probability of error in OFDMA system, for the accuracy of 70% channel estimation, still shows the good probability of error, with gain coding gain of 9 dB at Pe 10^{-5}. In this high-level modulation, accurate channel estimation is required because the distance between the symbols in the signal constellation is closer.



(a)



(b)

Fig. 10. The probability of error over SNRs on OFDM/OFDMA with (a) QPSK/4QAM, and (b) 16QAM Modulation.

IV. Conclusion

In this paper, we proposed the simple process of joint power loading and phase shifting on signal constellation for the OFDM/OFDMA downlink. By using process similarities such as channel equalization, but applied on the transmitter side, our proposed method can improve system performance until it is similar to the AWGN channel. When compared with the application of power loading only or phase shifting only, our proposed model gives a very significant probability of error. The more accurate the CSIT, then we get better system performance. In 10^{-5} P_e, CSIT accuracy increase from 70% to 80% get power savings of 2.5 times, CSIT accuracy increase from 80% to 90% power savings by 2 times, CSIT accuracy from 90% to100% get power savings equal to 1.6 times. Our proposed method also delivers results at low-level modulation for CSIT accuracy of 70%, obtaining a performance similar to the AWGN channel. When compared to the application of channel equalization on the receiving end, our proposed method can provide a lot of power savings, even reaching 17 dB on OFDMA system.

Acknowledgment

We would like to thank the Ministry of Research and Higher Education for the provision of research grants from the Directorate of Research and Community Service, Directorate General of Higher Education and Development with contract number 1603 / K4 / KM / 2017. We would also like to thank Telkom University for the assignment of doctoral studies.

References

[1] A. Lozano, A. M. Tulino, and S. Verdu, "Optimum Power Allocation for Parallel Gaussian Channels with Arbitrary Input Distributions," *IEEE Transactions on Information Theory*, Vol. 52, No. 7, pp. 3033–3051, July 2006.

[2] E. H. Choi, W. Choi, and J. G. Andrews, "*Power Loading Using Order Mapping in OFDM Systems with Limited Feedback", IEEE Signal Processing Letters*, Vol. 15, pp. 545-548, 2008.

[3] J. H. Lee, and W. Choi, "Multi-level Power Loading Using Limited Feedback," *IEEE Communications Letters*, Vol. 16, No. 12, pp. 2024-2027, December 2012.

[4] T. S. Rappaport, *Wireless communications: Principle and Practice*, 2nd edition, Prentice Hall Communications Engineering and Emerging Technologies Series, 2001.

[5] B. Sklar, *Digital Communications: Fundamentals & Applications*, 2nd Edition, Prentice Hall, 2009.

[6] B. Prasetya, A. Kurniawan, Iskandar, and A. Fahmi, "Use of Clustering Concept for Chunk Forming based on Constellation Signals on OFDMA Resource Allocation Systems," *Proc. of TSSA*, 2015, pp. 1-6.

[7] B. Prasetya, A. Kurniawan, Iskandar, and A. Fahmi, "K-Mean Clustering for Chunk Formation based on Channel Response on OFDMA Radio Resource Allocation Systems," *Advanced Science Letters*, Vol. 22, pp. 3060–3064, Oct. 2016.

[8] S. P. Herath, N. H. Tran, and T. Le-Ngoc, "Rotated Multi-D Constellations in Rayleigh Fading: Mutual Information Improvement and Pragmatic Approach for Near-Capacity Performance in High-Rate Regions," *IEEE Transactions on Communications*, Vol. 60, No. 12, pp. 3694-3704, Dec. 2012.

[9] K.A. Suharja, R. P. Astuti, L. Meylani, and A. Fahmi, "Enhancement of MC-CDMA Performance System using Rotated Modulation," *Proc. of COMNETSAT*, 2016, pp. 14-17.

[10] C. Han and T. Hashimoto, "Coded Constellation Rotated Vector OFDM with Almost Linear Interleaver," *Proc. of WCNC*, 2016, pp. 1-6.

[11] G. Xu, W. Mat, and Y. Ren, Energy-Efficient Resource Allocation for Downlink MIMO-OFDMA Systems with Proportional Rates Constraints," *Proc. of 10th International Conference on Communications and Networking in China*, 2015, pp. 37-41.

[12] Z. Wang, and L. Vandendorpe, "Subcarrier Allocation and Precoder Design for Energy Efficient MIMO-OFDMA Downlink Systems," *IEEE Transactions on Communications*, Vol. 65, No. 1, pp. 136-146, January 2017