Journal of information and
communication convergence engineering
http://jicce.org

J. Inf. Commun. Converg. Eng. 14(4): 227-232, Dec. 2016
Regular paper

Performance Analysis of 32-QAPM System with MRC Diversity in Rician Fading Channel

Jae Young Chun[1] and Eon Gon Kim[2*], ***Member, KIICE***

[1]Graduate School of Information & Communication Engineering, Hanbat National University, Daejeon 34158, Korea
[2]Department of Information & Communication Engineering, Hanbat National University, Daejeon 34158, Korea

Abstract

In this study, the performance of a 32-quadrature amplitude position modulation (QAPM) system is analyzed under a Rician fading channel condition when the maximal ratio combining (MRC) diversity technique is used in the receiver. The fading channel is modeled as a frequency non-selective slow Rician fading channel corrupted by additive white Gaussian noise (AWGN). QAPM is available to improve BER performance without amplifying transmit power, and MRC diversity makes the performance improvement of QAPM system even bigger by intentionally maximizing SNR. Error performances are shown for the 32-QAPM system and a 32-phase silence shift keying (PSSK) system in order to examine the effects of fading severity, for various values of the Rician parameter, *K*. The dependence of error rates on MRC diversity is also analyzed. The simulation results show that the BER performance of the 32-QAPM system is better than that of the 32-PSSK system under the above mentioned conditions.

Index Terms: Bandwidth efficiency, MRC diversity, Power efficiency, PSSK, QAPM, Rician fading

I. INTRODUCTION

Recently, low-power radio communication has been used widely due to the growth of the Internet of things (IoT) industry worldwide. Due to the technical maturity of mobile communication, even in the case of low-power radio communication, there is an increasing demand for good QoS [1]. In order to meet the minimum QoS requirement, it is absolutely necessary to secure an extension of the data throughput or an improvement in the transmit power during radio communication. Quadrature amplitude position modulation (QAPM) is a type of QAM that can effectively expand the transmit capacity without increasing the SNR. In addition, since QAPM includes a silence period in the symbol period, it has the advantage of increasing the power efficiency.

Despite these technical advances, most radio communication needs durability against fading, which degrades the QoS of the communication. Fortunately, the performance verification for diversity scheme has been confirmed to be valid in fading environments as in previous studies. We confirm the performance improvement for a combination of QAPM and MRC (maximal ratio combining) diversity in a fading environment.

Traditionally, QAM has been widely used for high data rate transmission by itself or as part of orthogonal frequency-division multiplexing (OFDM). In order to meet the QoS requirement, most radio communication first needs an expansion of the channel capacity. In this case, QAPM provides a mean to improve the data throughput without

Received 04 October 2016, **Revised** 07 October 2016, **Accepted** 15 November 2016
***Corresponding Author** Eon Gon Kim (E-mail:egk8996@hanbat.ac.kr, Tel: +82-10-3042-3836)
Department of Information & Communication Engineering, Hanbat National University, 125, Dongseo-daero, Yuseong-gu, Daejeon 34158, Korea.

Open Access http://doi.org/10.6109/jicce.2016.14.4.227
print ISSN: 2234-8255 online ISSN: 2234-8883

amplifying the transmit power [2]. QAPM is a modulation technique that combines QAM and PPM. As QAPM involves the transmission of two orthogonal signals, it is possible to achieve certain performance improvement by degrading the M/2 modulation order and setting the silence period during the symbol period [3]. As a result, QAPM generates the SNR improvement effect by securing the hamming distance for each symbol on the constellation and maintaining the zero envelope during the half period. QAPM is better in terms of power efficiency than QAM at the same modulation level. On the other hand, QAPM has worse bandwidth efficiency than QAM because of the two-time increase in the bandwidth. Nevertheless, the bandwidth efficiency of QAPM is still superior to FSK and OOK [4]. In particular, 32-ary QAPM has a more useful architecture with two orthogonal properties, which include the IQ modulator and the time orthogonal property. In terms of performance, we expect 32 QAPM to achieve a better performance than the other modulations. MRC diversity is known to be an optimal linear combination technique maximizing the SNR of the received signal in each branch. Adopting MRC diversity, the device in the receiver stage makes it possible to control the resistance to multipath fading. As the fading increases, the performance difference between QAPM and QAM can be clearly identified under the same test conditions.

The rest of this paper is organized as follows: Section II describes the communication model and the derivation of the error probability of the 32-QAPM system with MRC diversity reception in the Rician fading channel. The simulation results are discussed in Section III, and Section IV concludes this paper.

II. SYSTEM MODEL AND METHODS

Fig. 1 presents a schematic of the communication model. Data are mapped onto the streams modulating the I- and Q-carriers in the 32-QAPM transmitter. Through the Rician fading channel, the modulated 32-QAPM signal is corrupted by the multipath fading obtained as a result of receiving a direct component and a random diffuse component [5]. This fading imposes a random amplitude and phase onto the modulated 32-QAPM signal. Besides fading, the transmitted signal is corrupted by AWGN. The received signals disturbed by Rician fading and AWGN in each diversity branch are weighted (selected) and combined by the diversity circuit. In other words, each signal branch is multiplied by a weight factor that is proportional to the signal power; therefore, it is possible to obtain an optimum signal to maximize SNR. Diversity reception is usually regarded as a means of combating fading in radio transmissions. The output signal from the MRC diversity process is delivered to the 32-QAPM (8-PSSK) receiver. In the 32-QAPM receiver, the received signal is split into two paths and the I–Q components are placed in the reverse order to the transmitter process. The M-ary QAPM scheme is a combination of M/2-ary QAM and PPM with half the symbol duration. QAPM determines the silence-envelope position of the symbol by using the first bit, and $\log_2 M - 1$ bits determine the M/2-ary QAM symbols.

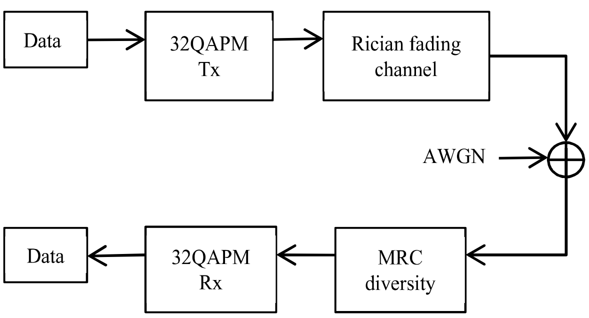

Fig. 1. Communication model.

In Fig. 2(a), the QAM symbol duration is T, which is the symbol period T_s, but the QAPM symbol duration is T/2, as shown in Fig. 2(b). Fig. 3 shows the signal and the constellation of 32 QAPM in which the white noise is added. In the constellation, the symbol near the zero point is concentrated due to the zero envelope with half the symbol duration. The m-th signal of 32 QAPM is represented as follows:

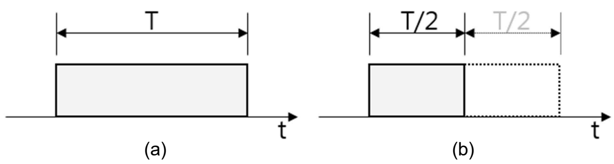

Fig. 2. A 32-QAPM symbol duration. (a) QAM, (b) QAPM.

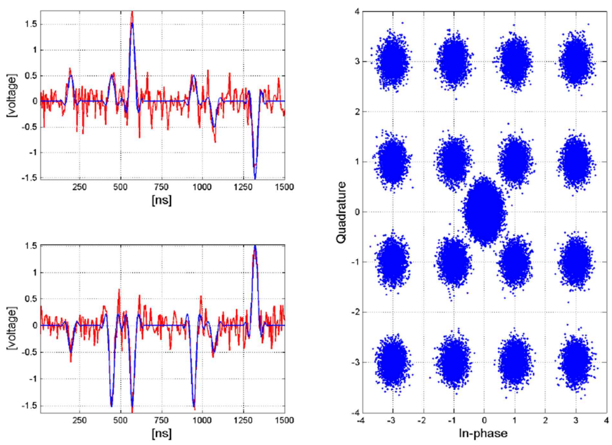

Fig. 3. A 32-QAPM signal and constellation.

$$s_m(t) = A_m\alpha(t)I(t)\cos(2\pi f_c t) + B_m\beta(t)Q(t)\sin(2\pi f_c t) \quad (1)$$

with

$$A_m = \begin{cases} 1 & 0 < t < \frac{T}{2} \\ 0 & \frac{T}{2} < t < 1 \end{cases}$$

$$\alpha(t) = \frac{4\sqrt{2\gamma}}{\pi\sqrt{T_s}} \times \frac{\cos\left\{2\pi(1-\gamma)\frac{t}{T_s} + \frac{\sin\left\{2\pi(1-\gamma)\frac{t}{T_s}+\right\}}{\left(8\gamma\frac{t}{T_s}\right)}\right\}}{1-\left(8\gamma\frac{t}{T_s}\right)^2}$$

where B_m = mod(A_m, 1) and $\beta(t) = \alpha(t - T_s/2)$. $\alpha(t)$ denotes the pulse shaping function (square root raised cosine), where γ represents the roll-off factor [3]. Therefore, the probability of the bit error of M-ary QAPM is derived from the symbol error probability of QAM as follows [6]:

$$P_{b-QAPM} = \frac{1}{\log_2 M} \times P_{s-QAM}\left(\frac{1}{2}M\right). \quad (2)$$

Further, the CNR of QAPM can be derived using the following equation:

$$\frac{E_b}{N_{0(QAPM)}} = \frac{\log_2 M}{\log_2 M - 1} \times \frac{E_b}{N_{0(QAM)}}. \quad (3)$$

According to Eq. (2), to derive the BER of 32 QAPM, a 16-QAM signal is split into the I channel and the Q channel and detected in each channel. Therefore, the symbol error probability of the 16-QAM signal of the I channel in AWGN can be derived as follows:

$$P_{NC1}(r_i, \Gamma_i) = \frac{1}{2}\,\mathrm{erfc}\left(\sqrt{\frac{r_i}{10}}\right) + \frac{1}{2}\mathrm{erfc}\left(\sqrt{\frac{2\Gamma_i}{5}} - \sqrt{\frac{r_i}{10}}\right) + \frac{1}{2}\mathrm{erfc}\left(\sqrt{\frac{9\Gamma_i}{10}} - \sqrt{\frac{2r_i}{5}}\right), \quad (4)$$

where r_i denotes the instantaneous CNR and Γ_i represents the average CNR.

Further, as the received signals of the I channel and the Q channel are mutually statistically independent, the symbol error probability of QAM can be calculated as follows:

$$P_{NC}(r_i, \Gamma_i) = P_{NC1}(r_i, \Gamma_i) - 1/4 P_{NC1}(r_i, \Gamma_i)^2. \quad (5)$$

In the considered communication system, the wireless channel is modeled as frequency non-selective slow Rician fading corrupted by the AWGN process. The fading processes in the MRC diversity channels are assumed to be mutually statistically independent. The noise processes are also assumed to be mutually independent, with identical autocorrelation functions. In Rician fading, the output instantaneous CNR of MRC diversity becomes a random variable and its PDF can be calculated as follows [7]:

$$P_{MRC}(r_s) = \left(\frac{K+1}{\Gamma_i}\right)^{\frac{L+1}{2}} \left(\frac{r_s}{KL}\right)^{\frac{L-1}{2}} \exp\left(-KL - \frac{(K+1)r_s}{\Gamma_i}\right) I_{L-1}\left(2\sqrt{\frac{K(K+1)Lr_s}{\Gamma_i}}\right), \quad (6)$$

where Γ_i denotes the input average CNR. K represents the Rician parameter. Further, I_{L-1} refers to the modified Bessel function of the first kind and order ($L - 1$).

The output average CNR of MRC diversity, Γ_o, can be derived as follows:

$$\Gamma_o = \int_0^\infty r_s \cdot P_{MRC}(r_s)dr_s = L \cdot \Gamma_i\ . \quad (7)$$

Assuming that the received 16-QAM signal corrupted by the Rician fading in each diversity branch is uncorrelated, we derive the SER of 16 QAM with MRC diversity reception by considering the variations of the instantaneous CNR and average CNR between the input and the output of the MRC diversity circuit as follows:

$$\begin{aligned} P_{s-QAM}(16) &= \int_0^\infty P_{NC}(r_s, \Gamma_o) \cdot P_{MRC}(r_s)dr_s \\ &= \sum_{n=1}^{3}\frac{1}{2}\left\{\mathrm{erfc}\left(B_n\sqrt{\frac{2\Gamma_o}{5}}\right) + \frac{2}{\sqrt{\pi}}\exp\left(-KL - B_n^2\sqrt{\frac{2\Gamma_o}{5}}\right)\right\} \\ &\cdot \sum_{k=1}^{\infty}\frac{(-1)^k}{k!}\left(\frac{A_n}{\sqrt{10}}\right)^k H_{k-1}\left(B_n\sqrt{\frac{2\Gamma_o}{5}}\right) \\ &\cdot \sum_{m=0}^{\infty}\frac{\Gamma\left(\frac{k}{2}+m+L\right)}{m!\Gamma(m+L)}\left(\frac{K+1}{\Gamma_i}\right)^{m+l+1} \cdot \left(\frac{5}{A_n^2}\right)^{2m+2L+\frac{k}{2}} KL^m\ , \end{aligned} \quad (8)$$

where $A_1 = B_2 = 1$, $A_2 = B_3 = -1$, $B_1 = 0$, and $A_3 = 3$. Further, H_k denotes the Hermite polynomial.

Finally, the BER of 32 QAPM can be calculated by substituting Eq. (8) into Eq. (2).

III. SIMULATION RESULTS

In this section, we present some of the simulation results. The BER has been evaluated and shown in Figs. 4–6 as a function of the fading parameter K and E_b/N_o. In the figures, as K increases, the depth of fading decreases. Fig. 4 presents the BER of 32 QAPM under the Rician fading condition with the parameter K. As shown in this figure, the performance is not improved much in spite of the high E_b/N_o, due to the deep fading effect. Therefore, to visualize 32 QAPM in a commercial system under a severe fading condition, a further improvement in its performance is necessary such as powerful coding and diversity techniques. When the fading depth is shallow (K = 12), the BER is 10^{-4} at about E_b/N_o = 13.6 dB. The simulation parameters used for proving the performance of 32 QAPM are listed in Table 1.

PSSK is implemented as a combination of PSK and PPM as in QAPM [8]. The PSSK method also shows better performance than PSK due to the pursuit of the power efficiency in principle. In this simulation, the parameters of the PSSK modulation are as listed in Table 2.

Fig. 5 shows the BER of 32 QAPM under the Rician fading condition with the parameter K when the two-branch MRC diversity is adopted. This figure shows that the error performance is well improved when MRC diversity is adopted. In the case of Rayleigh fading, which means deep fading (K = 0), the BER is 10^{-3} at E_b/N_o = 12.3 dB. In the other cases of K = 6 and 12, the same performance requires up to E_b/N_o = 9.3 dB and 7.6 dB, respectively. Therefore, according to the fading depth (K = 0–12), the margin of E_b/N_o is a maximum of 4.7 dB for achieving the performance of 10^{-3}.

As shown in these figures, the effects of diversity on performance become more pronounced with an increase in the fading. However, in this case, we could not achieve a high, reliable error performance for data communication in spite of diversity usage. When the fading is shallow, the performance is well improved. In the case of K = 12, when there is MRC diversity reception, there is a performance improvement of 4 dB for a BER of 10^{-4}.

Table 1. Parameters of 32 QAPM

Parameter	Value
Modulation type	QAM
Modulation order	16
Data rate	20 Mbps
Symbol period, T	250 ns
Diversity type	MRC
Number of antennas	2
Channel type	Rician
Filter type	Raised cosine

Table 2. Parameters of 32 PSSK

Parameter	Value
Modulation type	PSK
Modulation order	16
Data rate	20 Mbps
Symbol period, T	250 ns

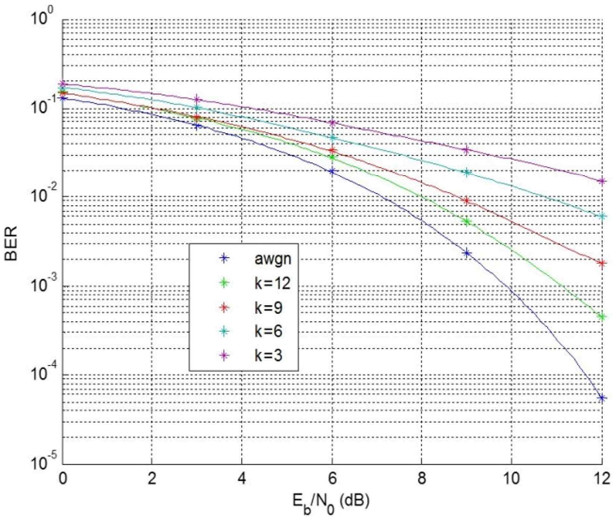

Fig. 4. BER of 32 QAPM in a Rician fading channel.

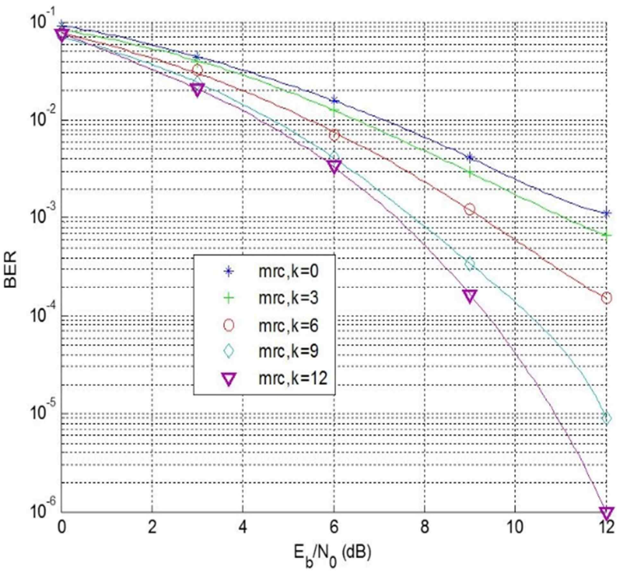

Fig. 5. BER of 32 QAPM with two-branch MRC diversity in a Rician fading channel.

Fig. 6 presents the BER of 32 QAPM and 32 PSSK under the Rician fading condition with the parameter K when the two-branch MRC diversity is adopted. As expected, QAPM is superior to PSSK because the Hamming distance is much longer as in the relation of QAM and PSK. When the fading depth is shallow (K = 12), the BER of QAPM is 10^{-3} at E_b/N_o = 7.2 dB, while that of PSSK is 10^{-3} at E_b/N_o = 11.5 dB. In the case of K = 6, the E_b/N_o of QAPM and that of PSSK are 9.1 dB and 12.2 dB, respectively. The amount of diversity that affects the performance improvement of 32 QAPM is superior to that affecting the performance improvement of 32 PSSK. Further, QAPM is more useful than PSSK according to the increase in the modulation level.

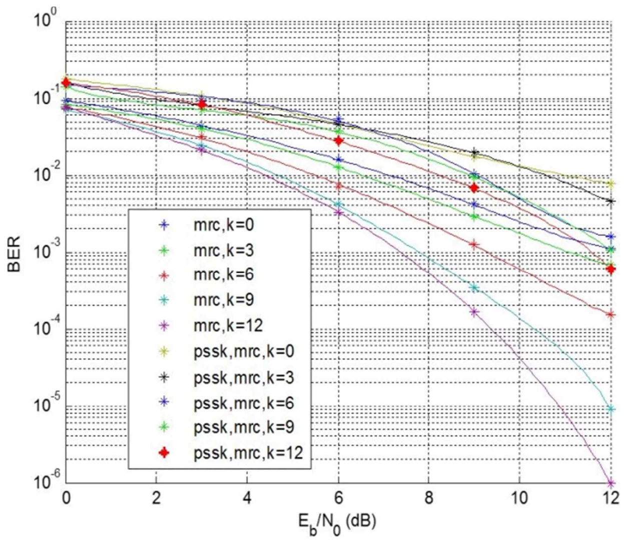

Fig. 6. BER of 32 QAPM and 32 PSSK with two-branch MRC diversity in a Rician fading channel.

On the basis of the abovementioned simulation results, we can estimate that the performance difference of QAPM and PSSK tends to increase when the number of diversity branches, the level of modulation, or the depth of fading increases. Similarly, such a result is valid between the QAPM and QAM when the same modulation level is used under the same test conditions. Despite the application of the same modulation order to QAPM and PSSK, QAPM is better because of the combination of diversity and modulation.

IV. CONCLUSION

In this paper, we presented the performance of a 32-QAPM system with or without MRC diversity reception in a Rician fading channel. The error performances were shown for 32 QAPM and 32 PSSK in order to examine the effects of fading severity, for various values of the Rician parameter, K. The dependence of error rates on MRC diversity was also analyzed. The results of the analysis and simulation presented in this paper showed that the BER performance of 32 QAPM was better than that of 32 PSSK under the abovementioned conditions.

REFERENCES

[1] D. H. Shin, S. H. Han, H. J. La, and S. D. Kim, "Technical issues and solutions for developing IoT applications," *KIPS Transactions on Software and Data Engineering*, vol. 4, no. 3, pp. 99-110, 2015.

[2] J. H. Choi and H. G. Ryu "A QAPM (Quadrature Amplitude Position Modulation) for low power consumption communication," in *Proceedings of 2011 6th International Symposium on Wireless and Pervasive Computing (ISWPC),* Hong Kong, pp. 1-4, 2011.

[3] J. Y. Oh, J. H. Kim, H. S. Lee, and J. Y. Kim, "PSSK modulation scheme for high-data rate implantable medical devices," *IEEE Transactions on Information Technology in Biomedicine*, vol. 14, no. 3, pp. 634-640, 2010.

[4] J. C. Lee and S. W. Nam, "Design and fabrication of low power and high speed OOK wireless capsule endoscopy system," *Information & Communications Magazine*, vol. 25, no. 2, pp. 41-46, 2008.

[5] W. C. Jakes, *Microwave Mobile Communications*. New York, NY: John Wiley & Sons, 1974.

[6] LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation (3GPP TS 36-211 version 8.4.0 Release 8) [Internet]. Available: http://www.etsi.org/deliver/etsi_ts/136200_136299/136211/08.04.00_60/ts_136211v080400p.pdf.

[7] W. P. Hong and C. H. Kim, "Performance analysis of MRC diversity system for detection of M-ary signals on Rician fading channel," *International Journal of KIMICS*, vol. 2, no. 4, pp. 224-227, 2004.

[8] D. K. Kim and H. S. Lee, "Phase-silence-shift-keying for power-efficient modulator," *IEICE Transactions on Communications*, vol. 92, no. 6, pp. 2324-2326, 2009.

Jae Young Chun

received his B.S. and M.S. in Computer Science from Hong-IK University and Mobile Communication Engineering from Han-Yang University, respectively. From 2004 to 2008, he worked as a radio communication standard engineer at ETRI. Since 2015, he has worked as an electronic engineer at G-Well Tech. His research interests include low-power radio communication related to IEEE 802.15.4.

Eon Gon Kim
received his B.S. and M.S. in Aerospace Electronic Engineering from Korea Aerospace University, Korea, in 1985 and 1997, respectively. From 1985 to 1994, he worked as a cellular system engineer at Samsung Electronics. Since 1995, he has worked as a professor in the Department of Information & Communication Engineering. His research interests include mobile communication, WBAN, and wireless modems.