

The Optimum Ring Ratio of 16-APSK in LTE Uplink over Nonlinear System

Sorapong Thuakaew and Pornpimon Chayratsami

*Department of Engineering Education, Industrial Education Faculty
King Mongkut Institute of Technology Ladkrabang, Bangkok 10520, Thailand
siamcreative@gmail.com, kcpornpi@gmail.com*

Abstract— Single Carrier Frequency Division Multiple Access (SC-FDMA) has been selected for use in the Long Term Evolution (LTE) uplink due to its lower Peak-to-Average Power Ratio (PAPR) relative to OFDMA. The resultant lower PAPR results in fewer excursions into the amplifier's nonlinear region, where signal distortion can occur and results in degraded bit error rate (BER). The SC-FDMA scheme normally applies 16-ary Quadrature Amplitude Modulation (16-QAM), but amplitude phase shift keying (APSK) modulation has a lower PAPR than does 16-QAM, resulting in improved BER. This paper investigates the constellation ring ratio of the 16-APSK modulation scheme and its effects on BER through its effects on the PAPR. Simulation results are used to conclude that a ring ratio that ranges from 2.5 to 3.5 delivers the best results.

Keywords— 16-APSK, SC-FDMA, LTE, Nonlinear system, PAPR

I. INTRODUCTION

3GPP Long Term Evolution or LTE is a standard that has been developed by the 3rd Generation Partnership Project (3GPP) to become a truly global mobile standard, to apply to high-speed wireless data transmission for mobile phone and data terminal [1], [2]. It is the next step in progression from GSM / EDGE and UMTS / HSPA technologies with higher capacity and faster speed.

In order to reduce the interference signals and to improve the channel capacity of the LTE system, orthogonal frequency division multiple access (OFDMA) and single carrier frequency multiple access (SC-FDMA) are employed for the downlink and uplink, respectively. The SC-FDMA is the multiplexing technique for the LTE uplink because it has lower PAPR than the OFDMA [1], [3], [4].

The high PAPR is a principal weakness of OFDM. It brings on the signal distortion in the nonlinear region of high power amplifier (HPA) [3]. The closer the HPA is operated to the saturation region, the more frequent are excursions into the nonlinear region and the more pronounced is the signal distortion. The signal distortion induces the degradation of bit error rate (BER). Therefore, it is desirable to have low PAPR to improve the BER performance.

To reduce the PAPR of OFDM, there are mainly two categories, which are signal scrambling techniques and signal distortion techniques [5]. The practical solutions of the signal

scrambling techniques include block coding, Selective Level Mapping (SLM), and Partial Transmit Sequences (PTS). The signal distortion techniques include clipping, peak windowing, peak cancellation, peak power suppression, weighted multicarrier transmission, companding, etc. Previously, there have been many researches on the PAPR reduction techniques [6]-[12]. However, the disadvantage of all these techniques is the complexity increase of the system.

Other than the PAPR reduction techniques stated above, J. Gazda, D. Dupak and D. Kocur in [4] proposed to apply the M-ary APSK modulation to reduce the PAPR in the LTE uplink. They show that 16-APSK outperforms the standardized 16-QAM, which is generally used in the LTE uplink. The BER performance of the 16-APSK system improves for two reasons, the low PAPR of the APSK modulation causes fewer excursions into the nonlinear region and the 16-APSK signal is more robust to the distortions caused by the amplifier nonlinearities than is 16-QAM. Also, W. Sung, S. Kang, P. Kim and D. Chang in [13] give the preliminary analysis on the PAPR of the 16-APSK modulation in the digital video broadcasting for satellites (DVB-S2). They show that the PAPR of the 16-APSK depends on a ratio of the radius of each ring.

However, according to the authors' knowledge, the effects of the constellation ring ratio of the 16-APSK (4+12 APSK) modulation scheme are not yet evaluated in the LTE uplink system. Therefore, this paper will present the investigation on the constellation ring ratio of the 16-APSK modulation used in the LTE uplink system with the nonlinear distortion due to a HPA. The optimal value of the ring ratio is also proposed.

The paper is organized as follows. First, the effects of the constellation ring ratio of the 16-APSK modulation, on both the PAPR and the BER, are presented in Section II. Section III shows the description of the system model adopted for the analysis and the simulation. Then, the simulation results are shown in section IV. Finally, section V provides conclusions.

II. EFFECTS OF THE APSK CONSTELLATION RING RATIO

Amplitude phase shift keying (APSK) is a digital modulation scheme that conveys data by changing or modulating both the amplitude and the phase. It is a combination of Amplitude shift keying (ASK) and Phase shift keying (PSK) applied to more effectively populate the signal space.

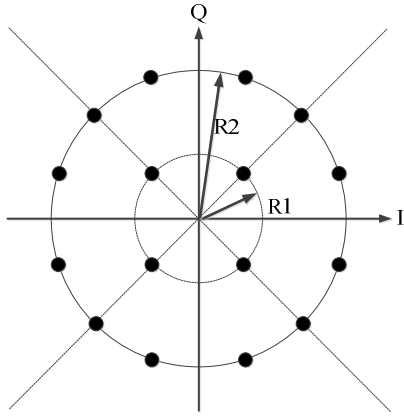


Figure 1. 16-APSK (4+12 APSK) Constellation

A. The Effects on PAPR

Peak to Average Power Ratio (PAPR) is the ratio between the maximum power and the average power of the transmitted signal. The PAPR is defined as [3]

$$PAPR = \frac{\max_{n=0,1,\dots,N-1} |\tilde{x}_n|^2}{\frac{1}{N} \sum_{n=0}^{N-1} |\tilde{x}_n|^2} \quad (1)$$

where $\tilde{x}_n$ is the transmitted signal.

For 16-APSK modulation, there are many types of constellation patterns, such as 4+12 ASPK, 5+11 ASPK, and 6+10 APSK. Each type assigns a different number of points to each ring, with the total number of points summing to 16. Here, the 4+12 APSK, which delivers the best performance under the nonlinear conditions imposed by the saturation region of a power amplifier and is adopted in DVB-S2 [14], is used in the investigation.

Figure 1 shows the 4+12 APSK constellation. It consists of two rings with 4 and 12 points on the inner and the outer ring, respectively. The average power level of the 4+12 APSK can be defined as [13]

$$E_s = \frac{R_1^2 + 3R_2^2}{4} = \frac{(1 + 3\beta_0^2)R_1^2}{4} \quad (2)$$

where R_1 is the radius of the inner ring,

R_2 is the radius of the outer ring,

and $\beta_0 = R_2 / R_1$ is the ratio between the outer and the inner ring radius.

From eq. (1) and (2), we can plot the relationship between the ratio (R2/R1) of the 4+12 APSK and the PAPR as shown in Figure 2. This shows that the PAPR increases when the ratio (R2/R1) increases.

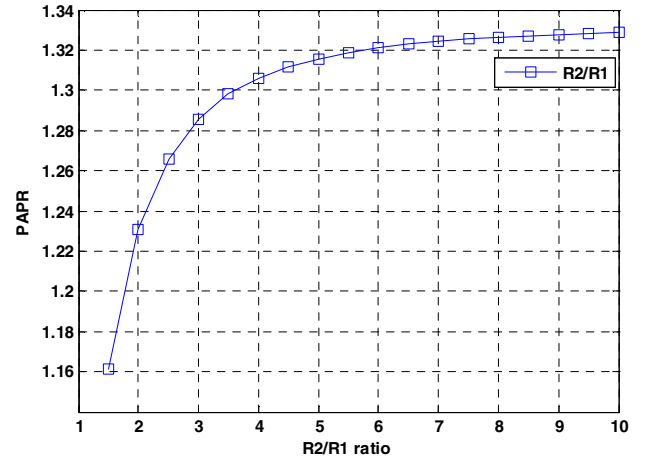


Figure 2. The relationship between the ratio (R2/R1) of 4+12 APSK and PAPR

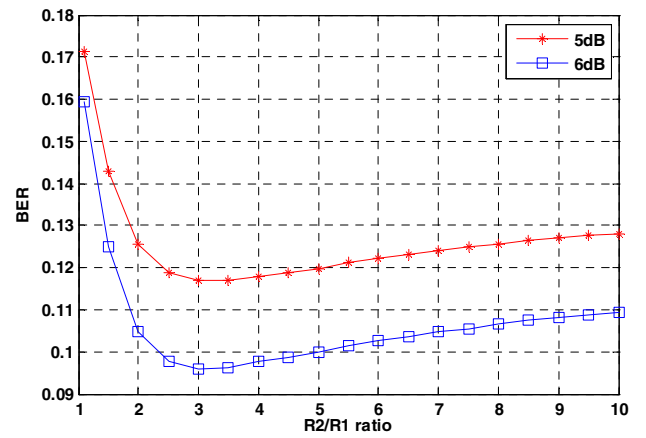


Figure 3. R2/R1 ratio vs. BER of 16-APSK for the linear transmission over AWGN channel

B. The Effects on BER

Considering the 16-APSK modulation for linear transmitter over an additive white Gaussian noise (AWGN) channel operating at energy per bit to noise power spectral density ratio (Eb/No) of 5 dB and 6 dB, the simulation results in Figure 3 show the effects of the ratio (R2/R1) on the performance of the system. From Figure 3, it is seen that the ratio in the range from 2.5 to 5 gives the lowest BER for both Eb/No values.

From the effects of the constellation ring ratio of 16-APSK modulation on the PAPR and BER, the appropriate value of the ratio can be determined by selecting the ratio that minimizes both the PAPR and the BER.

The previous analysis shows the effects of the constellation ring ratio of 16-APSK modulation on the PAPR in general and the BER strictly for the linear channel. This motivates the reasonable conclusion that the constellation ring ratio can play a significant role in the nonlinear channel as well.

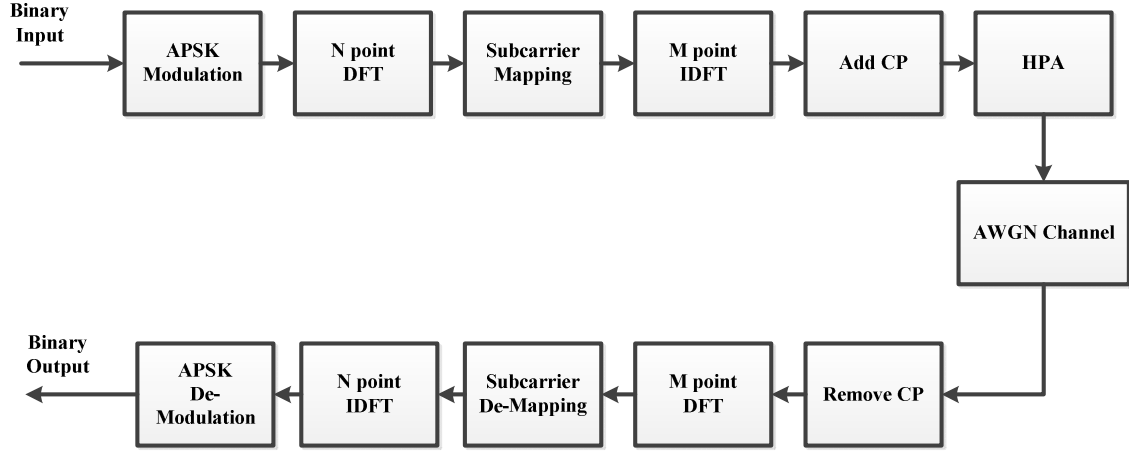


Figure 4. Block diagram of the SC-FDMA system with APSK modulation

Next, the optimal ratio values providing a low BER and PAPR in the presence of nonlinearities will be addressed.

III. SYSTEM MODEL

Figure 4 shows the block diagram of the general SC-FDMA system [3] with the APSK modulation. The binary sequence is modulated into data symbols by using the 4+12 APSK modulation scheme. Then, a block of N modulated symbols is applied to the N-point Discrete Fourier Transform (DFT) to produce a frequency domain representation. This output is fed to the Localized FDMA (LFDMA) subcarrier mapping block, which is the subcarrier mapping used in the LTE standard. At this point, each of the N-DFT outputs is mapped to one of M orthogonal subcarriers ($M > N$). Then, the M-point inverse DFT (IDFT) transforms these data symbols into the time-domain samples of these subcarriers. Similar to OFDM, the cyclic prefix is added to the symbols. Before entering the AWGN channel, the transmitted signal is amplified by the high power amplifier (HPA), which makes the overall channel nonlinear.

At the receiver, the received signal is processed by removing the cyclic prefix, first. Then, the signals are demodulated by using M-point DFT, subcarrier De-mapping, N-point IDFT and the APSK demodulator.

For this investigation, the nonlinear HPA uses the Soft limiter (SL) model, which defines the Amplitude Modulation to Amplitude Modulation (AM/AM) and the Amplitude Modulation to Phase Modulation (AM/PM) characteristics as follows [8]

$$F[\rho] = \begin{cases} -A, & \text{if } \rho < -A \\ \rho, & \text{if } -A \leq \rho \leq A \\ A, & \text{if } \rho > A \end{cases} \quad (3)$$

and

$$\Phi[\rho] = 0 \quad (4)$$

where A is the saturating level of the amplifier, ρ is the amplitude of the input signals, $F[\rho]$ is the amplitude of the output signals of the Soft Limiter, and $\Phi[\rho]$ is the phase of the output signals of the Soft Limiter.

There is only amplitude distortion and no phase distortion in the SL model. The severity of the distortion can be measured by the Input-Back-Off (IBO) of the PA, which can be calculated as follows [15]

$$IBO = 10 \log_{10} \frac{A_s^2}{P_{in}} \quad (5)$$

where A_s is the saturation level of the amplifier input and P_{in} is the average input power of the amplifier.

The investigation on the constellation ring ratio of the 16-APSK (4+12 APSK) modulation scheme, used in the LTE uplink system with the nonlinear distortion due to a PA, is based on the computer simulations. The results are shown in the next section.

IV. SIMULATION RESULTS

The simulation of a general SC-FDMA transmission is set up with the IDFT size (M) of 512, DFT size (N) of 300 and a cyclic prefix (CP) of 144 as stated in the LTE standard for 5 MHz bandwidth [3], [16]. The 16-APSK modulation scheme, with various constellation ring ratios, is used in place of the 16-QAM modulation that is normally used.

To determine the appropriate range of ratio (R2/R1) for the 16-APSK modulation scheme in the nonlinear channel, the BER and PAPR performances are shown in Figure 5, with the IBO of 1 dB and 2 dB at Eb/No of 5 dB and 6 dB. These results show that the ring ratio in the range of 2.5 to 3.5 gives the lowest BER range, but not the highest PAPR values.

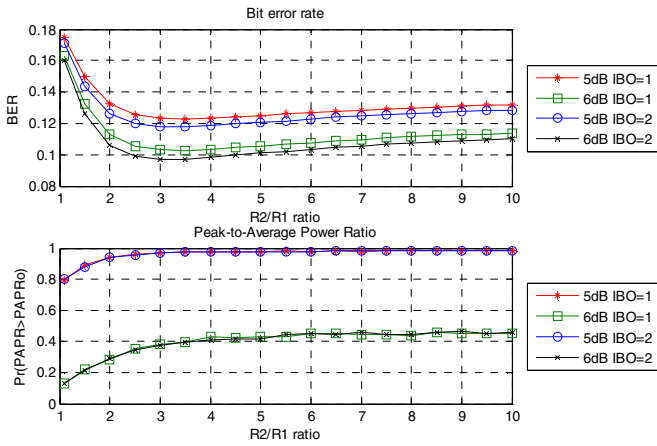


Figure 5. BER and PAPR under nonlinear PA at E_b/N_o of 5 dB and 6 dB

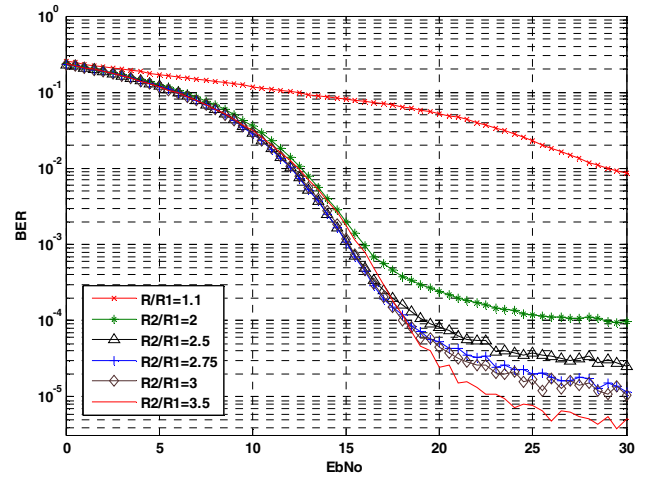


Figure 7. BER performance when IBO = 2 dB with various R2/R1

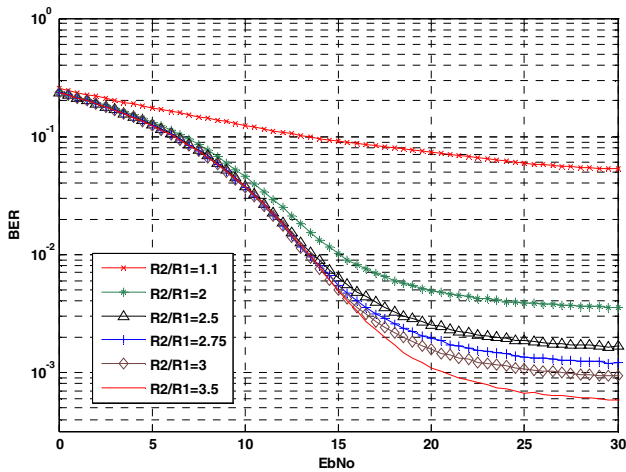


Figure 6. BER performance when IBO = 1 dB with various R2/R1

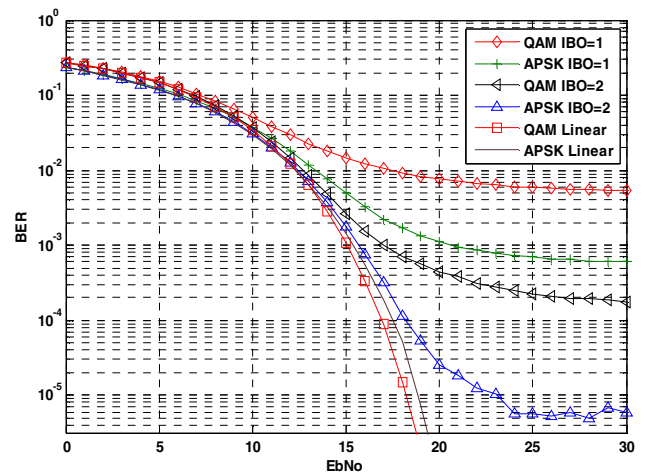


Figure 8. BER performance when the ratio = 3.5 with various IBO

Notice that the ratio R_2/R_1 gives low PAPR but high BER when the ratio is lower than 2.5. Figure 6 and 7 show the simulation results of the system with the IBO of 1 dB and 2 dB, and various values of ring ratios (1.1, 2, 2.5, 2.75, 3, and 3.5), respectively. The results show that the ratio of 2.5-3.5 gives better BER performance than that of 1.1 and 2. Also, the results from both figures agree that the best performance occurs when the ratio R_2/R_1 is equal to 3.5 at high E_b/N_o .

Figure 8 shows the simulation results of the LTE system to compare the BER performance of the standard 16-QAM and the 16-APSK with the ring ratio (R_2/R_1) of 3.5. The 16-APSK modulation scheme performs better than the 16-QAM in the nonlinear channel for LTE system. The error floors associated with the average bit error probability shift down from 5×10^{-3} to 6×10^{-4} and from 2×10^{-4} to 6×10^{-5} for the IBO of 1 dB and 2dB, respectively.

V. CONCLUSIONS

LTE technology is attractive in the telecommunications industry due to the high speed data transfer rate it offers. Therefore, the modulation techniques must be selected properly as an important consideration because it can push the system to its fullest potential. The APSK modulation works better than QAM in the nonlinear system, when comparing in both BER and PAPR. So, the APSK modulation is appropriate modulation scheme to be adopted, as studies have noted in [4], and the ratio of R_2/R_1 is an important factor affecting the PAPR and BER of the APSK. The PAPR increases as the ratio of R_2/R_1 increases. While BER changes differently to the R_2/R_1 ratio and is shown to have one range with a low BER. In this paper, it is shown that the optimal R_2/R_1 ratio of the 4+12 APSK is between 2.5 to 3.5. This optimal ratio range gives the best results in terms of the low BER and PAPR to the nonlinear LTE uplink system. Researchers hope that this paper will help to drive the performance of the LTE system that makes the implementation widespread in the future.

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