Power and Spectrally Efficient M-ARY QAM Schemes for Future Mobile Satellite Communications

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Abstract

An effective method to compensate nonlinear phase distortion caused by the mobile amplifier is proposed. As a first step towards the future use of spectrally efficient modulation schemes for mobile satellite applications, we have investigated effects of nonlinearities and the phase compensation method on 16-QAM. The new method provides about 2 dB savings in power for 16-QAM operation with cost effective amplifiers near saturation and thereby promising use of spectrally efficient linear modulation schemes for future mobile satellite applications.

1 INTRODUCTION

Mobile Satellite (MSAT) communications represent one of the most vital and key areas of the mobile communications field. As a result of extensive research, MSAT terminals accommodating speeds of 4.8 kb/s in 5 kHz bandwidth to provide good quality voice, have been developed. The need to use cost effective non-linear amplification, as well as robust operation to overcome the strong fading behaviour of the MSAT channel has forced the use of MCPSK type signal format (8PSK signal constellation are presently used). Also, to provide better power efficiency, the use of coding (in the form of trellis coded modulation (TCM)) has been applied [1].

Although the present spectral efficiency of 1 b/s/Hz (achieved by 4.8 kb/s in 5 kHz) may be sufficient for today's demand, it is quite certain that higher efficiency is required in the near future to provide new services and accommodate more users in the already congested radio frequency band. The natural direction is to consider the development of MSAT schemes based on the use of M-ary QAM signal formats. However, a few problems related to the mobile satellite channel has to be addressed. They include: Amplifier nonlinearities, fading, doppler effects, phase noise, etc. In [2] feasibility of multi-level signaling scheme (16-QAM) is demonstrated in land-mobile fading channels by employing a Rayleigh fading compensator. It is also shown that fade compensated 16-QAM does not suffer from error floors as compared to conventional GMSK. Use of 16-QAM modulation scheme for satellite channels has also been investigated in [3], [4].

The effect of nonlinearities in the form of AM/AM and AM/PM distortions have to
be considered seriously as they can produce high levels of signal distortion and interference. This problem has to be addressed in the MSAT terminal design to employ cost effective amplifiers. For operation near saturation, the performance of QAM schemes is dictated mainly by the outermost states. The degradations are caused by the phase rotation and amplitude compression of the various states with respect to their nominal positions. Most of the amplifiers exhibit fairly linear AM/AM characteristic if the output is backed slightly from saturation. However, their AM/PM characteristics are significantly nonlinear. As the system performance is mainly controlled by the phase change between the operating point (where the average power of the signal is present) and the point at which the outermost state lies, it is necessary to equalize the nonlinear phase to operate near saturation. The immunity of the QAM schemes can be expressed by their phase margins, where phase margin is defined as the phase rotation required from the nominal value to create the irreducible error floor. For 16-QAM, the phase margin is 16.87 degrees [7].

To overcome nonlinear distortion several methods are possible. For linear modulation schemes, the popular methods employed are, predistortion [5] and new signal constellations [6]. For smaller constellations (< 64 states), predistortion method either in analog or digital form is employed and for larger constellations (> 64 states), both methods are used.

In this paper, we propose the use of 16-QAM for future MSAT terminals. Towards this direction, we first analyze 16-QAM transmission in a Gaussian channel employing a cost effective amplifier in a mobile terminal. A novel phase compensation method to overcome the AM/PM distortion will be introduced. Next, the performance of this scheme is evaluated in the mobile satellite channel environment by using Rician fading model. The performance is analyzed using computer simulation. Organization of the paper is as follows: In section 2, the communication system model is described. In section 3, the performance results are discussed and finally, in section 4, conclusions are presented.

2 SYSTEM MODEL

Block diagram of the communication system is shown in Fig. 1. The transmitter consists of a signal mapper, a spectral shaping filter and a modulator. A square root ($\alpha = 0.5$) Nyquist I filter is equally apportioned between transmitter and receiver. A class-AB amplifier [5] is used as a model to simulate the mobile terminal nonlinear amplifier characteristic. Computer simulation is conducted using an equivalent quadrature baseband model. In order to account for the level compression due to the nonlinear AM/AM characteristic of the amplifier while operating near saturation, an adaptive threshold detector is employed at the receiver [7].

The transmitted signal $x_T(t)$ can be expressed as:

$$x_T(t) = Re\{b(t)e^{j\omega_c t}\}$$

where $b(t) = b_I(t) + j b_Q(t)$ is the filtered complex baseband signal and $\omega_c$ is the carrier frequency. The received signal $x_r(t)$ can be written as:

$$x_r(t) = Re\{c(t)x_T(t)e^{j\omega_c t} + n(t)\}$$

where $c(t)$ represents the fading process and $n(t)$ is the additive Gaussian noise. In the present case, the fading process is Rician in nature.
The received complex baseband signal expressed by Eq.(2) can be obtained by de-
modulating with a local oscillator whose fre-
quency is \( \omega_e \). It is assumed for the analysis,
that good estimates of the carrier phase and
symbol timing are available at the receiver.
The demodulated in-phase and quadrature
signals are sampled and passed on to the
threshold comparators in the receiver. For
a specified power of white Gaussian noise at
the threshold detector input, the error prob-
ability of the \( i^{th} \) symbol with respect to the
in-phase channel is computed as follows:

\[
P'_{e_i} = \begin{cases} 
  \frac{1}{2} e^{-f_c \frac{\text{Abs}(I_i) - S_{1i}}{\sigma\sqrt{2}}}, & i = \pm(2N - 1) \\
  \frac{1}{2} e^{-f_c \frac{\text{Abs}(I_i) - S_{1i}}{\sigma\sqrt{2}} + e^{-f_c \frac{\text{Abs}(I_i) - \text{Abs}(I_i)}{\sigma\sqrt{2}}}}, & i = \pm1, \pm3, \ldots, \pm(2N - 3)
\end{cases}
\]

(3)

where \( I_i \) is the magnitude of the \( i^{th} \) received
sample and \( S_{1i} \) and \( S_{2i} \) are the lower and up-
per thresholds. \( S_{1i} \) and \( S_{2i} \) are optimized to
lie in the middle of the each eye to minimize
the effect of signal distortion. The total sym-
bol error probability for a sequence of \( N \) sym-
bols is calculated as

\[
P_{e_s} = \frac{1}{N} \sum_{i=1}^{N} (p'_{e_i} + p'_{e_i} - p'_{e_i}p'_{e_i})
\]

(4)

The error performance in a Rician fading
channel can be computed as follows:

\[
P_e = \int P_s(e_s/r) f(r) dr
\]

(5)

where \( f(x) \) is the probability density function
for Rician channel and \( r \) is the gain attenua-
tion applied to the signal by the fading. \( f(x) \)
for \( x > 0 \) is given by [8]

\[
f(x) = \frac{2x(1 + K)e^{-K}e^{-(1+K)x^2}}{I_0(2x\sqrt{K(1 + K)})}
\]

(6)

where \( K \) is the ratio of specular to diffuse
power and \( I_0(x) \) is the zero order modified
Bessel function of the first kind. For MSAT
channels, \( K=10 \) dB has been considered [8].

In this paper, we propose a simple and ef-
fic method to cancel the effect of AM/PM
distortion due to the amplifier, thereby en-
abling the operation of the amplifier closer to
saturation. A block diagram of the proposed
method is shown in Fig. 2. By using look-up
tables, where the data regarding the relation-
ship between the sampled amplifier input en-
vlope and amplifier phase output are stored,,
we can predistort the carrier phase at the am-
plifier input and thereby effectively canceling
the AM/PM distortion. This can be effected
by providing a phase correction to the trans-
mmitter local oscillator as shown in Fig. 2.

3 PERFORMANCE RE-
SULTS

Error performance results in a Gaussian
channel is shown in Fig. 3 for phase un-
compensated and phase compensated oper-
ation. The transmitter is operated at 3 dB
output backoff from saturation. It can be
observed that by compensating the AM/PM
distortion, it is possible to operate with about
2 dB less CNR which is a significant saving
in power. The effect of AM/PM compensa-
tion can be seen in the signal state space di-
agrams shown in Figs. 4 & 5. It can be seen
that in both cases the outermost states are
compressed due to operation near saturation.
However, in Fig. 4 the outer states are dis-
torted due to nonlinear phase rotation as only
the average phase at the operating point is
compensated, while in Fig. 5 the all states are
in their nominal positions thereby providing
greater decision distance and improved error
performance. The BER performance of 16-QAM in Rician channel (K=10 dB) is also shown in Fig. 3. There is modest penalty in terms of power, but no error floor is observed over the range of observation.

The effect of Doppler shift due to the relative motion between the transmitter and the receiver has not been covered in this paper, as it has been demonstrated in [2] that it can be easily compensated using compensation techniques without significant performance degradations.

4 CONCLUSIONS

A simple and effective method to compensate the nonlinear phase distortion due to the amplifier is proposed. As a first step towards the future use of spectrally efficient modulation schemes for mobile satellite applications effects of nonlinearities on 16-QAM has been investigated. It is shown that about 2 dB power savings in transmitter power can be achieved by compensating phase nonlinearities for 16-QAM. We are confident that this method could be very effective in future mobile satellite systems while employing spectrally efficient modulation schemes.

References


Figure 1. System Model with Linearized Amplifier & Coherent Demodulator

Figure 2. Nonlinear Phase Compensation Method

Figure 3. Error Performance of 16-QAM
Figure 4. Signal State Space Diagram of 16-QAM Without Phase Compensation

Figure 5. Signal State Space Diagram of 16-QAM with Phase Compensation