UNEQUAL ERROR PROTECTION STAR 16 - QAM SCHEME FOR FIXED DIGITAL RADIO COMMUNICATIONS

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Abstract

An unequal error protection (UEP) modulation scheme using star 16-level quadrature amplitude modulation (QAM) is proposed. The proposed UEP 16-QAM scheme allows efficient source-matched digital transmission over fixed microwave radio channels with 4 b / s / Hz throughput. Comparisons to other 16-QAM schemes are given along with performance results on a Gaussian channel.

1. INTRODUCTION

Using quadrature amplitude modulation (QAM) in digital communication systems is a convenient way for achieving power- and bandwidth-efficient transmission. A large number of constellations have been investigated for QAM transmission over Gaussian or near Gaussian channels [1-8]. However, the two types of constellations often preferred are the square (or cross) QAM constellations and the star QAM constellations [9, 10]. The essential problem is to maintain a high minimum Euclidean distance d_{min} between signal points whilst keeping the average power required for the constellation to a minimum. Calculation of d_{min} and the average power is a straightforward geometric procedure, and has been performed for a range of constellations by Proakis [9]. The results show that the square 16-QAM constellation is optimal for Gaussian channels. However, there may be implementational reasons for favoring star QAM constellations over the square ones.

When designing a constellation, consideration must be given to: 1) The minimum Euclidean distance d_{min} amongst phasors, which is characteristic of the noise immunity of the scheme; 2) The minimum phase rotation φ_{min} amongst constellation points, determining the phase jitter immunity and hence the scheme's resilience against clock and carrier recovery imperfections; 3) The ratio r of the peak-to-average phasor power, which is a measure of robustness against non-linear distortions introduced by the power amplifier.

Further, for information sources having a hierarchical structure in their data it is necessary to employ source-matched transmission strategies in order to ensure that the recovered data has the requisite performance after decoding. Therefore, it is desirable to have a digital transmission system with easily and flexibly adjustable both equal and unequal error protection (UEP) properties.

In this paper, an UEP modulation scheme based on star 16-QAM constellation is proposed. The considered 16-QAM scheme support UEP digital transmission on two subchannels with 4 b / s / Hz overall throughput. As will be shown, the bit error rate (BER) properties of the High Importance Subchannel (HISCH) are easily and flexibly adjustable over a range of signal - to - noise ratios (SNR) whilst keeping small values of the ratio *r*.

2. SYSTEM DESCRIPTION AND PERFORMANCE RESULTS

A simplified model of a 16-QAM mapper is shown in Fig.1.

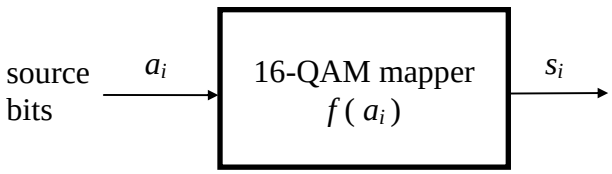

Figure 1. Basic 16-QAM mapper schematic

In Fig.1 $a_i = [\, a_i^1, a_i^2, a_i^3, a_i^4]$, $a_i^j \in \{0, 1\}$, is a binary vector of source bits presented at input of the 16-QAM mapper for each discrete time *i*. The mapper output at time *i* , say s_i, is a two-dimensional 16-QAM signal which depends on the values taken on by four binary variables, say

$$s_i = f(\, a_i^1, a_i^2\, a_i^3, a_i^4\,) = f(\, a_i\,) \qquad (1)$$

and the correspondence between s_i and a_i is one to one. The mapper output s_i will then depend only on the current value of the vector *a*. So, the vector a_i will be referred to as the label of signal s_i related to it by (1).

The considered here star 16-QAM mapping is shown in Fig.2.

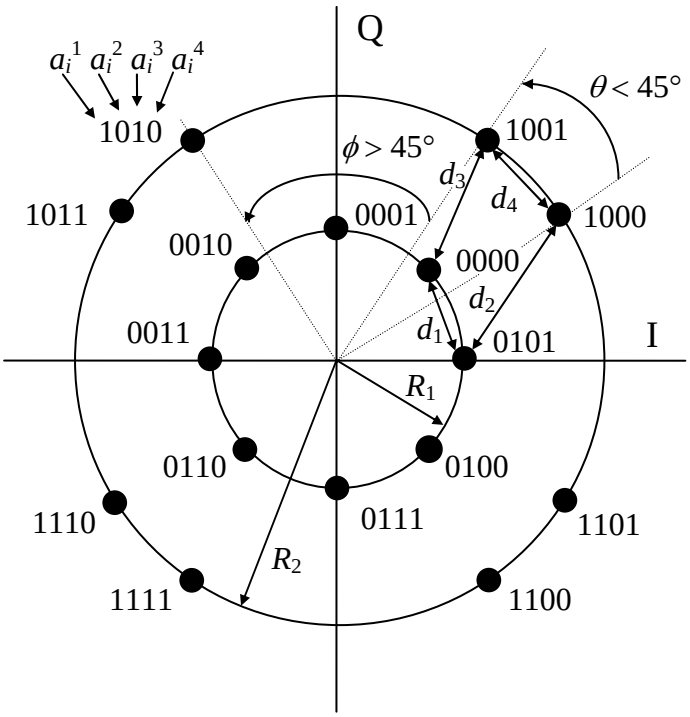

Figure 2. Star 16 - QAM mapping

First, it should be mentioned that for $\theta = \phi = 45°$ and a ring ratio of $RR = R_2 / R_1 = 1.59$ we deal with the "optimum" star 16-QAM constellation, first proposed by Lucky and Hancock [3]. In this case, we have $d_{min}^2 = d_1^2 = d_2^2 = d_3^2 = 0.33$ (for normalized to one average signal energy).

Now, consider the star 16-QAM mapping in Fig.2 with $\theta < 45°$ ($\theta + \phi = 90°$) and $RR < 1.59$. In this case, two subchannels with different minimum Euclidean distances (and, therefore, with different bit error rate (BER) properties) could be formed. The first subchannel, say $C1$, is formed by the bits a_i^2, a_i^3 and the second subchannel, say $C2$, is formed by the bits a_i^1, a_i^4. Further, we will consider the subchannel $C1$ as the High Importance Subchannel (HISCH) and the subchannel C2 as the Low Importance Subchannel (LISCH).

According to Fig.2, the minimum squared Euclidean distances of $C1$ and $C2$, denoted as d_{C1}^2 and d_{C2}^2, respectively, are given by

$$d_{C1}^2 = \min \{ d_1^2 ; d_2^2 \} \qquad (2)$$

$$d_{C2}^2 = \min \{ d_3^2 ; d_4^2 \}. \qquad (3)$$

It is clear that $d_{C1}^2 > d_{C2}^2$ for any values of $RR < 1.59$ and $\theta < 45°$. Further, for a given $RR < 1.59$, it is possible to have $d_2^2 > d_1^2$ for some values of $\theta < 45°$. Thus, for a given ring ratio $RR < 1.59$, the maximization of the minimum squared Euclidean distance for both the $C1$ and $C2$ subchannels is reached for $d_1^2 = d_2^2$. So, we require that

$$2R_1^2(1 - \cos (45°)) = R_1^2 + R_2^2 - 2 R_1R_2 \cos (45° - \theta / 2) \qquad (4)$$

or in terms of the ring ratio RR

$$2(1 - \cos (45°)) = 1 + RR^2 - 2 RR \cos (45° - \theta / 2). \qquad (5)$$

Clearly, for any $RR < 1.59$, the equality in (5) depends only of the value of θ.

The main parameters of the considered UEP star 16-QAM scheme for a specific example with $RR = 1.45$ and $\theta = 30°$ are given in Table I. In Table I are also given the parameters of the optimum square 16-QAM and star 16-QAM schemes.

TABLE I

Type	d_{min}^2	r	φ_{min}
Square 16-QAM	0.4	1.8	< 45°
Star 16-QAM ($RR = 1.59$)	0.33	1.43	45°
UEP star 16-QAM ($RR = 1.45$, $\theta = 30°$)	0.38* 0.193**	1.36	30°

*The minimum squared Euclidean distance d_{C1}^2 of the HISCH
**The minimum squared Euclidean distance d_{C2}^2 of the LISCH

As can be observed from Table I, the minimum squared Euclidean distance d_{C1}^2 is very close to that of the square 16-QAM scheme and, therefore, the BER performance for the HISCH and the square 16-QAM scheme will be identical on an additive white Gaussian noise (AWGN) channel. Further, the considered UEP star 16-QAM scheme has significantly smaller value of the ratio r then the square 16-QAM scheme which implies a better robustness against non-linear distortions introduced by the power amplifier.

The BER performance of the QAM schemes in Table I over AWGN channel is shown in Fig.3. The BER approximation is based on [9, 10]

$$P_b = (G_b / k) \, Q (d_{min}^2 \, kE_b / 2N_0)^{1/2} , \qquad (6)$$

where G_b is the average number of bit errors per signal, k is the number of bits in one signal, Q is the Gaussian error probability function and E_b / N_0 is the energy per information bit to single-sided noise density ratio.

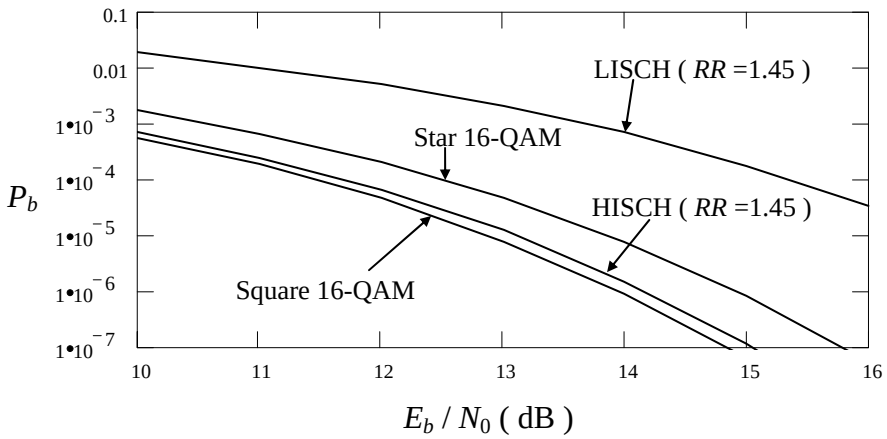

Figure 3. BER performance for various 16 - QAM schemes over AWGN channel

As can be observed from Fig.3, the energy loss for the HISCH as compared to the square 16-QAM scheme is below 0.25 dB for a wide range of BER values of practical importance. Further improvement in BER performance of the HISCH can be obtained for ring ratios $RR < 1.45$

The RR values of the UEP star 16 - QAM scheme versus channel SNR (AWGN channel) at $P_b \approx 1.10^{-5}$ on HISCH are shown in Fig.4.

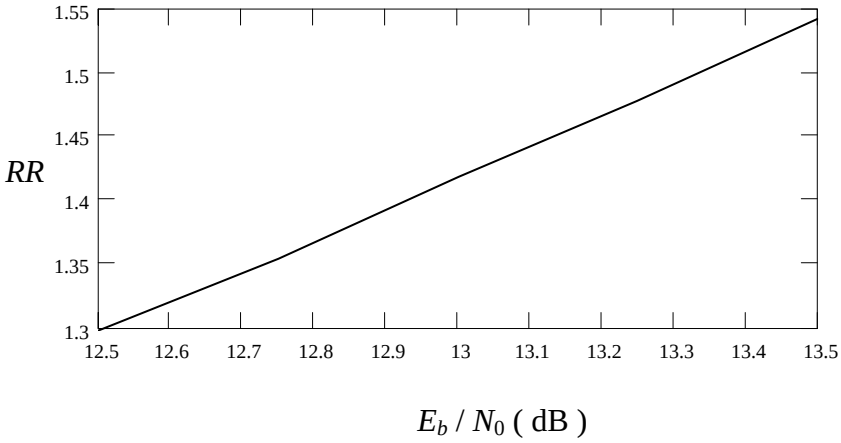

Figure 4. *RR* values of the UEP star 16 - QAM scheme versus channel SNR at $P_b \approx 1.10^{-5}$ on HISCH

3. CONCLUSION

A new UEP modulation scheme using star 16-QAM is proposed. The considered UEP 16-QAM scheme allows efficient, source-matched digital transmission over fixed radio channels. For ring ratios of order *RR* = 1.4 - 1.45, the BER performance of the HISCH is identical to that of the optimum square 16-QAM scheme at a significantly smaller value of the ratio *r* of the peak-to-average phasor power. Further, the BER properties of the HISCH are easily and flexibly adjustable over a range of signal - to - noise ratios whilst keeping small values of the ratio *r*.

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