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Effect of Changing the Symbol Rate of QAM Modem on the Performance of 32kb/s ADPCM System

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This paper presents three models of Quadrature Amplitude Modulation (QAM) modem operating at data rate of 16.8kb/s to be transmitted over 32kb/s Adaptive Differential Pulse Code Modulation (ADPCM) channel. These modems operate at symbol rates of 2400, 2800, and 3360 baud with associated number of bits per symbol of 7, 6, and 5 respectively. The performance of ADPCM is studied considering these modems with different constellations. The simulation results show that the performance of ADPCM degrades as the symbol rate decreases or number of bits per symbol increases. Also, the performance with circular constellation is better than rectangular one.

Keywords: QAM modem, 32kb/s ADPCM.

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Эффект изменения скорости передачи квадратурной амплитудной модуляции модема на производительность 32 кб/с адаптивной дифференциальной импульсно-кодовой модуляции канала

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В статье рассмотрены три модели квадратурной амплитудной модуляции (QAM) модема, работающего на скорости передачи данных 16,8 кб/с, при переходе на производительность 32кб/с адаптивной дифференциальной импульсно-кодовой модуляции канала (ADPCM). Эти модемы работают на скорости передачи символов 2400, 2800 и 3360 бит с соответствующим количеством битов на символ 7, 6 и 5 соответственно. Производительность ADPCM исследована с учетом различного расположения модемов в группах. Результаты моделирования показывают, что производительность ADPCM деградирует по мере уменьшения скорости передачи символов или в случае увеличения количества битов на символ. Кроме того, производительность с круговым расположением модемов лучше, чем с прямоугольным.

Ключевые слова: квадратурная амплитудная модуляция, модем, 32 кб/с, адаптивная дифференциальная импульсно-кодовая модуляция канала.

Introduction

With the increase in demand for efficient use of digital communication channel, various types of highly effective speech coding methods have been developed [1-7]. As one of these coding methods is international standard 32 kb/s Adaptive Differential Pulse Code Modulation (ADPCM) [1]. The superior performance, economy and application flexibility of ADPCM relative to other bandwidth reduction techniques were the prime reasons for its selection.

The specification of ADPCM opens the door to a host of applications in telecommunication networks [8-14]. These applications can be divided into three categories: telephone company use, end customer applications, and new service offerings.

A recommended definition of ADPCM algorithm was published by International Telephone & Telegraph Consultative Committee [CCITT, the new name is International Telecommunication Union (ITU)] as Recommendation G.721 [1].

It was recognized at study group XVIII meeting [1] that voiceband data performance at 9.6 kb/s would not be acceptable with standard 32 kb/s ADPCM because ADPCM adds severe nonlinear distortion to the voiceband data signal with speed greater than 4.8 kb/s.

Thus, the interest of many research workers has been directed towards the ADPCM codec capable of providing better performance for speech and voiceband data signal at speed greater than 4.8 kb/s.

Exhaustive work had been done to accommodate high speed voiceband data signal either by modifying the algorithm of ADPCM [15-25] or by modifying the model of data transmission [22, 26-27]. One way of modifying the model of data transmission is to use different constellations of Quadrature Amplitude Modulation (QAM) signal.

Structure of adpcm

The algorithm of 32 kb/s ADPCM which is described here is as in CCITT G.726 [15]. Fig. 1 shows simplified block diagram of ADPCM codec. Two major components form the algorithm: an adaptive quantizer and an adaptive predictor. The relation between the encoder and the decoder is also depicted. The difference between them is that the encoder has adaptive quantizer(**Q**) and inverse adaptive quantizer(**Q⁻¹**), while, the decoder has inverse adaptive quantizer only. The decoder is simply a subset of the encoder and transmits $r(n)$ as its output instead of $c(n)$. The adaptive predictor, which is composed of two poles and six zeros, computes an input signal estimate $\hat{s}(n)$ which is subtracted from input signal $s(n)$ resulting in a difference signal $d(n)$. The adaptive quantizer codes $d(n)$ into 4-bit codeword $c(n)$ which is sent over the transmission facility. At the receiving end, an ADPCM decoder uses $c(n)$ to attempt to reconstruct the original signal $s(n)$. Actually, only $r(n)$ can be reconstructed which is related to the original input signal $s(n)$ by

$$r(n) = s(n) + e(n) \tag{1}$$

where

$$e(n) = dq(n) - d(n) = r(n) - s(n) \tag{2}$$

is the error introduced by the quantizer, and $dq(n)$ is the output of inverse adaptive quantizer

A typical measure of the ADPCM performance is given by signal-to-noise ratio (SNR)

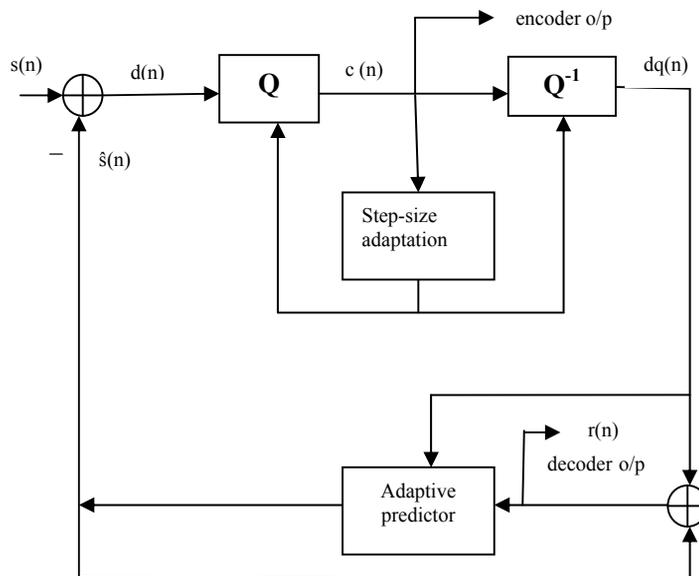


Fig. 1. ADPCM Codec

$$SNR = E[s^2(n)] / E[e^2(n)] = \sigma_s^2 / \sigma_e^2 \tag{3}$$

Where E denotes expectation, σ_s^2 is the power (or variance) of input signal, & σ_e^2 is the power (or variance) of the error signal.

Qam modem

The first QAM modem named modem-I operates at symbol rate of 2400 baud with each symbol is represented by 7 bits (trellis coding is excluded) giving data rate of $2400 \times 7 = 16.8$ kb/s. The number of points in M-ary QAM constellation is equal to $2^7 = 128$ points, while, modem V.34[28] uses the same symbol rate but with 192-point or 224-point constellation. The design of QAM constellation plays important role in reducing the effect of channel noise [29], also, in reducing the distortion of ADPCM[26]. Some of constellations which are considered here are shown in Fig.2, for 128-point, rectangular, & (6,12,18,24,30,38) circular. Because of symmetry, parts of rectangular and circular constellations are drawn.

The second QAM modem named modem-II operates at symbol rate of 2800 baud with each symbol is represented by six bits (trellis coding is excluded) giving data rate of $2800 \times 6 = 16.8$ kb/s, with $2^6 = 64$ -point constellation, while, modem V.34 uses the same symbol rate but with 96-point or 112-point constellation. Fig.3 shows some of 64-point constellations, rectangular, & (6,12,19,27) circular.

The third QAM modem named modem-III operates at symbol rate of 3360 baud (the maximum allowable symbol rate is 3429 baud[28]) with each symbol is represented by five bits (trellis coding is excluded) giving data rate of $3360 \times 5 = 16.8$ kb/s, with $2^5 = 32$ -point constellation. Fig.4 shows some of 32-point constellations, rectangular, (4,11,17), & (5,11,16) circular.

Computer simulation test

A series of computer simulation tests have been carried out on ADPCM codec using the three QAM modem signals at 16.8kb/s with constellations shown in Figs.2-4. The performance of ADPCM is measured by calculating SNR in equation 3.

Table 1 shows the results of testing ADPCM using modem-I. It seems that the performance of ADPCM with circular constellation is better than rectangular one by approximately 0.3dB.

Table 2 shows the results of testing ADPCM using modem-II. It seems that the performance of ADPCM with circular constellation is better than rectangular one by approximately 0.4dB.

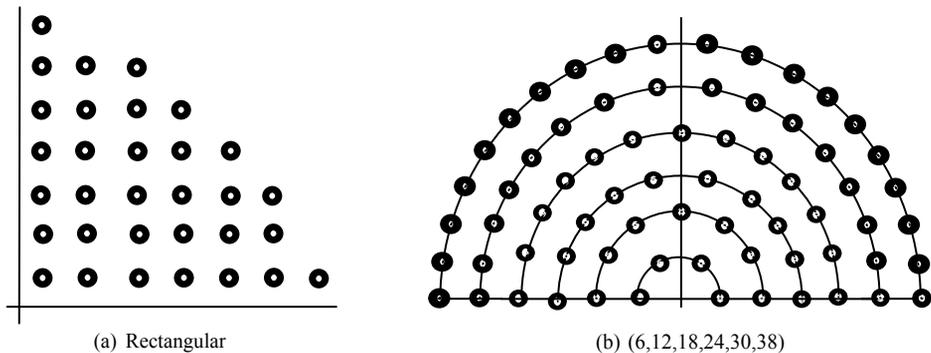


Fig. 2. 128-ary QAM constellations

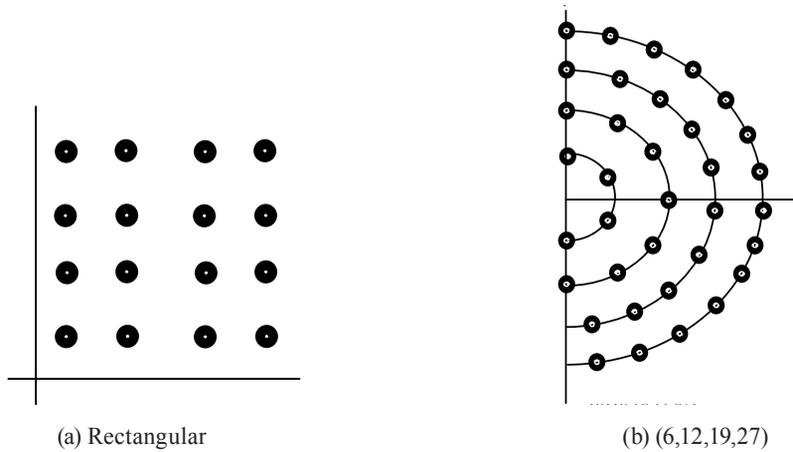


Fig. 3. 64-ary QAM constellations

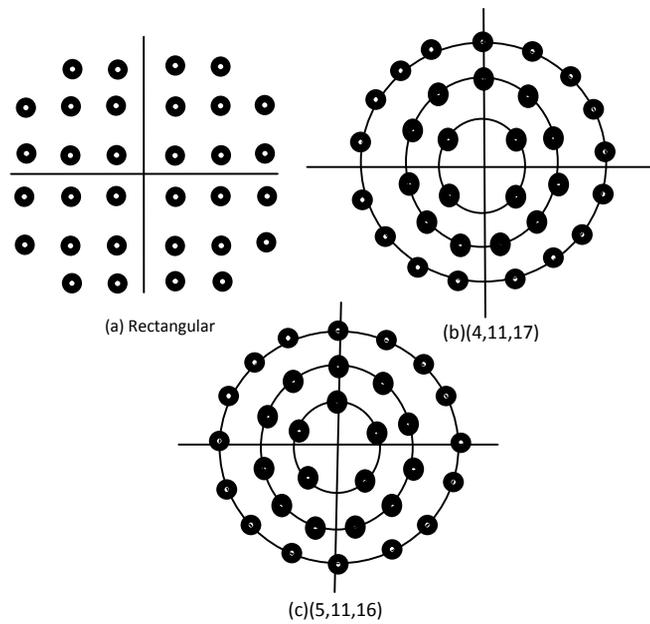


Fig. 4. 32-ary QAM constellations

Table 3 shows the results of testing ADPCM using modem-III. It seems that the performance of ADPCM with circular constellation is better than rectangular one by approximately 0.5dB.

The comparison among the three modems shows that the performance of ADPCM with modem-III is better than its performance with modem-II by approximately 1.1dB and the later is better than modem-I by approximately 1.2dB .

Summary and conclusion

Three QAM modems operate at data rate of 16.8kb/s have been considered in order to reduce the nonlinear distortion of ADPCM. The simulation results show that the performance of ADPCM with

Table 1. Performance of ADPCM

	Modem-I	
SNR(dB)	Rect	(6,12,18,24,30,38)
	19.7	20

Table 2. Performance of ADPCM

	Modem-II	
SNR(dB)	Rect	(6,12,19,27)
	20.9	21.3

Table 3. Performance of ADPCM

	Modem-III		
SNR(dB)	Rect	(4,11,17)	(5,11,16)
	21.8	22.2	22.3

modem-III is better than modem-II and the later is better than modem-I. Also, the performance with circular constellation is better than rectangular one.

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