UDC: 621.397.22 DOI: 10.20535/2312-1807.2017.22.1.92752

Muhanned AL-Rawi, PhD, OrcID: 0000-0003-1407-6519
e-mail: muhrawi@yahoo.com
University of Ibb, Yemen

PERFORMANCE STUDY OF ITU RECOMMENDATION G726

Due to its importance and its wide applications in telecommunication networks, the Adaptive Differential Pulse Code Modulation(ADPCM) was standardized by International Telecommunication Union(ITU) as recommendation G726. This recommendation represents four algorithms of ADPCM, 40kb/s, 32kb/s, 24kb/s, and 16kb/s. This paper studies the performances of these for algorithms using QAM signal at data rate of 9.6kb/s. The simulation results show that the performance of 40kb/s algorithm is better than that of 32kb/s algorithm, and the performance of 32kb/s algorithm is better than that of 24kb/s algorithm, and the latter is better than that of 16kb/s algorithm.

Ref. 16, fig. 4

Key words: *ITU recommendation; ADPCM; QAM.*

INTRODUCTION. With the increase in demand for efficient use of digital communication channel, various types of highly effective speech coding methods have been developed. As one of these coding methods which was standardized by International Telecommunication Union (ITU, the previous name is International Telephone &Telegraph Consultative Committee (CCITT)) as recommendation G726 is 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. These applications can be divided into three categories: telephone company use, end customer applications, and new service offerings. The recent ADPCM applications [2]–[5],which represent U.S. application patents, motivate the researchers to continue doing research in this field.

The main problem of ADPCM is that it adds severe nonlinear distortion to the voiceband data signal at high data rate. This problem can be solved either by modifying the algorithm of ADPCM [6]–[13], or by modifying the model of data transmission system [14]–[16].

I. STRUCTURE OF ADPCM

A. General Structure. 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 computes an input signal estimate ŝ(n) which is subtracted from input signal s(n) resulting in a difference signal d(n). The adaptive quantizer codes d(n) into 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

$$r(n) = s(n) + e(n) \quad (1)$$

where

$$e(n) = dq(n) - d(n) = r(n) - s(n) \quad (2)$$

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

B. 40kb/s ADPCM. The algorithm of 40kb/s ADPCM (named AD1) uses 5-bit quantizer with sampling rate of 8000 sample/sec. The characteristics of 5-bit quantizer are found in [1]. The adaptive predictor is composed of two poles and six zeros [1].

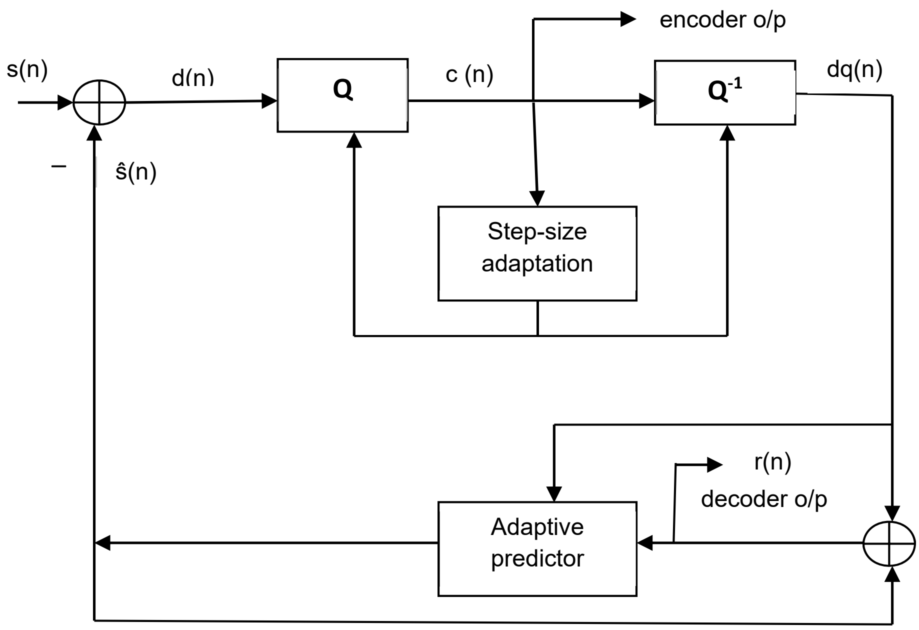

Fig.1 ADPCM Codec

C. 32kb/s ADPCM. The algorithm of 32kb/s ADPCM (named AD2) uses 4-bit quantizer with sampling rate of 8000 sample/sec. The characteristics of 4-bit quantizer are found in [1]. The adaptive predictor is similar to that for 40kb/s.

24kb/s ADPCM. The algorithm of 24kb/s ADPCM (named AD3) uses 3-bit quantizer with sampling rate of 8000 sample/sec. The characteristics of 3-bit quantizer are found in [1]. The adaptive predictor is similar to that for 40kb/s.

16kb/s ADPCM. The algorithm of 16kb/s ADPCM (named AD4) uses 2-bit quantizer with sampling rate of 8000 sample/sec. The characteristics of 2-bit quantizer are found in [1]. The adaptive predictor is similar to that for 40kb/s.

II. MODEL OF QAM MODEM. The model of QAM modem operates at symbol rate of 2400 baud with each symbol is represented by 4-bit (trellis coding is excluded) giving data rate of 2400x4=9.6kb/s. The number of points in M-ary QAM constellation is equal to 24=16-point. There are different types of QAM constellation but in this paper only rectangular constellation is considered as shown in Fig.2.

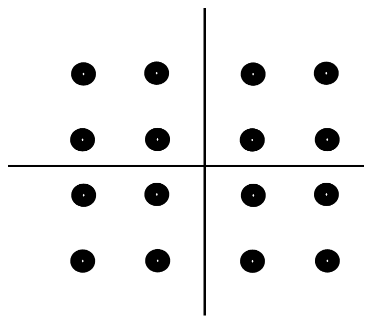

Fig.2 16-ary QAM rectangular

III. MODEL OF DATA TRANSMISSION. The model of data transmission used to measure the performance of ADPCM is shown in Fig.3. This model consists of random data generator which generates binary data (each 4-bit mapped into one of 16-point of QAM constellation), QAM modulator, ADPCM codec, Additive White Gaussian Noise (AWGN), QAM demodulator, and a detector which is a simple threshold (the output of detector takes one of 16-point which compared to the transmitted symbols to calculate the symbol error rate). In this model, only two types of impairment are considered, AWGN, and nonlinear distortion of ADPCM.

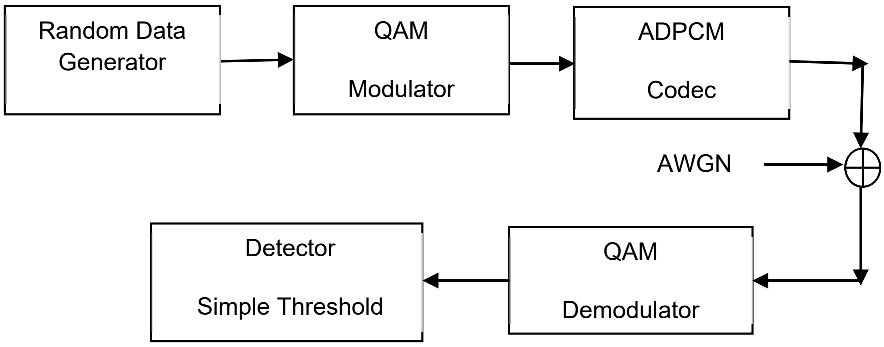

Fig.3 Model of data transmission

The performance of whole system is measured by drawing symbol error rate (SER) versus signal-to-noise-ratio (SNR). The SER is given by

$$SER = NEDS/NTS \quad (3)$$

where NEDS – is the number of erroneous detected symbols & NTS – is the number of total transmitted symbols.

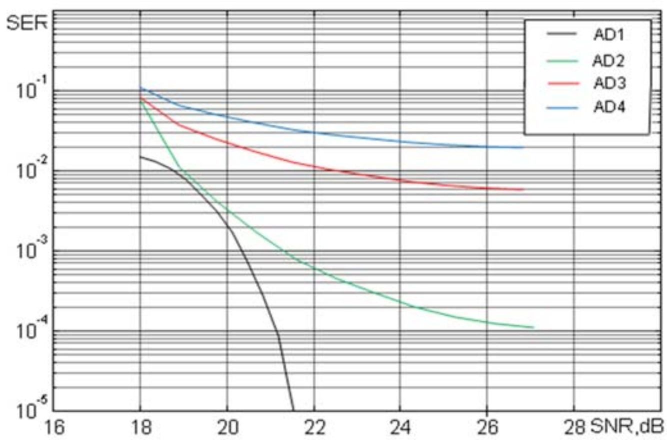

Fig.4 Error rate performance

It is important to say that, at high SNR, the impairment is dominated by the nonlinear distortion of ADPCM, so at high SNR, the error rate is due to the nonlinear distortion of ADPCM.

IV. COMPUTER SIMULATION TEST. A series of computer simulation tests have been carried out on the system in Fig.3. The performance of the whole system is measured by drawing SER versus signal-to-noise-ratio (SNR), where the SER is given by equation 3.

Fig.4 shows the performances of the system including the four ADPCM algorithms. It seems that the SER of the system with AD1 becomes negligible at SNR>21dB. Also, the SER of the system with AD2 remains constant at $1x10^{-4}$ at SNR>26dB, while the SER of the system with AD3 remains constant at $6x10^{-3}$ at SNR>26dB. Furthermore, The SER of the system with AD4 remains constant at $2x10^{-2}$ at SNR>26dB. These constant symbol error rates are due to the nonlinear distortion of ADPCM.

SUMMARY AND CONCLUSION. The ADPCM was specifically developed for speech coding or speech compression. It can compress the speech signal using 5 bit/sample, 4 bits/sample, 3 bit/samples, and 2bits/samples without significantly adding nonlinear distortion to the speech signal. Of course, as the degree of compression increases, the nonlinear distortion increases, but for speech signal is negligible. The reason of this negligible distortion is attributed to the nature of speech signal in sense that the correlation between speech samples is high. In case of voiceband data signal at 9.6kb/s, it can be concluded from the simulation results that as the number of bits per sample decreases, the nonlinear distortion increases, so, the distortion of 16kb/s algorithm is higher than the distortion of the 24kb/s algorithm, and the latter is higher than that of 32kb/s algorithm. The reason of this significant distortion is due to low correlation between the data samples, and this correlation becomes lower with increasing the data rate. Thus as the data rate increases, the nonlinear distortion increases. The 40kb/s algorithm was specifically developed for voiceband data signal at rate ≥ 9.6kb/s in order to reduce the distortion to a negligible value as proved by simulation result in Fig.4.

Надійшла до редакції 12 лютого 2017р.

REFERENCES

[1]. “40, 32, 24, 16 kbit/s Adaptive Differential Pulse Code Modulation (ADPCM).” ITU-T G.726 (12/1990), 1990. http://www.itu.int/ITU-T/recommendations/rec.aspx?rec=924

[2]. M. ZAUNSCHIRM and P. CASTIGLIONE, “Method of packet loss concealment in ADPCM Codec and ADPCM decoder with PLC circuit,” US 20160148619 A1, 2016. https://www.google.com/patents/US20160148619

[3]. A. Gur and O. Kiryat, “Non-synchronized ADPCM with discontinuous transmission,” US 9332585, 2016. http://patents.com/us-9332585.html

[4]. A. Shibuta, Y. Suwa, H. Ishihara, and K. Obana, “Wireless communication device and communication terminal,” US 9270419 B2, Feb-2016. www.google.ch/patents/US9270419

[5]. S. Ragot, B. Kovesi, and A. Le Guyader, “Controlling a noise-shaping feedback loop in a digital audio signal encoder avoiding instability risk of the feedback,” US 9489961 B2, 2016. www.google.ch/patents/US9489961

[6]. N. Benvenuto and W. R. Daumer, “Two approaches for waveform coding of 9.6 kbit/s voiceband data signals through 32 kbit/s ADPCM,” *IEEE Trans. Commun.*, vol. 36, no. 3, pp. 382–385, Mar. 1988. DOI: 10.1109/26.1465

[7]. Z. Shpiro, “Adaptive differential pulse code modulation (ADPCM) systems,” US 4860313 A, 1989. www.google.com/patents/US4860313

[8]. “5-, 4-, 3- and 2-bit/sample embedded adaptive differential pulse code modulation (ADPCM).” ITU-T G.727 (12/1990), 1990. http://www.itu.int/ITU-T/recommendations/rec.aspx?rec=927

[9]. “Comparison of ADPCM algorithms.” ITU-T G.726 App. III (05/1994), 1994. http://www.itu.int/ITU-T/recommendations/rec.aspx?rec=926&lang=en

[10]. M. AL-Rawi, “Simulation results of newly designed ADPCM for data transmission at 9.6kb/s,” in *Ninth International Conference on Microelectronics*, 1997.

[11]. M. F. Al-Rawi and M. Al-Rawi, “Modified 24 kb/s ADPCM System,” *J. Inst. Eng. Ser. B*, vol. 94, no. 3, pp. 169–172, Sep. 2013. DOI: 10.1007/s40031-013-0057-9

[12]. M. AL-Rawi and M. AL-Rawi, “Comparative study of 24 kb/s ADPCM algorithms,” *Radioelectron. Commun. Syst.*, vol. 57, no. 6, pp. 282–285, Jun. 2014. DOI: 10.3103/S0735272714060065

[13]. M. AL-Rawi and M. AL-Rawi, “Modified algorithm of 16 kb/s ADPCM,” *Pacific Sci. Rev. A Nat. Sci. Eng.*, vol. 17, no. 3, pp. 83–86, 2015. DOI: 10.1016/j.psra.2015.12.004

[14]. M. AL-Rawi and et al., “Computer simulation for newly designed 9.6kb/s data transmission system over standard ADPCM,” in *Ninth International Conference on Microelectronics*, 1997. http://jae.cycu.edu.tw/ABSTRACT/10-3/10-125-127a.pdf

[15]. M. AL-Rawi and M. AL-Rawi, “Analysis and Design of ADPCM System,” *J. Adv. Eng.*, vol. 10, no. 3, pp. 125–127, 2015.

[16]. M. Al-Rawi, “Performance study of multistage of 40 kb/s ADPCM systems,” *Int. Rev. Appl. Sci. Eng.*, vol. 6, no. 2, pp. 85–88, Dec. 2015. DOI: 10.1556/1848.2015.6.2.1

УДК: 621.397.22
Muhanned AL-Rawi, PhD, OrcID: 0000-0003-1407-6519
e-mail: muhrawi@yahoo.com
Університет Ібб, Ємен

ДОСЛІДЖЕННЯ ЕФЕКТИВНОСТІ РЕКОМЕНДАЦІЇ ITU G726

Зважаючи на важливість і широке застосування в телекомунікаційних мережах, адаптивна диференціальна імпульсно-кодова модуляція (ADPCM) була стандартизована Міжнародним союзом електрозв'язку (МСЕ) в якості рекомендації G726. Ця рекомендація містить чотири алгоритми ADPCM, 40 kb/c, 32 kb/c, 24 kb/c, і 16 kb/c. Стаття вивчає характеристики цих алгоритмів для сигналу з використанням QAM при швидкості передачі даних 9.6 kb/c. Результати моделювання показують, що: продуктивність 40 kb/c алгоритму краще, ніж 32кб/с алгоритмом; продуктивність 32 кб/с алгоритмом краще, ніж від 24 kb/c алгоритмом; алгоритм 24 kb/c краще, ніж 16 kb/c алгоритмом.

Бібл. 16, рис. 4.

Ключові слова: *рекомендації МСЕ; ADPCM; QAM.*

1. "40, 32, 24, 16 kbit/s Adaptive Differential Pulse Code Modulation (ADPCM)." ITU-T G.726 (12/1990), 1990. http://www.itu.int/ITU-T/recommendations/rec.aspx?rec=924
2. M. ZAUNSCHIRM and P. CASTIGLIONE, "Method of packet loss concealment in ADPCM Codec and ADPCM decoder with PLC circuit," US 20160148619 A1, 2016. https://www.google.com/patents/US20160148619
3. A. Gur and O. Kiryat, "Non-synchronized ADPCM with discontinuous transmission," US 9332585, 2016. http://patents.com/us-9332585.html
4. A. Shibuta, Y. Suwa, H. Ishihara, and K. Obana, "Wireless communication device and communication terminal," US 9270419 B2, Feb-2016. www.google.ch/patents/US9270419
5. S. Ragot, B. Kovesi, and A. Le Guyader, "Controlling a noise-shaping feedback loop in a digital audio signal encoder avoiding instability risk of the feedback," US 9489961 B2, 2016. www.google.ch/patents/US9489961
6. N. Benvenuto and W. R. Daumer, "Two approaches for waveform coding of 9.6 kbit/s voiceband data signals through 32 kbit/s ADPCM," *IEEE Trans. Commun.*, vol. 36, no. 3, pp. 382–385, Mar. 1988. DOI: 10.1109/26.1465
7. Z. Shpiro, "Adaptive differential pulse code modulation (ADPCM) systems," US 4860313 A, 1989. www.google.com/patents/US4860313
8. "5-, 4-, 3- and 2-bit/sample embedded adaptive differential pulse code modulation (ADPCM)." ITU-T G.727 (12/1990), 1990. http://www.itu.int/ITU-T/recommendations/rec.aspx?rec=927
9. "Comparison of ADPCM algorithms." ITU-T G.726 App. III (05/1994), 1994. http://www.itu.int/ITU-T/recommendations/rec.aspx?rec=926&lang=en
10. M. AL-Rawi, "Simulation results of newly designed ADPCM for data transmission at 9.6kb/s," in *Ninth International Conference on Microelectronics*, 1997.
11. M. F. Al-Rawi and M. Al-Rawi, "Modified 24 kb/s ADPCM System," *J. Inst. Eng. Ser. B*, vol. 94, no. 3, pp. 169–172, Sep. 2013. DOI: 10.1007/s40031-013-0057-9
12. M. AL-Rawi and M. AL-Rawi, "Comparative study of 24 kb/s ADPCM algorithms," *Radioelectron. Commun. Syst.*, vol. 57, no. 6, pp. 282–285, Jun. 2014. DOI: 10.3103/S0735272714060065
13. M. AL-Rawi and M. AL-Rawi, "Modified algorithm of 16 kb/s ADPCM," *Pacific Sci. Rev. A Nat. Sci. Eng.*, vol. 17, no. 3, pp. 83–86, 2015. DOI: 10.1016/j.psra.2015.12.004
14. M. AL-Rawi and et al., "Computer simulation for newly designed 9.6kb/s data transmission system over standard ADPCM," in *Ninth International Conference on Microelectronics*, 1997. http://jae.cycu.edu.tw/ABSTRACT/10-3/10-125-127a.pdf
15. M. AL-Rawi and M. AL-Rawi, "Analysis and Design of ADPCM System," *J. Adv. Eng.*, vol. 10, no. 3, pp. 125–127, 2015.
16. M. Al-Rawi, "Performance study of multistage of 40 kb/s ADPCM systems," *Int. Rev. Appl. Sci. Eng.*, vol. 6, no. 2, pp. 85–88, Dec. 2015. DOI: 10.1556/1848.2015.6.2.1

УДК: 621.397.22
Muhanned AL-Rawi, PhD, OrcID: 0000-0003-1407-6519
e-mail: muhrawi@yahoo.com
Университет Ибб, Йемен

ИССЛЕДОВАНИЕ ЭФФЕКТИВНОСТИ РЕКОМЕНДАЦИИ ITU G726

Учитывая важность и широкое применение в телекоммуникационных сетях, адаптивная дифференциальная импульсно-кодовая модуляция (ADPCM) была стандартизирована Международным сою зом электросвязи (МСЭ) в качестве рекомендации G726. Эта рекомендация содержит четыре алгоры-тми ADPCM, 40 kb/c, 32 kb/c, 24 kb/c, и 16 kb/c. Статья изучает характеристики этих алгоритмов для сигнала с использованием QAM при скорости передачи данных 9.6 kb/c. Результаты моделью ния показывают, что: производительность 40 kb/c алгоритма лучше, чем 32 кб/с алгоритмом; производительность 32 кб/с алгоритмом лучше, чем от 24 kb/c алгоритмом; алгоритм 24 kb/c лучше, чем 16 kb/c алгоритмом.

Библ. 16, рис. 4.

Ключевые слова: *рекомендации МСЕ; ADPCM; QAM.*