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STATISTICAL MODULATION FOR LOW-COMPLEXITY VIDEO TRANSMISSION

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ABSTRACT

This paper concerns problems of power consumption in the state-of-the-art video transmission systems in which (particularly in wide-band ones) video coding block traditionally is the most computationally complex element.

The suggested approach allows for significant decreasing of energy consumption of the overall video transmission system. First it is noticed that constellation points in QAM have unequal energy levels. Then it is verified experimentally that small image values after the low-complexity pre-processing using JPEG-LS context modelling are much more frequent than larger ones. Furthermore 90% of them lie in the near-zero area and the form of the probability distribution function does not change for images of different types.

The idea of the proposed Statistical QAM (S-QAM) is to map the most frequent input values into the QAM constellation points with the lowest energy. As the result average energy needed for image transmission is much smaller that allows for increasing the spacing between QAM constellation points for the same average energy. Therefore better Bit-Error-Rate (BER) is achievable for the same Signal-To-Noise-Ratio (SNR) in comparison with the standard QAM that does not utilizes the probabilities of input symbols.

Finally the suggested solution is compared with the conventional lossless transmission pipeline (two times compression using JPEG-LS, Error Correcting Code with R=0.5) for AWGN channel. It is shown that the BER-SNR ratio is similar for both schemes. But the proposed one has smaller complexity and power consumption because simpler pre-processing is used instead of full-featured compression.

I. INTRODUCTION

Real-time video transmission is one of the main usage models inside a home or an office wireless personal area network (WPAN) [1,2]. In residence communications for example a variety of devices within the entertainment cluster could be connected wirelessly: PDAs, cameras, HDTVs, STBs, players and other electronic devices throughout a home/office. Usually there are very strong limitations on the complexity and the power consumption of the video transmitters due to the limited battery life, orientation to small chip size and implementation costs [1]. Modern video transmission systems consist of the following main blocks [3]:

- **Video coding block**: compression, processing and packetizing of source video data
- **Transmission block**: channel coding, modulation etc.
- **RF-part**

Video coding is needed in the scheme for the two following reasons. Firstly, the rate of the compressed video data should fit the rate of the transmission system e.g. the amount of the transmitted video data should not exceed the channel capacity. Otherwise there could be the increase in the average delay or quality degradation at the receiver depending on the logic of the concrete system.

Secondly, compression decreases amount of information for transmission and therefore more redundancy bits could be added to compressed data for better error correction.

In the conventional video compression/transmission systems (particularly in wide-band systems) the video coding part is usually the most computationally complex element. Comparing some hardware implementations one could find that low-complexity compression block [5] consumes up to 10 times more power than the transmission part [2,6] including the channel coding, modulation and RF-part. So to reduce the overall system's complexity we first should reduce the complexity at the video coding stage.

Here we propose a method of joint processing of the input uncompressed video data and modulation symbols that allows reaching the same Error Rate without any preliminary compression and FEC. This leads to the significant decrease in the complexity costs and to the total power consumption reduce. It's assumed that channel throughput is enough for video transmission without preliminary compression. This assumption seems to be quite realistic, e.g. in future 60 GHZ initiative 2Gbps PHY throughput allows to deliver uncompressed HDTV1080i (~1,6 Gbps) video stream [1].

The text below is designed as follows. In the next section the main principles of the proposed Statistical QAM (by example of QAM256 [3]) and detailed algorithm description are presented. Then the proposed approach is compared with standard uncoded QAM256 (the SNR gain is demonstrated) and conventional video transmission with preliminary compression and forward error correction (FEC). In the last case the significant complexity gain is shown for the same average transmission power.

In section 4 the specifics of application of the Statistical QAM in real systems, particularly in OFDM [3] are discussed. Important parameters influencing efficiency of RF-part are also estimated, e.g. Peak-To-Average-Ratio.

II. STATISTICAL QAM

In well-known Quadrature Amplitude Modulation [3] constellation points have unequal power levels depending on their remoteness from the centre. Obviously the most frequent input values could be mapped to the QAM symbols with the lowest transmission energy that could reduce average power consumptions.

Unfortunately in conventional video transmission systems this fact is not considered usually. The distribution of symbols in a compressed and coded video stream is close to uniform one all the modulation symbols have the same probability.

On the other hand the distribution of the pixels' values of original non-compressed images is not usually uniform (if it is not an image with monochrome background). The distribution depends strongly on the image type (photo, text, screen, synthetic etc.). So it's a problem to design efficient universal mapping.

Therefore a special low-complexity algorithm is needed to change distribution of the original image values considering unequal energy levels of QAM points. The PDF of the resultant distribution should be quite similar for different images. The algorithm has to process an original image pixel-by-pixel to minimize delay.

A. Main Idea

The main idea of the proposed algorithm of Statistical QAM (S-QAM) for the video transmission is to map the most frequent input values after the low-complexity pre-processing (see next subsection) to the QAM symbols with the lowest transmission energy. As the result the power consumption of the transmission system is seriously decreased because the low-energy modulation symbols are transmitted more frequently than the symbols with the higher energy level.

To regulate values' distribution of input images low-complexity context modelling of JPEG-LS is used here. The distribution of values after that transform in the Figure 1 shows that smaller values are much more frequent than larger ones. Furthermore 90% of them lie in the near-zero area [-10;10]. So two mapping politics are possible:

- smaller values are mapped to the symbols with lower energy. This rule is universal and results from the form of distribution after context modelling. Anyway our experiments show that there could be small fluctuations for some images (for example computer graphics) and bigger values could be more frequent (in Figure 1b value 71 is more frequent than 50)
- more frequent values are mapped to the symbols with lower energy and transmitted with smaller power costs. It allows considering specific statistical properties of the transmitted images but needs to change mapping table depending on video sequence.

Here in this work the first method is used for all estimations.

For simplicity in this work we describe the transmission of images with the bit depth of 8 bits/pixel (one pixel can represent 256 different values) using QAM256 [3]. The numbers of the image values and the modulation points are equal and the one-to-one mapping is possible. But the same principles could be applied for the other QAM systems.

B. JPEG-LS Pre-processing

One could see that efficiency of the S-QAM depends a lot on the form of the distribution of input values. In this work error prediction mechanism of JPEG-LS [4] algorithm is used to regulate distribution of the input values for Statistical QAM. Of course it could be improved and other methods are also possible (differential frames for example). The context prediction works as follows.

The estimate prediction Px of the value Ix at the pixel at x is determined by the values at the neighbouring positions a, b, and c specified in Figure 2. The error prediction at current pixel is calculated as the difference between the predicted and the real values: DIFF = Ix – Px. Modulo reduction and range shift of the error values is made. After all these steps the DIFF values lie in range [0,255] for Range = 256 (8 bit images). The scheme has very small complexity level: to calculate error prediction of the current point (at coder or decoder side) 5 differences and 4 comparisons are needed. Only two rows of the original image are used for the image processing.

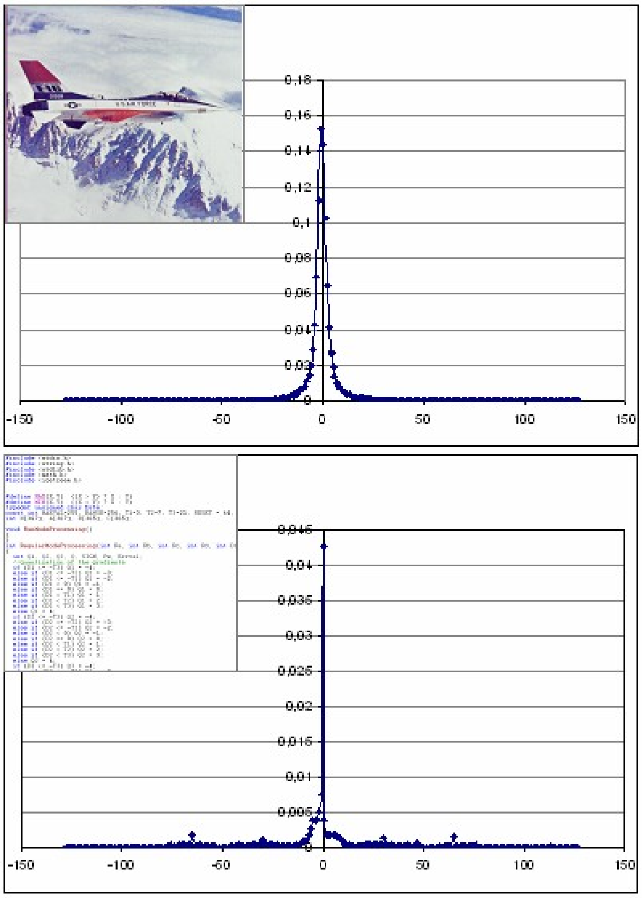

Figure 1. Distribution of values after pre-processing using context prediction of the JPEG-LS algorithm

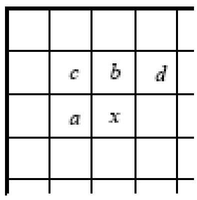

Figure 2. Image template used for error prediction in JPEG-LS

C. Algorithm Description

1) Preliminary Step

A special table (see Table 1) is constructed once for forward/backward mapping of the image values after pre-processing to QAM256 constellation points in the way that the smallest ones are mapped to the symbols with the lowest energy level. Optionally Grey coding [3] for better BER could be also applied.

2) Modulation Step

For every pixel error prediction is estimated using JPEG-LS context modelling and then a corresponding QAM256 symbol is selected according to the table constructed in the preliminary step. At the decoder side the process is absolutely symmetrical.

III. Practical Results

The suggested Statistical QAM256 is compared firstly with the standard uncoded QAM256 and secondly with the conventional video transmission scheme (compression + FEC + modulation).

Let first estimate the SNR gain for the proposed approach. The average power in general of standard M-QAM (see Figure 3 with QAM16) in which probability distribution of input values is considered to be uniform is calculated as follows [3]:

$$\overline{A}^2 = \frac{1}{M}\cdot\sum_{i=0}^{K-1}\sum_{i=0}^{K-1}(a^2(2i-K+1)^2 + a^2(2i-K+1)^2) = \frac{a^2}{M}\cdot\sum_{i=0}^{K-1}\sum_{i=0}^{K-1}((2i-K+1)^2+(2i-K+1)^2) \quad (1)$$

where M – the total number of constellation points (16, 64, 256 etc.), $K=\sqrt{M}$, a – halved distance between points.

The average power of Statistical-QAM is

$$\overline{A_s}^2 = \sum_{i=0}^{K-1}\sum_{i=0}^{K-1} p_i\cdot(a_s{}^2(2i-K+1)^2 + a_s{}^2(2i-K+1)^2) = a_s{}^2\sum_{i=0}^{K-1}\sum_{i=0}^{K-1} p_i\cdot((2i-K+1)^2+(2i-K+1)^2) \quad (2)$$

where p_i - probability of the i -th point; a_s – halved distance between points for S-QAM.

Assuming that the average power for both schemes is the same ($\overline{A_s}^2 = \overline{A}^2$) we have the larger distance between a_s modulation symbols in S-QAM that results in the better symbol error probability.

The estimations shows that the algorithm of Statistical QAM256 for video transmission demonstrates the SNR gain of about 13 - 15 dB in comparison to the standard uncoded QAM256 which supposes that the distribution of the incoming symbols is close to uniform. The gain size depends on the input type and the characteristics of the input images.

The suggested approach is also compared with the conventional video transmission scheme including video compression and error correction coding. Experiments show that modern video compression algorithms (JPEG-LS, H.264/AVC in lossless mode, JPEG 2000 in lossless mode) encode photorealistic images in the lossless mode up to 2 times in average. That allows applying the error-correcting code with R=0.5 (see Figure 4). In our estimations well-known convolution code (171, 133) [3] was used.

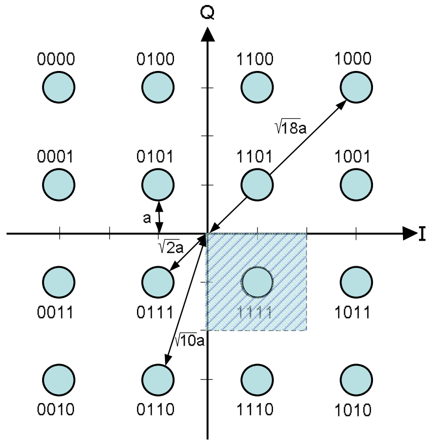

Figure 3. QAM16 constellation

The simulation pipelines (at the coder side) for both competitors are shown in Figure 4.

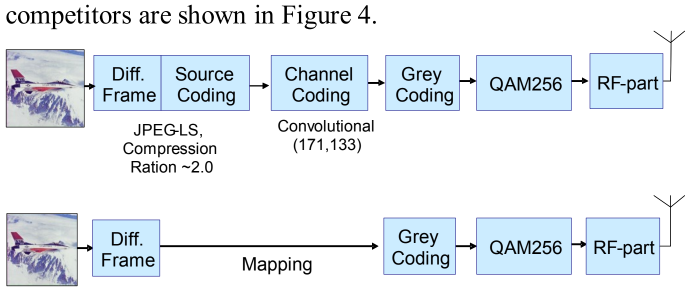

Figure 4. Schemes of the conventional image coding and transmission (a) and the Statistical Modulation (b)

AWGN channel is simulated for both transmission schemes.

The results are shown in Figure 5. The simulations show that the novel Statistical Modulation algorithm shows the same or better BER level for the same SNR comparing with the conventional video transmission pipeline (including compression and FEC). At the same time the Statistical Modulation algorithm has significantly smaller complexity costs and power consumption than the traditional scheme because the video encoding step is not needed.

IV. Peak-To-Average Power Ratio

In general the efficiency of an RF amplifier or an active circuit for a given transmit power, or receiver sensitivity/blocker performance is a function of linearity.

The Peak-To-Average Power Ratio (PAR) (also known as the crest factor) sets requirements for the linearity of the power amplifier. High PAR and high linearity requirements for the power amplifier leads to low power efficiency and therefore to high power consumption. Therefore PAR should be estimated for the base and the proposed schemes to correct comparison.

For instance, in commonly known OFDM systems as it is described in [7] the Gaussian nature of the composite multicarrier waveform results in the large variability of its instantaneous envelope, which depends on the phase of each composing subcarrier at any specific time instant. If all different subcarriers add in phase, the envelope peak signal is equal to the sum of the amplitudes of individual subcarriers. These amplitude spikes cause the multicarrier signal to be very sensitive to the nonlinear devices, such as analogue-to-digital converters, IFFT/FFT processors with the finite word length, RF power amplifiers, etc. The linear operation of all these devices over the large dynamic range entails significant cost and power penalties.

CCDF (Complementary Cumulative Distribution Function) PAR is estimated for the standard QAM256 with uniform distribution of input symbols and the proposed Statistical QAM256 (real images are processed). The PAR estimation is made for OFDM System with IFFT size 64 and 512. The results are shown in Figures 6 and 7. One could see that distance between PAR curves in OFDM system is quite small and does not exceed 0.3 dB for OFDM for $N = 64$ carriers and increases for $N = 512$. The reasoning is the following. As it was shown in [7] in the OFDM modulation for N carriers the worst-case PAR could be as large as N times the mean power of the signal. So the maximum value increases with increasing of N. Therefore the distance between PAR curves for two estimated modulation schemes is much smaller for $N = 64$ than for $N = 512$.

V. Conclusion

In this paper Statistical QAM was compared with conventional image transmission scheme (including full-featured compression and FEC). It was shown that for the same average power complexity costs for Statistical QAM could be significantly reduced. Some PAR increasing (0.3 dB for OFDM with 64 subcarriers) is the main disadvantage of the approach.

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References

[1] *IEEE 802.15.3c Usage Model Document Draft*, revised on 12 March 2007
[2] I. D. O'Donnell and R. W. Brodersen, "A 2.3mW Baseband Impulse-UWB Transceiver Front-end in CMOS," in *Proceedings of the Symposium on VLSI Circuits Dig. Tech. Papers*, Jun. 2006, pp.248-9.
[3] Alister Burr, *Modulation & Coding (Hardcover)*, Prentice Hall PTR, 2000
[4] ISO/IEC FCD 14495, *Lossless and near-lossless coding of continuous tone still images (JPEG-LS)*, 1997
[5] Andreas Savakis, Michael Piorun, "Benchmarking and hardware implantation of JPEG-LS," in *Proceedings of the 2002 International Conference on Image Processing*, 2002, pp. 949-952
[6] Lucian Stoica, *Non-coherent energy detection Transceivers for UWB Impulse Radio Systems*, Academic dissertation, Oulu University Press, Finland, 2008
[7] Simon Shepherd, John Orriss, Stephen Barton, "Asymptotic Limits in Peak Envelope Power Reduction by Redundant Coding in Orthogonal Frequency-Division Multiplex Modulation," in *IEEE Transactions On Communications*, January 1998, pp. 5-10
[8] Finnish-Russian University Cooperation Program in Telecommunications (FRUCT), http://www.fruct.org

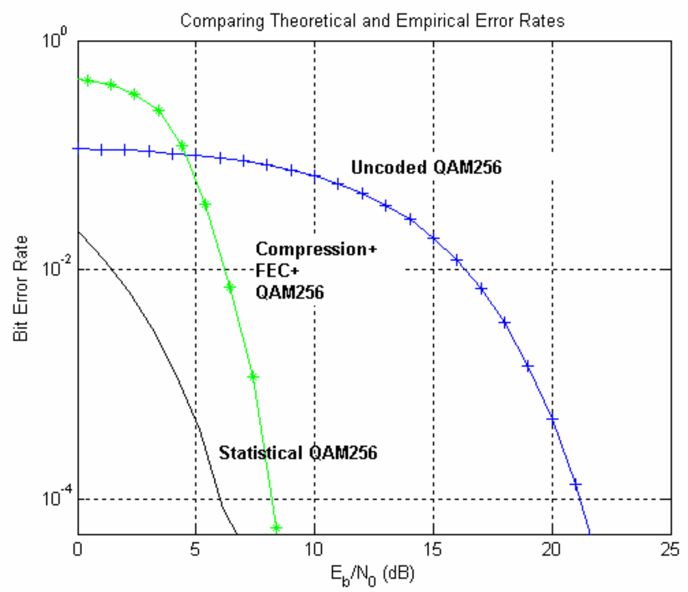

Figure 5. BER-SNR curves for AWGN channel: (a) Uncoded QAM256; (b) Conventional video transmission scheme; (c) Statistical QAM256

Table 1. A part of the Mapping Table for S-QAM256

Value of Diff Frame (decimal [-128 to 127])	Value of Diff Frame (decimal [0 to 255])	Input (mapped binary)	Grey coded	QAM Symbol		Energy
				Modulated (Im)	Modulated (Re)	
…						
-15	29	0 0 0 1 1 1 0 1	1 1 0 1 0 1 1 1	-5	3	34
-14	27	0 0 0 1 1 0 1 1	1 1 1 1 1 1 0 1	3	5	34
-13	25	0 0 0 1 1 0 0 1	1 1 1 1 0 1 0 1	-3	5	34
-12	23	0 0 0 1 0 1 1 1	1 1 0 0 1 1 1 1	5	1	26
-11	21	0 0 0 1 0 1 0 1	1 1 0 0 0 1 1 1	-5	1	26
-10	19	0 0 0 1 0 0 1 1	1 1 1 1 1 1 0 0	1	5	26
-9	17	0 0 0 1 0 0 0 1	1 1 1 1 0 1 0 0	-1	5	26
-8	15	0 0 0 0 1 1 1 1	1 1 0 1 1 1 0 1	3	3	18
-7	13	0 0 0 0 1 1 0 1	1 1 0 1 0 1 0 1	-3	3	18
-6	11	0 0 0 0 1 0 1 1	1 1 0 0 1 1 0 1	3	1	10
-5	9	0 0 0 0 1 0 0 1	1 1 0 0 0 1 0 1	-3	1	10
-4	7	0 0 0 0 0 1 1 1	1 1 0 1 1 1 0 0	1	3	10
-3	5	0 0 0 0 0 1 0 1	1 1 0 1 0 1 0 0	-1	3	10
-2	3	0 0 0 0 0 0 1 1	1 1 0 0 1 1 0 0	1	1	2
-1	1	0 0 0 0 0 0 0 1	1 1 0 0 0 1 0 0	-1	1	2
0	0	0 0 0 0 0 0 0 0	0 1 0 0 0 1 0 0	-1	-1	2
1	2	0 0 0 0 0 0 1 0	0 1 0 0 1 1 0 0	1	-1	2
2	4	0 0 0 0 0 1 0 0	0 1 0 1 0 1 0 0	-1	-3	10
3	6	0 0 0 0 0 1 1 0	0 1 0 1 1 1 0 0	1	-3	10
4	8	0 0 0 0 1 0 0 0	0 1 0 0 0 1 0 1	-3	-1	10
5	10	0 0 0 0 1 0 1 0	0 1 0 0 1 1 0 1	3	-1	10
6	12	0 0 0 0 1 1 0 0	0 1 0 1 0 1 0 1	-3	-3	18
7	14	0 0 0 0 1 1 1 0	0 1 0 1 1 1 0 1	3	-3	18
8	16	0 0 0 1 0 0 0 0	0 1 1 1 0 1 0 0	-1	-5	26
9	18	0 0 0 1 0 0 1 0	0 1 1 1 1 1 0 0	1	-5	26
10	20	0 0 0 1 0 1 0 0	0 1 0 0 0 1 1 1	-5	-1	26
11	22	0 0 0 1 0 1 1 0	0 1 0 0 1 1 1 1	5	-1	26
12	24	0 0 0 1 1 0 0 0	0 1 1 1 0 1 0 1	-3	-5	34
13	26	0 0 0 1 1 0 1 0	0 1 1 1 1 1 0 1	3	-5	34
14	28	0 0 0 1 1 1 0 0	0 1 0 1 0 1 1 1	-5	-3	34
15	30	0 0 0 1 1 1 1 0	0 1 0 1 1 1 1 1	5	-3	34
…						

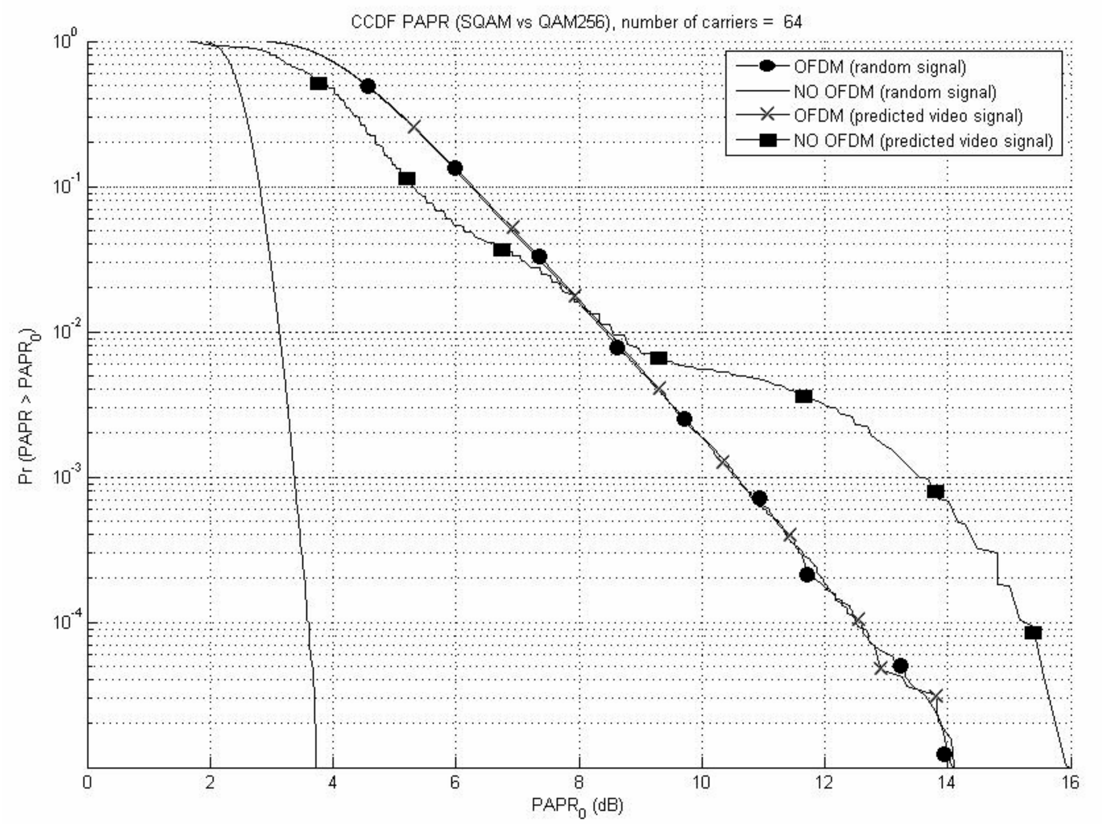

Figure 6. PAR for the Statistical QAM256 and the Standard QAM 256: OFDM(64 subcarriers) /non-OFDM

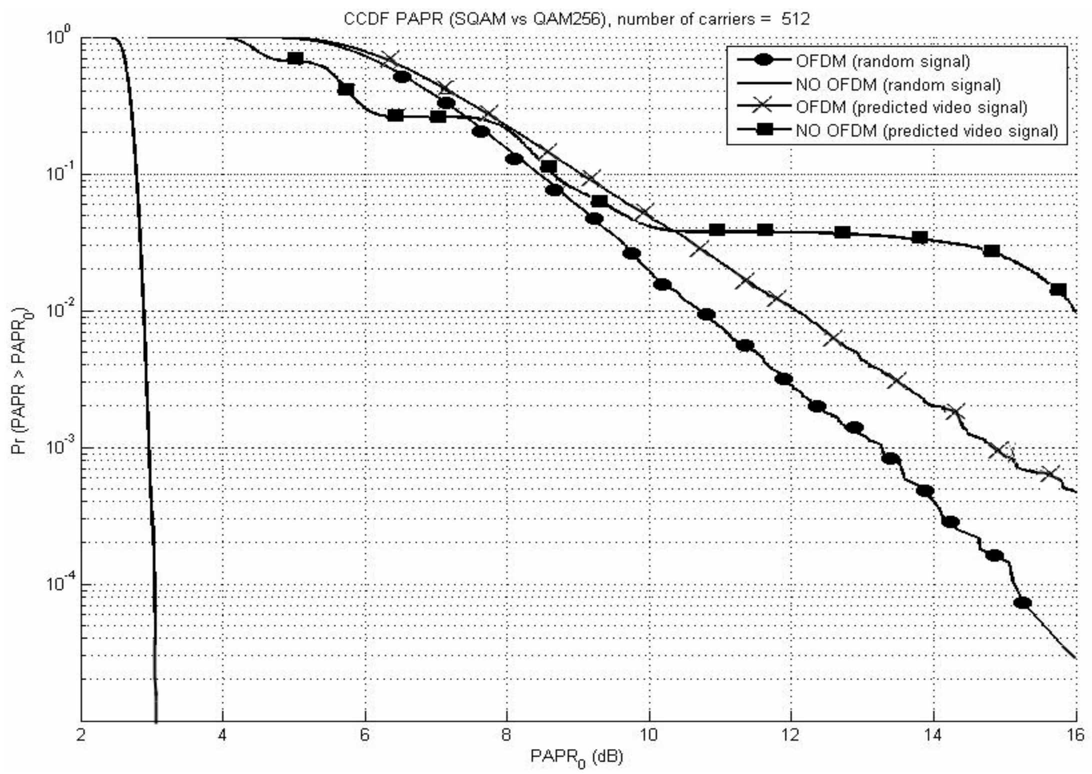

Figure 7. PAR for the Statistical QAM256 and the Standard QAM 256: OFDM (512 subcarriers)/non-OFDM