Joint Source Coding And Modulation For Low-Complexity Video Transmission

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Abstract

Abstract-In this paper we propose a Statistical QAM algorithm for video over wireless transmission - a joint approach for source coding and modulation utilizing two following ideas. Firstly context prediction is used to make distribution of image pixels values closer to bilateral geometrical distribution. Then the resultant values are mapped into the constellation points according to their frequency: more frequent values correspond to the points with lower energy level. It is shown that the proposed solution has significant power consumption gain if we consider power of video transmission and compression units jointly. The approach is analyzed from the position of Bit Error Rate, Peak-To-Average Power Ratio, implementation costs and image quality (PSNR) at the receiver. All explanations are shown for QAM modulation system.

I. Introduction

In this paper we propose a Statistical QAM algorithm for video over wireless transmission - a joint approach for source coding and modulation. It is shown that the described solution has significant power consumption gain if we consider power of transmission and compression units jointly. The suggested solution is analyzed from the position of Bit Error Rate, Peak-To-Average Power Ratio, implementation costs and image quality at the receiver. All the explanations are shown for QAM [1] modulation system. Statistical QAM is based on the following two ideas. Firstly the context prediction is used to make a distribution of image pixels values closer to the bilateral geometrical distribution. And secondly the resultant values of the processed image are mapped into the constellation point according to their frequency: more frequent values correspond to the points with lower energy level.

Video transmission is one of the main usage models for the next generation of Wireless Personal Area Networks (WPAN) [2]. All the industry and standardization groups developing future standards for short-range high speed communication are oriented mostly to video transmission tasks. Usage models and technical specifications suppose to deliver video within the office or entertainment cluster wirelessly for a huge variety of devices: digital camcorders, digital still cameras, high resolutions printers/scanners, DVD players, HDTV, set top boxes, game consoles. Application types include cable replacement, remote connection to HD displays, multimedia exchange within office and home, video transmission from informational kiosk and others.

Power consumption of the video transmission systems in the described WPAN devices is one of the most interesting questions influencing battery live time, mobility, convenience of usage and at all implementation costs.

The conventional video transmission system includes video compression block, BB (error-correcting coding, modulation) and RF parts. Compression is used to fit the channel usually. But even if we have a channel that can fit all raw HD it allows reducing the power consumption at BB and RF blocks due to the decreasing of the amount of the transmitted data. By the same reason compression allows using more redundancy bits and better forward error correction.

Currently several well-known lossy and lossless compression algorithms show similar results and could be used and tuned for video over wireless transmission depending on the system requirements: JPEG2000, H.264/AVC, JPEG-LS [3] etc. The most interesting questions sound as follows. Are there any alternative schemes that could effectively compete with the conventional ones? Is it possible to decrease the power consumption of the overall compression/transmission system using a joint solution for compression, modulation and coding?

As the answer for these questions a Statistical Modulation (S-QAM) algorithm is proposed in this paper. It could be classified as an algorithm of joint source coding and modulation because these two steps are processed jointly.

II. Statistical QAM

A. Main Idea

The main idea of the proposed Statistical SQAM is to map the most probable source image symbols to channel symbols with small amplitude in order to lower the average channel power. In contrast to previous works [4] [5] in the area of joint source-channel coding we suggest a constructive low-complexity algorithm of context prediction that allows to convert source image into the one having the probability distribution close to the bilateral geometrical distribution [3]. This uniforms and simplifies the source-channel mapping process and allows us to present a new algorithm of joint source-channel coding, providing both efficiency and low-complexity.

B. Context Prediction

A special mechanism of the low-complexity pre-processing context prediction is used to make the distribution of pixel values closer to bilateral geometrical distribution. Therefore more frequent input values could be efficiently mapped into the constellation points with a smaller energy level.

It is verified experimentally that small image values after context prediction and modelling are much more frequent than larger ones. Furthermore for all the testing images including photorealistic, synthetic ones and computer graphics 90% image values lie in the near-zero area. The form of the probability distribution function changes slightly for images of different types (see Fig. 2).

C. Source-Channel Mapping

Then the resultant values of the processed image are mapped into the constellation points according to their frequency: more frequent values correspond to the points with lower energy level. But the form of the distribution (see Fig. 2) after the context prediction allows using even simpler mapping rule: the smaller values are mapped to the constellation points with smaller energy. What mapping strategy to use depends on the concrete system requirements. The first one (by frequency) needs preliminary estimating step for investigating probability distribution of the predicted input stream in average but provides more efficient source-channel mapping. The second mapping strategy (by size) is more simple and universal but shows a slightly worse performance.

As the result the average power consumption of the transmission system is seriously decreased because modulation symbols with small energy costs are transmitted more frequently than symbols with higher energy level. Therefore spacing between constellation points could be increased if an average energy holds. Therefore better Bit-Error-Rate (BER) is achievable for

the same Signal-To-Noise-Ratio (SNR) in comparison with the standard QAM which does not utilizes the probability distribution of the input symbols. It could be noted here that in the conventional video compression and transmission schemes the encoded video data is considered to be distributed uniformly.
For simplicity here and below we describe transmission of the images with bit depth 8 bits/pixel (one pixel can represent 256 different values) using QAM256 (256 different modulation symbols). One can see the number of image values and modulation point is equal and therefore one-to-one mapping is possible. Anyway the same ideas and methods could be applied for other QAM systems: QAM16, 64, 128 etc. Transmission of video signal with other bit-depth is also possible.

D. Estimation criterion: from average energy to BER

First let's explain how energy gain of the described approach could be converted to BER-SNR gain for QAM systems. The average power in general of standard M-QAM (see Fig. 3 with QAM16) in which probability distribution of input values is considered to be uniform is calculated as follows [1]:

$$\begin{aligned}\bar{A}^2 &= \frac{1}{M}\sum_{i=0}^{K-1}\sum_{i=0}^{K-1}(a^2(2i-K+1)^2+a^2(2i-K+1)^2) = \\ &= \frac{a^2}{M}\sum_{i=0}^{K-1}\sum_{i=0}^{K-1}((2i-K+1)^2+(2i-K+1)^2) \end{aligned} \tag{1}$$

where M is the total number of constellation points (16, 64, 256 etc.), $K = \sqrt{M}$, a - halved distance between points. The average power of the proposed here Statistical-QAM is

$$\begin{aligned}\bar{A}_s^2 &= \sum_{i=0}^{K-1}\sum_{i=0}^{K-1}p_i(a_s^2(2i-K+1)^2+a_s^2(2i-K+1)^2) = \\ &= a_s^2\sum_{i=0}^{K-1}\sum_{i=0}^{K-1}p_i((2i-K+1)^2+(2i-K+1)^2) \end{aligned} \tag{2}$$

where p_i is probability of the i-th point; a_s - halved distance between points for S-QAM. As it was explained above Statistical Modulation has much smaller energy level due to sophisticated mechanism of mapping input symbols into constellation points. Therefore for S-QAM system with the same average energy consumption as at standard QAM ($\bar{A}_s^2 = \bar{A}^2$) we obtain bigger distance a_s between modulation symbols in S-QAM that leads to the better symbol and bit error probability.

III. Algorithm Description

The algorithm of Statistical Modulation for image transmission consists of the following main steps:

- Processing Step.
  - Context Prediction. The context-based prediction mechanism of JPEG-LS algorithm [3] uses the values of the three neighbourhood samples to form a prediction of the current sample. The prediction error is computed as the difference between the actual sample value at current position and its predicted value.

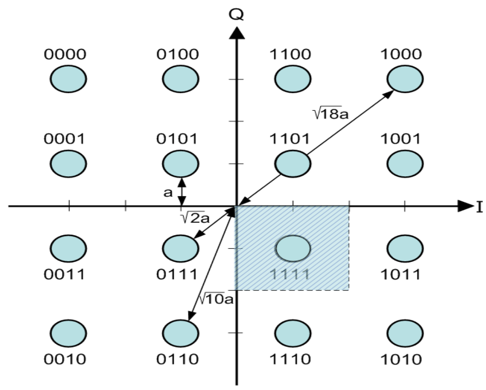

Fig. 1. QAM16 constellation

- Mapping. The predicted values are mapped to the constellation points according to the preliminary constructed mapping table. Optionally Grey coding for better BER could be also is used.

- Preliminary Step. At this step specific statistical properties of transmitted video sequences (movies, computer graphics etc.) could be estimated and source-channel mapping table should be constructed using one of the strategies described above (see section C.). The mapping table sets up a correspondence between the input values after context prediction and modulation symbols (and vice versa).

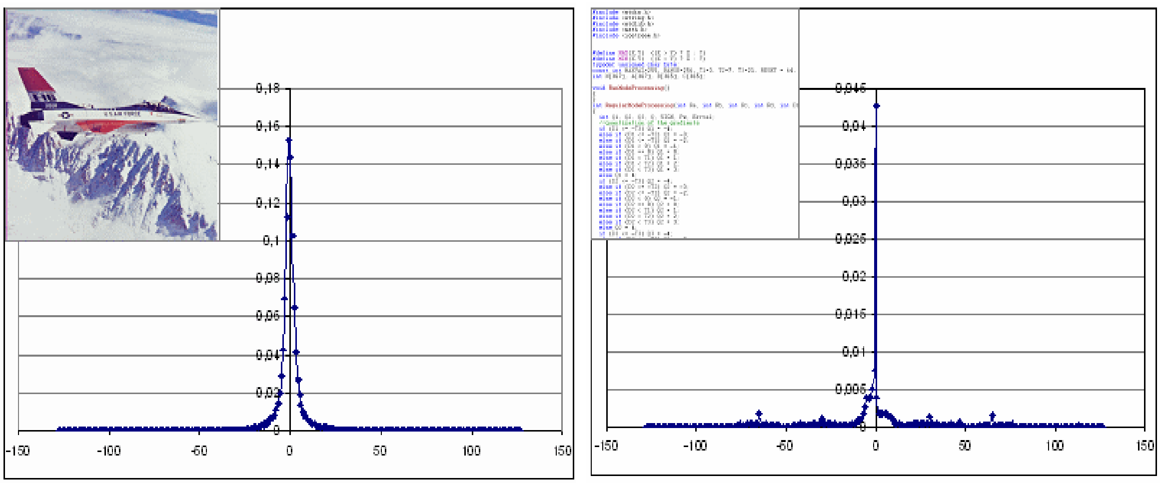

Fig. 2. Distribution of image values after low-complexity pre-processing using context prediction

Below the S-QAM algorithm is described for 256 constellation points and existing mapping table constructed at the preliminary step.

Video Coding Step at the Encoder Side. For every pixel of input frame:

- Predict value of the current pixel and calculate the prediction error
- For the prediction error select QAM256 symbol according the mapping table
- Use the selected modulation symbol for transmission

Video Decoding Step at the Decoder Side. For every received modulation symbol value:

- Select value of the prediction error according to the mapping table

- Predict the value of current pixel using the already predicted neighboring pixels as it is described above
- Put that reconstructed pixel into the corresponding position of the frame

As the result we obtain original frame at the decoder's side.

IV. Practical Results

A. Complexity

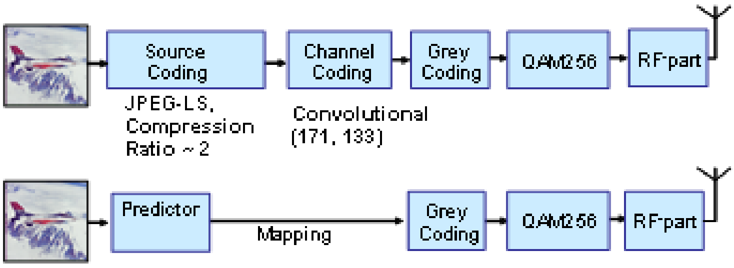

Fig. 3. Schemes of the conventional image coding and transmission (a) and the Statistical Modulation (b)

Statistical modulation has much smaller complexity level than conventional video transmission scheme because compression (source coding) and channel coding are mostly omitted. That could save up to 30% of total power consumption and significantly decrease implementation costs.

B. Bit Error Rate

The experiments show that the algorithm of Statistical QAM256 for video transmission demonstrates the SNR gain 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 type the characteristics of the input images. The simulation pipelines (at the coder's side) for both competitors are shown in Fig 3.

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 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) is used. AWGN channel is simulated for both transmission schemes.

The results are shown in Fig. 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).

C. 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 (PAPR) (also known as the crest factor) sets requirements for the linearity of the power amplifier. High PAPR and high linearity requirements for the power amplifier lead to low power efficiency and therefore to high power consumption.

Therefore PAPR should be estimated for both basic and proposed schemes to provide correct and full comparison. As it is estimated in [6] PAPR for S-QAM is up to 10 times bigger then for conventional systems. For OFDM PAPR increasing is much.

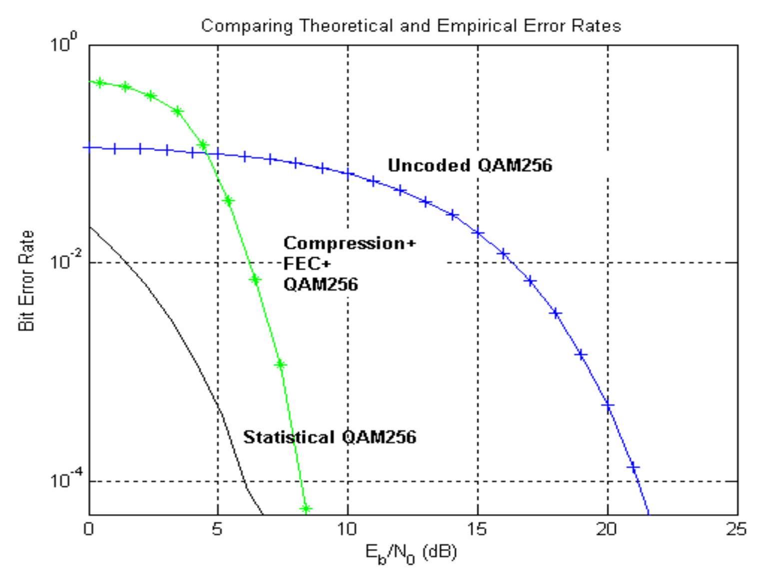

Fig. 4. BER-SNR curves for AWGN channel: (a) Uncoded QAM256; (b) Conventional video transmission scheme; (c) Statistical QAM256

D. Image Quality

The quality of the reconstructed images after transmission is one of the most interesting parameters when video compression and transmission systems are compared. JPEG2000 (one of the most powerful modern image codecs) was selected to compare performance of the conventional and statistical approaches.
At the same time quality at the receiver strongly depends on the selected error correcting and post-processing model. Is there tiling mode? What is the optimal tile size for the selected algorithm? What strategy for lossy image reconstruction at the receiver should be used in case of packet loss? Is it possible to use elements of previous frames to substitute image blocks missed during transmission?
To avoid answering these questions for building competent video transmission system we choose alternative and more general comparison strategy. For conventional video transmission scheme we a build bound for PSNR (SNR) function for the selected compression algorithm (JPEG2000). The JPEG2000 Bound for the selected image compression algorithm shows maximum achievable quality of the reconstructed image at the receiver when transmitting image over a noisy channel.

E. Image Quality: Statistical Modulation vs. Conventional JPEG2000 image transmission

The bound for quality of the images that are compressed by JPEG2000 and transmitted over a continuous channel with discrete time and additive white Gaussian noise is calculated as follows.
Firstly the average rate-distortion function is estimated for JPEG2000 on a variety of input images and compression rates. Then non-erroneous data transmitting with a rate close to

channel capacity is assumed. In other words we consider an ideal case when all the errors in channel are successfully corrected. Note that any other error correcting approach is worse than the describing one. Shannon's equation [7] for continuous channels with discrete time and additive white Gaussian noise is used to estimate channel capacity c:

$$c = \frac{1}{2} log_2(1 + SNR) \tag{3}$$

where SNR - signal-to-noise-ratio in channel (in times).
Now lets replace channel capacity by compression rate, i.e. assume that channel capacity is enough to transfer an image compressed with rate r:

$$r = c \tag{4}$$

Then using (3) and (4) we can derive signal-to-noise dependence versus transfer rate and calculate SNR in channel for every compression ratio:

$$SNR = 2^{2r} - 1 \tag{5}$$

At the last a new function $PSNR(SNR)$ function can be presented through relations $PSNR(r)$ and $SNR(r)$ received above. The received dependence is the bound for quality of the reconstructed image processed by JPEG2000 and transmitted over continuous channel with discrete time and additive white Gaussian noise.
Simulation results for the quality of the reconstructed video after transmission over AWGN channel using Statistical QAM are presented and compared with JPEG2000 bound (the best achievable result) in Fig. 5. One could see that the proposed S-QAM shows similar results at average and high SNRs.

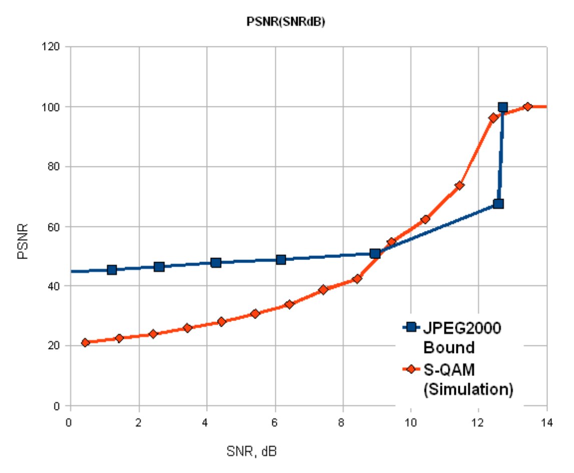

Fig. 5. PSNR(SNR) functions for JPEG2000 bound and S-QAM for simulation video transmission over AWGN channel

V. Conclusion

In this paper a new algorithm of Statistical QAM (S-QAM) is presented for joint video coding and modulation allowing significantly decrease power consumption of the video transmission system. The research results show that the proposed video transmission approach has much smaller energy consumption and complexity level than conventional video transmission schemes (including full-featured compression and FEC). Comparing PSNR of the reconstructed image shows that S-QAM could effectively compete with the best available conventional video transmission schemes. Some PAPR increasing is the main disadvantage of the approach.

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