Video Compression for Wireless Transmission: Reducing the Power Consumption of the WPAN Hi-Speed Systems

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Abstract. In this paper, we consider the power consumption aspects of video over wireless transmission in wireless personal area networks. We show that lossless and lossy compression always gives power consumption gains if we consider joint power consumption of transmission and compression units.

Keywords: wireless video transmission, compression, power saving, HDTV, WPAN, NGmS, 802.15.3c, wireless display.

1 Introduction

Video transmission in wireless personal networks (WPAN) has become a hot topic in the modern industry. The ability to use 60GHz spectrum led to new communication standards development to cover short range video delivery tasks. The standards like WirelessHD [1], IEEE 802.15.3c [2] and NGmS (Next Generation millimeter-wave Systems) are designed especially to transmit the uncompressed high-definition video (HD video) over wireless for video cable replacements in home or office use, to exchange multimedia data in WPAN networks using the handheld devices or to connect the handhelds to the remote display panels. Traditionally the compression (lossless or lossy) was aimed to decrease the data size to be transmitted, and everyone understands that if the channel bandwidth may become smaller that the uncompressed data size, then using of compression is the only solution. But if the channel bandwidth is always high enough to fit the uncompressed data the question is: do we need a compression in the transmission chain? Regarding the mobile devices such as handhelds the one of the most interesting questions is the battery power consumption and battery live time. When the device also has a capability to use the remote display connected with wireless protocol like NGmS or other the question is: how much will affected the total power consumption of the handheld by the video over wireless transmission? And is there any possibility to decrease the power consumption and to save battery?

In this paper, we show that even if we have a very high bandwidth channel that can fit all raw HD video data, it is always better to use lossless or lossy video compression

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before transmission to decrease the power consumption. It is clear that the compression scheme will also consume the battery power, but we show that it is possible to develop a very small and power efficient compression scheme based on JPEG-LS [3] or H.264/AVC [4] standards that allows to minimize the total power consumption of transmission and compression comparing to the uncompressed video transmission power consumption.

The paper is organized as follows.

In section 2 we formally define the problem of selecting an efficient video compression method while minimizing the total power consumption of the whole system. We also suggest the simple power-rate model introducing the overall power consumption at the transmitter as a function of the input data rate. In section 3, we present the compression schemes based on JPEG-LS and H.264/AVC standards showing what set of options we select to be used. Then we estimate the compression efficiency (simulation results for rate-distortion functions) considering HD video of three types: computer screen graphics, synthetic movie and natural movie. In section 4, we apply the power-rate model to estimate the power consumption of the real video compression/transmission system taking NGmS networking as an example. Section 5 concludes the paper.

2 Problem Statement

The goal of this work is to estimate the efficiency and advisability of compression in wireless video cable replacement from the power consumption point of view for the overall system. The main estimation criteria are the total power consumption at the transmitter side and the quality of the reconstructed video sequence at the receiver after transmission.

Therefore first of all we should find a relation between these criteria and define a power-distortion model connecting energy consumption for video processing/transmission and quality (PSNR) of the received frames. Such a model consists of several parts.

Firstly we introduce analytical power-rate function that refers to the overall power consumption at the transmitter required to support different compression rates. Models that use Shannon bound for power-rate approximation such as [5] are absolutely unsuitable here for WPAN systems due to much smaller WPAN rates for the given power consumption level. Therefore below we present and describe new wireless-oriented linear power-rate model.

Secondly real rate-distortion function is estimated for different video compression algorithms. For that we implemented the compared encoders in RTL. So the results obtained are well correlated with practice and our final goal – designing of the hardware low-complexity video transmission system. Existing complexity-rate models like in [6] are unfortunately quite inaccurate and provide very rough estimates only.

Summarizing the described two stages i.e. basing on analytical power-rate function and experimental rate-distortion function it is possible to estimate the required power-distortion function for the selected encoder and video transmission system.

In this work we assume the following scenario: the maximum channel bandwidth is high enough to fit all possible compressed video data (even if it is compressed with compression ratio 1, i.e. uncompressed). We want to compare the power consumption of the uncompressed transmission and two compression schemes in lossless mode, and then to compare two compression schemes when they produce the same reconstructed image PSNRs in the case of lossy.

We consider that data in wireless transport will be transmitted using the two following states:

Idle state. In this state data transmission is disabled and transport power consumption is P_0. z. The power consumption of the MAC (Media Access Control layer) and PHY (Physical Layer) is reduced because there are no data for handling and processing.

Maximum rate transmission state. In this state a data is transmitted with the maximum possible modulation and coding scheme that provides rate $R_{\max}$ and the wireless power consumption at the transmitter is $P_{\max}$.

Only these two transmission rates are available irrespectively to the amount of input data to be delivered. If an input data rate R is lower than $R_{\max}$ then the transmitter uses transmission state with $R_{\max}$ rate and goes to the idle state time-to-time. So the average power consumption of the wireless transmitter can be defined as

$$P_{transmitter}(R) = \frac{P_{\max} - P_0}{R_{\max}} \cdot R + P_0, \tag{1}$$

where R is the average bit-rate of transmitted video sequence. Therefore, the total power consumption of the transmitter side $P_{transmitter}$ considering video compression unit can be written as

$$P_{transmitter}(R) = \frac{P_{\max} - P_0}{R_{\max}} \cdot R + P_0 + P_{encoder} \tag{2}$$

where $P_{encoder}$ is the power consumption of the video encoder (see Fig. 1).

So the main idea of using video compression is that in average $P_{transmitter}(R)$ of such a system should be lower than the power demand in the uncompressed video transmission case:

$$P_{transmitter}(R) \le P_{\max} \tag{3}$$

It is obvious from the expressions (2) and (3) that the overall power gain is ensured when the encoder consumes less than $P_{\max} - P_0$ watts and the average compression ratio exceeds 1.0 (e.g. an amount of the transmitted data is not increased after compression).

One can see that the proposed model is quite simple. At the same time it takes into account the power consumption of the whole transmitter for signal processing, coding and radiating. Obviously Rower-Rate function of real systems strongly depends on the implementation, selected platform and technology and may be non-linear.

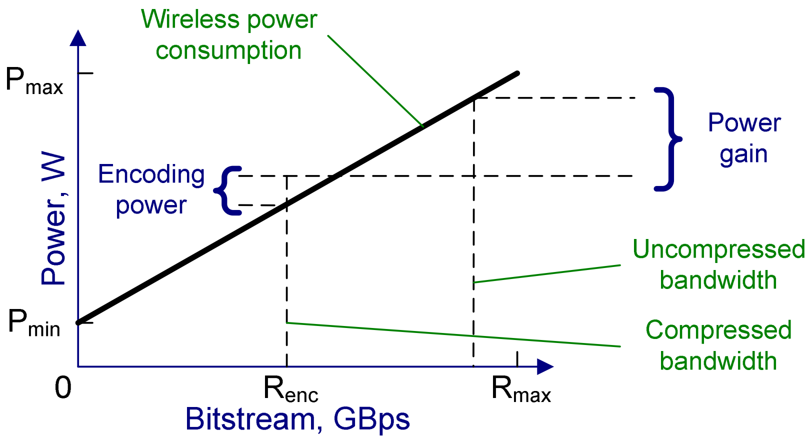

Fig. 1. Power-Rate model used for estimating the total power consumptions of the wireless video transmission system

3 Low Power Video Encoding

In this section, we consider the options we used to implement the video compression encoders that will consume the less possible power. We are trading off the compression performance efficiency to the encoding complexity and, as the result, the power consumption.

3.1 Selecting Video Encoder for Low Power Video Transmission

To meet the power consumption limitations defined above it is suggested here to use video encoders with relatively small level of operational complexity and very small memory utilization. To decrease complexity costs at the encoder side intra-coding mode only is used, i.e. the frames are compressed independently and are not stored after compression. Therefore we can not apply algorithms that exploit temporal redundancy such as motion estimation/compensation (ME/MC) or differential coding. It is clear that motion estimation/compensation requires at least one previously saved memory-based frame to find motion vectors. For HD resolution 1920x1080x24 bpp one frames takes ~6 Mbytes and can be stored using external memory units. That is quite expensive from the implementation complexity and the power consumption point of view. Moreover the operational complexity of the ME/MC algorithms is also very high.

In this work we concentrate on estimating power-distortion functions using the following two compression algorithms in the intra-coding mode: H.264/AVC and JPEG-LS. The reasons behind this choice are as follows. We consider H.264/AVC standard for compression because it is the latest industrial standard and has very high potential for profiling and complexity decreasing. JPEG-LS is selected because it is the latest international standard for lossless and near lossless still image compression. As it is shown in [8] and [9], when tested over a benchmark set of images of a wide variety of types, JPEG-LS provides the best lossless compression performance in comparison with other algorithms (JPEG2000 [10], MPEG2 [11]) at a much lower complexity level. Another near-lossless compression algorithm CALIC [12] is not selected because it has much higher complexity level despite the fact that it shows slightly better average lossless compression ratio.

The selected video encoding system should be really universal i.e. it should encode photorealistic, synthetic images and computer graphics with similar efficiency without single-purpose orientation to the compression of one image type only. Therefore compressors like PNG and GIF that are oriented to the mostly computer graphics are not considered. JPEG2000 performs reasonably well in terms of its ability to efficiently deal with various types of images and provides competitive compression ration but anyway it's is too complex due to arithmetic coding and multiple bitwise operations [9].

Both JPEG-LS and H.264/AVC in intra-mode do not require the entire image as a single atomic unit for efficient intra-compression. An image is split into smaller pieces, each piece is encoded independently and sequentially. More specifically, an image is partitioned into one or more disjoint rectangular regions called slices. Slices are quite small that greatly decreases the level of memory consumption. The slice size in our approaches is 1920x16 (<100 KByte for 24 bits/pixel). Therefore for intra-coding schemes considered a low-cost internal chip-based memory can be used.

In the case of several slices loss during transmission, other slices of the frame can be decoded and reconstructed successfully. It increases noise immunity and an ability of error concealment at the decoder side that is very important for video transmission over the time-variant wireless channel. Also the slicing structure of the processing decrease the end-to end latency.

3.2 JPEG-LS Based Compression

The main advantage of the JPEG-LS is a possibility to set up the max error value per pixel by choosing the difference bound for near-lossless coding (so-called "near" parameter or "lossy-factor"). Its advantage is an extremely small level of memory consumption at the encoder side (< 10KByte in our tests). Here we estimated JPEG-LS coding performance using different color space representations of the input frames.

- RGB, original Red-Green-Blue color space;
- YUV [4] color space, 8 bit/sample;
- YCoCg-R [13] colors space;
- RCT [10] colorspace transform from JPEG 2000 standard.

YCoCg-R and RCT use 8 bit per luma and 9 bit for chroma (color) components. They were tested using 2 modes: without subsampling and with 4:2:0 subsampling. It should be also noted that in case of a noise-like input image the size of the encoded row of pixels could exceed the size of the original one before the compression. Then the original row of pixels is transmitted without coding to provide an average compression ratio more or equal than 1.0.

During the experimental campaign RCT showed the best results from the position of rate-distortion ratio (PSNR vs. bit-rate) and was selected for further comparison with H.264-based scheme. As the result for HD picture size and 60 frames per second rate, we were able to design and implement in RTL the encoder with total power consumption of ~10mW working at 150MHz clock rate. TSMC 60nm technology was used.

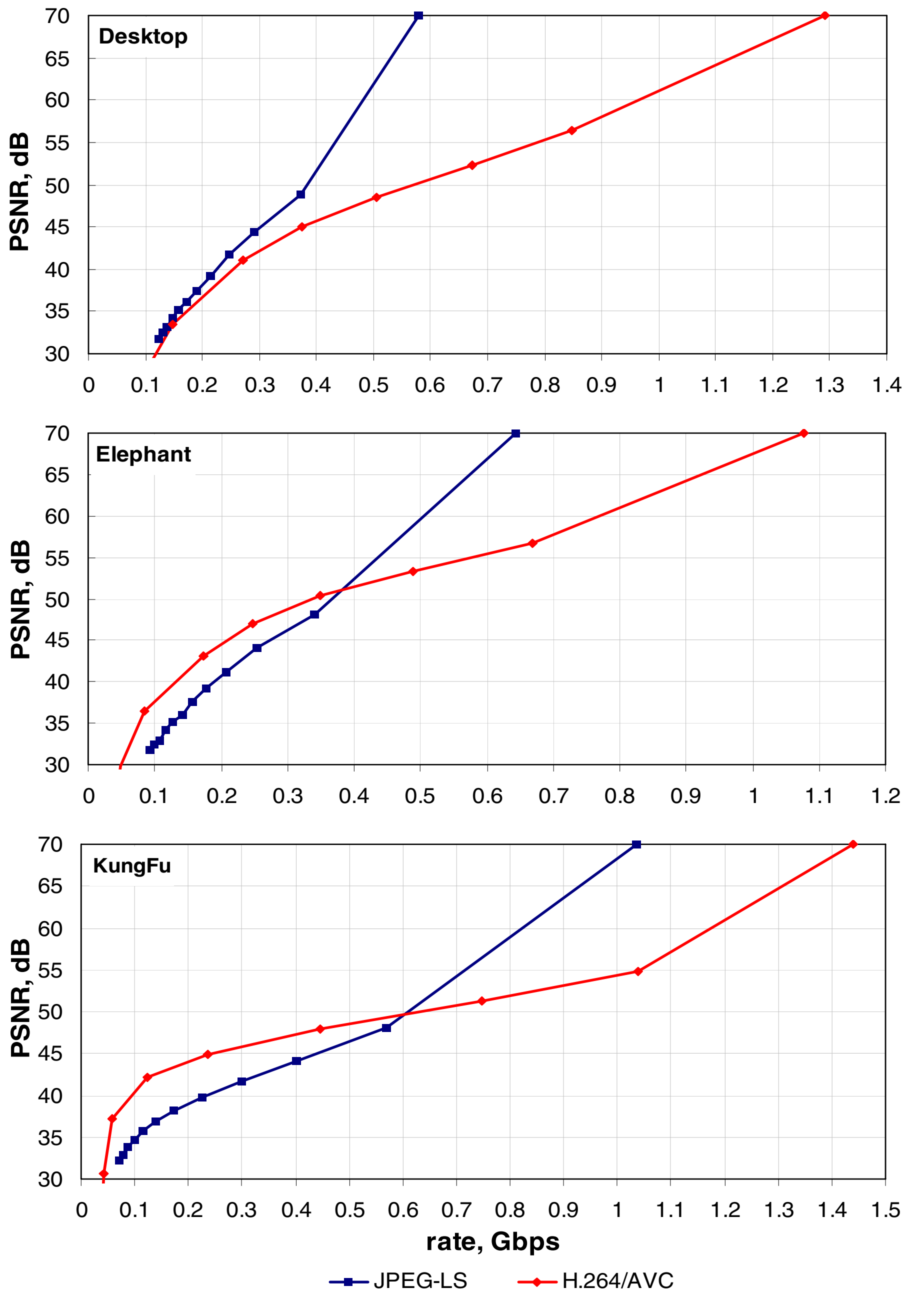

Fig. 2. Rate-Distortion function of JPEG-LS (*square marks*) and H.264/AVC (*diamond marks*) compression algorithms for video sequences “Desktop”, “Elephant” and “KungFu”

3.3 H.264/AVC Based Compression

The smallest possible configuration of the H.264/AVC encoder for the lossy compression mode (quantization parameter QP = 1 - 51) consists of the following operations:

- RGB to RCT color space transform
- Intra DC-prediction
- 4x4 DCT and 4x4 IDCT
- Scalar quantization.
- Intra/IPCM decision algorithm
- Context-based Adaptive Variable Length Coding.

For absolutely RGB-lossless compression mode (QP = 0) the same blocks are used except for DCT/IDCT and scalar quantization that are omitted. The best color space transform was chosen similar to JPEG-LS approach. To provide the average compression ratio more or equal than 1.0 we propose additionally using IPCM macro-block type (for acceptable processing of the video signals with noise).

As the result for HD picture size and 60 frames per second rate, we were able to design and implement in RTL the encoder with total power consumption of ~20mW working at 150MHz clock rate. TSMC 60nm technology was used.

3.4 Compression Efficiency

In this section, we present the simulation results obtained with 3 test image sequences: “Desktop”, “Elephant” and “KungFu”. The first test corresponds to computer desktop working: running office applications (MS Visio and Paint), dragging windows. The sequence was captured directly from the PC display driver. The second test is a small fragment of the cartoon “The Elephant Dreams”. Because the cartoon is synthetic (i.e. created without cameras), there are no noises in the frames. The last test “KungFu” is a small fragment from a natural video with motion and camera noises. The simulation result curves below show the best combination of the encoding mode, colorspace transform and subsampling scheme for the corresponding compression algorithm used. Below in the graphs 70dB PSNR means the infinity, i.e. absolutely RGB-lossless quality, all other PSNRs are real peak signal-to-noise ratios obtained in the simulations. One can see that JPEG-LS shows better results for higher rates that are closer to the point of lossless coding while H.264/AVC is better for low rates.

4 Estimating Power Consumption for NGmS Transmission

In this section, we apply the power-rate model proposed in section 2 for estimating power consumption of the real wireless video compression and transmission system. We consider the power consumption of the wireless video cable replacement chip that uses either JPEG-LS or low-complexity H.264/AVC compression and NGmS transmission taking into account the power consumption of the whole system.

The power consumption targets for 60GHz NGmS wireless transport (MAC and PHY together) are as follows:

Idle State. $P_0 = 0.3$ i.e. zero transmission rate consumes 300mW.

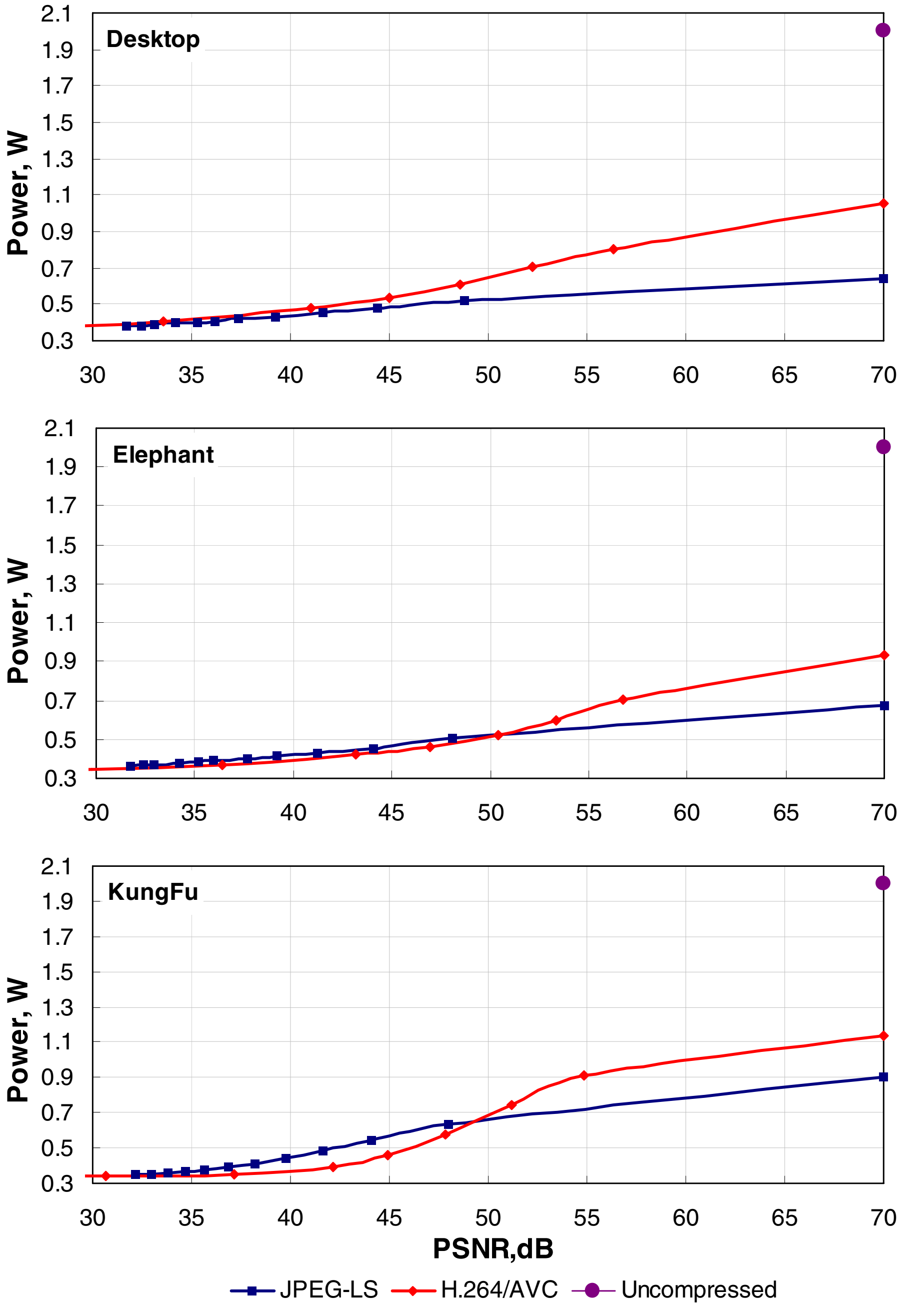

Fig. 3. Power-Quality function estimated for NGmS video transmission system using JPEG-LS (*square marks*) and H.264/AVC (*diamond marks*) encoders. The level of power consumption for uncompressed video transmission is also shown (*circular mark*).

Maximum Transmission State. $P_{\max} = 2$, $R_{\max} = 3$ i.e. max 3Gbps rate consumes 2W. Applying the given parameters to the equations obtained in section 2 we have

$$P_{Transmitter}(R) = 0.57 \cdot R + 0.3 \quad (4)$$

Basing on the unit RTL synthesis the power consumption of the schemes described above is ~10mW for JPEG-LS based solution, and ~20mW for low complexity H.264/AVC based solution. One can see that the level of power consumption for the both encoders is less than the limit defined by equation (3).

The average compression ratio of JPEG-LS in lossless mode is more than 3 times. It leads to average power gain more than 2 times (1.2 watts) in comparison with uncompressed video transmission system. Average power consumption of transmission scheme based on low-complexity H.264/AVC encoder is less than uncompressed approach by 0.9 watts.

It is important to note that all the measurements and estimations are done for HDTV resolution and frame per second rate. In case of lower resolution the absolute gain for video transmission systems will decrease.

Additional reduction of transmission power consumption can by obtained by using of lossy video compression which provides necessary power-quality trade-off.

The total power consumption of transmission and compression is presented in the Fig. 3. PSNR=70 dB corresponding to absolute RGB-lossless visual quality.

5 Conclusion

In the paper, we have presented a way to decrease the power consumption of the video transmission over 60GHz wireless by using low complexity lossless and lossy compression. In section IV, we show that for absolutely lossless video delivery the power consumption of joint compression and transmission can be 2 times lower than that of uncompressed video transmission, for lossy compression modes the power consumption gain can be as high as 5 times.

The low complexity compression schemes proposed can be used as for the remote wireless display connection as for multimedia data exchange among different handhelds, because they can provide both lossy and lossless quality.

The lossy options of the schemes were considered because the primary gain of compression usually is the radio spectrum efficiency. Using the compression we always save some bandwidth. This fact will also be useful in the future when the wireless video coexistence issues will be raised. Having the adaptive video compression option enabled in 60GHz wireless chips will make possible the quality-bandwidth trade-off if the network capacity is too small for the given number of users in it.

The power consumption gain is not the only advantage of the compression, it may also improve the end-to-end video delivery latency. Nevertheless the compression scheme itself consumes some time budget, but after compression the data amount to transmit becomes smaller, and the network utilization decreases. Having the multi-user network with MAC layer collision detection or scheduling, the lower is the stream size, the smaller is the end-to-end networking delay.

The task for the future research is to consider the delay gains with and without compression with some 60GHz network model (PHY-MAC level).

References

1. WirelessHD® Consortium, http://wirelesshd.org/
2. IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANS), Task Group 3c, Millimeter Wave Alternative PHY, http://www.ieee802.org/15/pub/TG3c.html
3. ISO/IEC JTC 1/SC 29/WG1 FCD 14495-public draft, JPEG-LS: lossless and near-lossless coding of continuous tone still images (July 16, 1997)
4. ITU-T. Recommendation H.264 and ISO/IEC 14496-10 (AVC). Advanced video coding for generic audiovisual services (2007)
5. Cover, T.M., Thomas, J.A.: Elements of Information Theory. Wiley Series in Telecommunication. John Wiley & Sons, New York (1991)
6. Li, Z., Zhai, F., Katsaggelos, A.K.: Joint Video Summarization and Transmission Adaptation for Energy-Efficient Wireless Video Streaming. EURASIP Journal on Advances in Signal Processing, special issue on Wireless Video (2008)
7. He, Z., Liang, Y., Chen, L., Ahmad, I., Wu, D.: Power-rate-distortion analysis for wireless video communication under energy constraints. IEEE Transactions on Circuits and Systems for Video Technology 15, 645–658 (2005)
8. Weinberger, M.J., Seroussi, G., Sapiro, G.: The LOCO-I lossless image compression algorithm: Principles and standardization into JPEG-LS. IEEE Trans. Image Proc. Available as Hewlett-Packard Laboratories Technical Report No. HPL-98-193 (2000), http://citeseer.ist.psu.edu/weinberger00locoi.html
9. Cruz, D.S., et al.: An analytical study of JPEG 2000 functionalities. In: Proceedings of SPIE, vol. 4115 (2000)
10. ITU-T and ISO/IEC JTC 1, JPEG 2000 Image Coding System: Core Coding System, ITU-T Recommendation T.800 and ISO/IEC 15444-1, JPEG 2000 Part 1 (2000)
11. ISO/IEC 13818 (MPEG-2): Generic coding of moving pictures and associated audio information (November 1994)
12. Wu, X., Memon, N.D.: Context-based, adaptive, lossless image coding. IEEE Trans. Commun. 45(4), 437–444 (1997)
13. Malvar, H., Sullivan, G.: YCoCg-R: A Color Space with RGB Reversibility and Low Dynamic Range. Joint Video Team (JVT) of ISO/IEC MPEG & ITU-T VCEG proposal JVT-I014r3 (2003)