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Optimization of high-definition video coding and hybrid fiber-wireless transmission in the 60 GHz band

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Abstract: We demonstrate that, by jointly optimizing video coding and radio-over-fiber transmission, we extend the reach of 60-GHz wireless distribution of high-quality high-definition video satisfying low complexity and low delay constraints, while preserving superb video quality.

OCIS codes: (060.2330) Fiber optics communications; (060.5625) Radio frequency photonics.

1. Introduction

The motivations for this work are three-fold. First, the unprecedented frequency band around 60 GHz (from 4 to 9 GHz within 57-66 GHz) has been regulated for unlicensed use in a number of countries around the world. Second motivation is the introduction of high quality video services such as high definition (HD) video conferencing and distributed video gaming. These services define both the demand on increased data rates in the access networks and need for optimization of video compression schemes. Third, efficient convergence of wired and wireless technologies is required to enable a concept of “anytime anywhere” wireless connectivity. Radio-over-fiber (RoF) is widely considered a promising example of such integration for optical networks [1].

Previous research in the area of 60 GHz RoF video transmission suggests the use of uncompressed video [2, 3]. The main drawback of this approach is reduced flexibility in terms of bitrate: bitrates are fixed depending on resolution, number of bits per pixel, and frame rate of the video sequence. This therefore results in extremely complex adaptation of the HD video system to significant signal-to-noise ratio (SNR) drops caused by severe attenuation for extended wireless distances.

Source coding (compression) gives us desired flexibility of bitrate but at expense of introducing delay and increase of power consumption. However, there is a trade-off between the power needed to radiate larger bandwidth for uncompressed video and the power consumed for the computations of an encoder and a decoder for compressed video transmission. According to [4], low complexity compression can, in fact, bring about reduction in power consumption for a 60 GHz wireless video transmission system compared to the uncompressed case, while at the same time keeping delay under the acceptable limit.

In this work we explore the notion of joint optimization of physical layer parameters of a RoF link (power levels, distance) and the codec parameters (quantization, error-resilience tools) based on peak signal-to-noise ratio (PSNR) as an objective quality metric. We experimentally demonstrate, for the first time to our knowledge, the combined optical access and wireless transmission of compressed HD video in the 60 GHz band employing simple envelope detection technique with extended reach up to 2 m preserving PSNR above 45 dB.

2. Experimental setup

The experimental setup of the 60 GHz optical-wireless RoF system is shown in Fig. 1(a). The binary sequence corresponding to compressed video file was uploaded to an arbitrary waveform generator (AWG). The non-return-to-zero (NRZ) electrical signal on the output of the AWG directly modulated a 1550 nm distributed feedback (DFB) laser. After the baseband data modulation, frequency up-conversion to the 60 GHz band was performed by driving a Mach-Zehnder modulator (MZM) biased at the minimum transmission point with a 30 GHz sinusoidal signal. A polarization controller (PC) was used before the MZM to minimize its polarization-dependant losses. After the MZM, two sidebands with a frequency spacing of $2f_{LO}$ were generated according to the optical carrier suppression intensity modulation scheme, as shown in Fig. 1(b). Optical carrier suppression of approximately 13.6 dB is achieved limited by the MZM extinction ratio. The generated sidebands have the same optical power (see fig. 1(b)) and the locked phase. Subsequently, an Erbium doped fiber amplifier (EDFA) is employed to compensate the losses, and an optical band pass filter (OBPF) is used afterwards to mitigate the amplified spontaneous emission (ASE) noise produced by the EDFA. Then the signal is launched into a 20 km span of non-zero dispersion shifted fiber (NZDSF). We employ the NZDSF in order to minimize dispersion induced impairments. A variable optical attenuator (VOA) is employed to control the optical power impinging the photodiode (PD) in order to evaluate BER performance of the system as a function of the received optical power.

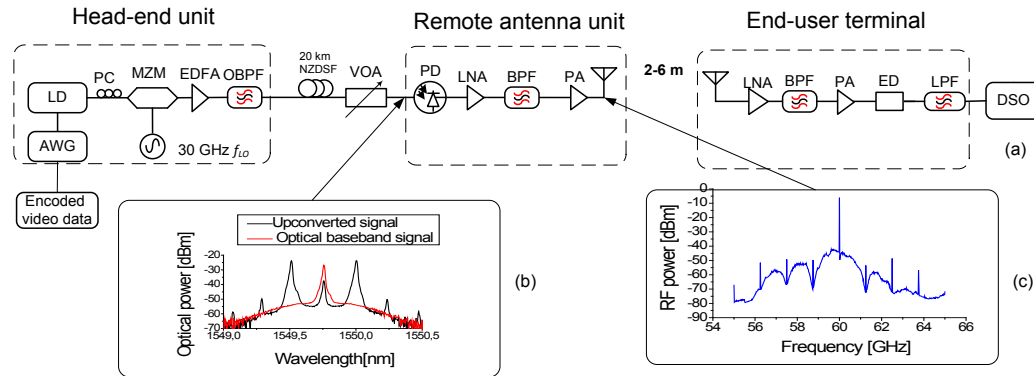


Fig. 1 (a) Experimental 60 GHz optical-wireless RoF system with envelope detection, LD-laser diode, PC-polarization controller, MZM-Mach-Zehnder modulator, LO-local oscillator, EDFA-Erbium doped fiber amplifier, OBPF-optical band pass filter, PD-photodiode, LNA-low noise amplifier, PA-power amplifier, BPF-band pass filter, ED- envelope detector, LPF-low pass filter, DSO-digital sampling oscilloscope. (b) The optical spectrum before the PD. (c) The electrical spectrum after the PD.

After photodetection the 60 GHz signal was amplified (gain of amplifiers – 16 dB and 28.7 dB) and filtered (58.1-61.9 GHz) before feeding it to an antenna for up to 6 meters of wireless transmission. The measured electrical spectrum of the 60 GHz signal to be radiated is shown in Fig. 1(c). After receiving the signal with an antenna and following filtering (58.1-61.9 GHz) and amplification (gain of amplifiers – 16 dB and 28.7 dB) envelope detection was employed for down-conversion. The detected envelope is low-pass filtered and digitized by a digital sampling oscilloscope (DSO). Both the transmitting and receiving antennas used throughout the experiment are commercially available horn antennas with 20 dBi gain and 12° beam width.

The encoding was performed using the Joint Model (JM) 17.0 implementation of the H.264 codec [5]. It is a realistic scenario since H.264 is one of the latest industrial video coding standards covering a wide range of applications, including, coding for transmission over wireless links and HDTV coding [6]. An Intra coding mode (the coding is performed frame by frame) only and a frame slicing mechanism were employed to achieve the low delay requirement. Both mechanisms are improving the error-resilience as well. Slicing was performed with the use of flexible macroblock ordering (FMO). [6]

H.264 is not capable of coping with the single-bit errors: its mechanisms of error-resilience on the encoding side and error concealment on the decoding side are adjusted to cope with packet loss when the packets affected by the errors are discarded such as usually occurs in networks. Packet error rate (PER) depends on bit error rate (BER) and a size of the packet; in general, the noisier the transmission the shorter length of the packet that is desirable. We used a packet size equal to 2500 bytes, each packet containing a slice of the frame. The uncompressed HD test video sequence ‘blue sky’ was used for encoding and transmission. The sequence was originally shot in 4:2:0 format 8 bits per color 1920 × 1080 pixels. However, in order to model the most bitrate demanding case upsampling to 4:4:4 format was performed (uncompressed bitrate – 3 Gbps for the frame rate of 60 frames per second).

We use PSNR as an objective quality metric for video, which is defined as:

$$\text{MSE} = \frac{1}{N} \sum_{i=1}^N (x_i - y_i)^2. \quad (1)$$

$$\text{PSNR} = 10 \log_{10} \left(\frac{L^2}{\text{MSE}} \right). \quad (2)$$

Where MSE stands for mean squared error, N is the number of pixels in the image or video signal, and x_i and y_i are the i -th pixels in the original and the distorted signals, respectively. L is the dynamic range of the pixel values. For an 8 bits/pixel signal, L is equal to 255. PSNR is evaluated for the luminance component of the transmitted video signal.

3. Results and discussion.

Our goal for optimization is to achieve the best video delivery quality for a given link budget. With regards to the role of the quantization of transform coefficients of the coded video in the optimization, roughly speaking, the smaller the quantization step size, the smaller the source distortion (loss due to compression), but the larger bandwidth is occupied by the signal, and as a result BER is increased. In the experiment we explored two cases. First, the chosen test video sequence (‘blue sky’ 4:4:4) was encoded with a bitrate of 312.5 Mbps. Second, the tested video sequence was encoded in a near-lossless case with the quantization parameter equal to 1, which gave us a compression ratio of 3.

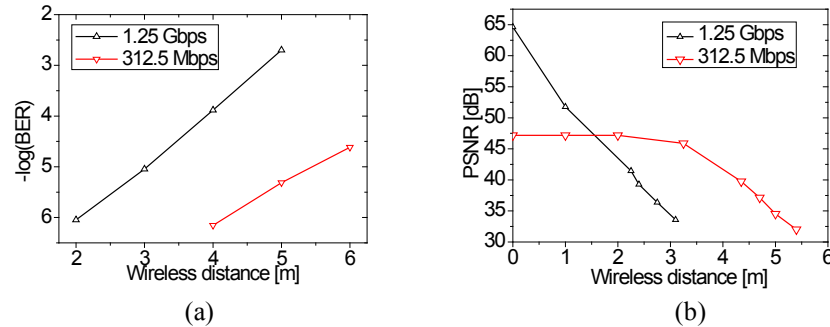


Fig. 2. BER (a) and PSNR (b) performance as a function of the wireless distance.

On the Fig. 2(a) BER at the power level at the photodiode equal to -10 dBm as a function of the wireless distance is depicted. From the Fig. 2(a) we can see that in general the distortion induced by the wireless channel is severe in our system, but video coded with use of higher quantization parameter has greater dynamic range of the wireless distance, as shown in Fig.2(b). The distance equal to 0 corresponds to the distortion introduced by the compression only. When we increase the wireless distance, in the beginning, the source distortion is dominant, and the use of lower quantization parameter is reasonable. Anyhow, we lose the advantage of lower source distortion (compression) after around 1.5 m of transmission when video is evaluated based on the PSNR metric only. We therefore can extend the distance by around 2 m compared to higher bitrate. We obtain similar curves for changing optical power level at the photodiode at 5 m of wireless distance, as shown in Fig. 3. With higher video compression we can work at lower optical power levels. This shows the potential of optimization of the power budget of the system under the constraint of video quality. At the same time, we should note that video quality is high in both cases, and the deterioration induced by compression itself can be regarded as not significant (PSNR of the video unimpaired by the channel is higher than 45 dB in both cases).

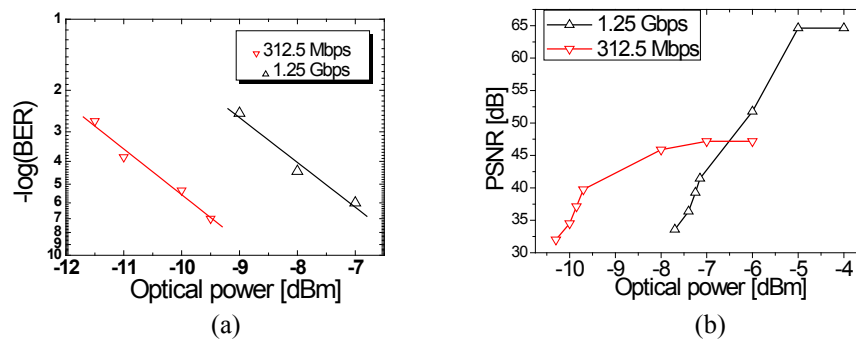


Fig. 3. BER (a) and PSNR (b) performance as a function of the optical power at the photodiode.

4. Conclusions.

We showed the extension of the wireless distance for 60 GHz RoF system with the use of low-complexity video coding and simple envelope detection scheme. Our experiment vividly demonstrates a trade-off between the distortion introduced by the source (lossy compression) and the distortion introduced by the channel for video transmission over the 60 GHz RoF optical-wireless access links. This demonstrates the potential for future joint source-channel optimization for RoF systems.

5. Acknowledgement

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