On the Use of Hierarchical Modulations for Robust Video Transmission over Power Line Medium

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***Abstract*— Real time transmission of compressed video data over power line channels is a challenging task because of the severe characteristics of the power line transmission medium. Several techniques have been investigated recently to make a compressed video bitstream robust to the channel distortions. In this paper, we consider the benefit of using hierarchical transmission for error resilience. We propose an original video transmission scheme based on layered video coding combined with unequal error protection. Here, unequal error protection is achieved using a hierarchical multi-carrier modulation scheme based on hierarchical quadrature amplitude modulation. In particular, we propose a hierarchical bit and power allocation algorithm specific to hierarchical MCM. Some simulation results are presented to show the interest of applying unequal error protection by hierarchical coding of layered video bitstreams.**

***Index Terms* — Power line communications, multimedia transmission, layered video coding, Data Partitioning, Unequal Error Protection, Hierarchical modulation, bit and power allocation.**

I. Introduction

POWERLINE Communication (PLC) technology offers nowadays a great opportunity for the development of multimedia communication in home networks, by using the existing household electrical power wiring as transmission medium [1,2]. Several applications are concerned including video surveillance, videoconferencing, games or video on demand (VoD). However, the powerline channel exhibits severe characteristics in terms of frequency selectivity as well as interference, which may strongly affect the quality of service (QoS) level of video services. Different techniques are currently used in order to overcome these problems, including forward error correction (FEC), data interleaving, or automatic repeat request (ARQ). In this paper, we propose to study the benefit of using hierarchical transmission to optimize the received video quality within the framework of digital video delivery using PLC technology. In order to obtain high data rates, Multi-Carrier Modulation (MCM) is used as the basic transmission technique [3]. The first part of the communication system consists in a bi-resolution video encoding scheme based on the data partitioning (DP) mode available in the most recent video coding standards. The compressed video bit stream is divided into a base layer (BL) containing the most significant data, and an enhancement layer (EL) containing high-frequency detail information. Then, the two corresponding video bit streams are transmitted by using hierarchical multi-carrier modulation, also called Embedded Multi-Carrier Modulation (EMCM) [4], in order to achieve unequal error protection (UEP). The hierarchical MCM is realized using hierarchical quadrature amplitude modulation (QAM) on each sub channel associated with a specific bit and power loading algorithm.

The paper is organized as follows. First, the characteristics of the power line channel are described. Then, the different parts of the proposed video communication system are described in detail: the Data Partitioning layering technique as well as EMCM, which are jointly applied to provide UEP. In particular, a specific bit and power allocation method is proposed for hierarchical MCM. Finally, simulation results are presented in order to illustrate the interest of the proposed approach in terms of robustness to powerline channel distortions.

II. Characteristics Of The Powerline Medium

The powerline channel can be considered as a heterogeneous communication network made of a variety of conductor types connected to different loads of varying impedance [5]. The corresponding frequency response is selective and severely disrupted, and generally presents notches in the frequency range of 0-25 MHz as illustrated in Fig. 1. The powerline medium is also affected by interferences and noise. In particular, electric appliances connected to the powerline network generate impulsive noise that can strongly disrupt data communication.

Finally, the channel can also exhibit sudden variations with time as the load of the network changes. We have performed experimentations on our laboratory's in-door electrical supply network to characterize this particular phenomenon. A simple sinusoidal waveform is transmitted from one electrical plug to another through coupling units, and the received signal is measured while electric appliances connected to the electrical network being switched on/off, plugged or unplugged. An example of measurement result is reported in Figure 2. We note that two stationary states characterized by a constant channel response exist. They are separated by transitory phases of varying length. The corresponding channel can be considered stationary piecewise with sudden changes; these changes can be detected and the erroneous symbols received during this phase can be retransmitted when the channel will be in a stationary state again [6].

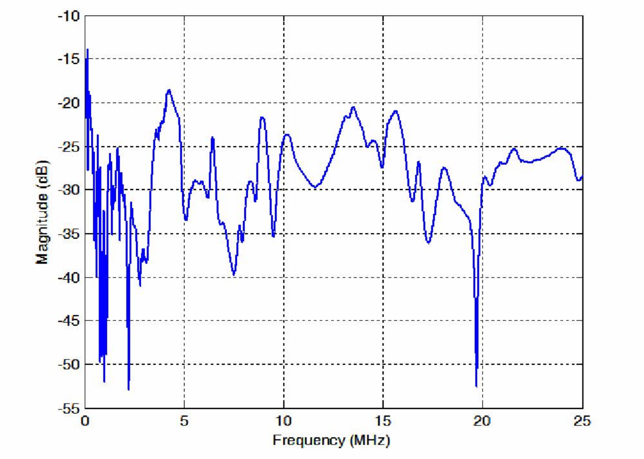

Fig. 1. Power line channel frequency response

Several well-known channel coding techniques have been integrated in powerline networking technology to overcome these problems and provide standard PLC video networks using MPEG compression [7, 8]. These techniques include:

- channel adaptation,
- pilot assisted modulation (PAM) [9],
- Viterbi and Reed-Solomon FEC, and more recently Turbo encoding [10],
- Scrambling and data interleaving,
- ARQ process.

In practice, the Physical Layer (PHY) of powerline communication systems generally uses a MCM scheme and a concatenation of these techniques, to ensure that the information is reliably transmitted at high data rates [11]. We propose in this paper to introduce hierarchical modulation in the conventional MCM scheme as a supplementary tool in order to further increase robustness to transmission errors.

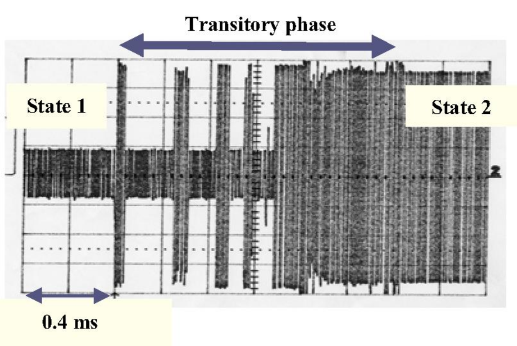

Fig. 2. Measurement of variations due to a sudden change of channel characteristics [9].

Hierarchical transmission is considered here in the specific context of layered video delivery over power line medium. In the next section, we briefly describe the DP mode as an effective video layering technique for applying UEP.

III. Layered Video Coding Based on Data Partitioning

In layered video communications, the transmitted video signals can be decomposed into several data streams with different informational significance [12]. Then, UEP can be applied to these data streams in order to guarantee minimal QoS level. Different robust video coding methods have been developed recently to increase the robustness to channel errors by allowing UEP [13-15]. Among these, DP is an effective layering technique that splits the compressed bit stream into separate streams of different importance. Digital video coding standards like MPEG-2 or H.264/MPEG-4 AVC authorize the use of DP [16]. In what follows, we consider the case of MPEG-2 video coding; the proposed scheme can be extended to H.264.

The main MPEG-2 bit stream is partitioned into two separate streams: the BL containing the most important data (headers, motion vectors, low frequency coefficients) and the EL containing high-frequency detail information. The BL corresponds to a single-decodable video bit stream. When decoding only BL, the image quality remains acceptable, providing a minimum QoS level. In practice, a so-called priority break-point (PBP) is defined which determines the number of non-zero DCT coefficients present in the BL. The PBP value ranges from 64 (DC coefficient + one VLC corresponding to the first non-zero AC coefficient) to 127 (all DCT coefficients in the BL). The higher the PBP is, the better the video quality of the BL is. Figure 3 represents the average repartition of the total video bit rate between BL and EL, as a function of the PBP value, for MP@ML MPEG-2 video streams compressed to 6 Mbps. We can note that the bit rate corresponding to the BL is at least equal to 2.8 Mbps, i.e. 47% of the total bit rate. This corresponds to the minimum data rate necessary for decoding of the video signal at the receiver. We can also verify that most of video energy is concentrated in few low-frequency DCT coefficients.

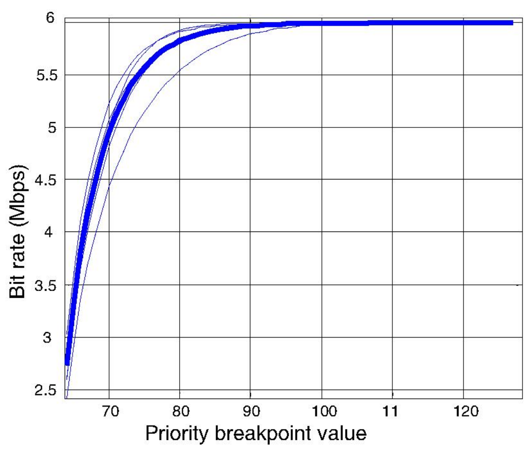

Fig. 3. Evolution of the BL bit rate as a function of the PBP value.

Once the compressed data have been partitioned into separate bits streams, these streams have to be transmitted using different priority levels: a high priority (HP) level for the BL resulting in quasi error-free transmission, and a low priority (LP) level for the EL. Such UEP is realized via the use of hierarchical QAM in a MCM scheme, which constitutes the main contribution of this paper.

IV. Description Of The Hierarchical MCM Scheme

As mentioned in Section II, MCM is the basic transmission technique used by most recent PLC communication systems. The idea of MCM is to divide the total bandwidth into several narrow-band independent sub-channels, each channel being considered as an AWGN channel. Then, QAM can be independently applied to each sub-channel with varying modulation density depending on the channel characteristics. In order to realize layered video transmission, we propose here to modulate each sub-channel using hierarchical QAM [17], so that the high priority and low priority bits are transmitted together over the same sub-channel with different levels of protection.

A. Hierarchical QAM

The principle is to transmit high priority and low priority bits in a single QAM symbol. Figure 4 shows an example of hierarchical QAM constellation. Here, HP bits are assigned to the clouds and the LP bits to the satellites. The distances d_1 and d_2 are unequal and are adjusted to meet the desired BERs.

In what follows, we consider the use of hierarchical N/M QAMs, with $N = 2^n$, n being equal to the number of HP bits, and $M = 2^{m+n}$, m being equal to the number of LP bits. The parameters n and m can take odd or even values. In the latter case, we consider as a first approach that the N/M QAM corresponding constellations are rectangular. By varying the parameter $\lambda = d_2/d_1$, we can increase the robustness of the HP bit stream compared to the EL one. A complete analysis of the performances of the HQAM is proposed in [18].

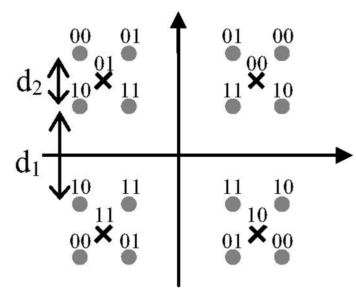

Fig. 4. Example of a 4/16 hierarchical QAM constellation.

B. Hierarchical Bit and Power Loading Algorithm

One of the main interests of MCM is that bit and power loading algorithm can be used to optimize the transmission after channel estimation. Different optimization techniques can be defined: we propose here to minimize the total transmit power for given BL and EL bit rates (R_H and R_L, respectively), and targeted BL and EL BERs (B_H and B_L, respectively). This choice is well suited to practical video applications. Indeed, the BL and EL throughput rates are fixed *a priori* by the encoding parameters of the hierarchical video encoder, so that it is difficult to adjust them. Similarly, the QoS levels are fixed according to the application constraints.

We now develop the bi-resolution allocation method. We have first studied this method in the context of ADSL transmission [19], but it can be extended to the case of PLC technology. The allocation method is based on the Hughes-Hartogs algorithm and applies in two consecutive steps. First, bits and power are allocated to the HP bits accounting for the high-priority constraint. Then, the second step consists of the power and bit loading of the LP bits over the HP bits in a "best effort" way.

The flow chart of the hierarchical bit and power allocation is given in Fig. 5, where k is the sub channel number, n_k and m_k are respectively the number of base information and refinement information bits per sub channel, P_k is the power allocated per sub channel and P_T is the total power from the allocation.

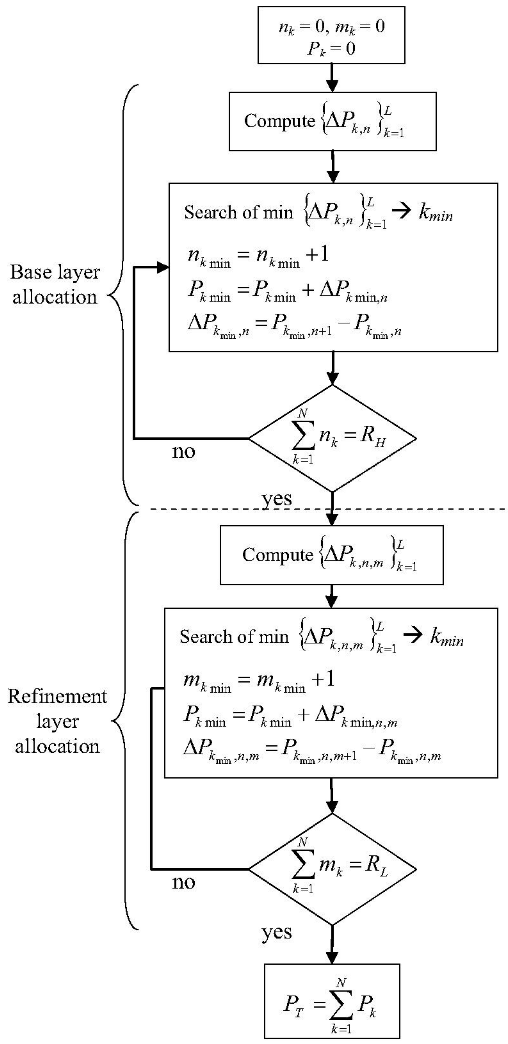

Fig. 5. Flow chart of the proposed hierarchical allocation method [19].

We note R_H and R_L the transmission rates for BL and EL, respectively. The symbol error rates for both BL and EL are considered to be independent of the sub-channel number, and are directly obtained from the BH and BL values. The proposed loading algorithm is based on the values of sub-channels frequency gain and noise power, which are obtained after channel estimation. It leads to the most appropriate sub-channel-to-layer assignment as follows:

- BL bits are assigned in an iterative way to the different sub-channels for the given BER B_H: one bit is added to the sub-channel with minimum additional power increase, until R_H is achieved.
- EL bits are then allocated in the same manner for the given BER B_L under R_L rate constraint.

V. Simulation Results

In this section, we illustrate the interest of the proposed hierarchical MCM scheme for digital video delivery using PLC technology. We consider that the total frequency bandwidth of 0-25 MHz is divided into several bands of about 1,5 MHz each, and different video services are simultaneously transmitted over the different bands. Another realistic scenario is to consider that the same video signal is transmitted simultaneously on several frequency bands in a redundant way, in order to over protect compressed video data.

In order to guarantee a minimum QoS level, BL transmission needs to be quasi error-free. To do that, hierarchical MCM is combined with a channel error correction module. The PBP value was fixed to 66. This corresponds to a good compromise between video quality of the BL, and R_H/R_{TOT} ratio (approximately 66% for a video sequence encoded at R_{TOT} = 6 Mbps). Reed-Solomon encoding with parameters (255,239) is applied on the BL, and the RS-encoded stream is transmitted with a B_H requirement equal to 10^{-6}. That corresponds to a B_H lower than 10^{-11} after RS decoding. Thus, only the low-priority EL stream is concerned with channel errors. The B_L parameter value is fixed to 10^{-3}.

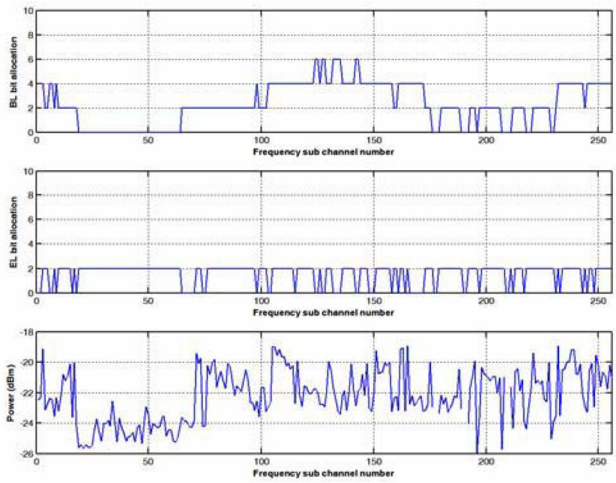

Fig. 6. Results of hierarchical bit and power allocation (from top): BL bit allocation, EL bit allocation, and power.

Figure 6 shows the result of applying our hierarchical power and bit allocation method. The measured channel frequency response shown in Fig. 1 was used to model the power line medium in order to take into account realistic channel conditions. We consider a limited frequency band ranging from 4.7 to 6.25 MHz. The power spectral density of noise is represented in Figure 7. The proposed hierarchical MCM minimizes the transmitted power under the (R_H, R_L) data rate and (B_H, B_L) BER requirements. We verify that the resulting allocation reflects the well-known water-filling principle: more bits are allocated to the sub carriers with lowest noise power characteristics. We have compared our algorithm with the one given in [20], which is known to be optimal. We verify that our loading algorithm gives quite similar performances with negligible power increase (less than 0.02 dB) as it is better suited to video transmission applications.

Finally, we illustrate the interest of the proposed hierarchical transmission scheme from an image quality point of view. As mentioned previously, channel errors will affect the EL data stream. The presence of erroneous bits in the EL may have different visual effects due to the characteristics of variable length encoding, ranging from local block mismatches to complete synchronization loss when decoding the bit stream. In this later case, complete slices are generally lost, because the synchronization markers in MPEG-2 bit streams are start codes of slices. Thus, a bit error in a VLC affects the rest of the slice. In the present case, however, the proposed hierarchical system allows substituting the erroneous EL slices by the corresponding error-free ones in the BL. The visual quality of the EL lost slice is then the one of the error-free decoded BL slice thanks to UEP. This leads to a significant improvement of reconstructed video quality, as illustrated in Fig. 8. Hence, if there is sudden error in power line channel, our proposed system is effective because it can reconstruct the coarse-quality video when the channel condition is bad and the fine-quality video when the channel condition is good.

VI. Conclusion

In this paper, we have considered the benefit of using hierarchical MCM scheme associated to layered video coding in order to ensure UEP of multimedia communications over power line channels. In this context, we have proposed an original bit and power allocation dedicated to hierarchical MCM. Finally, simulation results were given in order to illustrate the interest of our proposed hierarchical transmission scheme. Hierarchical MCM is an efficient tool that provides the unequal priority control for communication channels. It can be combined with other channel coding techniques as well as other scalable video coding modes (SNR scalability) in order to develop robust transmission schemes for video communications over power line channels.

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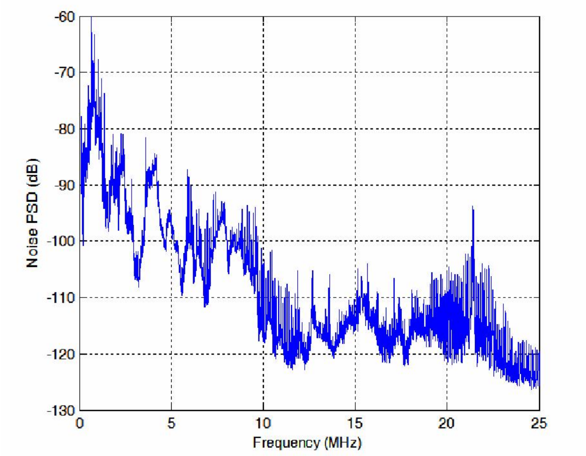
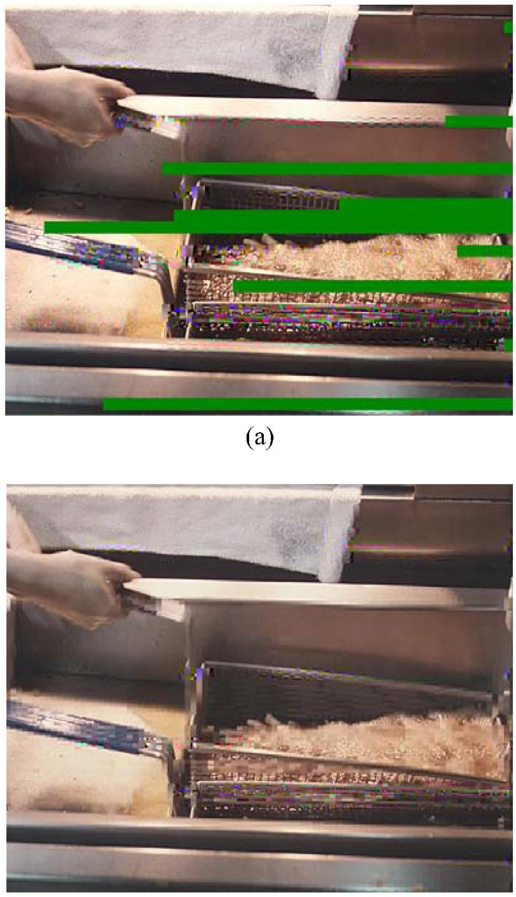


Fig. 7. Power spectral density of power line channel noise.


(a)

(b)

Fig. 8. Image quality of the reconstructed video after transmission in an error-prone environment: (a) conventional single-layered transmission scheme; (b) proposed hierarchical transmission scheme.