PARALLEL TRANSMISSION FRAMEWORK FOR LAYERED CODED MULTIMEDIA DATA OVER SPECTRALLY SHAPED CHANNELS

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ABSTRACT

This paper presents a new parallel transmission framework for reliable multimedia data transmission over spectrally shaped channels using multicarrier modulation. We propose to transmit source data layers of different perceptual importance in parallel, each occupying a number of subchannels. New loading algorithms are developed to efficiently allocate the available resources, e.g. transmitted power and bit rate, to the subchannels according to the source layers they transmit. Instead of making the bit error rate of all the subchannels equal as in most existing loading algorithms, the proposed algorithm assigns different error performance to the subchannels as to achieve unequal error protection for different layers. The channel induced distortion in mean-square sense is minimized. We show that the proposed system can be applied nicely to both fixed length coding and variable length coding. Numerical examples show that the proposed algorithm achieves significant performance improvement comparing to the existing work for spectrally shaped channels commonly used in in ADSL.

1. INTRODUCTION

Spectrally shaped channels are commonly used in asymmetric digital subscriber lines(ADSL)[1], a transmission system capable of realizing very high bit-rate services over existing telephone lines. Multicarrier modulation (MCM) [2] also referred is currently considered as a standard channel coding scheme for ADSL. MCM has elegant waveform properties that make it useful for a wide variety of applications. A crucial aspect in the design of MCM system is the need to optimize the system transmission bandwidth and power through an optimal loading algorithm. Each subchannel in MCM system has two variables: bit rate or modulation rate(number of bits per transmission, e.g. 4 for QAM16 and 6 for QAM64) and transmitted power. The loading algorithms in literature can be divided into two categories. Category one computes bit rate and power distribution for given bit error rate(BER)[2, 3, 4, 5]. Category two is based on minimizing the overall BER which reaching the data throughput under a power constraint[7]. The overall BER is unknown until the final stage of optimization. These algorithms are all constrained by the assumption that BERs are equal across the usable subchannels. To transmit multimedia data, such as image, video and audio through noisy channels, BER need not be very low to achieve adequate quality, and the channel induced distortion can not be ignored. Combined source/channel coding approaches in conjunction with scalable or layered source coding schemes can be used to minimize the overall distortion[8]. More specifically, source data can be decomposed into hierarchical perceptually relevant layers, each of which has different perceptual importance. Unequal error protection(UEP) for different layers achieves more robustness compared to equal error protection. It is well known that loading algorithms[2, 3, 4, 5, 7] are developed for data transmission. If we want to deliver layered coded multimedia data through spectrally shaped channels using these loading algorithms, the layers are transmitted consecutively with the same BER as shown in Figure 1 Type I, resulting in equal error protection. A combined source-channel coding scheme using MCM to provide unequal error protection for additive white Gaussian noise channel(AWGN) is developed in [6]. The number of subchannels used is decided by layer's codeword length. As such, the transmitter/receiver has to frequently update the transmission parameters including the number of subchannels, subchannel power and bit rate, which is not realizable.

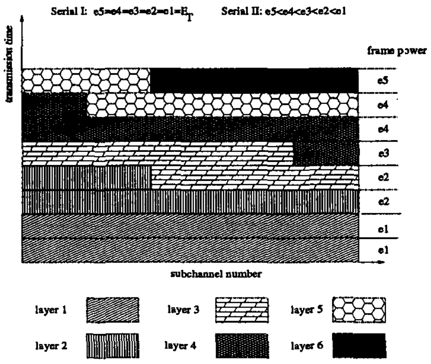

Figure 1: Serial Transmission

This paper aims to develop an efficient, powerful, yet simple scheme to transmit multimedia data through typical spectrally shaped ADSL channels. We consider fixed number of subchannels and data throughput, independent of source input data. Such assumption is different from the existing work [6] in which the above parameters are source dependent.

2. PARALLEL TRANSMISSION

Typically, the multimedia data layers are transmitted in consecutive order as in data transmission through spectrally shaped channels, namely serial transmission Type I as shown in Figure 1. The loading algorithm assigns the same BER to all subchannels by

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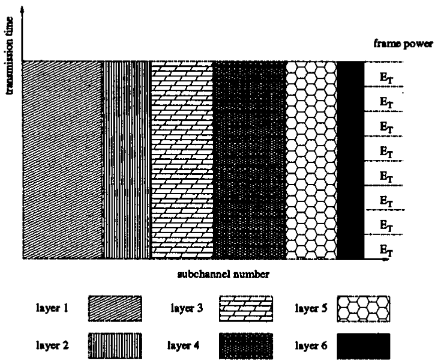

Figure 2: Parallel Transmission

adapting the power and bit rate, similar to that of [2, 4, 7]. Due to the fact that unequal importance exists among the layers, this type of transmission which achieves equal error protection is not optimal. We define the transmitted power sum over all the usable subchannels during a single transmission as frame power. Usually, larger frame power results in lower BER. Therefore, unequal error protection can be achieved in serial transmission by varying the frame power during each layer's transmission, shown in Figure 1 as serial Type II. Frame power distribution $\{e_m\}_{m=1}^{N}$ satisfies $e_i > e_j$ if layer i is more important than j. We describe this loading algorithm in detail later in 4.3. Since generally the layers differ greatly in bit data size and importance, the subchannel power and bit rate distributions during each layer's transmission period differ greatly. As such, frequent change of channel parameters during the transmission becomes one disadvantage of this approach.

The serial transmissions share the same criterion, namely during each single transmission, removing the difference in channel gain and noise variance, as well as assigning the same BER across the subchannels. This is still true for serial type II, although the BERs at a particular subchannel during two different transmissions may be different. In contrast, we believe that the existence of different channel gain and noise effect at different subchannels offers the potential for robust transmission, by considering the possibility of providing unequal error protection through optimally allocating the available communication resources. A combined layered coding and MCM would serve as a useful approach. Towards this, we propose to transmit the layers simultaneously, each occupying a number of subchannels, as illustrated in Figure 2. The transmission time of all the layers are forced to be the same so that the number of subchannels a layer occupying can be decided by the number of data bits of this particular layer as well as the data throughput required per transmission.

3. THE OPTIMIZATION PROBLEM

For layered image and video transmission, if applying vector quantization(VQ), the channel distortion can be approximated as $D_c = \sum_{m=1}^{N} P_m W_m$, where W_m represents the average distortion caused by a single bit error at layer m, deemed as the weighting factor of layer m. Usually, layers with high energy have larger weighting factor and therefore higher importance. P_m is the BER of layer m which is a function of power, bit rate and channel gain to noise ration(CGNR) of the subchannels assigned to layer m. Since the CGNR differs quite a lot at each subchannel, the assignment of subchannels to the layers has to be carefully designed to achieve maximum power efficiency. We want to assign the subchannels with higher CGNR to the layers of higher importance, as shown in Figure 3. Such assignment will ensure the most important layers are transmitted over reliable channels without large power usage. It becomes more advantageous under low power constraint. We sort the subchannel in increasing CGNR order, and the layers in increasing importance (weighting factor) order. Given the bit rate $\{R_m\}_{m=1}^{N}$, the number of subchannels that each layer needs can be computed as

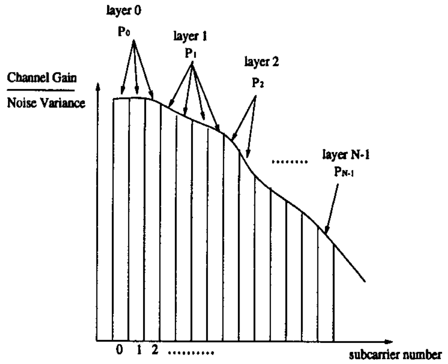

Figure 3: *Subchannel to Layer Assignment for Spectrally Shaped Channels*

$$c_m = \lfloor \frac{Bit_m B_T}{R_m Bit_{total}} \rfloor, \quad m = 1..M, \tag{1}$$

where Bit_m is the total number of bits of layer m, Bit_{total} is that of whole image and B_T is the number of bits that must be transmitted in every transmission. For given $\{R_m\}_{m=1}^{N}$, $\{c_m\}_{m=1}^{N}$ are adjusted until $\sum_{m=1}^{N} c_m R_m = B_T$. And for $m = 1$ to N, CGNR of the kth subchannel transmitting layer m as $G_{k,m} = g_{k+\sum_{n=1}^{m-1} c_n}, \quad k = 1..c_m$.

The algorithm developed in [7] is used to assign bit rate and power among the subchannels transmitting the same layer so that they perform at the same BER. We define $R_{m,T}$ as the number of bits of layer m per transmission, which can be decided by Bit_m and B_T. It can be shown that the error probability function of the subchannels transmitting layer m, using QAM modulation, is then

$$Pe \approx 4Q(\sqrt{\frac{3E_m G_m / c_m}{(2^{R_m} - 1)}}), \tag{2}$$

where $R_m = R_{m,T}/c_m$ is the averaged bit rate, $G_m = \frac{c_m}{\sum_{i=1}^{c_m} 2^{(R_{i,m} - R_m)}/G_{i,m}}$ is the averaged CGNR. Therefore, the optimization is for given $\{Bit_m\}_{m=1}^{N}, B_T$, find $\{E_m, R_m, c_m(R_m), G_m(R_m)\}_{m=1}^{N}$ to,

$$\text{Min} \quad D_c = \sum_{m=1}^{N} Pe(R_m, \frac{E_m G_m}{c_m}) W_m,$$

$$\text{subject to} \quad \sum_{m=1}^{N} E_m \le E_T, \quad \sum_{m=1}^{N} c_m \le C_T, \tag{3}$$

where E_T is the frame power constraint, C_T is the maximum number of subchannels allowed, and Pe is the BER function. For given $\{R_m\}_{m=1}^N$, $\{c_m\}_{m=1}^N$ are selected until the bit data rate constraint are satisfied. Therefore, the data rate constraint is turned into the number of subchannel constraint $\sum_{m=1}^N c_m \leq C_T$.

4. NEW LOADING ALGORITHM

Our goal is to develop a computationally efficient solution to the optimization problem (3). We start from power allocation for given bit rate distribution, then extend it to a complete loading algorithm for spectrally shaped channels.

4.1. Power Allocation

Assuming that all the subchannels use QAM modulations and the $\{R_m\}_{m=1}^N$ are preselected, (3) is simplified into

$$\text{Min} \sum_{m=1}^{N} 4Q\left(\sqrt{\frac{3E_m G_m}{c_m(2^{R_m}-1)}}\right)W_m,$$

$$\text{subject to} \quad \sum_{m=1}^{N} E_m \leq E_T. \tag{4}$$

By applying Lagrange multiplier, it can be shown that the optimal power distribution is $E_m = \Phi_{\alpha_m}^{-1}(\lambda_{opt}/W_m)$, where $\Phi_\alpha(x) = \sqrt{\frac{\alpha}{x}} exp(-\alpha x)$, $\alpha_m = \frac{3G_m}{2c_m(2^{R_m}-1)}$. And the λ_{opt} is the solution to $\sum_{m=1}^N \Phi_{\alpha_m}^{-1}(\lambda/W_m) = E_T$. Since $\Phi_\alpha(x)$ is a monotonic function of x for $\alpha > 0$, Φ^{-1} can be solved simply by bisection method.

4.2. Bit Rate and Power Allocation

The bit rate optimization is an integer programming problem. Usually the allowed bit rates are limited to the range $R_{min} \leq R_m \leq R_{max}$. Greedy search will go through all the $N^{R_{max}-R_{min}+1}$ $\{E_m, c_m\}_{m=1}^N$ computations, named as Algorithm C. We propose to start from $\{R_m = R_{max}, m = 1...N\}$ and approach the solution step by step, as described in Loading Algorithm A. Each step a layer is selected and the corresponding bit rate is reduced by one. This requires at most $N^2 \times (R_{max} - R_{min} + 1)$ $\{E_m, c_m\}_{m=1}^N$ computations.

Loading Algorithm A

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1. Initialization:
    (a) sort CGNR and the layers.
    (b) $R_m = R_{max}, m = 1..N$.
    (c) compute $\{E_m, c_m\}_{m=1}^N$ and $D_c$ .
    (d) $D_c^{min} = D_c, n = 0$.
2. Approach the solution: pick one layer, which yields minimum $D_c$, by reducing the bit rate by one.
    (a) $D_c(0) = D_c^{min}, n = n + 1$.
    (b) for $l$=1 to $N$
        i. $\{R_m^n\}_{m=1}^N = \{R_m^{n-1}\}_{m=1}^N, R_l^n = R_l^n - 1$.
        ii. compute $\{c_m, E_m\}_{m=1}^N$ and $C = \sum_{m=1}^N c_m$
            $D_c(l) = \begin{cases} \sum_{m=1}^N W_m Pe(R_m, E_m), & C \leq C_T \\ +\infty, & C > C_T \end{cases}$
        loop end.
    (c) find k=arg $\min_{l=0..N} D_c(l)$.
    (d) if $k > 0$   $R_k^n = R_k^n - 1, D_c^{min} = D_c(k)$.
        else $k = 0$,   → can not reduce $D_c$ anymore. Stop!
3. Continue 2 until $\{R_m\}_{m=1}^N = \{R_{min}, ..., R_{min}\}$ or reach Stop!.
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After changing any R_l, the whole $c_m, m = 1...N$ instead of c_m itself has to be rearranged to satisfy $\sum_{m=1}^N c_m R_m = B_T$. Thus, $C = \sum_{m=1}^N c_m \leq C_T$ has to be checked every time. In [11], we also proposed another simple scheme to pick the right layer, with only one $\{E_m\}_{m=1}^N$ computation, defined as Algorithm B.

4.3. Serial Loading Algorithm D

We develop a loading algorithm for serial transmission Type II as shown in Figure 1. We use the loading algorithm in [7] to achieve consistent BER performance among the subchannels. The frame powers during each layer transmission are allocated to provide different BER performance for different layers. Let the frame power during layer m transmission be e_m and the number of transmission layer m need be t_m. Assume C subchannels are used. It is possible that data from two or more layers are transmitted together. From the above assumption, the optimization function is as following:

$$\text{Min} \sum_{m=1}^{N} 4Q\left(\sqrt{\frac{3e_m/C}{(2^{\frac{B_T}{C}}-1)\frac{1}{C}\sum_{i=1}^{C}\frac{1}{g_i}2^{(R_i - B_T/C)}}}\right) \cdot$$

$$(W_m - \rho_m W_m + \rho_{m+1} W_{m+1}),$$

$$\text{subject to} \quad \sum_{m=1}^{N} e_m t_m \leq E_T \sum_{m=1}^{N} t_m, \tag{5}$$

where ρ_m is the portion of the bits which are transmitted with layer $m-1$, g_i is the CGNR at subchannel i and R_i is bit rate at subchannel i. It is easy to show that similarly to power allocation in 4.1, the optimal $\{e_m\}_{m=1}^N$ can be resolved by applying Lagrange multiplier.

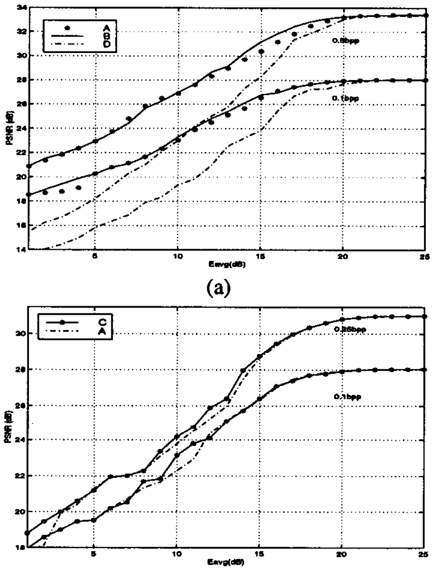
5. APPLICATION TO IMAGE AND VIDEO

The proposed loading algorithm is designed for any layered source coding applications that produce layers with different importance. In this section, we try to apply the proposed loading algorithm to transmit subband coded image and H.263 entropy coded video over spectrally shaped channels. These two applications correspond to fixed length source coding and variable length source coding, respectively.

5.1. Application to Fixed Length Coded Image

Subband coding combined with VQ has been a well known scheme for image and video compression. For an octave-band decomposition, the lowest subband contains most of the information and therefore is the most important. In our design, the images are first four level subband decomposed using Daubechies 16 wavelet filter and then vector quantized using full search LBG algorithm. The quantized result are fixed length coded in order to achieve more robustness against error. We assume a total of 256 subchannels, each MCM symbol carries 512 bits, e.g. $C_T = 256$,

$B_T = 512$. The bit rate is bounded by $R_{max} = 6$ and $R_{min} = 2$. We compare the loading algorithm A,B,C and D in Figure 4 using "Lena". The results are measured as received image PSNR versus $E_{avg} = \frac{E_T}{C_T}$(power per subchannel). Parallel transmission system optimized using A,B achieve 2-5dB gain over optimized serial transmission system for E_{avg} ranging 1-20dB. Meanwhile, A performs nearly as good as C with much lower complexity. Figure 5 illustrates the received PSNR curves of A and that of [7] which corresponds to the serial transmission type I. For $B_T = 512$, loading algorithm A achieves 8-10dB PSNR improvement at 0.5bpp source rate and 4-6dB at 0.1bpp source rate. Increasing B_T also increase the subchannel bit rates. With the same frame power, this would degrade overall performance. At the same time, the PSNR improvement over that of [7] increases, especially for E_{avg} above 10dB.



(a)

(b)

Figure 4: Comparison of proposed loading algorithm (a) A,B vs. D and (b) A vs. C using "lena"

5.2. Application to Variable Length Coded Video

From the above, the proposed algorithm achieves significant performance improvement compared to the existing loading algorithms. However, all these schemes are developed for fixed length coding. Many compression standards, such as JPEG, MPEG, H.261 and H.263 involve entropy coding, a type of variable length coding. UEP can be achieved by assigning different error correction codes to different video layers [9]. But due to the variable length property, the locations of the layers are unknown. Not only would the extra bits carrying the layer location information for every frame decrease the compression efficiency, they would also need to be highly protected, as this is very important information. The error-resilient entropy code (EREC) was applied to image and video coding[10] to give increased resilience to random and burst errors while maintaining high compression. The basic idea is to reorganize variable length blocks to fixed length slots such that each block starts at a known position. This ensures that the beginning of each block is more immune to error propagation than those at the end. Current EREC scheme is designed to transmit the bits of each slot with the same error designate performance. However, error happens to the data bits of higher importance will lead to more channel distortion and longer error propagation to other blocks.

In order to remove such shortcoming, we propose to combine EREC scheme with the MCM system into an efficient, robust transmission system[12]. The essence of the proposed approach is first block coding the video frames using the same algorithms as in H.263. Each macroblock layer is deemed as a data block which is further reorganized to put into fixed length slots. The bits belongs to each slot are classified into several layered components of different importance. The slot size and the frame type should be considered for classification. For intra frames, H.263 transmits six blocks corresponding to the same macroblock consecutively, resulting in unknown location of intra-DCs. However, intra-DCs are the most important information of the intra frame and should receive the highest protection. Therefore, we propose to code these six intra-DCs each as a 8bit codeword, and place them in beginning of each macroblock. This aims to obtain more precise layer classification and weighting factor computation as to ensure the correctness and efficiency of the protection. For inter frames, each macroblock begins with COD bit which is assigned with the highest importance. MCBPC (Macroblock type & block pattern) and MVD (motion vector data) are classified into the middle importance class. Inside each block layer, the inter-DCs and inter-ACs are together entropy coded to further reduce the bit rate and both are classified into the lowest importance class. Due to unpredictable length property of entropy coding, the importance weighting factor associate with the layers require intensive computation which is not quite practical. Instead, approximations are used. All the schemes associated with UEP face the same challenge, but the proposed scheme has the advantage of fixed layer locations.

The simulations are carried out on the combined system and the EREC system, based on 60 frames of the standard QCIF(176×144 pels) color sequences "Trevor" and "Miss America". We use the following parameters: a 512 real FFT, QAM modulation, 256 subchannels. An intra frame is inserted every 16 frames at 30 fps frame rate. Figure 6(a) (c) show the the performance comparison in terms of the $PSNR$ vs. frame number. As can be seen, the combined system achieves 2-7 dB gain over the EREC system. Figure 6(b)(d) sketch the system performances as averaged $PSNR$ over 60 frames vs. BER, where approximately 2dB gain for "Trevor" and 4dB gain for "Miss America" are achieved by the combined system.

6. CONCLUSION

We have proposed a robust multimedia data transmission system by combining layered source coding and MCM. Unlike the existing schemes, we propose to transmit all the layers in parallel through different subchannels. Several simple yet powerful loading algorithms are presented which efficiently allocates transmitted power and bit rate to the subchannels according to the importance of the information they transmit. It achieves significant PSNR improvement for spectrally shaped channels based on the idea that "good" channel transmitting more important information and "bad" channel transmitting less important information. The proposed algorithm can be used in both fixed length coding and variable length coding applications. For spectrally shaped channel, our scheme yields about 8-10dB PSNR improvement over that of [7]. Although most existing schemes are developed for fixed length coding applications, in this paper by combining MCM and EREC, we have proposed a robust and efficient system for entropy coded H.263 video transmission. Under noisy channels, not only synchronization-loss free, the proposed system achieves significant performance improvement.

The implementation of proposed algorithm requires only small amount of computation. For a given input, the power and bit rate distribution remains the same for all subchannels. Another important improvement is that the number of subchannel allowed and data throughput can be selected flexibly by the system, independent of source input. The complexity of the combined MCM and EREC system mainly depends on the implementation of EREC scheme, while the complexity of loading algorithm can be ignored. It should be pointed out that the proposed combined system can be used for all types of data which can be decomposed to produce layers of different importance.

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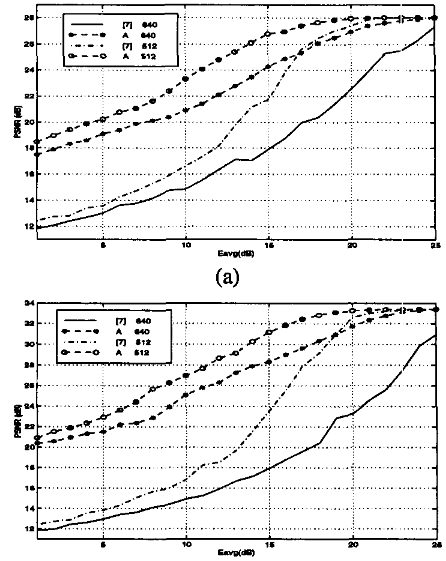
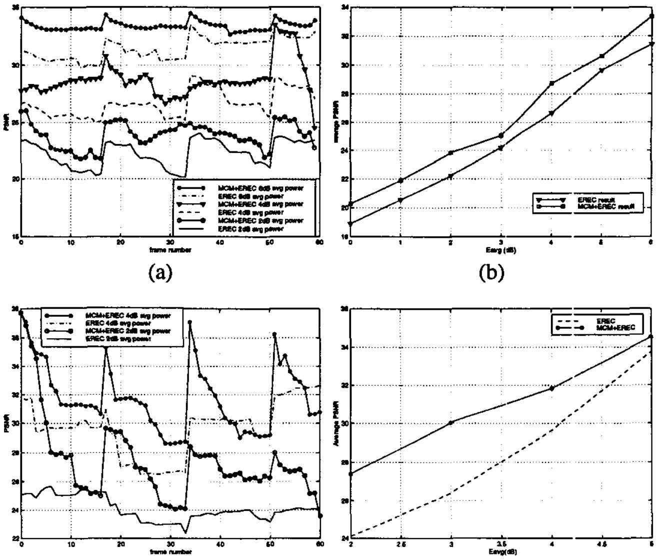


(a)

(b)

Figure 5: Comparison of proposed loading algorithm A to [7] using "Lena" at (a)0.1bpp (b) 0.5bpp



(a) (b)

(c) (d)

Figure 6: *Performance comparison of the proposed system and [24]. "Trevor":(a) PSNR performance vs. frame number, (b, averaged ; "Miss America":(c) PSNR performance vs. frame number, (d) averaged.*