SCALABLE VIDEO TRANSMISSION OVER MULTIRATE GMC-CDMA WIRELESS CHANNELS

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ABSTRACT

In this paper, we consider the problem of video transmission over wireless Generalized Multi Carrier Code Division Multiple Access (GMC-CDMA) systems. Such systems offer deterministic elimination of Multiple Access Interference (MAI). A scalable video source codec is used and a multirate setup is assumed, i.e., each video user is allowed to occupy more than one GMC-CDMA channels. Furthermore, each of these channels can utilize a different number of subcarriers. We solve an optimization problem to determine the source coding and channel coding rates for the user of interest, as well as the number of subcarriers for each GMC-CDMA channel. Experimental results are presented and conclusions are drawn.

1. INTRODUCTION

There is currently a significant interest in the topic of video transmission over wireless channels. However, very few papers have been published on video transmission over wireless multiple access systems. In [1], video transmission over correlated fading channels for narrowband Direct Sequence Code Division Multiple Access (DS-CDMA) systems (IS-95) was considered. In [2], a dual-priority video partitioning method for unequally protected video transmission over wireless DS-CDMA systems was presented. In these two papers, no rigorous resource optimization algorithm was given. In [3], a joint source-coding-power control approach for video transmission over DS-CDMA systems was presented. However, a theoretical study was performed in which no specific spreading sequences and despreading methods were assumed. The tradeoffs of source coding, channel coding and spreading for image transmission in DS-CDMA systems were considered in [4]. In [5, 6, 7, 8], video transmission over a DS-CDMA system was considered. The channel model that was used was frequency-selective (multipath) Rayleigh fading. At the receiver, an adaptive antenna array Auxiliary-Vector (AV) linear filter that provides space-time RAKE-type processing (thus, taking advantage of the multipath characteristics of the channel) and multiple-access interference suppression was employed. The choice of the AV receiver was dictated by realistic channel fading rates that limit the data record available for receiver adaptation and redesign.

In this paper, for the first time, we consider the problem of video transmission over wireless multirate Generalized Multi Carrier Code Division Multiple Access systems (GMC-CDMA) [9]. Compared to DS-CDMA, GMC-CDMA systems offer the advantage of guaranteeing deterministic elimination of Multi User Interference (MUI) in the presence of multipath fading. This is possible because the users are allocated disjoint sets of subcarriers.

In this work, an MPEG-4 [10] compliant video source codec is used. The scalability mode is invoked and a layered bitstream is produced, consisting of one base layer and one enhancement layer. Each layer is channel coded using Rate Compatible Punctured Convolutional (RCPC) codes [11].

A multirate GMC-CDMA system is assumed where each video user can be assigned two GMC-CDMA channels, one for the base layer and for the enhancement layer. Furthermore, each one of these channels is allowed to have a different bit rate by utilizing a variable number of subcarriers.

The rest of the paper is organized as follows. In section 2, the basics of GMC-CDMA are presented. In section 3, GMC-CDMA is extended to the multirate case. In section 4, the optimal resource allocation problem is formulated. In section 5, experimental results are presented. Finally, in section 6, conclusions are drawn.

2. GMC-CDMA BASICS

We next describe the basics of GMC-CDMA systems. More information can be found in [9]. In the following, a GMC-CDMA system is assumed with M users. A multipath fading channel is assumed that is modeled as a Finite Impulse Response (FIR) filter of order L. Transmission is block-based and, in the non-multirate case, each user is transmitting K information symbols per block. As will be explained later, these K information symbols are spread into $J = K + L$ symbols that correspond to the J subcarriers allocated to the user. The Inverse Fast Fourier Transform (IFFT) of size N is then taken followed by the addition of a Cyclic Prefix (CP) of size L to avoid Inter Block Interference (IBI). Thus, the length of transmitted block is $P = N + L$ and the user's K information symbols are spread into P transmitted symbols. At the receiver, after CP removal, the received signal for block i is

$$\tilde{\mathbf{x}}(i) = \sum_{\mu=0}^{M-1} \tilde{H}_\mu C_\mu \mathbf{s}_\mu(i) + \tilde{\eta}(i) \quad (1)$$

where $\mathbf{s}_\mu$ is the $K \times 1$ vector that denotes the K information symbols of user K and $\mathbf{u}_\mu(i) = C_\mu \mathbf{s}_\mu(i)$ denotes the $N \times 1$ transmitted symbols of user μ before the addition of the CP. C_μ is a $N \times K$ spreading matrix and $\tilde{H}_\mu$ is an $N \times N$ circulant matrix representing the multipath channel for user μ. $\tilde{\eta}(i)$ corresponds to additive noise. The received block for user μ is

$$\hat{\mathbf{s}}_\mu(i) = G_\mu \tilde{\mathbf{x}}(i) \quad (2)$$

where G_μ is user μ's $K \times N$ receive matrix.

In [9], C_μ and G_μ were defined as

$$C_\mu = F^H \Phi_\mu \Theta_\mu \quad (3)$$

and

$$G_\mu = \Gamma_\mu \Phi_\mu^T F. \quad (4)$$

F is the Discrete Fourier Transform (DFT) matrix. Thus, multiplication by F corresponds to taking the FFT of a signal while multiplication by F^H corresponds to taking the inverse FFT. Θ_μ is a $J \times K$ matrix, where $J = K + L$. This matrix spreads the user's K information symbols into J symbols. This is done in order to be able to recover the symbols even in the extreme case where all L zeros of the multipath channel coincide with the user's subcarriers. Φ_μ is a $N \times J$ matrix that maps these J symbols into J subcarriers and consists of only ones and zeros. An appropriate choice for Θ_μ is

$$[\Theta_\mu]_{l+1,k+1} = A_\mu \rho_{\mu,l}^{-k}, \quad (5)$$

where A_μ controls user μ's power. $\rho_{\mu,l}$, $l = 0, \ldots, J-1$ are the subcarriers of user μ. We chose to allocate the N subcarriers to the M users in a cyclic fashion:

$$\rho_{\mu,l} = e^{j\frac{2\pi}{N}(lM+\mu)}. \quad (6)$$

For Zero Forcing (ZF) detection, matrix Γ_μ can be defined as

$$\Gamma_\mu = (D_\mu \Theta_\mu)^\dagger, \quad (7)$$

where † denotes the pseudoinverse and

$$D_\mu = diag[H_\mu(\rho_{\mu,0}), \ldots, H_\mu(\rho_{\mu,J-1})] \quad (8)$$

where $H_\mu(z)$ is the z-transform of user μ's channel (FIR filter).

The above matrix selections guarantee that the received symbol block $\mathbf{s}_\mu(i)$ in (2) is free from Multiple Access Interference (MAI) and is degraded only by the additive noise [9].

3. EXTENSION TO THE MULTIRATE CASE

So far, we have assumed the case of M users (to which we also refer as "channels") each occupying J subcarriers ($MJ = N$). In the multirate GMC-CDMA case, we allow different users to occupy a different number of subcarriers and thus have different transmitted symbol rates. In the following, we assume two user classes, one that transmits K_L information symbols per block using $J_L = K_L + L$ subcarriers and one that transmits K_H information symbols per block using $J_H = K_H + L$ subcarriers, where $K_L < K_H$. Half the users ($M/2$) are low-rate (utilize J_L subcarriers), while the other have are high-rate users (utilize J_H subcarriers). As long as the sets of subcarriers of each user are disjoint, deterministic MUI elimination can still be guaranteed. In this work, we chose to allocate the first $M/2 \times J_L$ subcarriers to the low-rate users and the remaining $N - M/2 \times J_L$ subcarriers to the high-rate users.

Thus, for the low-rate users,

$$\rho_{\mu,l} = e^{\frac{j2\pi}{N}(lM/2+\mu)}, \quad (9)$$

for $l = 0, \ldots, J_L - 1$ and $\mu = 0, \ldots, M/2 - 1$. For the high-rate users,

$$\rho_{\mu,l} = e^{\frac{j2\pi}{N}[lM/2+(\mu-M/2)+J_L \times M/2]} \quad (10)$$

for $l = 0, \ldots, J_H - 1$ and $\mu = M/2, \ldots, M-1$.

If we assume, for example, $K_L = 15$ and $K_H = 30$, a low-rate user is transmitting 15 information symbols using P transmitted symbols (chips), whereas a high-rate user is transmitting 30 information symbols using P transmitted symbols. Assuming the same transmitted power per block for each user, low-rate users transmit at half the information symbol rate than the high-rate users, however, the low-rate users transmit at twice the energy per information symbol. Thus, the low-rate users are expected to have a lower symbol error rate than the high-rate users. This is a tradeoff that is similar to the one we explored for variable spreading code length DS-CDMA in [6, 7].

Channel Rate	K	$BER(16dB)$	$BER(12.98dB)$
1/2	30	1.05×10^{-4}	1.28×10^{-4}
1/2	15	3×10^{-6}	4.9×10^{-6}
2/3	30	1.77×10^{-4}	6.35×10^{-4}
2/3	15	1.07×10^{-4}	3.07×10^{-4}
4/5	30	7.78×10^{-4}	2.6×10^{-3}
4/5	15	3.85×10^{-4}	8.05×10^{-4}

Table 1. BER table comparison for 16 dB and 12.98 dB channels.

We next present some experimentally obtained bit error rates. 4-QAM (i.e., two bits per symbol) was used for modulation. The total number of subcarriers was $N = 220$. The length of the multipath was $L = 5$ and the six fading coefficients were independent complex Gaussian random variables with zero mean and equal variance. The total number of transmitting users was $M = 8$. Four of them were transmitting $K_L = 15$ symbols per block (low rate users) while the other four were transmitting $K_H = 30$ symbols per block (high rate users). RCPC codes with rates $1/2$, $2/3$ and $4/5$ were used for channel coding [11]. Two different SNRs were used for the user of interest: 16 dB and 12.98 dB (a user with SNR of 12.98 dB transmits at half the power than a user with SNR of 16 dB). All SNRs reported refer to the SNR per chip. It should be emphasized that the SNR of the interferers does not affect the Bit Error Rate (BER) of the user of interest, since in GMC-CDMA all interference is completely removed deterministically. The BERs can be seen in Table 1. As expected, for the same transmitted power, $K_L = 15$ gives a better BER than $K_H = 30$ at the expense of a lower transmission rate.

4. OPTIMAL RESOURCE ALLOCATION

We next describe the optimal resource allocation for the cases where each video user is allowed to transmit over one or two GMC-CDMA channels. The optimization constraint in both cases is the available chip rate R_{budget}^{chip}. We refer as chips to the symbols that are actually transmitted by each user, after taking the IFFT and adding the CP.

4.1. Single GMC-CDMA Channel Case

If a single GMC-CDMA channel is used for the transmission of all scalable layers of a video user, the layers are time-multiplexed. If J subcarriers are allocated to user μ, the user can transmit $K = J - L$ information symbols for every $P = N + L$ transmitted chips. If 4-QAM modulation is used, one information symbol corresponds to two bits. Thus, the available transmission bit rate is

$$R_{budget} = 2\frac{J-L}{P}R^{chip}_{budget}. \quad (11)$$

The available bit rate R_{budget} has to be allocated between scalable layers and, within each layer, between source and channel coding. The formal statement of the problem that we are solving is as follows: Given an overall bit rate R_{budget}, we want to optimally allocate bits between source and channel coding such that the overall mean-square distortion D_{s+c} is minimized; that is,

$$\min D_{s+c} \text{ subject to } R_{s+c} \leq R_{budget} \quad (12)$$

where R_{s+c} is the total bit rate used for source and channel coding for all layers and D_{s+c} is the resulting expected squared error distortion which is due to both source coding (quantization) errors and channel errors.

4.2. Multiple CDMA Channel Case

We next discuss the case where each scalable video layer is transmitted over a separate GMC-CDMA channel. In that case, we have

$$R_{s+c,i} = 2\frac{J_i-L}{P}R^{chip}_{budget} \quad (13)$$

where J_i is the number of subcarriers allocated to layer i. Thus, if two layers are assumed the ratio $R_{s+c,1}/R_{s+c,2}$ is fixed and equal to $(J_1 - L)/(J_2 - L)$. This is in contrast to the single CDMA channel case where the allocation of the available bit rate to each individual scalable layer is part of the optimization. Our optimization problem now is as follows, for the case of T layers:

$$\min D_{s+c} \text{ subject to } R_{s+c,i} \leq 2\frac{J_i-L}{P}R^{budget}_{chip}, \text{ for } i = 1, \ldots, T. \quad (14)$$

For each layer, we need to determine the source coding rate $R_{s,i}$, the channel coding rate $R_{c,i}$, and the number of allocated subcarriers J_i. As mentioned previously, the total bit rate allocated to a scalable layer depends only on J_i and not on any decisions made for another layer. Since the minimization of the distortion of each layer will result in the minimization of the overall distortion, our problem can be broken into separate problems for each layer, thus simplifying the optimization when compared to the single CDMA channel case.

To solve the problems of Eqs. (12) and (14), we need to estimate the expected distortion D_{s+c} that results from specific choices of the source coding rate $R_{s,i}$, channel coding rate $R_{c,i}$ and number of subcarriers J_i for each layer i. The distortion is estimated using a combination of Universal Rate Distortion Characteristics (URDC) and Channel Characteristic Plots (CCP) [12, 13].

5. EXPERIMENTAL RESULTS

We next present experimental results for video transmission over GMC-CDMA channels. The video sequence used is the "Foreman" sequence (176 × 144 size, 300 frames). An MPEG-4 compatible video source codec was used to create two SNR scalable layers. The admissible source coding rates for each of the two scalable layers are 64, 96, 128 and 256 kbps. The admissible channel coding rates are $1/2$, $2/3$ and $4/5$, using RCPC codes from [11]. A multirate GMC-CDMA system is assumed with $N = 220$, $L = 5$ and $M = 8$. Thus, there are eight user channels. Four of these channels have $K = 15$ and the other four have $K = 30$. Each video user of interest is allowed to occupy one or two of these user channels.

In one experiment, the video user of interest occupies a single channel (single GMC-CDMA channel case). The video user of interest has an SNR of 16 dB. The seven interfering channels also have an SNR of 16 dB, however, this doesn't affect the BER of the video user of interest, since the interference is completely removed deterministically. Table 2 shows the optimization results for different target chip rates R^{chip}_{budget}. The table shows the optimal choices of $R_{s,i}$, $R_{c,i}$ and K_i for each layer. Obviously, $K_1 = K_2$ in this case since there is only one channel per user.

In another experiment, the video user of interest occupies two channels (dual GMC-CDMA channel case). The base layer is transmitted over the first channel while the enhancement layer is transmitted over the second channel. In order to have a fair comparison, the SNR of each of the video user's of interest channels is 12.98 dB so that the total transmitted power of the video user of interest is exactly the same as in the single GMC-CDMA channel case. Table 3 shows the optimization results for this case.

Fig. 1 shows a plot of the expected PSNR versus the target chip rate for each one of the two cases. It can be seen that for low chip rates, the dual GMC-CDMA case exhibits a higher PSNR. For example, for a target chip rate of 960 kchips/s, the single channel case gives a PSNR of 19.53 dB while the dual channel case gives a PSNR of 26.14 dB. However, for chip rates greater than 1680 kchips/s, the single channel case performs better. At high chip rates, two-channel transmission can still support higher source coding rates than single-channel transmission but increasing the source coding rate beyond a point does not significantly improve video quality. Thus, single CDMA channel transmission (with lower bit error rates) outperforms two CDMA channel transmission at high chip rates.

6. CONCLUSIONS

In this paper, we have proposed the use of Generalized Multi Carrier Code Division Multiple Access (GMC-CDMA) systems for wireless video transmission. Such systems offer deterministic Multiple Access Interference (MAI) elimination, i.e., the interference can always be removed completely. The disadvantage of such systems compared with DS-CDMA systems is that the power of the transmitted waveform is not constant. Also, the number of users is fixed from the system design stage since the users need to be allocated disjoint sets of subcarriers. In this work, we have also explored the trade-offs of using multirate GMC-CDMA in video transmission. We have shown that, for the same transmitted power, allocating a larger number of subcarriers to a user increases the user's information symbol rate at the expense of an increase in symbol error rate. We have considered the case where the video user of interest occupies a single GMC-CDMA channel as well as the case where the video user of interest occupies two GMC-CDMA channels. In both cases, we solved an optimization problem to determine the source and channel coding rates for each scalable layer as well as the number of subcarriers for each GMC-CDMA channel. Our results show that, for chip rates of less than 1680 kchips/s, the dual GMC-CDMA case performs better. Future work in this area will involve the optimal power allocation between GMC-CDMA channels.

$R_{s,1}$	$R_{c,1}$	K_1	$R_{s,2}$	$R_{c,2}$	K_2	R_{budget}^{chip}	P_{s+c}^*
256	1/2	15	64	1/2	15	4800	35.81
128	1/2	15	64	1/2	15	2880	35.63
96	1/2	15	64	1/2	15	2400	32.52
96	2/3	15	64	1/2	15	2040	29.89
64	1/2	15	64	2/3	15	1680	28.84
64	4/5	15	64	1/2	15	1560	24.59
64	4/5	15	64	2/3	15	1320	23.14
64	4/5	15	64	4/5	15	1200	21.08
64	1/2	30	64	1/2	30	**960**	**19.53**
96	2/3	30	64	4/5	30	840	18.47
64	1/2	30	64	4/5	30	780	15.99
96	4/5	30	64	4/5	30	750	13.21
64	2/3	30	64	2/3	30	720	12.43
64	2/3	30	64	4/5	30	660	10.34
64	4/5	30	64	4/5	30	600	6.68

Table 2. Optimal bit allocation for two-layer SNR scalable video over a single 16 dB multirate GMC-CDMA channel.
* Total rate is in kcps and P_{s+c}^* was measured in dBs

$R_{s,1}$	$R_{c,1}$	K_1	$R_{s,2}$	$R_{c,2}$	K_2	R_{budget}^{chip}	P_{s+c}^*
256	1/2	15	256	1/2	15	3840	29.55
96	1/2	15	96	1/2	15	1440	26.92
64	1/2	15	64	1/2	15	**960**	**26.14**
64	2/3	15	96	1/2	30	720	25.667
64	4/5	15	64	4/5	15	600	19.29
64	2/3	30	64	2/3	30	360	18.77
64	4/5	30	64	4/5	30	300	9.05

Table 3. Optimal bit allocation for two-layer SNR scalable video over two GMC-CDMA channels with SNR = 12.98 dB per channel for the video user of interest.
* Total rate is in kcps and P_{s+c}^* was measured in dBs

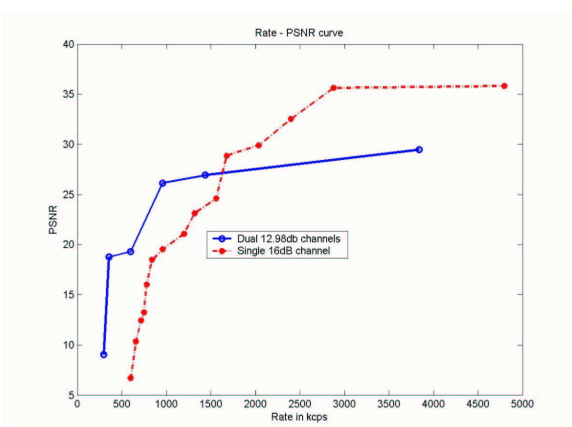

Fig. 1. PSNR comparison of scalable video transmission over wireless GMC-CDMA channels using one and two channel per video user.

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