# OPTIMAL RESOURCE ALLOCATION FOR VIDEO TRANSMISSION OVER DS-CDMA CHANNELS WITH MULTIRATE DETECTION

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**ABSTRACT**

In this paper, we consider the transmission of video over multirate wireless direct-sequence code-division multiple access (DS-CDMA) channels. The performance of transmitting scalable video over a multipath Rayleigh fading channel via a combination of *multi-code multirate CDMA* and *variable sequence length multirate CDMA* channel system is considered. At the other end, the signal is collected by an antenna array front and despreading is done using adaptive space-time auxiliary-vector (AV) filters. AV filter configurations suitable for multirate detection are designed and the rate-distortion optimization is carried out for each configuration. The experimental results show a comparison of the performance of such multirate DS-CDMA systems for wireless video transmission.

## 1. INTRODUCTION

In the recent past, a considerable amount of research has been devoted to joint source-channel scalable video coding and multirate DS-CDMA systems. Rate-distortion optimization procedures were used for joint source-channel coding in [1]. Details about several multirate access schemes have been discussed in [2]. Scalable video allows unequal error protection (UEP) to parts of the bitstream and aids in the error-resilient transmission of video bitstreams compatible for heterogenous receivers. CDMA systems that support users with different data rates are multirate CDMA systems and enable the transmission of voice, video and other traffic simultaneously. Hence scalable or layered video transmission via multirate CDMA offers an excellent solution for error-resilient video reception.

In our earlier work [3], a comparison was made between scalable video transmission over a single CDMA channel and two CDMA channels. A combination of *multi-code multirate CDMA* and *variable sequence length multirate CDMA* channel system was employed for the two-channel system using the auxiliary vector (AV) filter [4] which is designed for single-rate despreading. In both cases, an operational rate-distortion problem was defined and solved to optimally select the source coding rates, channel coding rates, and spreading code lengths (processing gains) used for the transmission.

While multiuser multirate designs have been studied extensively [5, 6], in this work, rate-distortion optimization is performed for joint source-channel coding using various single-user short-data record adaptive AV filter configurations designed to detect multirate signals.

A variable sequence length DS-CDMA system allocates different processing gains for different rate users while the chip rate is constant. The high-rate bit period is smaller than the low-rate bit period. Hence in this system, the higher rate users may experience greater inter-symbol interference (ISI) than the low-rate users. In a multi-code system, the higher data rate users transmit information on more than one channel depending on their data rate at a constant chip-rate. Multi-code systems can be used in single-rate systems because the spreading gain for each channel remains the same. However the cross-correlations between pairs of users may be non-zero while they will be zero due to orthogonality in the corresponding variable sequence length system.

The scalable video used for simulations in this work consists of a base layer and one enhancement layer. Each layer is transmitted over a separate CDMA channel. Different spreading code lengths are allowed for each CDMA channel leading to a different number of chips per bit. For a given fixed energy value per chip and chip rate, the selection of a spreading code length affects the transmitted energy per bit and bit rate for each layer. Consider as an example where Channel 1 is assigned a spreading code of length $L = 16$ and Channel 2 has a spreading code of length $L = 32$. Assuming equal energy per chip for the two channels, Channel 2 transmits twice as many chips per bit (and energy per bit) than Channel 1. However, Channel 1 transmits at twice the bit rate of Channel 2. Thus, Channel 2 exhibits a lower bit error rate than Channel 1, but Channel 1 allows for transmission at a higher data rate. A multipath Rayleigh fading channel model is assumed with antenna array reception.

In multirate scalable video reception, each video user has more than one CDMA channel to decode. The signature sequences of a user may not be orthogonal due to their different lengths. Now each video user needs a multi-user detector to detect the bits in the channels of interest. In our earlier works [3] and [7], the AV filter was used as a single-rate detector, since the interferers were considered to have the same spreading length as a channel for which despreading was done. However here we use multirate AV filter configurations to simultaneously detect bits in the channels.

## 2. RECEIVED MULTIRATE SIGNAL

A system with two data rates (two allowable processing gains) is considered. Here, the data rate of a channel refers to the rate before spreading and for the video user, it is equal to the product of the source coding rate ($R_s$) and inverse of the channel coding rate ($R_c$). In this system with $K$ CDMA channels, let $K/2$ channels have a low bit-rate and $K/2$ channels have a high bit-rate. If the bit time-periods of the high-rate and low-rate channels are $T_h$ and $T_l$ respectively, the number of bits of each high-rate channel during each low-rate bit period $T_l$ is denoted by $Q = T_l/T_h$. After conventional chip-matched filtering and sampling at the chip rate over a multipath extended symbol interval of $L_l + P$ chips, the $L_l + P$ data samples from the $m$th antenna element, $m = 1, \ldots, M$, are organized in the form of a vector $\mathbf{r}_m$ given by (1) with the first term for low-rate channels and the second for high-rate channels.

$$\mathbf{r}_m = \sum_{k=0}^{K/2-1} \sum_{p=0}^{P} c_{k,p}\sqrt{E_k}(b_k \mathbf{s}_{k_l,p} + b_k^- \mathbf{s}_{k_l,p}^- + b_k^+ \mathbf{s}_{k_l,p}^+)\mathbf{a}_{k,p}[\mathrm{m}] + \sum_{q=0}^{Q-1} \sum_{k=K/2}^{K-1} \sum_{p=0}^{P} c_{k,p}\sqrt{E_k}(b_{k,q}\mathbf{s}_{k_h,p} + b_{k,q}^- \mathbf{s}_{k_h,p}^- + b_{k,q}^+ \mathbf{s}_{k_h,p}^+)\mathbf{a}_{k,p}[\mathrm{m}] + \mathbf{n}\ ,\ m = 1, \ldots, M, Q = L_l/L_h, \tag{1}$$

where, with respect to the $k$th CDMA signal, $E_k$ is the transmitted energy per chip, $b_k$, $b_k^-$, and $b_k^+$ are the present, the previous, and the following transmitted bit of the low-rate user. $b_{k,q}$, $b_{k,q}^-$, and $b_{k,q}^+$ are the present, the previous, and the following transmitted bit of the high-rate user corresponding to the $q$th subinterval of the low-rate bit period. $\{c_{k,p}\}$ are the coefficients of the frequency-selective slowly fading channel modeled as independent zero-mean complex Gaussian random variables that are assumed to remain constant over a few symbol intervals. $L = \{L_l, L_h\}$ are the sequence lengths of $\mathbf{s}_{k_l}$ and $\mathbf{s}_{k_h}$ used for spreading the bits in the low-rate and high-rate channels respectively. $\mathbf{s}_{k_l,p}$ represents the 0-padded by $P$, $p$-cyclic-shifted version of the signature of the $k$th SS signal $\mathbf{s}_{kl}$, $\mathbf{s}_{k_l,p}^-$ is the 0-filled $(L_l - p)$-left-shifted version of $\mathbf{s}_{k_l,0}$, and $\mathbf{s}_{k_l,p}^+$ is the 0-filled $(L_l - p)$-right-shifted version of $\mathbf{s}_{k_l,0}$. Similar notations apply for the high-rate channels. Finally, $\mathbf{n}$ represents additive complex Gaussian noise with mean $\mathbf{0}$ and autocorrelation matrix $\sigma^2\mathbf{I}_M$, and $\mathbf{a}_{k,p}$[m] is the $m$th coordinate of the $k$th CDMA signal, $p$th path, array response vector:

$$\mathbf{a}_{k,p}[\mathrm{m}] = e^{j2\pi(m-1)\frac{\sin\theta_{k,p} d}{\lambda}}\ ,\ m = 1, \ldots, M, \tag{2}$$

where $\theta_{k,p}$ identifies the angle of arrival of the $p$th path of the $k$th CDMA signal, $\lambda$ is the carrier wavelength, and $d$ is the element spacing (usually $d = \lambda/2$).

An auxiliary-vector (AV) adaptive Filter is used for despreading. Theoretical analysis of the AV algorithm was pursued in [8]. The AV filter has been shown to be effective under limited data record support in rapidly changing wireless communications environment. An unsupervised (blind) J-divergence AV filter estimator procedure is presented in [4].

## 3. MULTIRATE AV

AV configurations that take into effect the different correlation properties of parts of the signature sequences of low-rate channel, with the signature sequence of the high-rate channel, during each bit period of the high-rate channel, are detailed below.

### 3.1. High-rate AV (AVHR) configuration

In the AVHR configuration, the individual AV filters perform filtering operations with the samples of each bit extending over the multipath symbol interval of $L_h + P$ chips. The individual AV filters are denoted as HR-AV filter blocks in Fig. 1. Each low-rate user is converted into $Q$ separate high-rate co-channels. The spreading chips are for the $q$th co-channel are then given by

$$[s_{k_l}[q * L_h], \ldots, s_{k_l}[(q+1) * L_h]] \qquad q = 0, \ldots, Q-1. \tag{3}$$

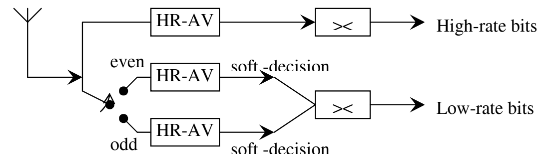


**Fig. 1**. High-rate AV based detector.

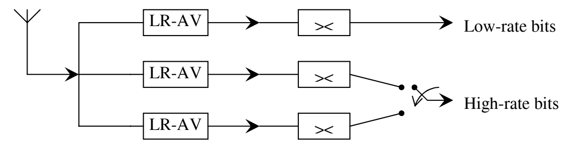


**Fig. 2**. Low-rate AV based detector.

For reconstructing each low-rate bit, $Q$ soft estimates are maintained over each high-rate bit interval. For a dual-rate system with $Q$ being equal to 2, three AV filters processing in parallel are required as in Fig. 1.

### 3.2. Low-rate AV (AVLR) configuration

In the AVLR configuration, the individual AV filters perform filtering operations with the samples of each bit extending over the multipath symbol interval of $L_l + P$ chips. The individual AV filters are denoted as LR-AV filter blocks in Fig. 2. The bits are detected at the end of the low-rate bit interval. Each high-rate user is converted into $Q$ separate low-rate co-channels with spreading sequences of length $L_l$. For the $q$th co-channel, the spreading sequence is $\mathbf{s}_{k_h}$ in the $q$th high-rate bit interval but zero otherwise. For a dual-rate system with $Q$ having a value of 2, three AV filters processing in parallel are required as in Fig. 2.

### 3.3. Interference Canceling AV (AV-IC) configuration

For detecting the high-rate user's bits, an AV filter is used to perform filtering operations with the samples of each bit extending over the multipath symbol interval of $L_h + P$ chips. Then, the signal corresponding to the high-rate bits is reconstructed and subtracted from the received signal. The low-rate bits are then detected by using another AV filter to perform filtering operations with the samples of each bit extending over $L_l + P$ chips. This behaves like an interference canceler that cancels the multiple access interference (MAI) of the high-rate channel leading to an improved bit error rate (BER) performance. This requires just two AV filters as shown in Fig. 3 to detect the high-rate bits and then the low-rate bits at the expense of some delay.

Since we have shown how the multi-rate channels can be converted into many single-rate channels, we can henceforth use the AV filter operations as used in a single-rate scenario.

## 4. OPTIMAL RESOURCE ALLOCATION

In this section the optimal resource allocation procedure for scalable video transmission over two CDMA channels is described.

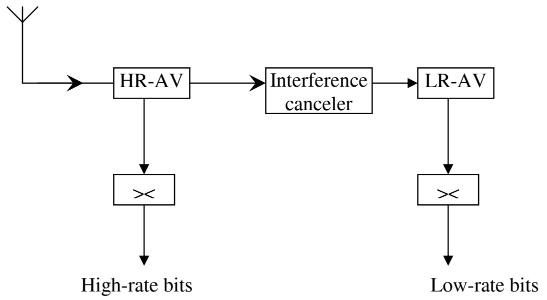


**Fig. 3**. Interference Canceling AV based detector.

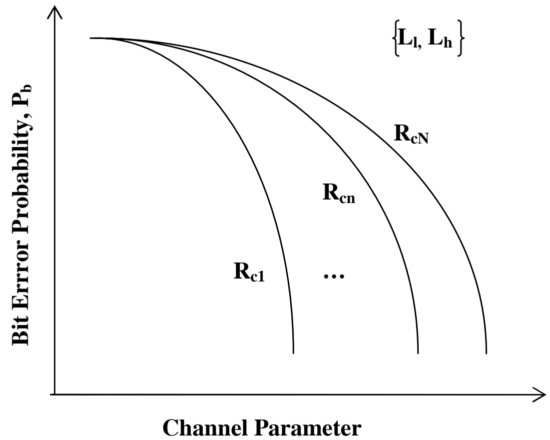


**Fig. 4**. Channel Characteristic Plots.

The base layer is transmitted on one channel while the enhancement layer is sent via the other channel. The optimization constraint is the available chip rate, $R_{budget}^{chip}$. Fixed energy per chip is assumed.

The available bit rate for layer $i$ is

$$R_{s+c,i} = \frac{R_{budget}^{chip}}{L_i}, \tag{4}$$

where $L_i$ is the spreading length for layer $i$. Thus, if two layers are assumed the ratio $R_{s+c,1}/R_{s+c,2}$ is fixed and equal to $L_2/L_1$.

The optimization problem now is as follows (for the case of $T$ layers):

$$\min D_{s+c} \text{ subject to } L_i R_{s+c,i} \leq R_{budget}^{chip}, \text{ for } i = 1, \ldots, T. \tag{5}$$

For each layer, the source coding rate $R_{s,i}$, the channel coding rate $R_{c,i}$, and the spreading length $L_i$ are to be determined.

The total bit rate allocated to a scalable layer depends only on $L_i$ and not on any decisions made for another layer. Since $D_{s+c} = \sum_{i=1}^{T} D_{s+c,i}(R_{s+c,1}, \ldots, R_{s+c,li})$, the problem is broken into separate problems for each layer. Now, the two problems to be solved are

$$\{R_{s,1}^*, R_{c,1}^*, L_1^*\} = \arg\min D_{s+c,1}(R_{s+c,1}) \quad \text{subject to } L_1 R_{s+c,1} \leq R_{budget}^{chip} \tag{6}$$

and

$$\{R_{s,2}^*, R_{c,2}^*, L_2^*\} = \arg\min D_{s+c,2}(R_{s+c,1}^*, R_{s+c,2}) \quad \text{subject to } L_2 R_{s+c,2} \leq R_{budget}^{chip}. \tag{7}$$

There is no dependency between the two layers and so the above problems can be solved independently by using Lagrangian optimization. We need to obtain the rate-distortion functions using universal rate-distortion characteristics as explained next.

## 5. UNIVERSAL RATE-DISTORTION CHARACTERISTICS

The optimal rate-distortion characteristics, $D_{s+c,i}(.), i = 1, 2$ of the individual layers can be obtained as given below. In order to simulate the transmission of the actual source coded data over a channel, for every bitstream, we will have to simulate data transmission over the channel using all combinations of source and channel coding rates per scalable layer and for channel conditions of interest. Clearly, the computational complexity is prohibitive. To circumvent this problem, *universal rate-distortion characteristics* (URDC) of the source coding scheme are utilized [1, 9].

For given channel SNRs, spreading lengths, and choice of channel codes, the probability of bit error of a channel, $P_b$, is dependent on the channel coding rate and spreading length of the channel and also on the spreading length of the user's second channel. Hence $P_b$ is calculated for the set of channel coding rates of interest and each combination of spreading lengths of the two CDMA channels used by the user of interest. $P_b$ of the low-rate channel of the video user is also calculated for each of the spreading lengths of the high-rate channel and vice-versa. $P_b$ establishes a reference as to the performance of channel coding over the particular channel with the given parameters and this performance analysis is done once for each AV filter configuration. These plots will be called *Channel Characteristic Plots* and differ from the plots for single-rate CDMA [3].

The impact of the errors due to both lossy source coding and channel disturbance is calculated as follows. The distortion for a particular layer, $D_{s+c,i}$, given a particular source coding rate, $R_{s,i}$, is a function of the bit error rate. Thus, the rate-distortion function of the layer for a fixed source rate, $R_{s,i}$ (given the preceding layer source rates), is a function of the bit error rate (after channel decoding), $P_b$. A family of $D_{s+c,i}$ versus $1/P_b$ curves given a set of source coding rates of interest is obtained. These are the URDCs of the source. Due to the use of variable length codes in the video coding standards, it would be a formidable task to analytically obtain the URDCs. Thus, the URDCs are obtained experimentally using simulations. To obtain the URDC for $D_{s+c,i}$, the $i$th layer of the bitstream is corrupted with independent errors with bit error rate $P_b$. Layers $1, \ldots, i-1$ are not corrupted, decoded and the mean squared error is calculated. The experiment is repeated many times (in our studies, 30 times). If $i > 1$, for the URDC for an enhancement layer, we need to subtract the distortion of the first $i-1$ uncorrupted layers.

The operational rate-distortion functions for each scalable layer are constructed as follows. First, for the given channel parameters, the channel characteristic plot is used to determine the resulting bit error rates for each of the available channel coding rates and spreading lengths. Then, for each of these probability values, the URDC is used to obtain the resulting distortion for each available source coding rate. By also obtaining the total rate $R_{s+c}$ for each combination of source codes, channel codes and spreading lengths, the rate-distortion operating points are generated for the given channel conditions.

## 6. COMPARISON OF PERFORMANCE OF DIFFERENT MULTIRATE RECEIVERS

For the experiments conducted in this work, the physical-layer receiver is equipped with a uniform linear antenna array of $M = 4$ elements. All received CDMA signals $k = 0, 1, \ldots, K-1$ experience $P = 3$ resolvable multipaths with independent fading per path and equal mean power $E\{|c_{k,p}|^2\}$, $p = 0, 1, \ldots, P$. All paths of all signals have independent angle of arrival $\Theta_{k,p}$ drawn uniformly in $-90^o, 90^o)$. The fading realization $c_{k,p}$ of each path of each signal remains constant across the antenna elements (antenna diversity effects are not considered/exploited here). The SNR values refer to the total SNR per chip and are defined as $\frac{\sum_{p=1}^{P} E\{|c_{k,p}|^2\}E_k}{\sigma^2}$, $k = 0, 1, \ldots, K-1$.

An MPEG-4 compatible video source codec is used along with rate compatible punctured convolutional (RCPC) channel codes. Error-resilience tools of MPEG-4 such as resynchronization markers, data partitioning and reversible variable length codes (RVLC)s were enabled. Auxiliary-vector filtering followed by soft decision Viterbi decoding is used at the receiver. A dual-rate system is modeled with eight active CDMA interferers occupying eight distinct channels (spreading codes), all at an SNR of 8 dB. Two channels (codes) are used by the video user of interest and have an SNR of 4.98 dB.

The admissible source coding rates are 64000, 96000, 128000, and 256000 bits per second for both the base and enhancement layer. The admissible channel coding rates for both layers are $1/2$, $2/3$, and $4/5$, while the admissible spreading codes are Walsh-Hadamard codes of length 16 and 32. Four of the interferers have a high-bit rate with a spreading length of 16 while the other interferers have a low-bit rate with a spreading length of 32. Figure 5 shows a comparison of the performance of scalable video transmission over a DS-CDMA system when the video user of interest occupies two channels. The mean squared error is plotted against the total chip rate. It can be seen that, for the SNRs under consideration, the AV-IC gives better performance than the simple AV, AVHR and AVLR configurations. The AVHR has poor performance for low-rate users and hence performs poorly at many rates. The AVLR gives a lower distortion than AVHR as it gives a lower BER for both low and high-rate channels. The AV-IC offers a lower BER due to interference cancellation and consequently a better rate-distortion performance than the other multirate AV configurations.

## 7. CONCLUSION

AV filter configurations such as the AVHR, AVLR and AV-IC configurations, suitable for multirate DS-CDMA detection were designed. The rate-distortion optimization performance of scalable video transmission over multirate DS-CDMA systems using the multirate AV filter configurations was compared. It was experimentally found that the AV-IC design gives the best rate-distortion performance suitable for scalable video transmission over a wide range of chip rates.

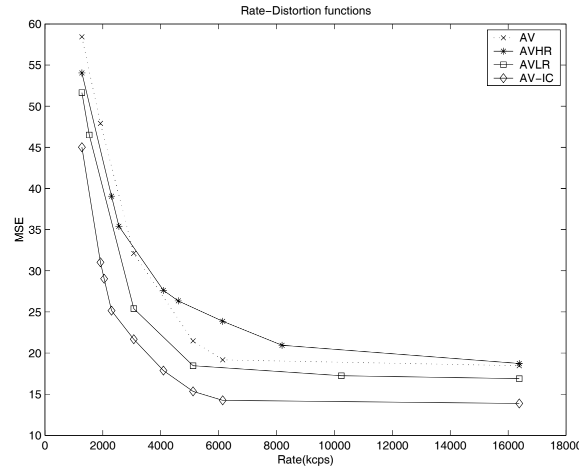


**Fig. 5**. Rate-distortion performance of scalable video transmission over a DS-CDMA wireless system using different AV filter configurations.

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