DISTRIBUTED VIDEO STREAMING USING COMPLETE COMPLEMENTARY SEQUENCES

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ABSTRACT

In many distributed video streaming applications multiple terminals stream correlated video data to a central station to be processed. The fact that those terminals may be placed within a short range of each other in a time-varying environment, results in a high level of interference, multipath fading and noise effects. One classical solution to reduce those effects is to employ the well-known spread spectrum technique; however, this leads to a substantial increase in the required bandwidth and usually makes the system not acceptable for real-time wireless video communications. In this paper we provide a novel spreading scheme that reduces the required bandwidth by exploiting correlation among different terminal observations of a video source without performance penalty. Results obtained show reduction in a terminal transmission rate of approximately 1 Mbit/sec per terminal for the same reconstructed video quality.

***Index Terms*—** Distributed source coding, spread spectrum modulation, wireless video, adaptive coding

1. INTRODUCTION

In many emerging applications, there is a need for streaming correlated information from multiple remote terminals to a central station where processing is done. The most appealing example is a wireless sensor network for video surveillance, where multiple, light cameras observe a scene and send their compressed observations to the fusion point for joint decoding. Since all the cameras obtain a different (noisy) shot of the same scene, the data present at different cameras are correlated; hence, efficient distributed compression can be used to reduce the required transmission bandwidth. Another application of distributed compression is 3D/stereo video coding [1], where multiple views of the scene (from multiple cameras) are collected, aiming at generating a 3D effect at the decoder. The third considered application is wireless video ad hoc networks and multihop transmission scenario [2], where distributed source coding can be applied to multicast video from a source via multiple servers to a client in real time. This idea was taken forward in our previous work [3], where mobile communication over multiple base stations is considered.

Very often (as in the above applications) correlated video data are sent from multiple terminals. We show in this paper that by exploiting correlation among the video data present at the terminals (e.g., wireless video sensor cameras), we can significantly reduce the required bandwidth without sacrificing the performance. Our system is capable of supporting heterogeneous wireless clients with regards to their various bandwidths, computing power, and most importantly for sensor networks applications, power limitations.

To combat fading, interference and wireless noise, spread spectrum modulation is necessary. Conventionally, data are spread separately at each node; at the receiver, the streams from different sending nodes are separated using despreading. Spreading provides efficient interference reduction and protection at the expense of enlarging required bandwidth. For efficient spreading codes, the higher the bandwidth used, the better the protection. However, in time-constrained video communications, where huge amount of data needs to be delivered in real time, the system can only afford very limited amount of spreading.

We introduce the notion of spreading correlated information and design a practical system for real-time multimedia streaming over wireless fading channels. Correlated sources at two (or more) network terminals (nodes) are separately encoded using low-complexity complete complementary (CC) sequences [4]. By exploiting correlation among the sources this single coding not only provides multiple access and robustness to interference and fading (due to spreading), but also distributed compression. The client collects the encoding signals from both sending nodes and decodes them *jointly* before reconstructing the video.

Our video system design takes advantage of the ideal correlation properties, zero cross-correlation and zero out-of-phase auto-correlation, of the CC sequences [3] to allow the receiver to separate signals from other terminals and help filter out multiple received signals which are delayed due to multipath propagation. Systems based on CC sequences use offset stacked (OS) spreading modulation technique [4] to spread video data before the transmission of different CC element sequences on orthogonal frequencies. Due to the OS the systems using

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CC sequences are inherently capable of multirate transmission simply by shifting different number of chips between consecutive spread bits to slow down or speed up the data rate. No complex rate matching algorithms are needed. This makes CC sequences very attractive for multimedia services with variable rate requirements to which data rate change should be made scalable, continuous and in real time.

We develop new encoding and decoding schemes based on CC sequences that reduce the required bandwidth (compared to classical spreading without correlated compression) while maintaining the video performance. Our simulation results show great performance improvements obtained by exploiting the correlation of the incoming video sequences.

Our key idea comes from distributed source coding (DSC) framework. DSC refers to separate compression and joint decompression of sources by exploiting their mutual correlation. Its foundation has been set up by Slepian and Wolf [5], who considered separate lossless compression and joint decompression of two discrete correlated sources, and showed that separate compression is as efficient as the joint one as long as the two sources are decoded together at the joint decoder. The work of Slepian and Wolf was generalized by Berger and Tung [6] in the framework called multiterminal source coding (MT-SC). The MT-SC problem considers lossy, separate compression and joint decompression of multiple correlated sources.

We distinguish two types of MT-SC. In direct MT-SC [6], the encoders have direct access to the sources which are to be compressed; the compressed bitstreams are sent over a noiseless channel to the joint decoder which reconstructs all of them under separate distortion constraints. In indirect MT-SC [7] (the CEO problem), a single source X is observed by the terminals. Each terminal obtains only a noisy version of the original source. The terminals separately compress their observations and send the result of a noiseless channel to the joint decoder whose task is to recover X under a distortion constraint. The two problems are shown in Figure 1. Note that in the direct case observations from both cameras, Y_1 and Y_2, are to be reconstructed at the joint decoder under two distortion constraints. On the other hand, in the indirect MT-SC setup two noisy versions of a single source X are compressed separately and jointly decompressed to recover the original source X under a single distortion constraint.

DSC has been exploited for video compression (for example, see [8] and references therein). However, none of previous schemes addresses spreading the transmitted signals to reduce interference and fading. Our idea is closest to the work of [9] where transmission of Wyner-Ziv compressed video bitstreams over bit error and erasure channels is considered. In [9] a single Digital Fountain Raptor code is used to provide both scalable DSC and protection against packet erasures. By sending additional parity symbols (above the Slepian-Wolf limit) protection against erasures is achieved. Only interference-free memoryless channels were considered in [9].

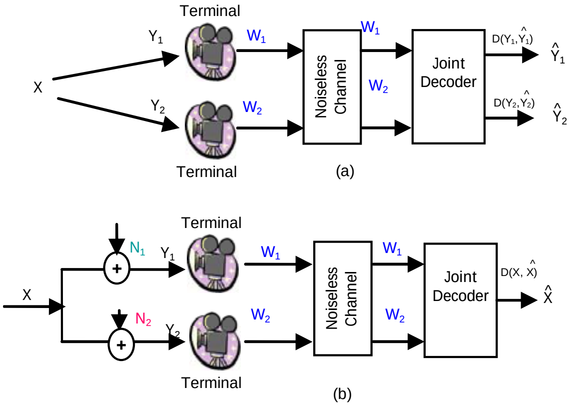

Fig. 1 MT-SC: (a) The direct setup and (b) the indirect setup.

The paper is organized as follows. In Section 2 we review encoding and decoding of CC sequences and explain their ideal correlation properties. In Section 3 we describe our proposed system for wireless distributed video streaming over multiple stations. Section 4 showcases our experimental results, and the last section contains conclusions and directions for future work.

2. COMPLETE COMPLEMENTARY SEQUENCES

The origin of CC sequences can be traced back to the 1960s, when Turyn [10] described a class of binary sequences whose elements are either -1 or +1, and whose auto-correlation function is zero for all even (2-multiple) shifts except the zero shift. Suehiro [11] extended the concepts to the generation of CC sequence families (sets) whose auto-correlation function is zero for all even and odd shifts except the zero shift, and whose cross-correlation function, for any pair of element sequences, is zero for all possible shifts.

According to [11], in order for N sets, each made up of N sequences, to be a CC sequence of order N, they must satisfy the following properties: (i) the sum of the N auto-correlation function for each set is zero for any shift except the zero shift (this set is called 'auto-complementary sequence of order N'); (ii) the sum of the N cross-correlation functions between two sets of N sequences is zero for any shift (each of these two sets is called 'cross-complementary sequence of order N'). For the generation of CC sequences refer to [12].

CC sequences exhibit the following fundamental differences compared to traditional CDMA spreading sequences (such as Gold sequences, m-sequences, Walsh Hadamard sequences, etc.). First, the mutual orthogonality of CC sequences is observed between 'sets' (sets of constituent sequences), instead of between single constituent sequences as for traditional spreading sequences. In other words, in the proposed system using CC sequences each terminal is assigned one set of sequences where the total number of available sets $F = N = \sqrt{K_{CC}} = 2^j$ and $j = 1, 2, \ldots$ is a positive integer, and K_{CC} is the length of each element sequence.

For example, consider $K_{CC} = 4$, then the total number of available CC sets is $F = 2$; the first set consists of two elements sequences $w_1 = [+,+,+,-]$ and $w_2 = [+,-,+,+]$, while the second contains $\mathrm{w}_3 = [+,+,-,+]$ and $\mathrm{w}_4 = [+,-,-,-]$ (here, "+" denotes +1 and "-" is -1). Second, the processing gain of the CC sequences equals to the aggregate length of all sequences in each set (for $K_{CC} = 4$, the processing gain is 2×4 = 8). Third, CC sequences possess unique correlation properties with zero cross-correlation and zero out-of-phase auto-correlation for any relative shifts between two sequences. From previous example, Terminals 1 and 2 will be assigned two sets of CC sequences each, $\mathbf{X} = [w_1, w_2]$ and $\mathbf{Y} = [w_3, w_4]$, respectively. For i=1,..,4, let $w_i \otimes w_i$ denote the shift-and-add operation for calculating auto-correlation function for w_i. Then, the auto-correlation functions for CC sets **X** and **Y** are $\psi_{\mathbf{XX}} = w_1 \otimes w_1 + w_2 \otimes w_2 = [0,0,0,8,0,0,0]$ and $\psi_{\mathbf{YY}} = w_3 \otimes w_3 + w_4 \otimes w_4 = [0,0,0,8,0,0,0]$. Similarly, we can obtain the cross-correlation functions between CC sets **X** and **Y** as the sum of all cross-correlation functions between any pair of constituent sequences in those sets $\psi_{\mathbf{XY}} = w_1 \otimes w_3 + w_2 \otimes w_4 = [0,0,0,0,0,0,0]$. From the example, and due to the ideal correlation properties, one can expect the performance using CC sequences to surpass that of any of the classical spreading sequences. This observation agrees with the results in [4, 12].

CC element sequences can be sent to the receiver either in parallel using different orthogonal carrier frequencies, such as in multi-carrier transmission mode, or serially where all element sequences are sent using the same carrier. In this paper, the former approach is adopted.

3. PROPOSED SYSTEM

In this section we highlight the key idea behind our proposed video streaming system.

In conventional spreading, the transmitted spread signal consists of $N = \sqrt{K_{CC}}$ components that are transmitted in parallel over N orthogonal carrier frequencies. Suppose that the CC element sequence of length Kcc=4 is used, i.e., both terminals transmit signals consisting of two components on N=2 orthogonal carrier frequencies. Since both terminals transmit their components on the same two carrier frequencies the signals reach the client virtually combined. Hence, for four video encoded symbols, seven symbols are transmitted at each of the two frequencies from each terminal. These symbols are separated at the receiver through a despreading process. However, provided information about correlation among two video sequences is available at the terminals, the number of sent symbols can be reduced, if effective combing technique is applied at the client.

Indeed, some of the transmitted symbols may be punctured facilitating rate/bandwidth adaptability. The number of punctured symbols and the best puncturing pattern depends on the correlation of the two source observations and the transmission channel quality.

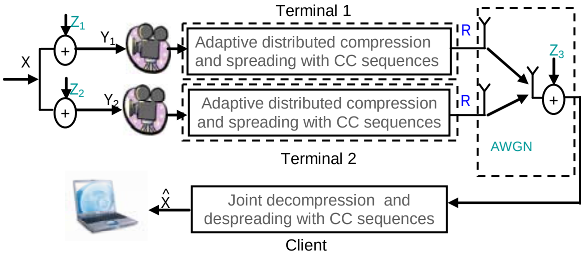

Fig.2: The block diagram of the proposed system.

The block diagram of our adaptive system is shown in Figure 2. Video is encoded frame-by-frame using any video compression method (e.g., H.264 [13]). The encoded video stream X is packetized and broadcast to two terminals. Each terminal obtains only a noisy version of X due to noise in the wireless links Z_i. These two noisy observations, Y_1 and Y_2, are hence correlated; they are compressed and spread using CC sequences at Terminals 1 and 2. A client (within the coverage range of both terminals) downloads the stream simultaneously in real time from both terminals. The client then reconstructs the desired video by effectively combining the two received streams, via joint decompression and despreading, and video decoding,

At the client side, the CC sets correlators/despreaders, operate inversely to the spreading process. For example, let us remove the second signal components transmitted from either terminal alternately. When the symbols are punctured at Terminal 1, the signal belonging to Terminal 2 will be despread in the conventional manner and the estimated symbols will be used to estimate Terminal 1 symbols by: (i) first, spreading the Terminal 2 estimated symbols (possibly corrupted by the correlation channel [9] if the correlation model is known at the receiver) with the second CC element sequence assigned to Terminal 1 (the one that is missing at the receiver); (ii) then adding this component to the original combined signal received at the client; (iii) extracting the symbols belonging to Terminal 1 by despreading the reconstructed combined signal at the client. Then all estimated symbols will be used to recover video source X. The system also applies to the direct MT-SC setup when both observations need to be recovered.

Note that, the system operates by: (i) observing the characteristics of the wireless environment (available bandwidth and error-rate performance), (ii) increasing /decreasing the rate of the video stream so as to maximize quality at the client, (iii) offering trade-offs between transmission rates (adaptive spreading), delay, and video quality.

4. SIMULATION RESULTS

First we model the video as a uniform random binary source with video coding rate of 1 Mbit/sec; transmission rate from each terminal is on average 2.625 Mbit/sec. The correlation between the two sources (at the two terminals) is modeled as a binary symmetric channel (BSC) with crossover probability p. CC element sequence of length four with two carrier frequencies is used. The same transmissions rates at both terminals are achieved by puncturing the second signal components transmitted form both terminals.

Figure 3 shows the obtained performance as bit-error-rate (BER) versus channel SNR for variable crossover probability p. The proposed system, with puncturing, is compared to conventional spreading with CC codes without puncturing. For SNR $\geq$ 9dB, the system is able to operate under the error-free state, with BER $\leq 10^{-4}$, for crossover probability $p \leq 10^{-4}$. It can be seen that only a small performance loss is incurred compared to the conventional spreading system (based on the same CC sequences) which requires approximately 40% more bandwidth.

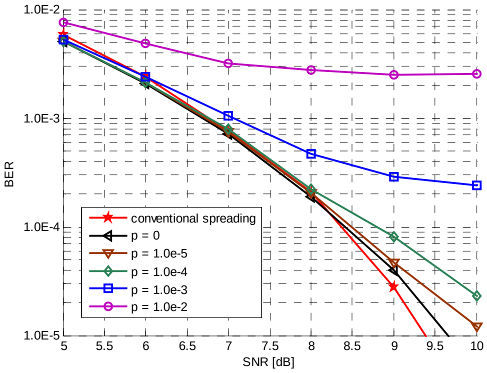

Fig. 3: BER vs channel SNR for two terminals using CC sequences of $K_{CC} = 4$ under AWGN channel. The results are shown for five different values of crossover probability p. The system operates in the asynchronous mode with inter-terminal delay of one chip.

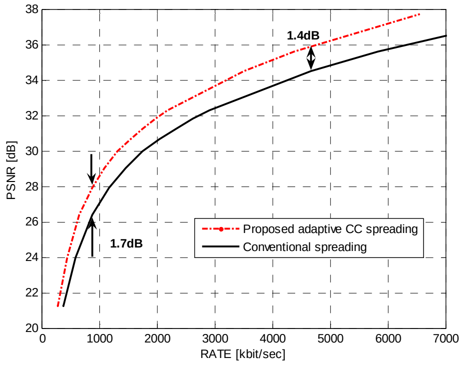

Fig.4: The average PSNR over 100 frames of the CIF "Stefan" video sequence as a function of the transmission rate per terminal per carrier frequency for both the proposed and the conventional system.

Next, we test our system with the standard H.264 coder [13]. We encode 100 frames of the 352x288 CIF "Stefan" video at rate 30 f/s. We assume that one terminal has the original video data, and the other one has a noisy version obtained by passing the original through a BSC with crossover probability $p = 10^{-4}$. The encoded signals are sent to the decoder over independent AWGN channels with SNR=9 dB. Figure 4 shows the resulting PSNR of the Y component averaged over all 100 frames as a function of the transmission rate per terminal per carrier frequency. Results obtained with the conventional spreading system (that does not exploit correlation at the two terminals) are also included. It can be seen from the figure that for the same video reconstruction quality, our system achieves 1Mbit/sec bandwidth reduction. On the other hand, at the same transmission rate our system provides quality improvement of roughly 1.7 dB. Similar results are obtained for different video sequences.

5. CONCLUSIONS

We introduce a wireless communication system that exploits correlation among information during spreading. This novel idea extends joint distributed source-channel coding [9] by introducing another component that enables multiple access and reduces interference. We design a practical system based on CC codes for wireless video communication and show the advantages in terms of significant bandwidth reduction by using correlation information in spreading. In future work we will consider achieving rate trade-off among terminals, fast fading, and more terminals and clients.

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