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Cross-layer optimization for 3-D video transmission over cooperative relay systems

Omar H. Salim [*,a,b], Wei Xiang [a], John Leis [a], Lei Cao [c]

[a] School of Mechanical and Electrical Engineering, University of Southern Queensland, Toowoomba, QLD 4350, Australia
[b] Computer Engineering Department, University of Mosul, Mosul, Iraq
[c] Department of Electrical Engineering, University of Mississippi, University, MS 38677, USA

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ABSTRACT

The rate budget constraint and the available instantaneous signal-to-noise ratio of the best relay selection in cooperative systems can dramatically impact the system performance and complexity of video applications, since they determine the video distortion. By taking into account these constrained factors, we first outline the signal model and formulate the system optimization problem. Next, we propose a new approach to cross-layer optimization for 3-D video transmission over cooperative relay systems. We propose procedures for estimation of the end-to-end instantaneous signal-to-noise ratio using an estimate of the available instantaneous signal-to-noise ratios between the source–destination, and source–relay–destination before starting to send the video signal to the best relay and destination. A novel approach using Lagrange multipliers is developed to solve the optimum bit allocation problem. Based on the rate budget constraint and the estimated the end-to-end instantaneous signal-to-noise ratio, the proposed joint source–channel coding (JSCC) algorithm simultaneously assigns source code rates for the application layer, the number of high and low priority packets for the network layer, and channel code rates for the physical layer based on criteria that maximize the quality of video, whilst minimizing the complexity of the system. Finally, we investigate the impact of the estimated the end-to-end instantaneous signal-to-noise ratio on the video system performance and complexity. Experimental results show that the proposed JSCC algorithm outperforms existing algorithms in terms of peak signal-to-noise ratio. Moreover, the proposed JSCC algorithm is found to be computationally more efficient since it can minimize the overall video distortion in a few iterations.

1. Introduction

The delivery of three-dimensional (3-D) video services over wireless communication networks is anticipated to grow substantially in the near future. This requires further development of the physical layer efficiency, through adoption of spatial modulation multiplexing techniques such as multi-input multi-output-orthogonal frequency division multiplexing (MIMO-OFDM) to provide high data rates and increased bandwidth efficiency. However, the utilization of multiple antennas in the transmitter and/or receiver increases the size and power consumption of MIMO devices. Therefore, the use of cooperative diversity has been proposed to provide spatial diversity, so that the source node cooperates with other nodes (or relays) in forwarding its information to the destination [1]. Cooperative relay protocols have been proposed for use in fourth generation (4G) systems [2].

In cooperative systems, there are two protocols adopted at the relays. The first protocol is termed decode-and-forward (DF), while the second one is termed amplify-and-forward (AF). Usually, a hybrid of one these two protocols is adopted

* Corresponding author.

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according to the system application. For example, forward error correction (FEC) techniques are usually used which require a decoding method that is performed in an iterative manner such as the sum–product algorithm (SPA) of low-density parity-check (LDPC) codes [3]. Therefore, the DF protocol may not be suitable for use in relay networks for video applications because it results in both a high computational complexity and time delay. The increased complexity may also lead to increased power consumption [4]. On the other hand, the AF protocol amplifies the received signal, including noise, and forwards it to the destination. However, the AF protocol has lower complexity, and hence processing time [4]. Therefore, in this paper, we consider the AF protocol through adopting the best relay selection for video applications to reduce the system complexity.

The concept of the best relay selection has previously been examined in the literature to efficiently implement the AF protocol in relay systems [5–9]. The best relay selection depends on selecting a single relay, out of the set of available relays, which has the maximum instantaneous signal-to-noise ratio (γ_{SRD}) between the source–relay–destination. In addition, the selection procedures are automatically repeated every time the channel gains vary [6].

At each time of relay selection, the γ_{SRD} value is varied as well as the variation of the γ_{SD} value in the source–destination channel. Hence, the end-to-end instantaneous signal-to-noise ratio (γ_{coop}) must be communicated to the source and destination, where $\gamma_{coop} \triangleq \gamma_{SD} + \gamma_{SRD}$. The feedback of γ_{coop} can be used to adapt the structure design of the source and destination to the variations of the channels before starting to transmit the video signal. Therefore, the design complexity of the transmitter and receiver, as well as the system performance, is completely determined by the accuracy of estimation of the overall SNR (γ_{coop}). This accuracy estimation of γ_{coop} dramatically impacts on the overall performance and complexity of the system. Errors in the estimation of γ_{coop} degrade the overall performance and increase the complexity of the system.

In wireless systems, there is fixed data budget (R_{budget}) related to the system parameters such as the target rate for each video frame according to its energy and type, channel coding rate and modulation scheme [10,11]. The target rate for each video frame refers to the source coding rate (R_s), which is determined by quantization parameters in the video encoder. The channel coding rate (R_c) is determined by the forward error correction algorithm employed. Joint source–channel coding (JSCC) optimization for video streaming aims to optimally share the available R_{budget} between the source and channel coding rates. This can be very useful to combat the combined effects of source quantization noise and packet losses over wireless channels [12].

1.1. Related work

The feedback scenario utilized in [13–15] is proposed for 2-D and 3-D video transmission to adapt the system to variations in the channels. However, in [13–15], the adaptation scheme is based on the assumption that γ_{coop} is *perfectly* known at the source and destination. The study of the impact of feedback estimation (γ_{coop}) on the system performance for 3-D video transmission over cooperative systems has not been addressed in the literature to date.

Recently, in [13,14,16], we proposed a new unequal error protection (UEP) scheme, called video packet partitioning for 3-D video transmission. Two video transmission schemes were proposed, called direct and packet partitioning schemes. The system alleviates the complexity of the packet partitioning operation by switching to direct schemes at high γ_{coop}. However, in [13,14,16], the allocation of the group of pictures (GOP) packets was fixed for high-priority (HP) and low-priority (LP) streams. Moreover, the source rates were fixed at certain values and the channel code rates were fixed at certain values of 4/16, 8/16 and 13/16 at different signal-to-noise ratios (SNRs) in the channel. More importantly, a JSCC algorithm for cross-layer optimization was not derived.

The existing JSCC algorithms focus on sharing R_{budget} between the source and channel coding operations based only on fixed UEP operations [17,18]. Here, an end-to-end rate-distortion (R-D) model is proposed for multi-view video coding (MVC) to achieve the optimal encoder bit rates and channel code rates. Moreover, the UEP is performed on a fixed structure of three MVC layers, called layer 0, layer 1 and layer 2, with fixed number of frames in each layer. However, this restricted model makes the video system unable to be adapted with the variations in wireless channels. In [19], the JSCC algorithm is proposed for the color plus depth (VpD) transmission over WiMax systems. However, the UEP scheme adopted for transmission based on direct schemes, which requires high data rates for transmission and has lower performance compared to packet partitioning schemes. Moreover, the JSCC algorithm in [19] depends on certain values of source and channel code rates. In addition, the proposed system in [19] used a single antenna and did not utilize any type of diversity techniques to improve the system performance. More importantly, UEP based on packet partitioning schemes for 3-D video transmission has not been considered in the proposed JSCC algorithms in [17–19]. Moreover, the unequal importance of packets inside the right (color) and left/depth is not considered in [17–19] in formatting the HP and LP streams of JSCC algorithms.

In the existing studies in the literature such as [20,21], the problem of cross-layer design of joint video encoding rate control, power control, relay selection and channel assignment for cognitive ad hoc networks and cooperative relays is addressed. Moreover, the problem of joint optimization of power and cache control to support real-time video streaming is addressed in [22]. However, the proposed algorithms in [20–22] are only applicable for 2-D video applications. More importantly, UEP schemes based on packet partitioning are not considered in [20–22].

To the best of authors' knowledge, the framework of the estimation procedures of the end-to-end instantaneous signal-to-noise ratio for cooperative systems based on the best relay selection, and efficient JSCC algorithms for cross-layer optimization based on packet partitioning schemes, is not addressed in the literature. In addition, our simulations show that JSCC approaches reported in the literature are significantly outperformed by the JSCC algorithm proposed in this paper.

It is worth mentioning that this paper does not exploit any advanced estimation techniques for γ_{coop}, since channel estimation techniques are beyond the scope of the