Multiple Description Video Coding for Underlay Cognitive Radio Network

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Abstract. Cognitive radio (CR) with spectrum sharing allows new or secondary devices to co-exist with primary (licensed) users (PU) in accessing the spectrum. This is known as underlay CR. It allows the secondary users (SU) to transmit multimedia data services (video transmission) at low power and low data rate when the PU is using the spectrum. Hence SU can still enjoy uninterrupted video services with minimum tolerable quality. However, problem arises when SUs are subjected to interferences mainly from PU and other SUs. The objective of this paper is to provide error-free video transmission to SU in the underlay CR transmission by using an error resilience method, namely Multiple Description Coding (MDC). Since the underlay mode CR is characterized by low power, low data rate and possibly high packet loss rate, base layer video streaming of a Scalable Video Coding (SVC) with MDC is a feasible solution. The base layer video is coded using MDC with even and odd frames generating two descriptions. Simulation results show that transmitting video in the underlay CR using MDC perform better objectively and subjectively than using a single description coding (SDC).

Keywords: Cognitive radio · Underlay · Multiple description video coding · Scalable video coding · Error resilience

1 Introduction

Cognitive Radio (CR) is a technology that can address the problem of inefficient usage of radio spectrum through enhanced spectrum management capabilities [1]. The spectrum management includes opportunistic access to the spectrum and spectrum sharing. In opportunistic access, CR system allows new or secondary devices to opportunistically access a portion of spectrum, which belongs to PU as in the overlay CR [2]. In spectrum sharing, the low power SU share the spectrum with the PU as in the case of underlay CR. In underlay CR technique, the SU spreads it bandwidth large enough to ensure tolerable amount of interference to the PU.

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Video transmission over CR networks has received many attentions from the research community to fully utilize the available bandwidth resulting from the usage of CR, for example in [3]-[8]. Most of the papers use cross-layer technique to optimize video transmission over CR. Recently, video transmission over underlay CR has been investigated in [7] and [8]. It is a great challenge to obtain high quality video transmission in underlay CR [7]. The challenges are due to the need for the SU to use low transmission power and low transmission rate so that they do not generate interference to the PU. Moreover, SU will suffer interferences from both the PUs and other SUs. In [8], uninterrupted video services are provided to the SU by allowing the SU to receive video in both overlay and underlay mode of CR. The base layer of the scalable video coding (SVC) is transmitted with I-frame error resilience technique during the underlay mode for acceptable video quality.

The underlay mode can be characterized as having low data throughput due to the low transmission power and high packet loss due to interferences from both the PUs and other SUs [7],[9]-[11]. Hence, an error resilience video transmission in the underlay CR network is needed. One of the ways to provide the error resilience is by using multiple description coding (MDC) technique [12].

MDC has been used in video coding community to provide error resilience 2D and 3D video transmission ([12] and [13]). MDC allows a source to be encoded into two or more correlated redundant descriptions. If one of the descriptions is received, acceptable video quality can be achieved. More descriptions will provide higher video quality.

MDC for CR has been studied in [14], [15] and [16]. In [14], MDC is used to transmit images in single and two cognitive radio channels with optimized coding rates within certain amount of time. MDC is employed to cope with the packet losses caused by PU traffic interruptions. However, application of MDC for video transmission in the underlay CR is not considered in this paper. In [15], MDC framework based on Priority Encoding Transmission packetization technique is employed to cope with both primary interruptions and secondary collisions. Different amount of Forward Error Correction (FEC) is assigned to the different descriptions. Again, only image data is used as the source in this paper. Furthermore, underlay transmission is not considered in [15]. MDC multicast (MDCM) in orthogonal frequency division multiplexing (OFDM-based) cognitive radio network (CRN) is studied in [16]. The paper shows that the system throughput using the MDCM scheme with optimized resource allocation is much higher than using the conventional multicast (CM) scheme. However, the proposed system in [16] does not consider video transmission using underlay CR.

The problem of video transmission using MDC in the underlay CR is investigated in this paper. The underlay CR can be subjected to video packet loss as described in [7] and [8]. Specifically, in this paper, we propose technique of using MDC for the transmission of the SVC's base layer to enhance its error resilience property. The remainders of this paper will be organized as follows. Section 2 of the paper presents an overview of MDC followed by the proposed system model in Section 3. Section 4 presents the simulation results and discussion. The paper is concluded in Section 5.

2 Overview of MDC

MDC is one of the error resilience coding techniques that generate multiple/separate descriptions which are correlated and equally important. The descriptions can be in the form of multimedia data such as audio, video and text. In this paper, the concentration is on video data. Any descriptions provide low but at acceptable video quality. Additional descriptions provide incremental improvements to the video quality. The multiple descriptions of the video data may be sent through either the same or separate physical channels. Acceptable video quality can be maintained as long as the two video descriptions are not simultaneously (in terms of the spatial location and time) affected by packet losses [12].

Commonly, two descriptions are generated by MDC encoder. In general more than two descriptions are possible. MDC is popular because it can provide adequate video quality without retransmission and it is suitable for low delay application, hence suited for real time application such as video communication. It also simplifies network design where feedback is not needed and all MDC packets can be equally treated. When MDC is combined with Multi Path Transport (MPT), traffic dispersion and load balancing in network can be achieved [12]. However, due to the redundancies generated, MDC has less coding efficiency than a single description coder (SDC).

Fig. 1 shows the general block diagram of MDC encoder and decoder for two descriptions. In general, it can be extended to more than two descriptions. In Fig. 1, the two descriptions created by the encoder are sent separately across two channels. The total bit rate is $R = R_1 + R_2$, where R_1 and R_2 are the bit rates used to send each description. In the case of two channels, if *E1* and *E2* are received, the decoder invokes Decoder 0 to decode *E1* and *E2*, and produces a high-quality reconstruction with central distortion D_0. If only *E1* is received, Decoder 1 is invoked to decode signal from Channel 1 producing a lower, but still acceptable quality reconstructions with side distortions D_{11}. Decoder 2 is invoked when only *E2* is received, producing acceptable quality reconstructions with side distortions D_{12}. A balanced design is achieved when R_1=R_2 and D_1=D_{11}=D_{12}.

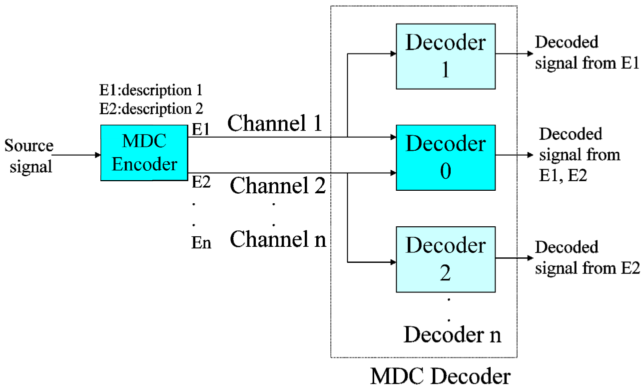


Fig. 1. General block diagram of MDC [12].

A single description coder (SDC) minimises D_0 for a fixed total rate R, and rate-distortion function $R(D_0)$ is used to measure the performance. MDC has contradictory requirements to simultaneously minimise both D_0 and D_1. At one extreme, minimising D_0 by simply alternating the R bits of an SDC bit stream into each description will have unacceptably high D_1. At the other extreme, minimising D_1 by simply duplicating the SDC bit stream with rate R into each description will have a large D_0 because it uses $2R$ bits to achieve D_0. The redundancy r is defined as the additional bit rate required by the MDC coder, $r = R\text{-}R^*$, where R is the total bit rate of the two streams in MDC, and R^* is the reference bit rate from (SDC).

In Fig. 1, the mismatch occurs when only *E1* or *E2* is received and only Decoder 0 is available. Decoder 0 is designed to decode both *E1* and *E2* together. It fails to decode when only *E1* or *E2* is received. The mismatch can be eliminated by having Decoder 1 and 2 specially designed to decode *E1* and *E2* respectively [12].

3 System Models

The scenario for SVC-MDC video streaming over the CR wireless network is illustrated in Fig. 2. The H.264/SVC-MDC encoder ([17] and [18]) is used to generate the multiple descriptions. The H.264/SVC-MDC encoder is based on even and odd frames MDC [19]. The video sequence is decomposed into even and odd frames. H264/SVC-MDC will encode the video once and many layers of video that can support spatial, temporal or quality scalability will be generated at the server. It also includes the two MDC layers, *E1* and *E2*.

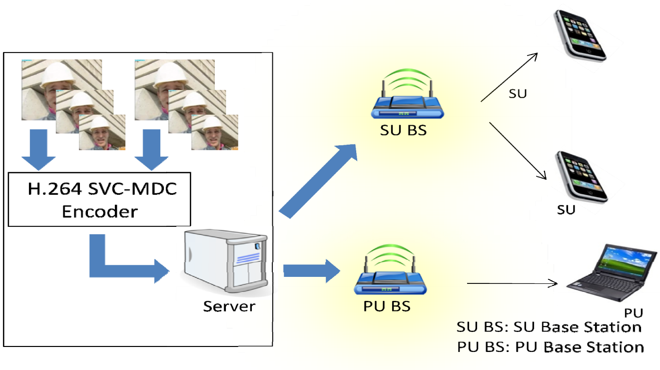


Fig. 2. Scenario for SVC-MDC video streaming in CR network.

The PU and SU are sharing the same channel. Initially, the SU will perform spectrum sensing to find unoccupied spectrum for overlay mode, during which all the scalable layers can be transmitted to the SU. In the next spectrum sensing process, if a PU is found, the SU Base Station (BS) system will switch to underlay mode and transmit the base layer only with MDC capabilities to SU. Fig. 3 shows how the MDC layers, *E1* and *E2*, are generated at the server in Fig. 2. The *E1* and *E2* MDC layers can be selected by the SU BS to be delivered to SU under the error prone underlay CR mode.

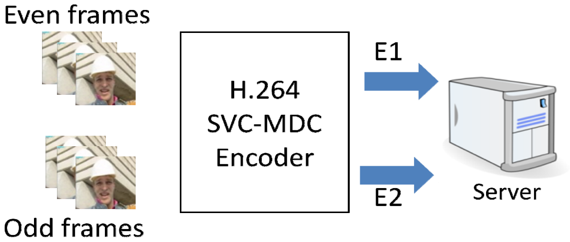


Fig. 3. E1 and E2 MDC layer generation at the server.

The even and odd frames based MDC [19] are used because of simpler implementation and theoretically does not involve modification to the existing encoder, hence less extra processing. It also can avoid mismatch coding due to each frame in *E1* and *E2* is predicted from the previous even frame and odd frame respectively. Due to this configuration, no side information is needed to prevent the mismatch coding. Furthermore, the even and odd frames based MDC can be implemented on various video encoder such as MPEG2, MPEG4 and H.264. The method can also be easily extended to more than two descriptions.

The underlay model for CR used in this paper is as described in [8]. The model produces high packet error rate of about 20%. This high packet error rate is due to the interference from PU and other SU.

4 Simulation Results

For video simulation, H.264/SVC-MDC codec [18] is used to code and decode the video sequence. The main simulation parameters for the codec are shown in Table1. The original video sequence is decomposed into even and odd frames video sequence. H.264/SVC-MDC is used to encode the decomposed video sequence to generate two descriptions, namely *E1* and *E2* as shown in Fig. 3.

Table 1. SVC Parameters.

Parameters	Value
Input video	foreman_cif.yuv
Video width	352
Video height	288
Quantisation parameters	27.5 for SDC
	30 for MDC
Frame format	IPPP
No of I-frame	One I-frame for every 60 P-frames (SDC)
	One I-frame for every 30 P-frames (MDC)

4.1 Error Free Environment

The coding performance of the proposed H.264/SVC-MDC codec in underlay condition is first evaluated under error free environment where there are no packet losses. Table 2 shows the error free performance of coding the 'foreman' sequence using SDC and the proposed MDC. The PSNR is compared between original and compressed video sequence. The source bit rates for both SDC and MDC is about 540 kbit/s. There is minor difference in PSNR as MDC is coded at slightly lower bit rates.

Table 2. Error free performance of SDC and MDC.

Parameters	SDC	MDC
Bit rates (kbit/s)	541.31	533.28
Average PSNR (dB)	37.69	36.35
Quantisation parameter	27.5	30

4.2 Underlay - Ideal MDC Channel

Ideal MDC channel assumes only one of the MDC streams are received by the decoder and the other stream is completely lost [19]. In this experiment, the two descriptions will be sent by the SU base station to the SU in the underlay mode. It was found in [8] that the video Packet Error Rate (PER) is about 20%. The video frames within the two MDC descriptions (*E1* and *E2*) are dropped according to the PER. For fair comparison, the video frames from the SDC are also dropped using the same PER.

In the simulation, when *E1* is subjected to 20% PER, *E1* description is considered lost completely due to the very high PER. The decoded video sequence is reconstructed from just *E2* utilizing frame interpolation to reconstruct the full sequence. Similarly, when *E2* is subjected to 20% PER, *E2* description is considered lost completely and video sequence is reconstructed from just *E1*.

Table 3 shows the error prone performance of coding the same sequence using SDC and MDC in the underlay mode that is subjected to 20% PER. It is assumed that when the *E1* or *E2* MDC description is subjected to 20% PER, it is considered lost completely. The results show that even though E2 MDC stream is completely lost by the 20% PER, a good video quality of PSNR 32.53dB can be achieved by just using *E1* MDC stream. Similarly, when *E1* MDC stream is completely lost, an acceptable video quality of PSNR 32.55dB can be achieved by just using E2 MDC stream.

Table 3. Performance of SDC and MDC in ideal MDC channel for underlay CR.

Average PSNR (dB)	SDC	MDC
Error free	37.69	36.35
At 20% packet loss (underlay mode)	26.86	32.53 (using *E1*) 32.55 (using *E2*)

Fig. 4 shows the subjective quality comparison of the video sequence with SDC and MDC during transmission in the underlay mode. It can be seen that MDC perform better than SDC subjectively. However, due to the average frame interpolation MDC results in ghost or double image artifact as shown in Fig. 4(c) and Fig. 4(d) that can hardly be noticed when the sequence is played. Improved results can be obtained by using frame interpolation that considers motion information between frames.

(a) Original (b) SDC, 20% PER

(c) MDC, 20% PER on E2 (d) MDC, 20% PER on E1

Fig. 4. Subjective quality of video transmission in ideal MDC channel for underlay CR.

4.3 Underlay – MC-CDMA

In this experiment, the SU is modeled as Multi Carrier CDMA (MC-CDMA) with BPSK modulation ([8] and [9]). The simulation results are based upon Additive White Gaussian Noise (AWGN) channel and the video packet size L = 1000 bits. Fig. 5 shows the theoretical AWGN and simulation performance for underlay CR mode for two SUs. As an example, the video packet for both SDC and the proposed MDC is dropped according to the BER at 4dB and 5dB E_b/N_o. There is more video packet dropped at 4dB E_b/N_o compared to 5dB E_b/N_o. In this experiment, any of the two of the MDC streams can be subjected to the video packet loss. The PSNR of the proposed MDC and the SDC is shown in Table 4.

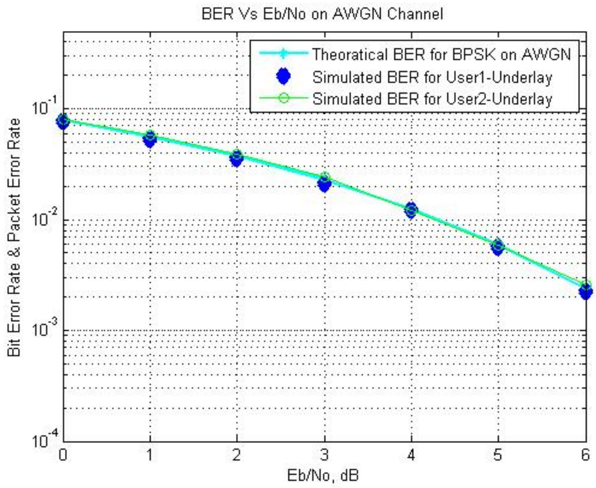
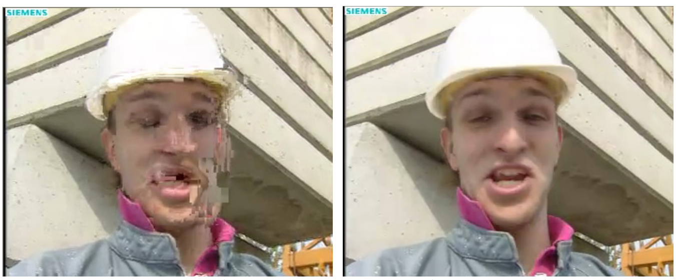


Fig. 5. BER performance for SU in underlay CR.

Table 4. Average PSNR Performance of SDC and MDC in underlay CR.

Channel Condition	Average PSNR (dB)	
	SDC	MDC
Error-free	37.69	36.35
5 dB E_b/N_o	35.36	35.29
4 dB E_b/N_o	32.96	35.15

It can be seen from Table 4 that the proposed MDC outperforms SDC at 4dB E_b/N_o with average PSNR of 35.15dB compared to 32.96dB. At 5dB E_b/N_o, where there is less packet loss, average PSNR of the proposed MDC is slightly lower than SDC due to the redundancies generated by the MDC. However, the redundancies from the proposed MDC can be used to mitigate the error (high packet loss) in the underlay CR channel. Fig. 6 shows the subjective quality improvement obtain with the proposed MDC during transmission in the underlay mode. Improved results can be obtained with proper error concealment at the MDC decoder and is subjected to future studies.



(a) SDC at 4dB E_b/N_o (b) MDC at 4dB E_b/N_o

Fig. 6. Subjective quality of video transmission in simulated underlay CR.

5 Conclusion

In this paper, the problem of video streaming using SVC in underlay mode of wireless CR has been investigated to allow uninterrupted multimedia services to the SU. In the underlay mode, interferences from PU and other SU results in video packet loss to the existing SU. Hence, some form of error resilience need to be embedded during the scalable video encoding process. In this paper, even and odd frame MDC is used as the error resilience technique to mitigate the packet losses in the underlay CR. Simulation results shows PSNR improvement of 7 dB for 'foreman' sequence is achieved by the proposed MDC at 20% PER in ideal MDC channel for underlay CR. The results also shows PSNR improvement of about 2 dB by the proposed MDC for the same sequence in simulated underlay CR channel at 4dB E_b/N_o. Future works include using channel coding to improve performance at the physical layer and using MDC with proper error concealment at the application/video.

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