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Multiple Description Coding for Enhancing Outage and Video Performance Over Relay-Assisted Cognitive Radio Networks

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ABSTRACT Multimedia content delivery, such as video transmission over wireless networks, imposes significant challenges include spectrum capacity and packet losses. The cognitive radio (CR) technology is developed to solve the spectrum issue, while multiple description coding (MDC) is one of the promising source coding techniques to alleviate packet loss problems and exploit the benefit of path diversity. The source information was split into several descriptions in MDC, then transmitted over a network with multiple paths. The quality of the received data increases with the number of descriptions received at the receiver. In this paper, the proposed system comprises of relay-assisted cognitive radio network using the MDC technique for video transmission. In the simulations, the outage performance of the MDC scheme over two networks, which were relay-assisted network and non-relay network, were compared. Then, the outage probability was used to estimate the video quality, peak signal to noise ratio (PSNR) of the received video. The results obtained show the benefits of the relay assisted networks by 9% improvement on average outage performance over the non-relay network. Furthermore, the video performance improved by an average of 9% in PSNR compared to the non-relay system.

INDEX TERMS Cognitive radio, cognitive radio networks, H.264/AVC, multiple description coding (MDC), outage performance, interweave, peak signal to noise ratio (PSNR), relay.

I. INTRODUCTION

Multimedia services are growing fast as heterogeneous communication networks. The number of users using higher bandwidth services such as video streaming is skyrocketing in popularity. Video transmission over wireless networks is rapidly growing due to its continuous deployment in various applications such as in military and disaster recovery.

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It is essential to provide error-prone video transmissions as they are imperative and widely deployed. However, the video transmission challenges arise on bandwidth requirements and interference during the transmission. The cognitive radio (CR) technology was developed to solve the spectrum issue for high bandwidth multimedia applications. At the same time, the relay network is one of the path diversity techniques to combat packet losses for multimedia transmission. Then multiple descriptions created by the MDC source coding approach can be transmitted through the different paths.

From an investigation by FCC (Federal Communications Commission) [1], there are significant allocations of the licensed spectrum that are unoccupied continuously. The vacant radio spectrum has attracted attention of researchers on how to better utilise them. In CR, an unlicensed user known as the secondary user (SU) is allowed to utilise the spectrum when there is an absence of a licensed user, known as primary user (PU), or co-located with the presence of PU. These scenarios are called interweave and underlay modes of CR. In interweave mode, the SU will utilise the spectrum that is currently unexploited by the PU [2]. If PU is present, the SU will only use the spectrum without giving any harmful interference, and this scenario is called the underlay mode of CR. In [3], the researchers concluded that CR technology could exploit underutilised spectrum for a video-aware wireless network and bring enormous benefits to media transmissions.

MDC is a renowned source coding technique that appear as a viable coding mechanism for delivering multimedia data such as images and videos. The MDC coding splits the given data into multiple descriptions such that the received data quality can be dependent on the number of descriptions received. Some of the recent works using MDC techniques for image and video coding are as in [4]–[7]. In [4], MDC was used with the K-singular value decomposition (K-SVD) algorithm to achieve the sparse transform for reconstruction accuracy in image coding. The study in [5] proposed an MDC framework with auto-encoder to produce high-quality image reconstruction. As in video coding, [6] introduced MDC with a scalable coding technique (MDSC) for adaptive video streaming applications over cellular networks. In [7], the MDC was approached as a low latency coding technique for video streaming over Vehicular Ad-hoc NETworks (VANETs).

A combination of relay networks and MDC is a promising solution to combat the problems related to networks such as bandwidth inefficiency and delay constrained [8]. MDC generates several descriptions that can be decoded independently and are suitable to apply in relay-assisted networks. The generated descriptions are equally important and can be routed through a different path to exploit network diversity. The descriptions are also individually decodable, which makes the MDC relevant in the network with no packet delivery priority. MDC with error concealment technique also emerged as an effective method and a promising approach to enhance error resilience and reduce packet loss in video delivery over the various wireless networks. MDC is also compatible with real-time application such as video streaming, where acceptable video quality can be achieved without re-transmission.

In this paper, we model a relay-assisted CR network using path loss and independent slowly varying flat Rayleigh fading channel model with a CR network parameter used in our preliminary study [9]. We split the video source into multiple descriptions using MDC technique then transmit them over multiple paths. The focus of the paper was to investigate the outage and analyse the video performance by maximising the benefits of the following: (i) the exploitation of path diversity via a relay-assisted network over CR; (ii) MDC as the source coding technique to mitigate packet losses; (iii) the combination of multipath relaying with MDC to combat noise.

Then the contributions of this paper can be summarised as follows:

- We proposed a new system for video transmission via a relay-assisted CR network with an MDC approach called the RC-MDC method using H.264/AVC. We first explored the relationship between MDC and relay-assisted CR networks, then developed the system.
- The outage probability is investigated and measured when transmitting the data over the proposed system. The outage performance is compared based on: (1) the relay-assisted network and the non-relay network; (2) the distance from the source to the destination.
- The estimation of the PSNR is measured, and the video performance is analysed using the outage probability investigated in the previous contribution. This analysis provides new insight into the benefits of combining the relay-assisted network and the MDC technique.

The remainder of the paper is structured as follows. Section II discusses the related works, and section III introduces the proposed systems model. Section IV implements the proposed method in a simulation setup. Simulation results and discussion are presented in section V. This paper is concluded in Section VI.

II. RELATED WORKS

The first part of this section covers the functions of a relay in the CR networks, and the second part presents the contributions of MDC in multipath and CR networks.

A. RELAY-ASSISTED COGNITIVE RADIO NETWORK

The CR technology solved the shortage of spectrum resource problems, where it supports the rapid growth in mobile communication by providing enough spectrum resources. On the other parts, channel fading and shadowing may interrupt and degrade the transmission performance. Different diversity techniques are utilised to avoid multimedia transmission interruptions to the mobile user by resolving the noise and fading effects [10]. The relay-assisted CR network has been widely studied in [11]–[26].

The study in [11] considered a relay assisted hybrid overlay/underlay CR with peak interference power constraint to protect the PU. Then, the SU outage probability with the power limit was derived, and the performance improved. In [12], an exact closed-form outage probability was extracted for underlay relay-assisted CR. The correlation of received SNR, power constraints and independent identically distributed (i.i.d) channels were considered in their derivation. As in [13], the study investigates the power allocation for overlay and underlay of CR via a common relay. In this work, they proposed the auction algorithm and analysed the outage performance.

A cognitive relay was used as an underlay CR system deployed in [14]. In their study, the cognitive relay as the SU, follows the underlay paradigm to endorse the secondary usage of the spectrum to the indoor devices. In [15], the study proposed a multi-relay selection for CR to examine outage performance. The outage probability closed-form expression is derived under the Rayleigh fading channel. The SU performance in relay-assisted overlay mode of CR network is analysed in [9]. Their simulation results showed the impact of distance on outage performance, where the outage probability increased with the increase in distance. In [16], the study investigated the effects of multiple relays with cognitive capabilities. They proposed an optimization formula to enhance the QoS requirements for both SU and PU. The CR relaying network with simultaneous wireless information and power transfer (SWIPT) is studied in [17]. They applied the studied system to a fading channel and derived the outage probability. Meanwhile, the outage probability of CR relaying networks with energy harvesting was explored in [18]. The outage performance in their study was analysed over Nakagami-m fading channel. In [19], the study maximised the channel capacity and decreased the outage by proposing two optimal power allocations for hybrid interweave-underlay mode of CR relay networks. They applied the proposed method to a Rayleigh fading channel. In [20], the researchers designed and analysed their proposed framework for wireless energy harvesting in relay-assisted underlay mode of CR networks. They introduced an efficient relay selection to determine the suitable relay to select during the transmission.

The relay selection policies in a full-duplex (FD) based underlay CRN was investigated in [21]. The study also proposed two low-complexity relay selection schemes based on the sum rate maximization. In [22], they proposed a link selection policy to utilise the direct link communication for a buffer-aided relaying in cognitive relay networks. The improvement in outage probability and end-to-end average packet delay can be achieved by their proposed policy. While in [23], a novel buffer state-based relaying selection scheme in relay-assisted CRN was proposed. The scheme incorporates the simultaneous activation of multiple links between the secondary source (SS) and secondary relay (SR) nodes. In [24], they developed a framework for the outage probability of energy harvesting for underlay CRN. The framework facilitates the data transfer among SUs for N-hop primary transmission. A novel decentralised scheduling technique is developed in [25] for the cognitive multi-user multi-relay network. Their proposed technique provides an acceptable outage performance when the relaying links are stronger than the direct links. Recently, [26] developed a framework to incorporate the interference cancellation in the outage analysis of the energy harvesting cognitive relay network. The optimal relay selection range is derived in their work then deployed to minimise the outage probability.

B. MULTIPLE DESCRIPTION CODING (MDC) APPROACH IN RELAY AND COGNITIVE RADIO NETWORKS

MDC with multipath diversity can effectively mitigate noise, fading and shadowing in a mobile channel [27]. However, the constraints emerged on; (1) the processing capabilities that require simple processing at the encoder or decoder, (2) the packet loss caused by the wireless communication environment [28]. MDC is one of the coding techniques that generate several descriptions and can be independently decoded in contrast to layered coding (LC), where there is no hierarchy among descriptions [29]. Several studies investigating the contributions of MDC in the relay and CR networks were carried out by [30]–[38].

The study in [30] demonstrate the MDC for source coding in the CR system to deal with PU interruptions when the traffic of data is delay sensitive and distortion is tolerable. In [31], the study proposed MDC with a specific packetisation framework for the CR network under collision error. However, both studies were only used image sources in their works. The MDC multicast in the CR network-based orthogonal frequency division multiplexing (OFDM)were applied in [32] and [33]. The studies investigated the resource allocation scheme using MDC compared to the conventional multicast scheme. However, they only focused on the resource allocation problem instead of video transmission performance. In contrast, a novel distributed system for CR network was explored in [34] using the MDC technique. The proposed method was applied in realistic cases and either PU interruptions or sub-channel fading is considered. However, they only used an image as their transmission source. In [35], they applied the MDC at the base of the SVC layer to improve error resilience for video transmission over the underlay mode of CR. In this study, MDC was used as an error resilience technique to mitigate the packet loss, but the video performance was measured without using any error concealment at the decoder.

Furthermore, [36] investigated the performance of video transmission in CR. The study proposed a joint design of the MDC technique with H.264/AVC video coding. However, the relay network was excluded in their CR network design. Next, the video delivery over cognitive cellular networks are investigated in [37] and [6]. The video sequence was separated into odd and even streams, and later encoded to produce two independent descriptions. Their studies focused on investigating the ideal combination of layered and multiple description coding without adding any relay to the network. The application of MDC to improve system throughput and transmission robustness was proposed in [38]. The study derived the outage probability closed-form expression to analyse the PSNR, but they focused only on image transmission.

Combining the multipath scheme with the multiple descriptions generated using the MDC approach is a promising solution to combat noise and delay to mitigate packet loss in wireless networks. This paper adopts the combination of multipath and multiple descriptions techniques

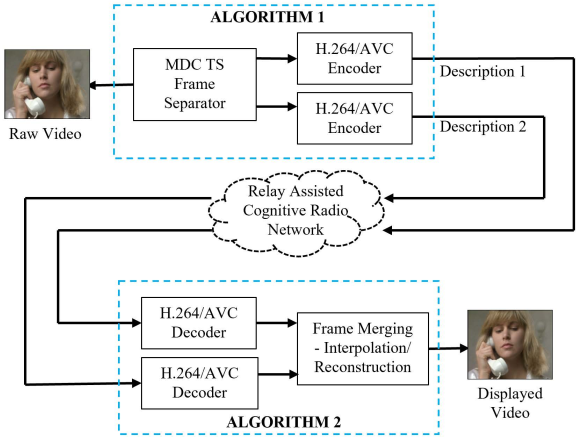


FIGURE 1. The proposed system architecture for relay-assisted CR network using MDC (RC-MDC).

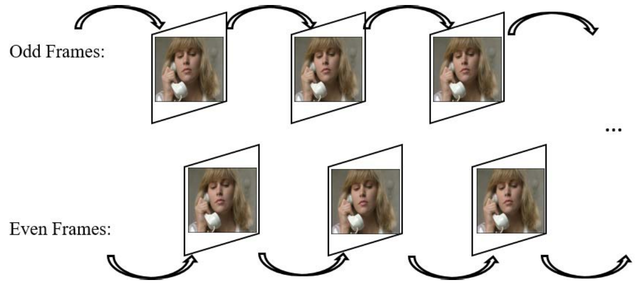


FIGURE 2. Temporal splitting MD coding method.

for transmitting video data over CR networks. The MDC approach was first applied to compare the outage performance of the relay and non-relay network then the outage probability is used to evaluate the video performance. The selection combining (SC) technique is considered in this paper to combine the relay and direct paths. The SC technique has been used as a receiver diversity technique to analyse the system performance, such as in [39], [40] and [41].

III. ARCHITECTURE OF THE RC-MDC SYSTEM

Figure 1 shows the system architecture of the proposed system, RC-MDC. The multiple description (MD) source coding with H.264/AVC video encoder generates two video descriptions based on the temporal splitting (TS) MD coding method. The generated descriptions are transmitted via two paths over the relay-assisted CR network model to the receiver. MD with H.264/AVC video decoder decodes the descriptions at the receiver. The error concealment method in [42] was applied in the decoding process to reconstruct the video frame sequence from the received descriptions. The following subsection discusses the detailed explanations on the process of video encoding/decoding and network model.

A. MULTIPLE DESCRIPTION CODING (MDC) WITH H.264/AVC VIDEO ENCODER AND DECODER

In MDC, the generated descriptions are encoded and decoded individually and mutually refinable [43]. The descriptions transmitted over multiple channels can compensate for the dynamic and unpredictable channel conditions, where each channel may have different error characteristics. The TS MD mode proposed in [44] was used in our proposed system. The video sequence effectively partitioned along the time dimension to generate odd and even video frames. Prediction of odd frames is done from the odd frames, and the same to even frames where it is predicted from the even frames, as shown in Fig. 2. In frame prediction, the future frame is predicted by using motion compensation technique. This technique is employed at the encoding part in video coding. The prediction is done by accounting motion of the object in the video frame and the encoder will find for the block similar to the previously encoded frame. The technique is used to increase the efficiency of video encoder [45]. Each of the descriptions has half the temporal resolution of the original video. At the encoder, two descriptions are encoded by the odd and even video sequence generated by TS mode using the H.264/AVC video encoder.

At the decoder, if both descriptions are received, the frames from descriptions 1 and 2 are interleaved to reconstruct the full sequence. If only one description is received, the interpolation algorithm is applied to obtain the full frames sequence. The received video frames can have a distortion caused by possible losses during the transmission. An error concealment method, as in [42] is performed to refine the packet loss. The temporal frame-copy concealment method is applied to conceal the lost macro block (MB). The MB corresponding to a 16 x 16 pixel region of a video frame is the basic unit for motion compensated prediction in H.264/AVC codec. The lost MBs in the intra-frame is covered by refining the intra-MB using the temporal correlation between adjacent intra-frames in two descriptions. Hence, the lost inter-MB is concealed by applying motion-compensated prediction by estimating the lost motion vector from the MB's reference.

B. RELAY-ASSISTED COGNITIVE RADIO NETWORK MODEL

This work considers the proposed system model operating under interweave mode of CR, where PU is in idle mode. The SU can transmit with maximum power while not giving any harmful interference to the PU. Figure 3 shows the relay-assisted CR network model. For combining MDC with multipath to exploit path diversity, a relay is added between the source and destination through the CR network. The type of relay used for secondary network in this work is known as supportive relaying model (SRM) [46]. SRM provides two different paths from the source node to the destination node, where the MDC technique can be applied here. The secondary relay (SR) relays the information from the secondary source (SS) to the secondary destination (SD) on the relay path. Meanwhile, the path between SS and SD is known as the direct path. The relaying protocol applied in the relay path is known as decode and forward (DF) protocol. In this protocol, the relay will receive the information from the source and forward it to the destination. In our system model, d_{SS}^{SR} and

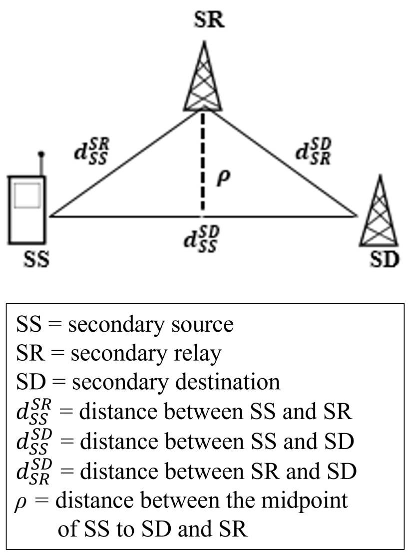


FIGURE 3. Relay-assisted CR network model.

TABLE 1. Notation.

Symbols	Definitions
G	channel gain
α	path loss exponent
N_0	noise variance
λ	parameter of exponentially distributed RV
γ	SNR
ξ	threshold for received SNR
P_S	transmit power of SS
P_R	transmit power of SR
R	threshold rate

d_{SR}^{SD} indicates the distance between SS to SR and SR to SD respectively. The distances are obtained by the calculation of Pythagoras' theorem using distance value between SS to SD, d_{SS}^{SD} and ρ. The distance calculation is given as,

$$d_{SS}^{SR} = d_{SR}^{SD} = \sqrt{(\frac{1}{2}d_{SS}^{SD})^2 + \rho^2} \tag{1}$$

C. OUTAGE PROBABILITY

In the proposed model, the channel is assumed to consist of path loss and slowly varying flat Rayleigh fading with parameter $1/\lambda_A^B$ as the variance and the average power channel is defined as $1/\lambda_A^B = E[G_A^B] = d_A^{B^{-\alpha}}$ where $E[.]$ denotes expectation, d is the distance and α is the path loss exponent. Therefore, the channel gain denoted as $G_A^B = |h_A^B|^2$ is exponentially distribution random variable with probability density function (PDF) $f_{G_A^B}(x) = \lambda_A^B e^{-\lambda_A^B x}$. Let the notations A and B represent the parameter between A and B, or from A to B and vice versa. So that the channel gain and its PDF in this work are given by

$$G_{SS}^{SD} = |h_{SS}^{SD}|^2 \quad f_{G_{SS}^{SD}}(x) = \lambda_{SS}^{SD} e^{-\lambda_{SS}^{SD} x} \tag{2}$$

$$G_{SS}^{SR} = |h_{SS}^{SR}|^2 \quad f_{G_{SS}^{SR}}(x) = \lambda_{SS}^{SR} e^{-\lambda_{SS}^{SR} x} \tag{3}$$

$$G_{SR}^{SD} = |h_{SR}^{SD}|^2 \quad f_{G_{SR}^{SD}}(x) = \lambda_{SR}^{SD} e^{-\lambda_{SR}^{SD} x} \tag{4}$$

Assume an i.i.d channel and the channel gain, G_{SS}^{SD}, G_{SS}^{SR} and G_{SR}^{SD} are exponentially distributed with parameter λ_{SS}^{SD}, λ_{SS}^{SR} and λ_{SR}^{SD} respectively. Interference power and maximum transmit power constraint can be ignored in our proposed interweave CR model.

The outage occurs when the receiver unsuccessfully recovers the signal from the transmitter. The outage probability can be estimated when the mutual information, Δ, is under a certain rate threshold, R, which can be denoted as follows:

$$\begin{aligned} \Delta &< R \\ \frac{1}{2}log_2(1+SNR) &< R \\ SNR &< 2^{2R} - 1 \end{aligned} \tag{5}$$

From Equation (5), let $\gamma = SNR$ and $\xi = 2^{2R} - 1$. $\frac{1}{2}$ indicates that the entire transmission process passes two phases, the same as our preliminary study in [9]. The first phase covers the transmission between SS to SD and SS to SR. The received SNR at SD, γ_{SS}^{SD} and SR, γ_{SS}^{SR} using the transmit power of SS, P_S is given by

$$\gamma_{SS}^{SD} = \frac{P_S G_{SS}^{SD}}{N_0} \tag{6}$$

$$\gamma_{SS}^{SR} = \frac{P_S G_{SS}^{SR}}{N_0} \tag{7}$$

where N_0 is the variance of additive white Gaussian Noise (AWGN). The transmission in relay path is completed in the second phase when SR successfully recovers the information and forwards them to SD. By using the transmit power of SR, the received SNR at SD, γ_{SR}^{SD} is given by

$$\gamma_{SR}^{SD} = \frac{P_R G_{SR}^{SD}}{N_0} \tag{8}$$

The outage probability of the relay path is denoted by $Pout_1$ and in DF scheme, an outage occurs when either the SS to SR or the SR to SD path fails. Then, the outage probability of the source-relay-destination, SS-SR-SD path is given by

$$\begin{aligned} Pout_1 &= P_R\{\gamma_{SS}^{SR} < \xi\} or P_R\{\gamma_{SR}^{SD} < \xi\} \\ &= 1 - e^{-\lambda_{SS}^{SR}\theta} e^{-\lambda_{SR}^{SD}\beta} \end{aligned} \tag{9}$$

While, the outage probability of the direct path is denoted as $Pout_2$. The outage probability from source to destination, SS-SD is given by

$$\begin{aligned} Pout_2 &= P_R\{\gamma_{SS}^{SD} < \xi\} \\ &= 1 - e^{-\lambda_{SS}^{SD}\theta} \end{aligned} \tag{10}$$

Details of the derivation for $Pout_1$ and $Pout_2$ are given in the Appendix.

This paper applied the SC technique as a receiver diversity technique to combine or decode the received signals at the destination. The overall outage probability with SC can be expressed as a function of the outage probabilities of the respective paths. Thus, the overall outage probability of SC as in [39] is given by

$$Pout = Pout_1 \times Pout_2$$

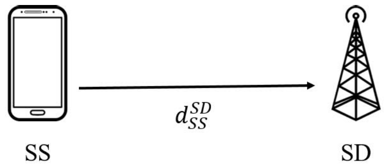
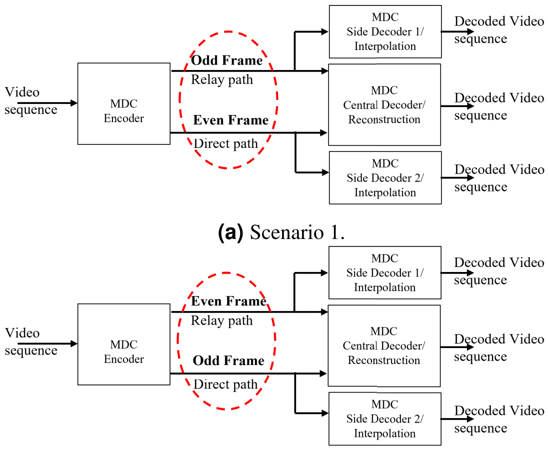


FIGURE 4. Non-relay CR network model.



(a) Scenario 1.

(b) Scenario 2.

FIGURE 5. Simulation scenarios.

TABLE 2. Video coding parameters.

Parameters	Value
Input Video	suzie_qcif.yuv & foreman_cif.yuv [41]
Video width	176 & 352
Video height	144 & 288
Videocodec	H.264/AVC
Quantisation parameter	20
Frame format	IPPP
No. of Frame	30 frames
Error concealment	Frame-copy method

$$= (1 - e^{-\lambda_{SS}^{SR}\theta} e^{-\lambda_{SR}^{SD}\beta})(1 - e^{-\lambda_{SS}^{SD}\theta}) \quad (11)$$

where $\theta = \frac{\xi N_O}{P_S}$ and $\beta = \frac{\xi N_O}{P_R}$ is the multiplication of outage probability event with noise over source transmit power or relay transmit power, respectively.

As a comparison, we calculated the outage probability for the non-relay CR network model, as illustrated in Fig. 4. For non-relay model, only direct transmission is involve without relay existence. The outage probability for non-relay as in [47] is given by

$$Pout_{non-relay} = 1 - e^{-\lambda_{SS}^{SD}\theta} \quad (12)$$

IV. SIMULATION SETUP

In the RC-MDC network model, we set up the simulation for two scenarios to evaluate the PSNR based on the description received. In Scenario 1, the odd frames are sending over the relay path, and the even frames are over the direct path and vice versa in Scenario 2. These scenarios are as illustrated in Fig. 5.

(a) Suzie sequence. (b) Foreman sequence.

FIGURE 6. Video sequence [49].

TABLE 3. RC-MDC network parameters [9].

Parameters	Value
Path loss exponent, α	4
Noise variance, N_0	10^{-13}
Transmit power of SS, P_S	0.01 W to 0.1 W
Transmit power of SR, P_R	0.2 W
Threshold rate, R	1

Algorithm 1 Video Encoding

1: Transmit video sequence.
2: Separate video sequence into odd and even frames using temporal splitting MD mode.
3: Store the frames in a different file in the colour encoding system, the YUV format.
4: Encode both frames to create two descriptions using the H.264/AVC encoder.
5: Send the descriptions through separate paths for relay-assisted network, and over one path for non-relay network.

A. ENCODING AND DECODING PROCESS

H.264/AVC is an established standard for video compression. It is a document published by the international standard bodies International Telecommunication Union-Telecommunications (ITU-T) and International Organisation for Standardization International Electrotechnical Commission (ISO/IEC) [48]. Video compression is an essential technology for video transmission. H.264 video encoder predicts, transforms and encodes the video to generate a compressed bitstream, which is then converted back into an uncompressed format known as the decoded video sequence by a decoder. The decoding processes include the complementary process, inverse transform and frame merging process (reconstruction or interpolation). The new video sequence with the same temporal resolution will be generated after the decoded descriptions are merged. The total number of the video frame is now the same as the number of the original video frame sent by the transmitter. The H.264/AVC is the best standard for video compression in widespread use that introduces intra-frame and inter-frame compressions. High coding efficiency can be achieved and with a high degree of flexibility for operation in a variety of network conditions [43].

The simulation parameters for video coding as suggested in [36] is presented in Table 2. We considered the Suzie and

Algorithm 2 Video Decoding

1: Receive the descriptions in generated video traces at the decoder part.
2: Decode each description independently by the H.264/AVC decoder.
3: Perform error concealment to refine the packet loss.
4: **for** both odd and even descriptions are received **do**
5: Execute frame reconstruction. ▷ merge odd and even descriptions
6: **for** either odd or even description is received **do**
7: Execute frame interpolation. ▷ merge same descriptions

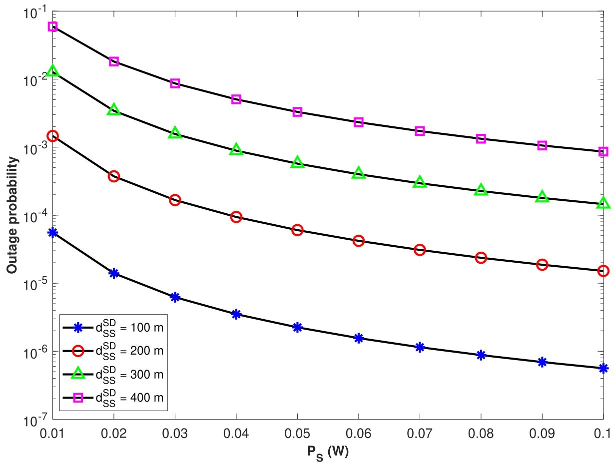


FIGURE 7. RC-MDC outage performance at a different distance of SS to SD.

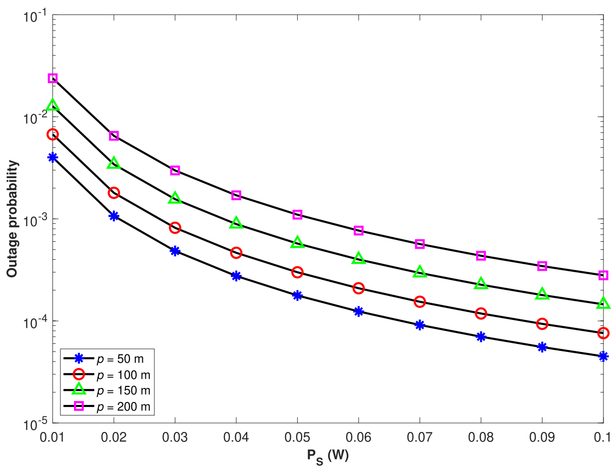


FIGURE 8. RC-MDC outage performance for different ρ value.

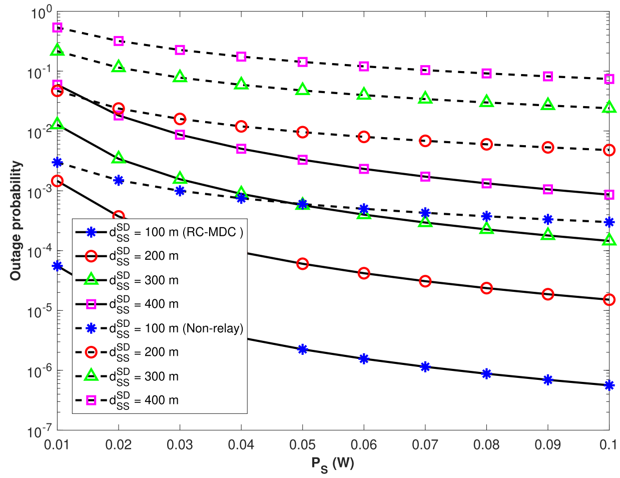
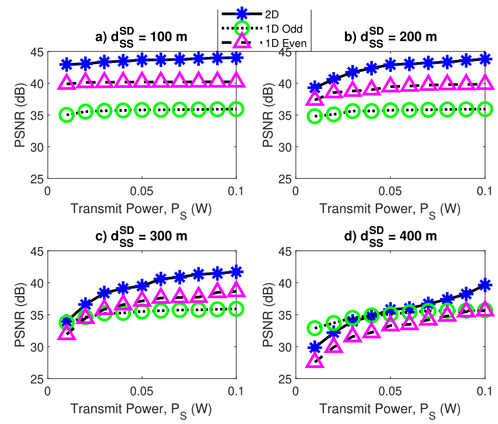
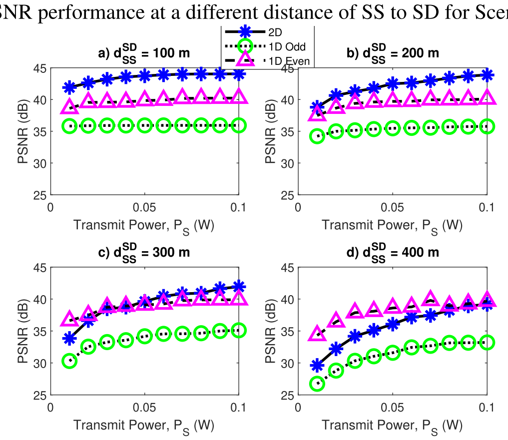


FIGURE 9. Comparing outage performance of RC-MDC and non-relay network at a different distance of SS to SD.



(a) PSNR performance at a different distance of SS to SD for Scenario 1.



(b) PSNR performance at a different distance of SS to SD for Scenario 2.

FIGURE 10. PSNR performance of RC-MDC for Suzie sequence.

Foreman video sequence shown in Fig. 6, which were in quarter common intermediate format (QCIF) and common intermediate format (CIF) respectively. The video sequence is converted into grayscale for simulation processes. The frame rate of Suzie and Foreman is 30 fps.

The encoding and decoding processes as in Fig. 1 are explained in Algorithm 1 and 2.

B. RC-MDC NETWORK SYSTEM PARAMETERS

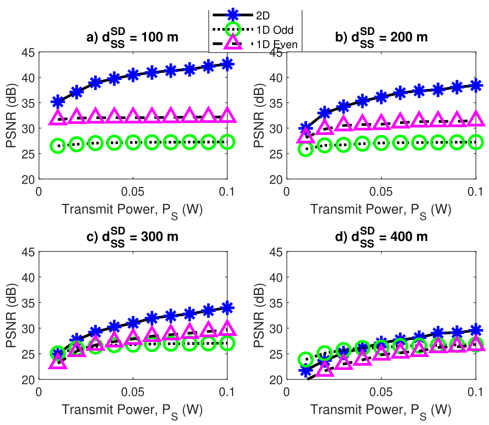
Table 3 presents the system parameter used in this work. The parameter values were used in outage probability versus transmit power of SS, P_S measurement. We modelled the network based on the different distance of SS to SD, d_{SS}^{SD}. The distance between SS to SD and SR, ρ is fixed.

TABLE 4. Average PSNR of RC-MDC at variations of d_{SS}^{SD} for Scenario 1.

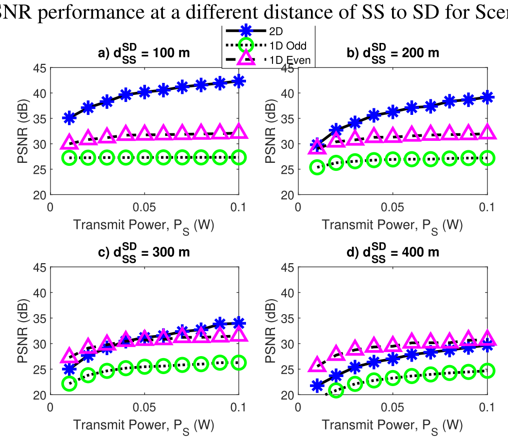
d_{SS}^{SD} (m)	Suzie - PSNR (dB)			Foreman - PSNR (dB)		
	2D received	1D odd received	1D even received	2D received	1D odd received	1D even received
100	43.5817	35.7069	40.1465	39.9942	27.0924	32.0379
200	42.3906	35.6180	39.0991	35.6888	26.8938	30.6399
300	39.3468	35.3246	36.4598	30.7593	26.5916	27.5803
400	35.4540	34.8949	32.7895	26.7436	26.0312	24.2998

TABLE 5. Average PSNR of RC-MDC at variations of d_{SS}^{SD} for Scenario 2.

d_{SS}^{SD} (m)	Suzie - PSNR (dB)			Foreman - PSNR (dB)		
	2D received	1D odd received	1D even received	2D received	1D odd received	1D even received
100	43.4963	35.9003	39.7061	39.8340	27.2959	31.4621
200	42.1461	35.3474	39.3803	35.9165	26.7071	31.1005
300	39.2998	33.7277	38.9367	30.7911	25.1243	30.3289
400	35.8102	31.2722	38.0833	26.8098	22.9394	29.2706

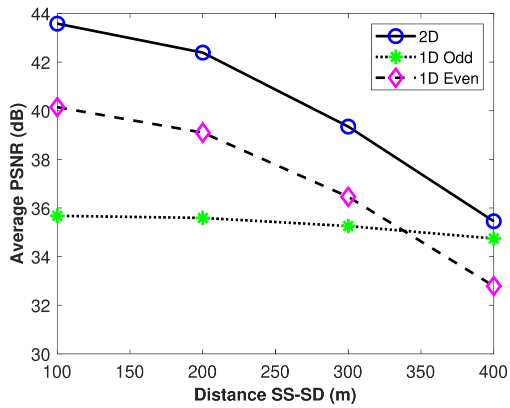


(a) PSNR performance at a different distance of SS to SD for Scenario 1.

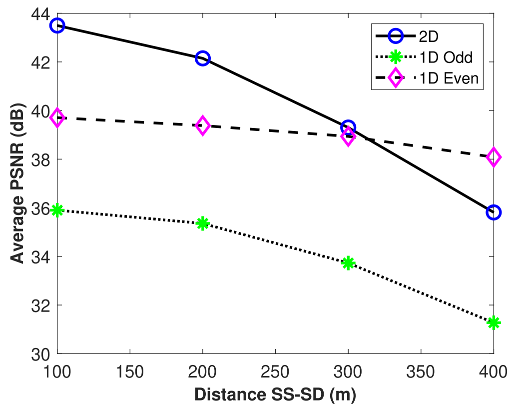


(b) PSNR performance at a different distance of SS to SD for Scenario 2.

FIGURE 11. PSNR performance of RC-MDC for Foreman sequence.



(a) PSNR comparison for Scenario 1.



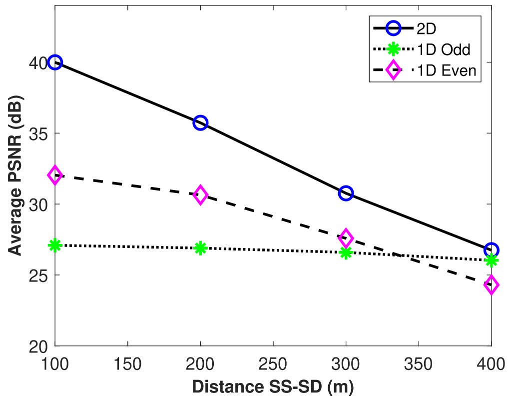
(b) PSNR comparison for Scenario 2.

FIGURE 12. PSNR comparison of RC-MDC for Suzie sequence.

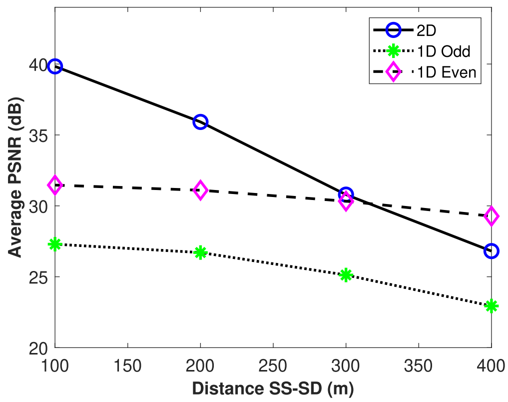
V. RESULTS AND DISCUSSION

The simulation setup in Section IV was used to simulate the proposed system, RC-MDC. First, the outage probability is evaluated when the system model is set to a different distance of SS to SD. The distances were 100 m, 200 m, 300 m and 400 m and ρ is fixed at 150 m. Figure 7 shows the results for the total outage probability calculated using equation (11) in different distance of SS to SD. The outage probability showed as a function of the transmit power of SS, P_S. As can be seen from the figure, the increase in the source to destination distance has increased the probability of outage. The longer the distance from SS to SD, the lower the channel gain, which resulted in higher outage probability.

The second outage evaluation was simulated when the rho value was set to 50 m, 100 m, 150 m and 200 m, with the d_{SS}^{SD} fixed at 300 m. The total outage probability is calculated using equation (11) for different value of ρ. As shown in Fig. 8, it can be observed that the distance between source to relay, d_{SS}^{SR} and relay to the destination, d_{SR}^{SD} was affected by

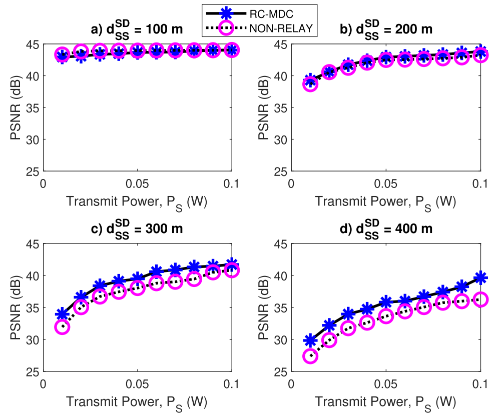


(a) PSNR comparison for scenario 1.

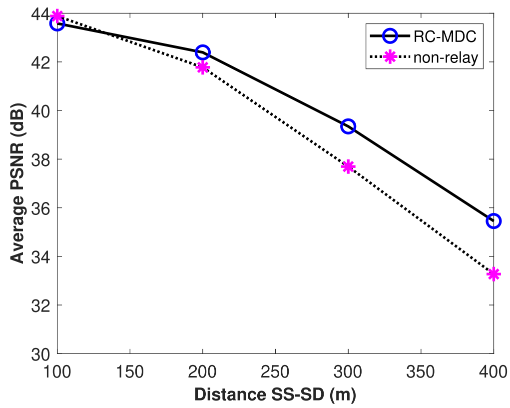


(b) PSNR comparison for scenario 2.

FIGURE 13. PSNR comparison of RC-MDC for Foreman sequence.



(a) PSNR of relay and non-relay at variation of SS-SD.



(b) PSNR comparison relay and non-relay.

FIGURE 14. PSNR performance of RC-MDC and non-relay network for Suzie sequence.

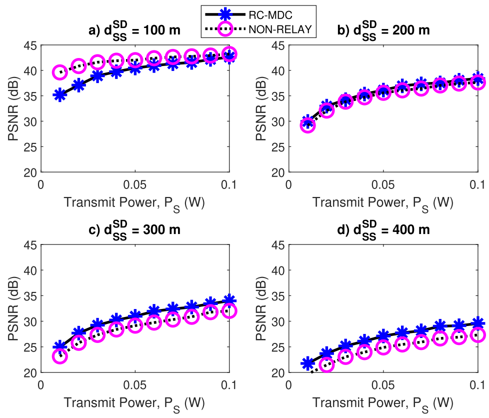
ρ. Higher ρ resulted in increasing outage probability as d_{SS}^{SR} and d_{SR}^{SD} increased.

Next, we compared the outage performance between the relay network and a non-relay network at different distance of SS to SD. The comparison result is shown in Fig. 9. For the descriptions transmitted over the network without the relay, the outage probability calculated using equation (12) was higher than a network with a relay. The RC-MDC achieved 9 % improvement of outage probability over a non-relay network. In a non-relay network, transmission depends only on the single path from SS to SD, where the quality of data received degraded due to path loss and fading effects. Meanwhile, adding a relay in transmission can improve the quality of the data received when the distance of transmission becomes larger.

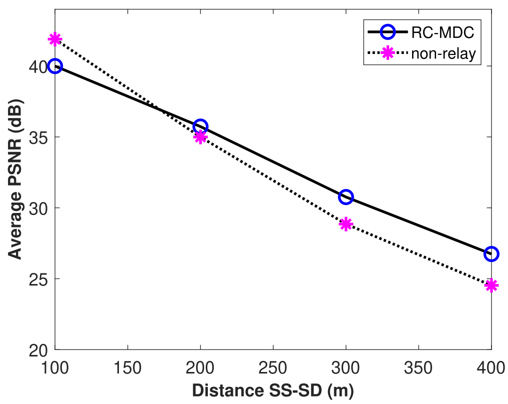
The PSNR was used as the performance metric to evaluate the video quality of the decoded video sequence from the descriptions received at the destination. First, the PSNR performance based on the different d_{SS}^{SD} was simulated. Figures 10 and 11 present the performance for Suzie and Foreman sequence, respectively. The results show the PSNR of the reconstructed and interpolated sequence representing both descriptions (2D) and one description (1D even or 1D odd) received, respectively. Sub-figure (a) for both sequences shows the PSNR for Scenario 1 and sub-figure (b) for Scenario 2. At $d_{SS}^{SD} = 400$ m in Scenario 2, the PSNR of one description (1D) which transmitted via relay path is slightly higher than when two descriptions (2D) are received at the receiver as the outage probability for the relay path is lower than the direct path. For both sequences, if the receiver received a set of even or odd frames when either relay or direct path fails, the acceptable video quality was produced. The video quality improved if both descriptions are obtained at the destination. Figures 12 and 13 show the overall PSNR performance comparison for 2D and 1D at the different d_{SS}^{SD}.

Tables 4 and 5 present the average PSNR of Suzie and Foreman sequence from 10 trials for Scenario 1 and 2 respectively. At the variations of d_{SS}^{SD}, when both descriptions are received, the overall average PSNR improved by 17% for the Suzie sequence, and 27% dB for the Foreman sequence, compared to only one description received. The highest PSNR improved at $d_{SS}^{SD} = 100$ m with 8 dB for Suzie and 13 dB for Foreman. In terms of distance effects, the PSNR value decreased when the distance of d_{SS}^{SD} increased.

Next, the PSNR of the proposed method RC-MDC was compared to the non-relay network. In a non-relay network, the odd and even frames are interleaved and transmitted over a direct path. The PSNR results are shown in Fig. 14 and 15 for Suzie and Foreman sequence, respectively. The PSNR using



(a) PSNR of relay and non-relay at variation of SS-SD.



(b) PSNR comparison relay and non-relay.

FIGURE 15. PSNR performance of RC-MDC and non-relay network for Foreman sequence.

TABLE 6. Average PSNR of RC-MDC and non-relay.

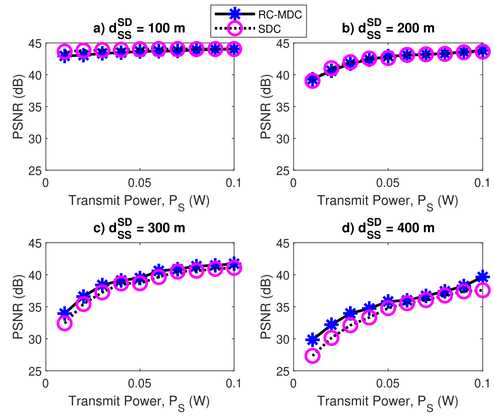
d_{SS}^{SD} (m)	Suzie - PSNR (dB)		Foreman - PSNR (dB)	
	RC-MDC	non-relay	RC-MDC	non-relay
100	43.5817	43.8850	39.9949	41.8925
200	42.3906	41.7747	35.6888	34.9924
300	39.3468	37.6940	30.7593	28.8531
400	35.4540	33.2717	26.7436	24.5303

RC-MDC has an improvement of 6% for the Suzie sequence and 9% for the Foreman sequence compared to the non-relay network. Table 6 compares the average PSNR results in dB. The results observations show that a relay-assisted network offers better performance than a network without a relay. With large scale transmission, the efficiency of data worsens when the distance between SS to SD increases, which leads to signal degradation. By deploying a relay in the middle, it can adequately cover the signal coverage and achieve better transmission quality.

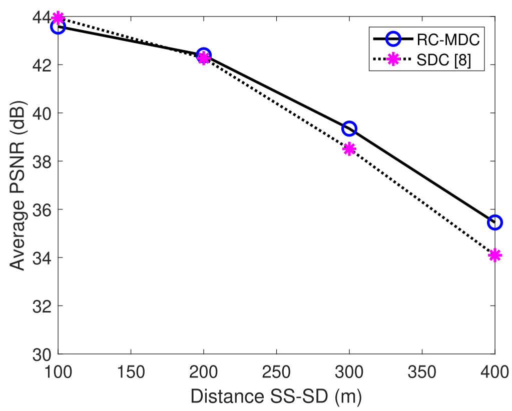
A comparison was also made for the proposed system with the MDC and SDC approach. For SDC, the single description contains the odd and even frames transmitted over the direct path. The result obtained in Fig. 16 and Fig. 17 show that the RC-MDC outperformed SDC by 4% and 2%improvement for Suzie and Foreman sequences, respectively. Even with slight improvement, the RC-MDC still has the advantage of receiving the description via relay path if the outage occurs in the direct path compared to only one description transmitted over a single path. Table 7 summarises the PSNR in dB.

TABLE 7. Average PSNR of RC-MDC and SDC.

d_{SS}^{SD} (m)	Suzie - PSNR (dB)		Foreman - PSNR (dB)	
	RC-MDC	SDC	RC-MDC	SDC
100	43.5817	43.9412	39.9942	43.5050
200	42.3906	42.2720	35.6888	36.7810
300	39.3468	38.5089	30.7593	30.7525
400	35.4540	34.0973	26.7436	26.1736



(a) PSNR of RC-MDC and SDC at variation of SS-SD.

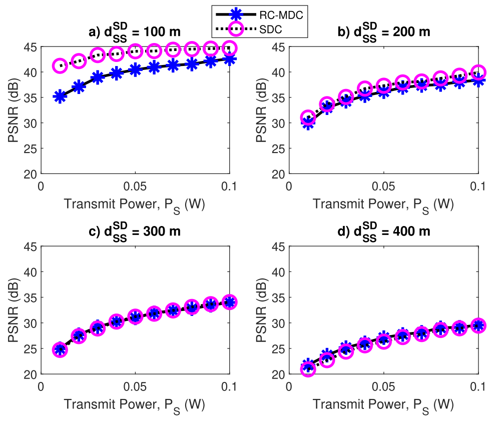


(b) PSNR comparison RC-MDC and SDC.

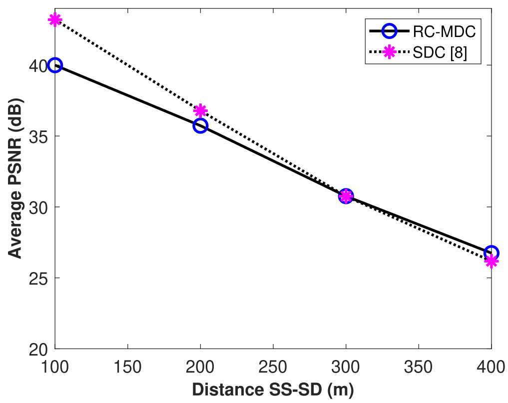
FIGURE 16. PSNR performance over RC-MDC and SDC for Suzie sequence.

VI. CONCLUSION

This paper proposed the MDC approach on relay-assisted CR networks (RC-MDC) to investigate the outage and video performance. This approach uses the MDC technique combining with the relay-assisted network to exploit the path diversity benefits. The multiple descriptions generated by MDC can be routed over the different paths in the relay-assisted network and independently decoded. The outage probability was defined and analysed to measure the performance of our proposed system and compared to the network without relay-assist. We then used the outage probability for estimating the PSNR to analyse the video performance. Higher video quality is achieved when more descriptions are received at



(a) PSNR of RC-MDC and SDC at variation of SS-SD.



(b) PSNR comparison RC-MDC and SDC.

FIGURE 17. PSNR performance over RC-MDC and SDC for Foreman sequence.

the destination. The effect of the different distances from the source to the destination on the performance was also investigated. Our RC-MDC showed an outage performance improvement of 9% over the network without relay assisted. Furthermore, the PSNR results obtained show the advantage of the proposed system by 20% improvement when two descriptions were received, 9% improvement over the non-relay network and 4% improvement over SDC.

APPENDIX

Derivation of Outage Probability for SS-SR-SD path

$Pout_{S,R}$,

$$\begin{aligned} Pout_{S,R} &= P_R\{\gamma_{SS}^{SR} < \xi\} \\ &= P_R\{\frac{P_S G_{SS}^{SR}}{N_0} < \xi\} \\ &= P_R\{G_{SS}^{SR} < \theta\} \\ &= \int_0^{\theta} \lambda_{SS}^{SR} e^{-\lambda_{SS}^{SR} x} dx \\ &= 1 - e^{-\lambda_{SS}^{SR}\theta} \end{aligned}$$

$Pout_{R,D}$,

$$\begin{aligned} Pout_{R,D} &= P_R\{\gamma_{SR}^{SD} < \xi\} \\ &= P_R\{\frac{P_R G_{SR}^{SD}}{N_0} < \xi\} \\ &= P_R\{G_{SR}^{SD} < \beta\} \\ &= \int_0^{\beta} \lambda_{SR}^{SD} e^{-\lambda_{SR}^{SD} x} dx \\ &= 1 - e^{-\lambda_{SR}^{SD}\beta} \end{aligned}$$

$Pout_1$,

$$\begin{aligned} Pout_1 &= 1 - P_R\{\gamma_{SS}^{SR} > \xi\} P_R\{\gamma_{SR}^{SD} > \xi\} \\ &= 1 - (1 - Pout_{S,R})(1 - Pout_{R,D}) \\ &= 1 - (1 - (1 - e^{-\lambda_{SS}^{SR}\theta}))(1 - (1 - e^{-\lambda_{SR}^{SD}\beta})) \\ &= 1 - e^{-\lambda_{SS}^{SR}\theta} e^{-\lambda_{SR}^{SD}\beta} \end{aligned}$$

Derivation of Outage Probability for SS-SD path.

$$\begin{aligned} Pout_2 &= P_R\{\gamma_{SS}^{SD} < \xi\} \\ &= P_R\{\frac{P_S G_{SS}^{SD}}{N_0} < \xi\} \\ &= P_R\{G_{SS}^{SD} < \theta\} \\ &= \int_0^{\theta} \lambda_{SS}^{SD} e^{-\lambda_{SS}^{SD} x} dx \\ &= 1 - e^{-\lambda_{SS}^{SD}\theta} \end{aligned}$$

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