# ROUTING-AWARE MULTIPLE DESCRIPTION VIDEO CODING OVER WIRELESS AD-HOC NETWORKS USING MULTIPLE PATHS

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## ABSTRACT

Supporting video transmission over error-prone wireless ad-hoc networks is becoming increasingly important as these networks become more widely deployed. In this paper, we propose a routing-aware multiple description video coding approach to support video transmission over wireless ad-hoc networks with path diversity. Our method uses the standard ad-hoc routing messages to estimate the possible packet losses in the networks and dynamically selects reference frames in order to alleviate error propagation caused by packet losses. We conducted experiments using the QualNet simulator that accounts for node mobility, channel properties, MAC operation, multipath routing, and traffic type. The results demonstrate that our proposed method provides up to 2.3 dB gains in PSNR and significantly improves the perceptual video quality for multiple users.

***Index Terms*—** multiple description video coding, multipath routing, wireless ad-hoc networks, error resilience

## 1. INTRODUCTION

Video transmission is becoming increasingly important in wireless ad-hoc networks due to the deployment of ad hoc networks in military, homeland defense, and disaster recovery applications. However, wireless ad-hoc networks imposes significant challenges to video transmissions because of frequent route failures due to node mobility and lost packets due to unreliable wireless channels.

Video transmission over wireless ad-hoc networks has been shown to benefit substantially from multiple description video coding (MDVC) with path diversity. Different MDVC methods have been proposed to incorporate path diversity over ad hoc networks, in which the authors either simply assume that two-disjoint paths are used, or the set of paths is given [1–3]. While [4] has shown that the multipath routing and rate allocation problem can also affect the performance of MDVC over wireless ad-hoc networks.

In this paper, we consider a more practical network with multiple hops and many nodes and propose a routing-aware MDVC approach that utilizes the routing messages to improve the error resilience of MDVC. We use routing messages to retrieve packet loss information, and select reference frames for MDVC based on this information. This approach effectively alleviates the error propagation caused by the packet losses, thus improving the video quality. We examine our proposed approach by QualNet simulations, in which the impact of node mobility, channel characteristics, MAC operation, multipath routing, and traffic type are jointly considered. The results show a performance gain by up to 2.3 dB in PSNR and substantial improvements in perceptual video quality for multiple users.

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## 2. RELATED WORK

Combining MDVC with path diversity for video communications over wireless ad hoc networks has drawn significant attention in recent years. The research in this area can be generally divided into two categories. One category studies the effectiveness of MDVC methods based on a specific network model with path diversity [1–3, 5]. In [1], the authors proposed a MDVC method based on the lapped orthogonal transform and examined the performance on a two-path system with the same capacity and error characteristics. An adaptive MD mode selection approach is proposed in [2] to adapt to the network conditions as well as to the video characteristics. This approach selects the optimal MD mode by calculating the end-to-end distortion based on the Gilbert packet loss model. In [3], Mao et. al. compared feedback based reference picture selection, layered coding, and MDVC schemes with multipath transport and found that MDVC is preferable when a feedback channel cannot be set up. Badarneh et. al. [5] developed an algorithm to assign MD video for multicast transport to improve user's satisfaction.

The other category of work addresses the path selection and rate allocation problem for MDVC given a particular MDVC scheme [6–8]. Begen et. al. proposed a multi-path selection method that chooses a set of paths maximizing the overall quality at the client based on the network parameters, media characteristics and application requirements [6]. The authors in [7] formulated a routing optimization problem that minimizes the application layer video distortion and provided a genetic-algorithm based approach to compute two disjoint paths for video transmission. Different metrics used for the path selection for MDVC are discussed in [8], and a practical interference aware distributed routing protocol is proposed.

Our proposed method falls into the first category; however, instead of assuming that two node-disjoint paths with the same error characteristics are available or the set of paths is given, we consider multipath routing in a more practical network and make use of the route messages to select the proper reference frames. Our work is inspired by the reference picture selection (RPS) methods proposed in [9, 10]. Most of the RPS work assumes an extra feedback control channel from the video receiver to the sender, and the receiver would thus send a ACK/NACK for every video packet [9]. Such an approach can lead to extra overhead and cost, especially in a large network. Our work, on the other hand, does not require any additional control packets or extra channel in the network. We just extract and utilize the information embedded in normal routing messages, thus saving precious network bandwidth. Our approach, while

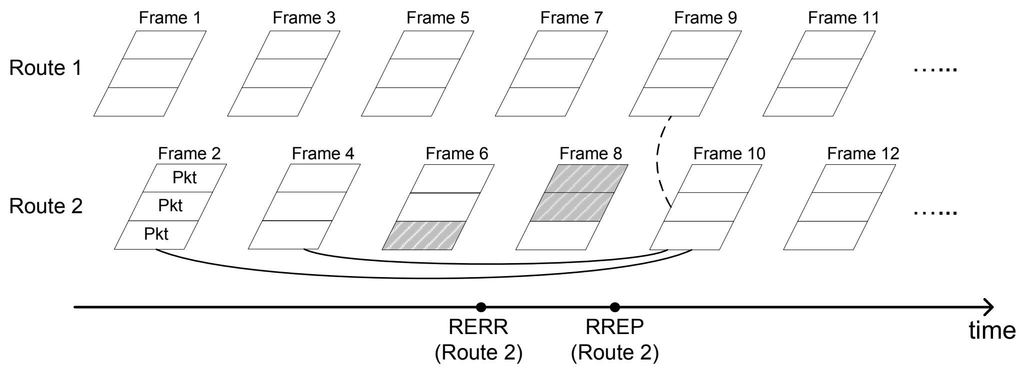



**Fig. 1**. Proposed Routing-aware MSVC Approach

saving network resources, is nonideal, since the ACK/NACK provides timely and accurate information for packet losses, while the routing messages in our approach do not indicate the exact packet losses. Still, the routing messages have a better correlation to the actual packet losses than the Gilbert model used in [10].

## 3. PROPOSED ROUTING-AWARE MDVC

In our work, we apply one of the most popular MDVC methods called multiple state video coding (MSVC) [11] using an H.264 coder. In MSVC, the video sequence is first temporally downsampled into two subsequences with odd and even frames, and the odd and even frames are encoded as two descriptions. The two descriptions are then transmitted over the ad-hoc network over two different paths. Finally, the two descriptions are decoded and interleaved to get the reconstructed video sequence. Notice that different levels of reconstruction quality can be achieved from different subsets of descriptions.

To achieve two paths in the network, we consider a typical multipath routing algorithm called split multipath routing (SMR) [12]. The SMR protocol aims at building and maintaining the maximally disjointed paths based on the dynamic source routing (DSR) protocol. In SMR, a route discovery process is initiated whenever a source node needs to send packets to a destination. The source node broadcasts the route request (RREQ) message to the entire network. Once the destination node gets RREQs through different routes, it selects the maximally disjoint routes and sends route reply (RREP) messages back to the source. Multiple paths are set up when RREPs are received at the source. If the link in a route is broken, a route error (RERR) message is flooded to the source and the source either reconstructs the route from the route cache or sends a RREQ to find a new route. We see that RERR implies a link failure of a route. Packets previously transmitted through that route can be lost with a high probability and the packets scheduled to be sent through the broken route are also lost until a new route is discovered.

Therefore, we use the route messages to determine if a packet is lost as shown in Procedure 1. Each time we receive a RERR message that indicates a broken route, we consider the preceding packet transmitted over the broken route as lost. Meanwhile, the protocol attempts to recover the route from the route cache. If a route is available in the route cache, the broken route is restored instantly and packets are sent over this new route. Otherwise, a route recovery process is initiated. Packets scheduled to be sent during the route recovery process are thrown away until the transmission is resumed when a RREP message is received by the source node.

**Procedure 1** Check Packet Loss Based on Route Messages

```
while have packets to send do
    Encode a packet for transmission, avoid using damaged frame
    as reference
    Transmit a packet through one of the two paths
    if receive a RERR Msg that indicates a route is broken then
        Mark the previous packet transmitted through this broken
        route as lost
        if a route is available in the route cache then
            Recover the broken route from the route cache
        else
            Initiate the route recovery process
            repeat
                Mark the packets scheduled to be sent through the
                broken route as lost
            until receive a RREP Msg to reconstruct a new route
        end if
    end if
end while
```

Based on the packet loss information discerned from route messages, we then dynamically select the reference frames for the two descriptions as shown in Fig. 1. The shadow in Fig. 1 represents the packets marked as “lost” based on the RERR and RREP messages and the frames corresponding to the “lost” packets are considered as damaged. From the reference frame buffer, we select the undamaged frames in the same description as reference. If no reference frame in the same description is available, we use the undamaged frames from the other description as reference.

By not using the possible damaged frame as reference, we expect to reduce error propagation due to packet losses. Moreover, our proposed approach only relies on standard ad-hoc routing messages and it does not incur any extra overhead. Although the routing message is a good indicator of the packet losses in the networks, it is not completely accurate. There may be undetected packet losses since the RERR packet could be lost during transmission, or the packet losses are due to delay constraints (but no route errors). Furthermore, when a RERR packet is received, we simply assume that the preceding packet transmitted over the broken route is lost. In practice, however, one RERR may indicate more than one preceding packet loss over the broken route. This is because of the delay of RERR in reaching the source node. Several packets may be lost during the period that RERR is being transmitted back to the video sender through the network. Therefore, instead of always assuming the loss of one

**Table 1**. Simulation Parameters

| | |
|---|---|
| Region | 500 m× 500 m |
| Number of nodes | 50 |
| Mobility model | Random waypoint model: node speed 0 ∼ 10 m/s, pause time 120 s |
| PHY data rate | 5.5 Mbps |
| MAC layer protocol | 802.11b CSMA/CA |
| Playout deadline | 350 ms |

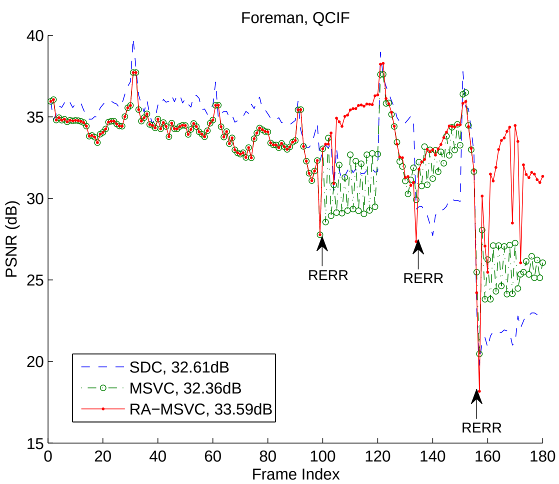



**Fig. 2**. PSNR vs Frame Index in one realization

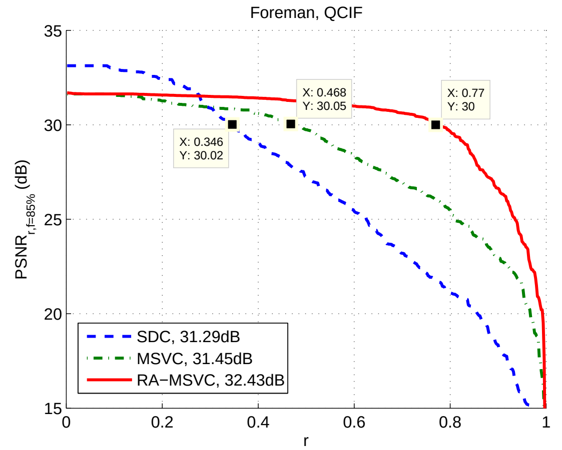
preceding packet based on received RERR, we can model the packet losses from RERR messages in a statistical way and this is part of our future work.

## 4. PERFORMANCE EVALUATION

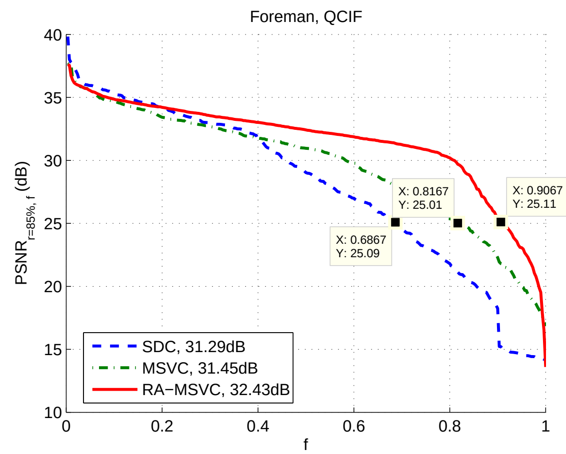
### 4.1. Simulation Settings

We use a QualNet simulator to evaluate our method for video transmission over a wireless ad-hoc network, and we choose some typical network parameters as shown in Table 1. In this ad-hoc network, nodes are uniformly placed in a $500m \times 500m$ region, where the connectivity of any two nodes is determined by the network topology, and the communication range. The movement of each node is characterized by a random waypoint model with parameters shown in Table 1. A pair of source and destination nodes is randomly chosen to transmit video packets. We use IEEE 802.11b, which employs CSMA/CA as the MAC layer protocol and we implement SMR as the multipath routing protocol. Packets are dropped if they do not reach the destination by the playout deadline of 350 ms.

To examine the performance of our proposed method, we compare it to the regular single description coding (SDC) and multiple state video coding (MSVC). After encoding, the odd and even frames are transmitted through two different routes. We examine the Foreman sequence of 300 frames in QCIF format. The frame rate is 30 fps and the sequence is packetized to RTP format with three packets per frame. The coding bitrate is 200 kbps and for each network setting and each coding method, 500 realizations are simulated for evaluation.




(a) $PSNR_{r,f=85\%}$




(b) $PSNR_{r=85\%,f}$

**Fig. 3**. Comparing $PSNR_{r,f}$ of SDC, MSVC, and RA-MSVC, Foreman sequence at bitrate 200 kbps, packet loss rate 4.4%

### 4.2. Results and Analysis

First, we examine the case that the transmission range is about 240 m and the overall packet loss rate in the networks is about 4.4%. Figure 2 shows PSNR performance vs frame number in one realization. In this example, we see that for the SDC method, the packet loss causes errors to be propagated to all the following frames over two routes, while for the MSVC method, the errors only propagate in one description on the broken route. Meanwhile, the RERR packets indicate the packet losses in the network fairly well and our proposed RA-MSVC method can effectively stop the error propagation in the subsequent frames.

We calculate the average PSNR over all frames and all realizations in this network setting (around 4.4% packet loss rate) and the average PSNRs for SDC, MSVC and RA-MSVC are 31.29 dB, 31.45 dB, and 32.43 dB, respectively (shown in the legend of Fig. 3). Therefore, RA-MSVC provides 1dB objective quality gain in PSNR.

Next, we use $PSNR_{r,f}$ proposed in [13] to assess the perceptual video quality of the three methods. $PSNR_{r,f}$ is defined as the PSNR achieved by $f\%$ of frames for the $r\%$ of realizations, which represents the video quality guaranteed for $r\%$ of realizations among $f\%$ frames. Figure 3 compares the $PSNR_{r,f}$ results with fixed values of

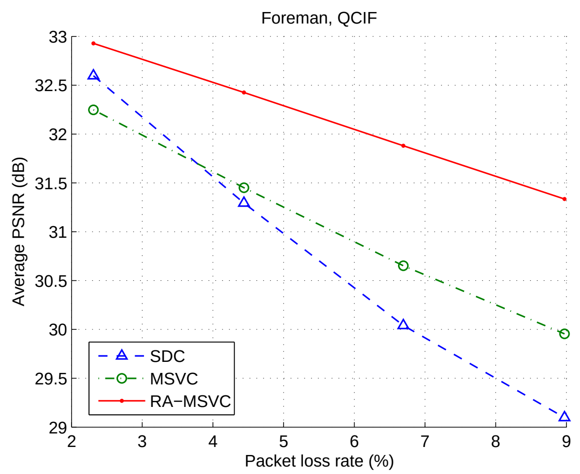



**Fig. 4**. Average PSNR vs packet loss rate

$f$ and $r$ respectively. In Fig. 3(a), we see that RA-MSVC guarantees a better video quality for most of the realizations compared to the other two methods. For example, only 34.4% of the realizations in SDC and 46.8% of the realizations in MSVC can achieve a PSNR higher than 30 dB in 85% of the frames. While 77% of realizations in RA-MSVC can have over 30 dB PSNR in 85% of the frames. In other words, RA-MSVC provides better video quality for a larger fraction of the users. Figure 3(b) shows $PSNR_{r,f}$ for SDC, MSVC, and RA-MSVC with fixed $r = 85\%$. In Fig. 3(b), we see that SDC and MSVC have a larger number of low-quality frames than RA-MSVC in 85% of the realizations. Fewer than 10% of the frames in 85% of the realizations for RA-MSVC have a PSNR lower than 25 dB, while over 31% of the frames in 85% of the realizations for SDC have a PSNR lower than 25 dB. In conclusion, Fig. 3 shows that our proposed RA-MSVC method provides better perceptual video quality for multiple users than SDC and MSVC.

Finally, we examine the performance of the three methods under different packet loss rates. In the simulation, we varied the transmission range from 180 m to 280 m, which achieves packet loss rates in the range of 2.3% - 9.0%. For each packet loss rate and each method, 500 realizations are simulated and the average PSNR over all frames and realizations are calculated. Figure 4 shows PSNR over different packet loss rates for the three coding methods. We see that the performance gains of our proposed method increase as the packet loss rate increases. Further, our RA-MSVC method achieves up to 2.3 dB and 1.4 dB gains in PSNR compared to SDC and MSVC, respectively. We have run simulations for different video sequences and these show similar gains for our proposed approach. We do not include these results due to space limitations.

## 5. CONCLUSIONS

In this paper, we propose a routing-aware MDVC approach with path diversity to enhance the error robustness of video transmission over wireless ad-hoc networks. By using the routing messages as a packet loss indicator, we dynamically select the reference frames for MDVC to reduce the error propagation. Our proposed method does not require any additional feedback channel or extra overhead while it nicely estimates the packet losses in the network. However, the packet loss information provided by the route messages is not completely accurate. Therefore, as a future work, we intend to establish a statistical model to estimate the packet status based on more network information such as number of hop counts and route packet delay.

## 6. REFERENCES


[1] N. Gogate, D. M. Chung, S. S. Panwar, Y. Wang, F. N. Commun, and P. River, "Supporting image and video applications in a multihop radio environment using path diversity and multiple description coding," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 12, no. 9, pp. 777–792, 2002.

[2] Brian A. Heng, John G. Apostolopoulos, and Jae S. Lim, "End-to-end rate-distortion optimized MD mode selection for multiple description video coding," *EURASIP Journal on Applied Signal Processing*, 2006.

[3] S. Mao, S. Lin, S. S. Panwar, Y. Wang, and E. Celebi, "Video transport over ad hoc networks: multistream coding with multipath transport," *IEEE Journal on Selected Areas in Communications*, vol. 21, no. 10, pp. 1721–1737, 2003.

[4] W. Wei and A. Zakhor, "Robust multipath source routing protocol (RMPSR) for video communication over wireless ad hoc networks," in *IEEE International Conference on Multimedia and Expo.*, 2004, vol. 2.

[5] O.S. Badarneh, Yi Qian, Bo Rong, A. K. Elhakeem, and M. Kadoch, "Multiple description coding based video multicast over heterogeneous wireless ad hoc networks," in *IEEE International Conference on Communications*, 2009, pp. 1–6.

[6] A. C. Begen, Y. Altunbasak, and O. Ergun, "Multi-path selection for multiple description encoded video streaming," in *IEEE International Conference on Communications*, May 2003, vol. 3, pp. 1583–1589.

[7] S. Mao, Y. T. Hou, X. Cheng, H. D. Sherali, S. F. Midkiff, and Y. Q. Zhang, "On routing for multiple description video over wireless ad hoc networks," *IEEE Transactions on Multimedia*, vol. 8, no. 5, pp. 1063–1074, 2006.

[8] S. Murthy, P. Hegde, V. Parameswaran, B. Li, and A. Sen, "Improved path selection algorithms for multipath video streaming in wireless ad-hoc networks," in *Proceedings of Military Communications Conference*, 2007, pp. 1–7.

[9] Shunan Lin, Shiwen Mao, Yao Wang, and S. Panwar, "A reference picture selection scheme for video transmission over ad-hoc networks using multiple paths," in *Proceedings of the 2001 IEEE International Conference on Multimedia and Expo*, Aug. 2001, pp. 96–99.

[10] Y. J. Liang, E. Setton, and B. Girod, "Channel-adaptive video streaming using packet path diversity and rate-distortion optimized reference picture selection," in *IEEE Workshop on Multimedia Signal Processing*, Dec. 2002, pp. 420–423.

[11] John G. Apostolopoulos, "Reliable video communication over lossy packet networks using multiple state encoding and path diversity," in *SPIE Proceedings on Visual Communications and Image Processing*, 2001, vol. 4310, pp. 392–409.

[12] S. J. Lee and M. Gerla, "Split multipath routing with maximally disjoint paths in ad hocnetworks," in *IEEE International Conference on Communications*, 2001, vol. 10, pp. 3201–3205.

[13] Jing Hu, S. Choudhury, and J.D. Gibson, "Video capacity of WLANs with a multiuser perceptual quality constraint," *IEEE Transactions on Multimedia*, vol. 10, no. 8, pp. 1465–1478, Dec. 2008.