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# Robust scalable video multi-cast with multiple sources and inter-source network decoding in lossy networks

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This paper presents a robust scalable video multi-cast scheme with source diversity and inter-source network decoding in lossy networks. The source diversity technique gives path diversity, providing a better quality of layered video transmission under hostile environments. For each source, an optimization formulation is set up to find the best transmission route of each transmitting video layer. The objectives of the formulation are to maximize the total information values of video layers reflecting the end-to-end video quality and transmission reliability. The source providing the best overall achievable data rate, which is the data rate destination can expect to receive from the transmission, is selected to be the primary source, while the rest will be secondary sources. When the Quality-of-Service (QoS) guarantees of some transmitting video layers cannot be fulfilled by the primary source, the secondary source with the best QoS parameters is selected to transmit the layers to destinations. The number of secondary sources used for transmissions is increased until the QoS guarantees of all transmitting video layers are satisfied or all network resources are utilized. Network coding is deployed to multi-cast video layers from the same source for efficient resource usage. Network coded data from different sources can be used to decode the transmitting video data. In other words, at each destination, it needs only a sufficient number of video packets from different sources to recover all transmitting video data. Simulations with different network topologies show the improvement in both objective and subjective qualities of layered video multi-cast under lossy environments.



## 1. Introduction

Reliable transmissions in hostile networks can be achieved by utilizing path diversity and network coding [1]. Furthermore, when there is more than one transmitting source in a network, data from other sources can be used to improve the reliability of data at all destinations, resulting in better multimedia quality. However, it may affect the efficiency in network resource usage, when the number of sources transmitting the same data increases. Scalable video coding [2] encodes a video sequence into a base layer and successive refinement layers [3] to allow heterogeneous transmission rates. Scalabilities of a video sequence can be in either or the combination of SNR, temporal, and spatial scalabilities [2]. A destination that can receive more layers perceives better video quality than a destination that receives fewer layers. A received packet of a lower layer contributes to the end-quality of a video sequence more than that of a higher layer. Thus, prioritized transmission of data layers is essential in layered video transmission.

In this work, we investigate QoS-aware scalable video multi-cast in lossy networks with two objectives: (1) to support layered video multi-cast transmissions with QoS guarantee under lossy environments and (2) to improve transmission reliability and network resource usage by applying a new inter-source network decoding technique. To achieve the first objective, our proposed scheme uses an optimization formulation to find transmission paths of all layered video multi-cast flows for each source. QoS requirements, network resources and video transmission rates are the optimization constraints. To fulfill the second objective, the proposed scheme decides whether or not only the primary source can multi-cast video layers with each video layer's QoS requirement. If not, the secondary sources will multi-cast the same set of video layers to the destinations. The utilized number of secondary sources is increased until all QoS requirements of video layers are achieved or the network resources are depleted. Inter-source network decoding can be further adopted in the second step to enhance reliability by allowing destinations using packet data from different sources to decode transmitted data. The

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destinations need only to obtain a sufficient number of video packets to decode video data regardless of where they come from.

Fig. 1 shows an example of layered video multi-cast transmission over lossy networks. In this figure, we consider a wireless mesh network, which is a subset of lossy networks. The network topology is assumed to be known and link quality statistics such as the packet loss rate can be collected over time. The capacity of each link is set to one unit, which can be translated to kilobits per second. The objective of the transmission is to multi-cast video layers to all destinations with QoS guarantee. The sources can search for the routes having the maximal reliability in the best-effort manner for layered video multi-casting to destinations. In some cases, reliability of the obtained routes may not meet the QoS requirements of the destinations because of time-varying characteristics of wireless links. Moreover, if some sources or wireless network nodes are lost, video packets may not arrive at destinations.

To enhance reliability of video multi-cast, path diversity can be used by transmitting the same video layers from different source locations and different transmission paths. Destinations can have higher successful probabilities in receiving video packets. As shown in Fig. 1, source $i$ multi-casts the same layered data $L_1$ with two data units, $L^i_{1,0}$ and $L^i_{1,1}$. To use network resource effectively, wireless nodes can apply network coding [1] to transmit data starting from the source node. A packet transmitted through each link is a linear combination of $L^i_{1,0}$ and $L^i_{1,1}$. For example, $a_1L^1_{1,0} + b_1L^1_{1,1}$ is transmitted through the link connected with Source 1, where $a_1$ and $b_1$ are network coding coefficients that are randomly selected from a finite field [4].

The use of network coding can combat bottlenecks in the network. For instance, a bottleneck appearing in the routes connecting Source 1 to Destinations 1 and 2 can be solved by transmitting network coded data, *i.e.*, $a_6L^1_{1,0} + b_6L^1_{1,1}$, instead of transmitting either $L^1_{1,0}$ or $L^1_{1,1}$ through the bottleneck link. At each destination in this example, it needs only two network coded packets to recover the transmitted data. For example, it requires $a_7L^1_{1,0} + b_7L^1_{1,1}$ and $a_8L^1_{1,0} + b_8L^1_{1,1}$ to obtain layered data $L_1$. When path diversity with multiple sources is used, destinations can have more degrees of freedom in selecting network coding packets from other sources to recover layered data $L_1$. This can be done because the network coded coefficients are randomly selected at different wireless nodes. With a sufficiently large field size, the linear combinations at wireless nodes will be independent among others with a high probability. Therefore, destinations need only two packets no matter which source they come from to decode layered data $L_1$. For example, Destination 1 can recover $L_1$ by using two packets from $a_7L^1_{1,0} + b_7L^1_{1,1}$, $a_8L^1_{1,0} + b_8L^1_{1,1}$, $a_{17}L^2_{1,0} + b_{17}L^2_{1,1}$, and $a_{18}L^2_{1,0} + b_{18}L^2_{1,1}$. This approach further increases a successful decoding probability of layered data, when some packets are lost without a concern on additional latency caused by packet retransmissions.

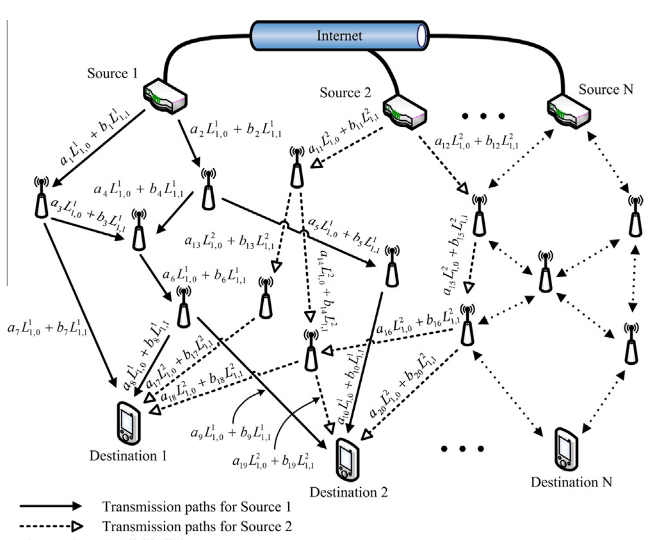


**Fig. 1.** Layered multi-cast with multiple sources and inter-source network decoding.

There are two major contributions in this research. First, the proposed scheme provides a method to select the optimal path for layered video multi-cast transmission maximizing information values of transmitted video layers, which reflects transmission reliability and reconstructed video quality at destinations. Layered multi-cast transmission is suitable in heterogeneous network environments. Destinations with different network capacities or device displays can select to receive an amount of data matching with their profiles. The maximal reliability is provided to each multi-cast based on link quality in terms of packet loss probabilities. The network resource usage is considered in terms of bandwidth utilization. Second, more robust and efficient transmission is achieved by source diversity, network coding, and inter-source network decoding technique. Random network coding is applied at intermediate nodes. Since the reliability obtained from the optimization formulation may not achieve the QoS requirements of transmitting layers, using multiple sources and inter-source network decoding enhances the decoding probability of layered data.

The rest of this paper is organized as follows. Related work is reviewed in Section 2. Section 3 defines a network model and assumptions used in this paper. Besides, the optimization formulation is set up to compute the optimal routes for layered video transmission. Section 4 describes the proposed QoS-aware multi-source routing scheme and the use of random network coding in multi-cast transmission. Table 1 and Table 2 list the notations that we will use in this paper. The concept of the inter-source network decoding is also described in this section. Section 5 evaluates the advantages of the proposed video routing scheme using objective and subjective qualities of reconstructed video obtained from computer simulations. Conclusion remarks are given in Section 6.

## 2. Related work

The QoS routing of multi-cast transmission has been studied extensively in the network community. Nguyen et al. and Ahn et al. [5,6] used the shortest path routing scheme for the QoS routing in multi-cast scenarios. However, the shortest path routing is not the most efficient solution for multi-casting compressed video data because severe video packet loss from some shortest paths may affect the end-video quality significantly. To use network resource more efficiently in multi-cast scenarios, network coding is used since it can enhance overall throughput of the transmission. Network coding was introduced by Ahlswede et al. [1], where destinations can receive data equaling their max-flow under multi-cast transmission. Multi-rate multi-cast with network coding were investigated in [4,7–13].

Zhu et al. [7] presented a set of distributed algorithms to improve the achievable data rate of an end-to-end multi-cast session using network coding. They used redundant paths from a single source to multiple sinks to achieve a better achievable data rate. Sundaram *et al.* [8] proposed a polynomial-time algorithm for multi-casting layered data to heterogeneous receivers using network coding. The algorithm gives a transmission rate equaling max flows of all receivers. Supittayapornpong et al. [9] proposed a framework for multi-casting layered data with QoS guarantee. They formulated an optimization problem to select reliable paths for layered data transmission. A heuristic algorithm for selecting static