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NCVCS: Network-coding-based video conference system for mobile devices in multicast networks

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ABSTRACT

The user experience has become an important aspect during the design of modern mobile communication devices. The image resolution, fluency and delay are significant factors that affect the user experience during video transmission. To address this issue, this paper proposes a reliable system called NCVCS (Network-Coding-Based Video Conference System) to improve the user experience during video conference with mobile devices. NCVCS is based on network coding, and the coding operation is performed at the intermediate nodes to improve the performance. A coding server is introduced, acting as an intermediate node to perform the coding operation. During the network coding process, NCVCS re-organizes the original data to implement multi-rate multicast such that the heterogeneous devices with different specifications and different locations could join the conference with different resolutions. A real-world testbed consisting of 15 wireless Android devices is implemented to verify whether it is feasible to use network coding in such scenarios. And the performance of NCVCS is evaluated in the testbed. Compared with the traditional multicasting technology, NCVCS could provide higher delivery ratio and better user experience. Especially, when the link quality is poor, our scheme could provide clearer and more fluent media stream.

1. Introduction

The video conference system is a typical application of video transmission technology over the Internet. The development of mobile devices makes such application promising. High-quality video conference system for mobile devices will become more and more popular in the coming years. Limited network bandwidth and extreme link quality are some of the challenges we face during the implementation of multi-user video transmission. In such application, each user needs to establish and maintain unicast connections with all other users, which tends to reduce the efficiency of network. Just like the unicast connections, the multicast connections can also be used over the Internet. When the multicast technology is adopted, the users with the same data requirement could share a common link. Therefore, the multicast technology could significantly reduce the number of connections, thereby increasing the network throughput. However, the traditional approach to multicast data over IEEE 802.11 wireless networks is in fact used in an open-loop fashion (i.e., no feedback), which doesn't support QoS (Quality of Service) for video transmission. In particular, when there is interference in the wireless environment, the service quality could not be guaranteed. Related researches [1–3] conducted in the last decade show that network coding is a promising technology to implement QoS in both the wired networks and wireless networks [4]. There are various video compression standards such as H.264/AVC and H.265. In accordance with some of the previous studies [5,6], network coding could work together with some video compression standards such as H.264/AVC. Network coding is always adopted to transmit the data after compression in video systems. T. T. Thai et al. [7] proposed a network-coding-based redundancy adaptation algorithm for real-time video transmission, and they showed that their scheme outperforms the traditional block-based FEC codes. For real-time applications, A. Le et al. [8] came out with a scheme based on network coding. In their scheme, a recovered packet is immediately beneficial to the maximum number of users. Their method takes advantage of network coding, such as high throughput and reliability. And in the meantime, the side effect of network coding, such as play delay, is reduced. S. Nazir et al. [9] proposed to use random linear codes (RLC) for data par-

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titioning in H.264/SVC. Their empirical results show that RLC is a promising method for multimedia broadcasting applications.

After more than ten years' theoretical research, some authors have started the research on real application systems based on network coding. Recently, some practical network-coding-based applications have also been proposed. D. Ferreira et al. [12] proposed a RTNC (Real-Time Network Coding) system for stream media multicast in hyper-dense WiFi space. They compared their system with the traditional unicast scheme, and their results show that the bandwidth usage could be significantly increased when network coding is adopted. F.H.P. Fitzek et al. [13–15] conducted several practical researches on network coding, and in Literature [15], they implemented a network-coding-based picture sharing system.

Although some prototypes have been proposed by previous researchers, there are still very few researches on the practical applications of network coding. In this paper, we implement network coding in the multi-user video conference system (namely NCVCS) to obtain better user experience. Compared to the traditional multicast technology, both the reliability of transmission and the usage ratio of network bandwidth are increased. The proposed NCVCS could be adopted for the video conference over both the Internet and Intranet, such as the networks of school, government and enterprise.

This paper is organized as follows. In Section 2, some related studies are introduced. In Section 3, we will describe the research objective and the system design. In Section 4, the experiments were carried out in our testbed, and the performance of NCVCS is evaluated. Finally, the conclusion is made in Section 5.

2. Related works

Network coding had been steadily moving from a mathematical concept to implementations with different network technologies and architectures [10,11]. In recent years, some practical solutions based on network coding have been proposed to implement video distribution. D. Ferreira el al. [12] presented a reliable and scalable live streaming solution based on wireless multicast with real-time network coding. They implemented an error control scheme by generating the repair packets simultaneously useful for multiple clients, which could reduce the overhead required for re-transmission. In our system, NCVCS proactively sends the repair packets to avoid the transmission delay caused by re-transmission. Moreover, they evaluated their system on five notebooks, while our system is implemented and evaluated for wireless smartphone networks. The computation ability of smartphone is much weaker than that of notebooks. Therefore, we paid much attention to the two aspects of feasibility and reliability.

F.H.P. Fitzek et al. have done some practical researches [13–15] based on network coding. In Literature [13], they proposed using network coding in the social mobile cloud. When a mobile device needs to download a file from a server on the Internet, all the devices in the same cloud could download some pieces of the file. After all the pieces are downloaded to the cloud, the original file could be re-constructed, and the file could be shared by all the devices in the cloud via WiFi connections. The architecture in their system is a little bit different from NCVCS. In their system, the file is in a specified server on the Internet, while in NCVCS, each mobile device may be a data source, and the devices not only generate video data, but also share their own data with all the other devices.

Due to the diversity of camera specification, access distance, and different transmission power of APs, the clients may connect to the network in different transmission rates. Some studies proposed using multi-rate network coding [5,6,16–19] to cope with the heterogeneity. The main idea of these studies is to combine network coding with multi-description coding or multi-resolution

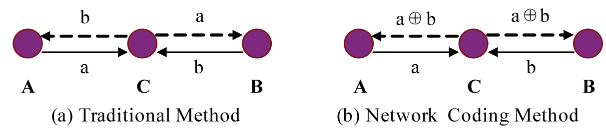

Fig. 1. Classic Example of Network Coding in Wireless Networks.

coding. A. Tassi et al. [16,17] proposed a resource allocation frameworks for network-coding-based layered multicast. With the analysis frameworks, optimal schemes could be achieved, and the minimal number of packets required for pre-determined video quality could be computed in advance. M. Kim et al. [5] and J. Widmer et al. [6] designed some heuristic algorithms for practical applications. By re-encoding layered video data at the intermediate nodes, the throughput and user experience could be improved. NCVCS could also satisfy the requirement of different resolutions and frame rates, but this goal is achieved by re-organizing the original data at the intermediate node. This method is different from the multi-rate network coding theory introduced in those papers, but they are based on the same principle: both of them implement on-demand media transmission through the re-encoding operation at the intermediate nodes.

When network coding is applied to the Android devices, the coding ability is vital. L. Keller et al. [20] pointed out that through the combination of several optimization methods, the coding rate could reach 5 Mbps when the finite field size is 256 and k is 25. In our experiments, we obtain similar result, but the result is obtained under the condition that all the computation resources of devices are fully occupied. Therefore, in this paper, we tested the practical coding ability in the running NCVCS. Based on the new result, we designed a rate control strategy to dynamically adjust the video definition and frame rate.

3. Objective and system design

3.1. Network architecture

The most well-known wireless model for network coding was proposed by S. Katti et al. [21], which is as shown in the following Fig. 1.

In the example, all the nodes need to receive data a and b. In the initial state, node A has data a, and node B has data b. In the traditional method, it requires 4 transmissions to finish the receiving process. While by using network coding, it only requires 3 transmissions because node C can multicast data $a \oplus b$ to nodes A and B with one transmission. Nodes A and B could decode the original data with the received symbols. There are two features in Fig. 1: firstly, the intermediate node C is able to re-encode the received data; secondly, node C can multicast the encoded data to all other nodes with one transmission. Re-encoding at the intermediate nodes is the most striking feature of network coding. And all the performance improvements of network coding are achieved through the re-encoding operation. When these two features are considered, the performance gain of network coding can be obtained. Therefore, the first issue we encountered is to determine who acts as the intermediate node in NCVCS.

In accordance with Fig. 2, NCVCS uses a coding server directly connected to an AP (Access Point) via wired link. Such configuration means that we have extended the function of ordinary AP. This server is regarded as an intermediate node. The data flow in NCVCS could be described as follows: firstly, all the users transmit their current frames to the coding sever through TCP connections; secondly, after the coding server successfully receives the frames from different users, it will re-encode the received frames, and then sends the encoded data back to all the users via multicast