Multi-hop D2D Assisted Real-time Video Streaming Transmission System in Infrastructure-less Networks

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***Abstract*—With the drastic increase in the number and capabilities of mobile devices, user demands for bandwidth-hungry applications such as video streaming and multimedia file sharing are pushing the limits of current cellular systems. Offloading resources sharing services from the cellular infrastructure to device-to-device (D2D) networks can improve spectrum efficiency and expand system capacity. This paper designs and implements new D2D networks formation mechanism based on commercial off-the-shelf smartphones, and data transmission mechanism among these devices using Wi-Fi Direct(WFD). In this system, we realize the single-hop and multi-hop real-time video streaming transmissions, and compare the performance between the multicast and the unicast transmission mechanisms. To demonstrate and evaluate the system, we implement a prototype system using various brand handsets with Andorid OS and conduct experiments. The results show that the system can transmit real-time videos at the bitrate of 2200kbps and frame rate (fps) of 25 for 4-5 receivers simultaneously within 75 meters in case of single-hop transmission. As for performing multi-hop transmission, the real-time videos can be transmitted to 1 recevier at the bitrate of 5000kbps and fps of 25.**

***Index Terms*—Wi-Fi Direct; real-time video; mobile multi-hop transmission; traffic offloading; D2D Networks**

I. Introduction

According to a report [1] from Cisco, the growth of video traffic is the main factor to promote the growth of overall network traffic. It also shows that live video accounts for 5 percent of Internet video traffic and will grow 15-fold to reach 17 percent by 2022. However, rapidly growing video traffic has entered the next generation network(5G) but has brought huge challenges to traditional mobile operators' networks. D2D network paradigm undoubtedly provides more choices for solving above issues. D2D with special features like high data rate and low delay has obvious advantages particularly in transmission of live video streaming. D2D communication is also used in some occasions where the infrastructure-based networks are restricted or even unavailable (e.g. some areas for public safety, back country in the mountains, stadium of World Cup). The networks often get crowded during the Olympic or the World Cup, and people usually watch the same live video stream on their devices. Therefore, it is feasible to choose devices with good channel quality and high sharing willingness to forward live video streaming traffic for proximity devices by utilizing D2D links. There are some other cases [2][3][4] where D2D communication is used to offload cellular traffic. Although some D2D multicast-hop schemes[5] are proposed,most traffic offloading services are implemented by single-hop D2D communication.

In this paper, we design and implement an application on Android platform with Wi-Fi Direct. This application could not only transmit video or audio files but also share real-time multimedia resources like video streaming. We implement multi-hop issues and the one-to-many transmission scheme of real-time video streaming. The main contributions of this paper are as follow:

1) Implemented video encoding and decoding on Android and realized the real-time video transmission: The sender captures the video raw data from the camera or screen of Android device and these data will be encoded. The encoded video data is transmitted to the receiver via D2D link. The receiver decodes the video data and renders it on video player.

2) Designed and implemented a one-to-many video transmission scheme: This scheme not only allows one-to-one video transmission like Miracast on TV, but also supports one-to-many video transmission. Some video parameters can be modified to adapt to network conditions in different scenarios.

3) Realized two multi-hop video transmission scheme: We list the challenges and analyze the practical difficulties of implementing multi-hop in D2D network constructed by WFD. In order to address above issues, we design two multi-hop real-time video transmission schemes.

4) Evaluated the system performance: We evaluated the impact of distance, video bitrate, etc. on the frame loss rate and came up with an optimal use recommendation.

The remainder of this paper is organized as follows: We discuss the related work in Section II. In Section III, we present the architecture of our system and multi-hop communication mechanisms separately. Specific implementation of systems and transmission schemes in Section IV. Section V evaluates the performance of the system. Finally, Section VI concludes the whole paper.

II. Related Work

There are some articles focuses on the issues such as cooperation between LTE and D2D network, traffic offloading and multi-hop in D2D network. In [6] the proximity devices cooperate to download a fragment of video resources by LTE and then share the fragment they downloaded with others by D2D. This cooperation approach reduces the transfer of data traffic in D2D link among adjacent devices. [7] presented a solution to balance the delay and reliability in real-time video

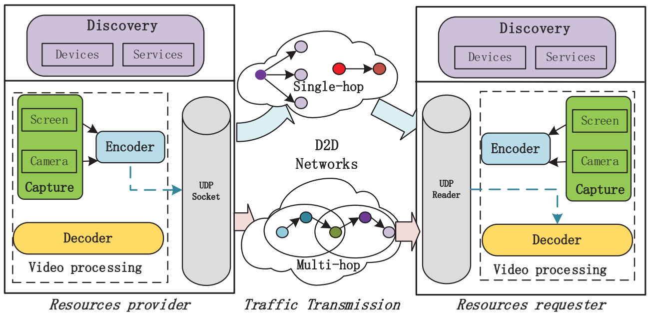


Fig. 1. Overall design of the real-time video streaming transmission system

transmission. In their design, after receiving the data packet, the video receiver sends an ACK which notifies the sender to adjust the sender buffer and the data transmission rate. Yang Cao, et al. designs a video multicast system leveraging D2D communication in [8]. Devices in a D2D group can use the system to request lost video frame from others and repair incomplete frames. Some researchers have looked at video caching and distributed using D2D networks. Kaichuan Zhao et al. [9] proposed a local caching system under heterogeneous preferences of moblie subscribers. This system caches videos and uses the D2D links to improve the quality of content delivering services in the cellular networks. They used Stackelberg game solution to maximize system utility. Ming-Chun Lee et al. uses the real data set to evaluate the throughput-out tradeoff of random D2D caching scheme[10]. They find the scheme can achieve an order-of-magnitude improvements and the gains depend on the size of local cache in devices. Some researches [6] focused on multimedia files transmission rather than real-time traffic such as video streaming when using D2D network. Most of the above research is done by simulation, and we are doing it on a real machine.And we have realized the real-time video transmission scheme on the real devices.

Wi-Fi Direct (WFD) as a technology supporting D2D communication presented by Wi-Fi Alliance can be used on the vast majority of Android devices. This makes it possible for us to implement our design on a real devices.

III. System Design

In this section, some problems we have faced and the system architecture will be introduced. After that ,we will list and explain the use cases for our system.

A. Problem Description

1) Devices discovery: There are two types of device discovery for D2D communication, namely centralized discovery and distributed discovery [11]. In centralized discovery scheme, all devices discover the other devices need help with centralized device such as base station (BS). The devices transmit the control messages periodically to the nearby devices without BS and locate each other in distributed. Under the distributed discovery scheme, synchronization, energy consumption control and how to efficiently discover devices are still serious challenges.

2) Real-time video streaming: The difficulty with transmission of real-time video streaming is that lower delay, lower packet loss, and as low as possible network resource occupation. We also need to consider the CPU, power consumption, and video quality impact when the video stream is transmitted one-to-many in the real-time resource sharing mode.

3) Multi-hop transmission: In *Wi-Fi p2p framework*, it only allows devices communicate with others in a WFD group. In actual test, we found that the devices which is previously added to the group would be dropped when there were more than 5 members in a WFD group. Therefore, it limits the number of nodes in the WFD group and the transmission distance of video streaming sharing system.

B. System Architecture

Fig.1 shows the overall design of the system. We develope the system using WFD in Android system. We mainly design related schemes and develop the system at the application layer. Then, the relevant modules of our system will be described in detail.

1) Discovery: The discovery module has two function including services discovery and devices discovery. In addition to descovering proximity devices, the most important is to find devices running the same application and this process usually takes place after the devices has established a connection.

2) Video processing: There are three submodules in video processing module, and they are video capture, encoding and decoding sepatately. The submodule of video capture and encode are usually called simultaneously on one device. However, the decode is only called when the device acts as a receiver.

3) Traffic transmission: After being encoded by the video processing module, the video traffic needs to be transmitted through the traffic transmission module. In this model, there are two types of transmission methods: single-hop and multi-hop transmission. Users can select the corresponding transmission scheme according to the actual scenario.

a) Single-hop transmission

In this scheme, device creates a WFD group as group owner (GO) and several devices with willingness join in the group as group mebers (GMs). These devices in the group constitute a small wireless local area network with star topology. Each GM can communicate with GO or other GMs in a WFD group.

- One-to-one

This is the most used scenarios in daily life, such as mobile devices mirror their screen to TV or projector. Two peer devices play different roles that are GO and GM respectively in this model. One creates a group and the other join in it. After this process, GO and GM can send message to each other.

- One-to-many

In addition to one-to-one transmission, WFD also supports one-to-many data transmission schemes. Since WFD has a sufficiently high bandwidth, the one-to-many transmission scheme that provides more application scenarios is completely feasible.

b) Multi-hop transmission

Although single-hop transmission can achieve one-to-many secheme, there are some restrictions on transmission distances and the number of members in a WFD group. In order to solve above issues, we design the multi-hop transmission mechanism including two schemes which are GO as relay node(RN) and GM as relay node. We will introduce the two schemes in detail in the following chapters.

C. Use Cases

The live video streaming sharing system based on WFD has many significant application scenarios as follow:

1) Ball stadium, conference or concert hall: Large-scale sports events such as the World Cup, the opening ceremony of the Olympic Games, etc. which are usually held in open-air venues, and there are no big screens like NBA Arena. Pittites often have no a good view to see the highlights from a long distance. In order to address this issue, front audiences can use their mobile phone to take live video and transmit it for pittites.

2) An impromptu small meeting: It is common to have an impromptu small meeting but no projector. With the live video streaming sharing system, users can play Power Point on their mobile devices and mirror the screen to others' devices.

3) Traveling by train: Although there is high quality cellular network coverage in most areas of the journey, people usually cannot afford high traffic charges. With the video sharing system, Passengers can use their mobile devices to form resource sharing groups, and they can share their own video resources or request from other people.

IV. Implementation

This section describes the implementation of the three modules of the application layer in system architecture proposed in section III.

A. Discovery

We use the public methods provided by *WifiP2pManager* class under the *Wi-Fi p2p framework* to implement the device discovery process. when start device discovery thread, we can get a list that contain proximity devices.

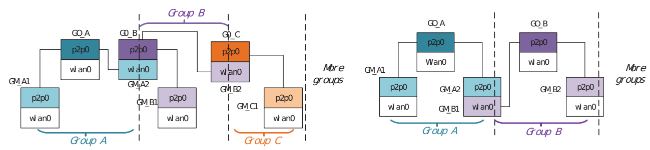
We can advertise a service for our system before a connection setup with othe devices. For example, when watching a game or performance at stadium, users can publish their location information so that others can decide whether to request video, which caprured at the user's perspective before connecting.

B. Video Processing

1) Video capture: In order to adapt to different application scenarios, we use the camera and screen on the Android devices as the source of video capture. Starting with Android 5, Lollipop, the *Android Media Framework* provides an API for developers to get screen data.

2) Encoder: Only re-encoded videos are suitable for transmission over the network. We use *MediaCodec* in the *Android Media Framework* to implement video encoding and raw video data is encoded into *h.264* format in this process.

3) Decoder: This submodule is only used when the device as a receiver. Its function is to decode the received video data and render them on the screen. We also implemented a decoder using *MediaCodec* in *Android Media Framwork*.



(a) GO as the relay nodes (b) GM as the relay nodes

Fig. 2. The topology for mulit-hop transmission.

C. Traffic Transmission

1) Single-hop transmission: This process generally occurs within a group. After the process of the networking connection, the traffic can be directly forwarded via the application layer. The premise of intra-group communication implementation is that each member of the group has information about all members in the group, including the IP address and resource type. In this case, we specify that when the device joins the group, it needs to periodically send a report message to the group owner, including its own IP address, resource type and index, and selectively report the location information. The group master aggregates the information of all members to generate a member list and broadcasts it to the group in time. In this way, members of the group will update the list in time according to the broadcast.

2) Multi-hop transmission: There are some restrictions on the implementation of multi-hop under the *Wi-Fi p2p framework*. There is a network adapter *wlan0* which used to connect an access point (AP) and multiple virtual network adapters like *p2p0*, *dummy0* and *lo* on Android devices. However, only *wlan0* and *p2p0* will be used in our system. When device creates the WFD group, its *p2p0* adapter is occupied, and other devices can connect the GO with *p2p0* or *wlan0*. The IP address of GO is *'192.168.49.1'*, and the GMs' are randomly assigned with *'192.168.49.2-254'*. The multi-hop transmission scheme we design includes two implementations, which are mentioned in the section III.

- GO as the RN.

The GO acts as a relay node to forward traffic and the connection mode is shown in Fig. 2a. The relay nodes with two colors in Fig. 2a create a group (eg. group B and group C) firstly, and their *wlan0* adapter connects to another group. We recommend using this approach for multi-hop communication. The following is an example of inter-group communication between group A and group B and the communication process of the scheme is described in detail. The process is divided into two steps. 1) Finding the relay node: After group A is

TABLE I
PACKET CAPTURE RESULTS OF ARP PROTOCOL

		Sending adapter	*Response adapter*	
			GO_A	GO_B
Default	GM_A2 *(p2p0)*	√	√	
	GM_B1 *(wlan0)*			
Bind wlan0	GM_A2 *(p2p0)*	√		
	GM_B1 *(wlan0)*		√ *(can't receive)*	

created, the GO_B needs to join in group A with its *wlan0* adapter. The priority of *p2p0* is higher than wlan0 [12], as mentioned above, so GO_B cannot send the report message to GO_A from its wlan0. GM_A2 will send the report message from *wlan0* to itself and receive by *p2p0*, because it is also a GO.

GO_A obtains the GMs' info like IP address in two ways. One is to receive the report info from GMs, and the other is to read its own ARP cache table. The specific implementation method is to read the record of the ARP file under the directory "/proc/net/" line by line. Each line consists of six items, which are respectively *IP address*, *HW type*, *Flags*, *MAC*, *Mask*, and *Device*. The record whose Device corresponds to *"wlan0"* is the information of device that acts as a relay node in this group. 2) forwarding the traffic to relay nodes. GMs which needs to initiate inter-group communication can send video or other traffic to relay nodes like GM_A2 in group A and then GM_A2 (GO_B) will forward the traffic to the destination node in group B via *p2p0*.

- GM as the RN.

GMs as relay nodes and the connection mode is shown in Fig. 2b. GO_A and GO_B create group A with aquamarine and group B with purple respectively. There are several devices join in the two groups at the same time such as GM_A2(GM_B1) connect to GO_A with *p2p0* and connect to GO_B with *wlan0*. The inter-group communication process is also divided two steps: 1) determining relay nodes. All devices first determine whether they are relay nodes by checking whether their own *wlan0* adapter is assigned an IP like "192.168.49.x". The device with the above IP on the *wlan0* adapter is considered to be a relay node under this scheme and it should tag itself when sending report message to GO. 2) relay node forwards the traffic to destination node which is in the other group. We still use the communication between group A and group B as an example to illustrate this step. GM_B1 should forward the traffic to destination node from *wlan0*. However, the traffic automatically goes out from *p2p0* since it has a higher priority than *wlan0* in case of unicast [12]. We use the *tcpdump*[13] to capture packages and then analyze the execution process of the ARP protocol under topology shown in Fig. 2b. In this test,we use UDP unicast. GM_A2(GM_B1) as the sender and destination IP address is *'192.168.49.1'*. We expect that GM_A2(GM_B1) sends an ARP requset through *wlan0* and gets the ARP response from GO_B. But we find that the ARP request message will be automatically sent from *p2p0*, so GM_B1 only can receive the ARP response from GO_A. Even though we bind the *wlan0*, the ARP requset will

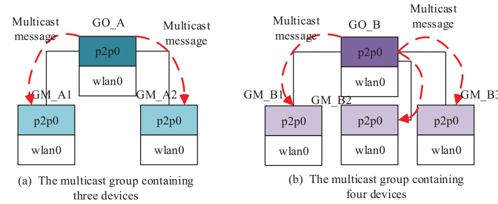


Fig. 3. The multicast scheme 1 that GO as the sender for single-hop transmission

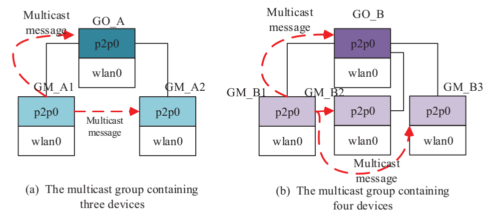


Fig. 4. The multicast scheme 2 that GM as the sender for single-hop transmission

be sent from *p2p0*. However, GO_A should have sent the ARP reponse to the *wlan0* of GM_B1, but there is no a connection between the *wlan0* of GM_B1 and GO_A. The results are shown as TABLE I.

Inspired by multicast scenarios in [14], the solution we propose is to add GM_B1 and GO_B to a multicast group, so that GM_B1 can send message to GO_B using UDP multicast via *wlan0*. When GO_B receiving data from group A, it forwards these data to its GMs.

V. PERFORMANCE EVALUATION

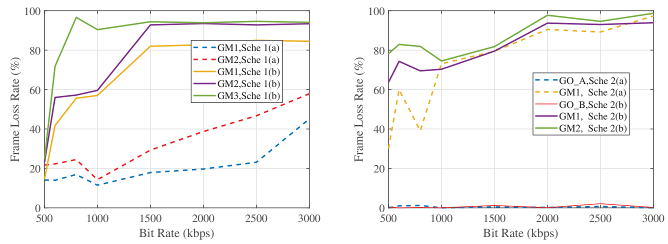
We implement the video sharing system on real Android devices and evaluate the performance of the system in this section. Our test machines come in a variety of brands, including Huawei P10 with Android O, Redmi Note 4X, Smartisan U2 pro with Android N and SAMSUNG Galaxy C7000 with Android M.

A. Single-hop Transmission Evaluation

1) Bitrate: In digital multimedia, bitrate represents the amount of information, or detail, that is stored per unit of time of a recording [15]. Bitrate is not the determinant of video quality, but it affects video quality to some extent.

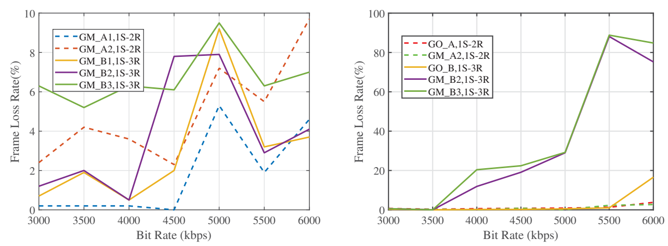
2) Fps (Frame per second): Fps means frame rate. In general, the frame rate of movies and PAL TV is 24, 25 respectively. Obviously the higher the frame rate, the smoother the video display.

In this section,we evaluate the performance of one-to-many single-hop real-time video streaming transmission within a WFD group. We calculate the frame loss rate of receiver with different bitrate videos from transmitting terminal. Transmitting terminal sends 1000 video frames to other receivers in the group at the same time and we count the number of frames recevice in these receivers. Since video emphasizes



(a) Multicast scheme 1 (b) Multicast scheme 2

Fig. 5. FLR vs. BitRate under the two mulitcast schemes for single-hop transmission (FLR=Frame Loss Rate).



(a) GO as a sender (b) GM as a sender

Fig. 6. FLR vs. BitRate for single-hop transmission (”1S-2R” = ”1 sender to 2 receivers”).

real-time performance and transmission rate, UDP has obvious advantages over TCP. So UDP is chosen as transport layer protocol in our system and we evaluate the performance of UDP multicast and UDP unicast separately.

- UDP Multicast

There are two transmission schemes for UDP multicast as follow: 1) GO sends multicast messages. As shown in Fig. 3, we test scenarios in different multicast groups which contatin three or four devices. The evaluation results of this scheme is shown in Fig. 5a. In general, when there are three devices in a multicast group, the frame loss rate is lower than when there are four devices. Fig. 5a also shows that the frame loss rate in the situation where there are four members in the multicast group is over 90%, when the bitrate at 1500kbps. Although the bitrate is reduced to 500 kbps, the frame loss rate in both scenarios is around 20%. In the actual test, we find that when GO sends multicast messages, there is not only a high frame loss rate, but also a high delay, which cause that the receiver can not decode and broadcast normally after receiving video data. Then, we test the scheme for the GM sends multicast messages. 2)GM sends multicast message. As shown in Fig. 4, we separately evaluate the situation where there are two receivers and three receivers in the multicast group. Fig. 5b shows the evaluation result of this scheme. When the GM sends multicast message, the frame loss rate of GO in both situations is almost 0 and negligible. But the frame loss rate of other receivers (GMs) in the multicast group is high. It can be seen from the Fig. 5b that when there are two receivers in the multicast group, the frame loss rate of GM is obviously lower than the situation where there are three receivers.

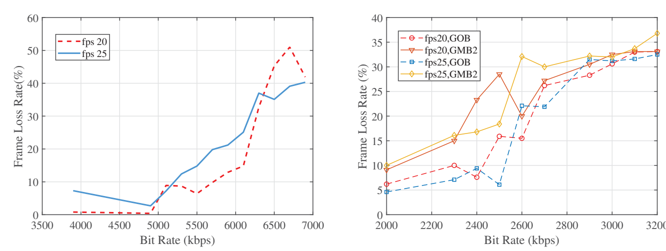
In general, we cannot use UDP multicast for a one-to-many single hop transmission.

- UDP Unicast

We evaluate the performance of UDP unicast according to the method of UDP multicast evaluation. 1)Firstly, the GO as a sender. Fig. 6a shows the result of the frame loss rate when there are two and three devices as receivers, respectively, during a single-hop transmission using UDP unicast. Although the video bitrate increase to 6000 kbps, the frame loss rate of all receivers is less than 10%. Compare to multicast scheme 1, the performance of UDP unicast is much higher than UDP multicast. 2). The GM as a sender. Fig. 6b shows the results of frame loss rate when the video data sent by GM. The dotted line indicates the frame loss rate when sending to two receivers simultaneously. The results of frame loss rate when there are three devices as receivers simultaneously are shown by solid lines in Fig. 6b. We can find easily from Fig. 6b that the frame loss rate of GO is obviously lower than that of GMs when GM as a sender and three devices as recevers simultaneously. The transmission from the source GM to the destination GM is a single-hop at the *IP layer*, but at the *MAC layer*, the traffic sent to the GO first, and then forwarded by the GO to the destination GM.

B. Multi-hop Transmission Evaluation

Firstly, we evaluate and compare the two schemes for multi-hop transmission proposed in section III. Then we test the impact of distance on system performance.



(a) GO as relay nodes (b) GM as relay nodes

Fig. 7. FLR vs. BitRate for mulit-hop transmission.

1) GO as the RN : We first connect the devices according to the topology shown in Fig. 2b. GM_A1 and GM_B1 servers as the transmitting terminal and receiving terminal respectively in this evaluation. The frame loss rate is still used as a system

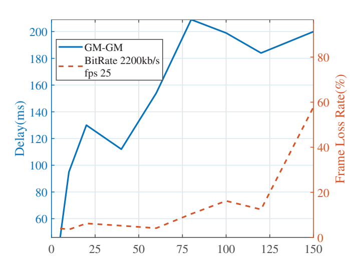


Fig. 8. Impact of distance on the system performance

performance evaluation index and we also test two kinds of videos with 20 fps and 25 fps separately. Fig. 7a shows that when the bitrate of two kinds of videos are less than 5000kbps, their frame loss rate are almost 0. The frame loss rate begins to increase dramatic with the growth of bitrate when bitrate exceed 5500kbps.

2) GM as the RN: We then evaluate another multi-hop transmission scheme that the GMs as relay nodes. Test devices are connected according to the topology shown in Fig. 2b. Due to the use of multicast in the scheme, we specifically tested the frame loss rate of two devices (GO_B and GM_B2 in Fig. 2b)in this evaluation. GM_A1 server as a tramsmitting terminal and GM_B2 server as a receiving terminal. We enable GM_A2(GM_B1) to forward traffic to GO_B using udp multicast. Therefore, the measurement results on GO_B also represent the performance of multicast to a certain extent. Other devices in the group B that request video data are theoretically feasible to join the multicast group where the GM_B1 and GO_B are located. So, the devices which request the video traffic in group B need to negotiate with the GO_B and request it to forward the data using unicast. Fig. 7b depicts our result that when the bitrate reaches 3200kbps, the frame loss rate has exceeded 30%. This aspect shows that this scheme is not as well as last scheme (GO as relay node), and it also indicates that the performance of multicast is much lower than that of unicast. Obviously, when the bitrate is lower than 2300kbps, the frame loss rate of the two videos(the fps is 20 and 25 respectively) is lower than 15% . It is clearly that the frame loss rate of GO_B is significantly lower than GO_B2. Finally, we recommened to tramsmit video with a bitrate lower than 2300kbps in the case of GM as the RN.

3) Impact of distance on the system performance: Since we need to use the video system in an open-air stadium, the impact of distance on the system performance is critical. We finish the evaluation at the open stadium in our school. Fig. 8 describes the effect of distance on thenetwork delay. The experimental results show that the network delay is less than 120ms when the distance is less than 50 meters. The network delay increases with the growth of distance on the whole and the devices only can keep connection within about 150 meters range. Since we want to test the effect of distance on the frame loss, we set the video bitrate to 2200 kbps to reduce the impact of bitrate on the experimental results. As shown in Fig. 8, the frame loss rate is less than 10% which is negligible within 75 meters. The reason for a serious frame loss at 150 meters is that connection amongs devices is interrupted during transmission. The results show that distance is not the main factor affecting frame loss, but distance affect network delay.

VI. Conclusion

In order to better utilize D2D network for traffic offloading, we design and implement a real-time video system on Android platform. We not only design one-to-many transmission scheme, but also achieve multi-hop video transmission across groups. Finally, we evaluate our system on real devices. The results show that the devices can form network quickly and easily, and the successful rates of real-time video streaming transmission are high enough for real-life, such as public safety or crowded scene occasions, like concert, World Cup stadium and other areas where the infrastructure-based network may be unavailable.

In the future work, we will design the adaptive bitrate algorithm, and provide more options for the multi-hop transmission using other wireless interfaces like Bluetooth, Wi-Fi hotspot in the system.

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