Real-time 360-Degree Video Streaming over Millimeter Wave Communication

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Abstract This paper provides an adaptive scheme of real-time video streaming in millimeter wave (mmWave) system. It consists of two parts: (1) real-time video streaming over mmWave 802.11ad 60 GHz wireless link; (2) 360-degree video decoding, post-processing and displaying by using Scalable high-efficiency video coding (SHVC). The mmWave communication is high-speed wireless technology to increase the capacity of video transmission. However, the current video streaming over mmWave researches are for long-distance and mobile device almost processes many tasks such as video decoding, post processing and display by itself. Therefore, the performance of mobile device is quite low in case high-resolution video streaming like 4K. In addition, the synchronization of real-time video streaming in high speed is big issue to ensure the quality of service (QoS), especially when mobile device is moving. Thus, this paper focus on real-time video streaming over mmWave with optimized QoS for high-resolution video. Specifically, this paper implemented an offloading mechanism to handle the offloading task between two UEs. The experimental demonstration shows that the proposed scheme provided real-time video streaming with high performance in accepted QoS-sensitive video streaming applications.

Keywords— 360 video streaming; mmWave; HEVC; SHVC; offloading

I. Introduction

Nowadays, video streaming is most popular service of multimedia systems. The transmission of compressed video over 2.4 GHz or 5GHz wireless network may not suitable for some delay sensitive applications such as wireless VR, interacting game with high resolution like 4K. Specially, the high-resolution video streaming in real-time model is big challenge to ensure the QoS. Because 4K video streaming applications require the wireless network capacity much more than previous HD services, it is hard to maintain the performance of 360-degree video streaming. Therefore, currently many researches proposes the methods to handle video streaming over mmWave communication in providing high capacity for video transmission.

Due to the development of huge spectrum resources of multimedia services, mmWave communication is a promising technique to become the core technology for high-bandwidth

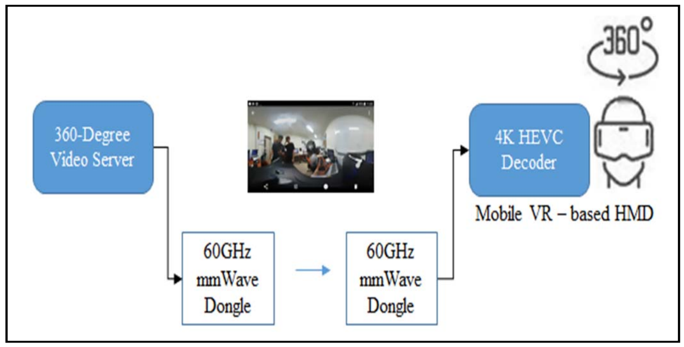

Fig. 1. Conceptual architecture of proposed system

Multimedia systems. Recently, mmWave 60GHz band has been being interest because it could provide up to 7GHz contiguous bandwidth. Thus, it has a great potential to satisfy the fast growing up of demand on wireless network capacity.

As shown in Fig. 1, the new video coding technology was standardized and provided commercial version as High-Efficiency Video Coding (HEVC). The HEVC could provide higher bandwidth as twice when comparing with H.264 AVC technology. In other words, HEVC could double the bandwidth capacity for video transmission at the same data rate. Fig.1 also shows that the prosed system consists of 360-degree video server and client (mobile VR – based HMD). Here, mobile VR supports both software and hardware 4K HEVC decoder. Now, in a joint effort between VR video and 360-degree video streaming, our purpose is to make 360 and VR videos look even more realistic in a higher bandwidth system. Specially, proposed scheme aims to implementing a flexible system in fact with the Equirectangular Projection. The most familiar representation is one where latitudes and longitudes are used to form a square grid. This is known as Equirectangular Projection (ERP). The ERP has the advantages of being both rectangular and straightforward to visualize. It is also relatively easy to manipulate using existing video editing tools. However, when used for video transmission, it has serious problems. First, the poles get many pixels, and the equator gets relatively few. This is challenging, because spherical videos usually have their important content distributed around the equatorial regions, which is the viewer's horizon. It also has high distortion, which makes existing video compression technology work harder.

Currenttly, almost previous video streaming over mmWave researches focus on long-distance environment, and the support for SHVC video encoding/decoding has not dealt with a system in fact yet. In addition, the mobile device always handle all video decoding and processing the decoded video by itself, so the performance of video processing is not enough power to play 4K or 8K resolution video stream. Therefore, this paper proposes a scheme to handle the high-resolution real-time video streaming for mobile by using mmWave wireless communication. Besides that, the scheme also provides an implementation of offloading mechanism to share the working tasks between mobile device and powerful PC.

The remaining part of this paper will be organized as following: Section II will describe related work, what are considered and experimental tested by demonstration. Section III will address challenge issues for real-time video streaming with high-resolution video stream and present proposed scheme. Section IV shows the implemented demonstration and evaluated results. Finally, section V will make a conclusion about proposed scheme and future works to do.

II. RELATED WORK

A. The Milimeter Wave Communication for Indoor Environment

Firstly, our target is to verify the performance effected by reality environment for deployment mmWave communication indoor environment. While state-of-art literature has not addressed this issue directly, there are various other well-researched papers, such as [1], [2], [3] and [7], which provide us more details with relevant conclusion. Moreover, these researches also encouraged us to gain our effort in deployment indoor mmWave network in reality. Specially, the proposal idea in [4] provides an investigation about object blockage on the performance of mmWave links. In the other hand, these studies also shows which is necessary for network designer to decide what their intended end user is. In [1] it has been shown 60-GHz mmWave channel measurements and modeling are carried out for indoor office environments. Furthermore, it also provided a 60-GHz channel model and its parameterization for office environment based on specified model, temporal, and spatial clustering properties. The performance of mmWave communication highly depends on the system model and network design. In [2] a beam forming mechanism was proposed, and this enables mmWave access point (AP) to estimate the best beam to communicate with other UE. Moreover, the sector sweep issue also addressed AP to cover the best beam selection. There is useful details to handle point-to-point mmWave connection between two hosts.

In a mmWave indoor scenario, characterized by much smaller distances between UE and the other UE, the main factor limiting deployment options are blockages by physical objects such as human bodies. Human body blockage was shown to cause severe signal blockages that reduce the spectral efficiency gains obtained from operation over larger bandwidths available in mmWave communication as in [5]. Furthermore, as it was shown in [6], which studies peer-to-peer indoor mmWave communications scenario, it is shown that, under the assumption of a random direction of the interferer's main-lobe, highly directional beams will be required to maintain Gbit/s links in crowded indoor areas.

Despite these detailed insights on the impact of affected elements, still little is known about the operation of Wigig mmWave device in fact. Thus, in this paper, test-bed scenario is processed in large indoor-environment with short distance between server and client.

B. Real-time Video Streaming with SHVC

Currently, the High-Efficiency Video Coding's (also known as H.265 or MPEG-H part2) really hot keyword in video coding area. Therefore, nowadays, almost operating system platforms or video applications are upgrading themselves for the highly-coverage of supporting HEVC. The first version of HEVC achieved roughly 50% bitrate reduction over its predecessor H.264 AVC at a comparable subjective quality [8]. The second version of HEVC [9] includes scalability extensions (SHVC), multi-view extensions (MV-HEVC), and format range extensions. The analyzed details of HEVC and SHVC could be reviewed in [10] and [11]. The extension SHVC coding provides selective different resolutions of output decoded video within one input encoded video bitstream. In best effort to enhance video transmission to mobile device, [12], [13] and [14] already provided some adaptive methods. From these studies, this paper also considered related aspects, which affects to video streaming to mobile device in fact.

The SHVC provides a mechanism for coding video in multiple layers, where each layer represents a different quality representation of the same video scene. The base layer (BL) is the lowest quality representation. One or more enhancement layers (ELs) may be coded by referencing lower layers and provide improved video quality. Decoding a subset of layers of a scalable coded video bitstream results in video with a lower but still acceptable quality than would result if the full bitstream were decoded. This allows a more graceful degradation compared with non-scalable video bitstreams, where reduction in bitrate typically causes more severe drops in video quality, oftentimes rapidly becoming of unacceptable quality for viewing. Compared with non-scalable video coding, scalable video coding typically costs more bits to achieve the same video quality.

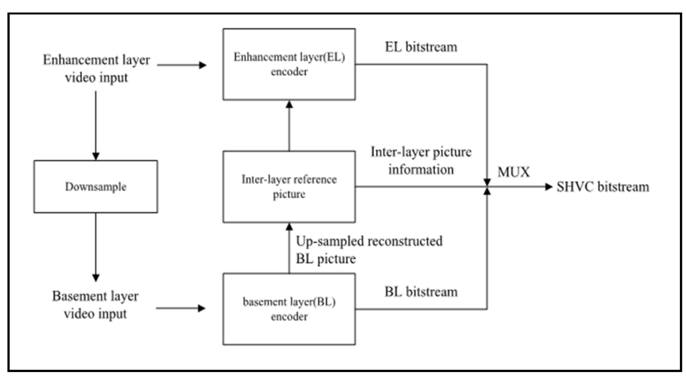

Fig. 2. SHVC Encoder Architecture

In addition, Fig. 2 show the block of structure of single SHVC encoder, and from this architecture of SHVC, we can see that it handles many resolution input videos and gives one output-encoded bitstream. This means that the client can get selective resolution decoded videos to display. Therefore, to enhance the capability of video streaming, instead of using single HEVC, the proposed system used video coding with SHVC as in Fig. 3.

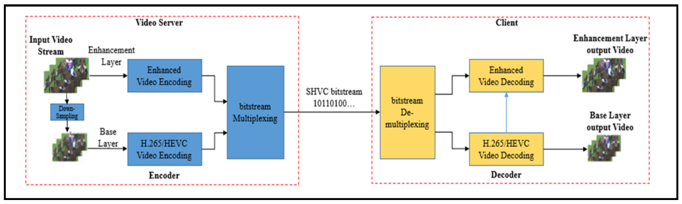

Fig. 3. Video streaming processes using SHVC

III. 360-DEGREE VIDEO STREAMING OVER MMWAVE

In this section, we give the details of addressed issues and proposed scheme. The proposed scheme is used to effectively ensure the performance of real-time video streaming with SHVC video bitstream. In addition, this part also shows the challenge and limited points of real-time video streaming with high-resolution video. The last part in this section is about the implementation of proposed scheme. In this part, a real-system was implemented with Wigig Dongle mmWave devices [15].

A. The Proposed Scheme

The main idea behind the proposed scheme could express as followings:

- To solve the 4K 360-degree video streaming, instead of other wireless 802.11, the mmWave 802.11ad 60GHz link applied to support high-bandwidth. In addition, an adaptive synchronization mechanism also implemented to cover real-time issues in high-speed of video transmission.
- To avoid the overflow issue or quite low performance issued of high-resolution video processing on mobile device, the proposed scheme also developed an offloading mechanism to offload some tasks from mobile device to powerful PC. A proposed system with offloading mechanism, as shown in Fig. 4, it would help mobile device could decrease the processing time with good performance to handle playing 4K decoded video. SHVC bitstream from server has to separate to BLs bitstream and ELs bitstream to enhance the performance of offloading task.
- To enhance the performance of overall proposed system in indoor environment, in demonstration, mmWave communication are fixed as Line-Of-Sight and the demonstration used an effective parameter set. In addition, some optimized techniques was also applied to proposed system such as buffer queue, memory management, etc. Specially, the scheme implemented a synchronization mechanism to ensure the performance of connected link.

From these main ideas of proposed scheme, an implementation needed to demonstrate the operation of proposed system in fact.

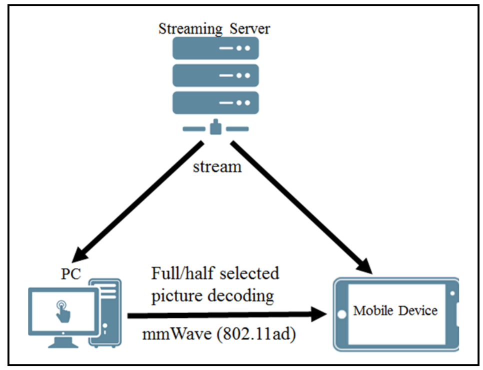

Fig. 4. The proposed system for PC offloading

B. The Implementation

To handle the real-time video streaming, we designed the proposed system as a technical concept of proposed scheme. In proposed system, the streaming server and powerful PC could regroup to the one. This work is considering as best choice for our implementation.

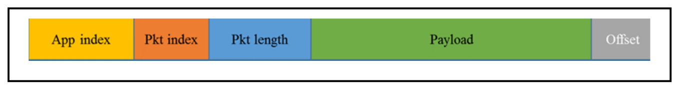

Fig. 5. The data structure of video streaming application

1) The reformated data strucutre for mmWave wireless communication: the redesigned data structure on application layer as illustrated in Fig. 5, the raw data of video streaming application was designed with “app index” and “pkt index” to prevent the packet loss and cover syncronization issue by using a synchronization mechanism. The “pkt length” was optimzed following the resolution of video streaming to ensure the performance of video transmission in high-speed. The payload contains video data for both cases, encoded video bitstream and raw decoded video. And the last four bytes are “offset” bytes for synchronization. In addition, the offset part also includes “reserved” bytes for future works to enhance the performance of mmWave communication.

2) PC Offloading mechanism: As shown in Fig.6, proposed scheme provides an offloading mechanism to share tasks from mobie devices to powerful PC. The procedures of both devices are descripted as following.

a) Encoded bitstream devision: From an input encoded video bitstream, the streaming server made a separtion into two new bistreams by using a picure parser , then once is transmitted to mobile device and other once’s sent to powerful PC.

b) Bitstream BL handling: Base layer of bitstream is handled by mobile device and decoded, post-processing and display by itself. This task’s quite low-loading and the remaining resources of mobile device are spent for other tasks.

c) Bitstream ELs processing: ELs of bitstream (includes reference details BL) is decoded by powerful PC and the raw output video will be sent to mobile devices over mmWave link.

This task's high-loading by processing big size of data, such as 4K video. By this way, the powerful PC shareed the ELs decoding with mobile device, when mobile device is doing other task. This work of powerful PC is called as offloading, then it could help mobile device to enhance the probability in playing high-resolution 4K video.

3) Synchronization mechanism: To handle the issue of synchronization in real-time between sender and receiver UEs. The mechanism can be explained as followings: 1) each picture of video is consisted of one identified number as indexing number; 2) sender sends picture by picture to receiver in real-time; 3) the index would be used again to build ACK packet at receiver and send back ACK to sender; 4) After confirmation of ACK at sender, sender will send next packet to receiver. More details of operation shows as formal algorithm in below.

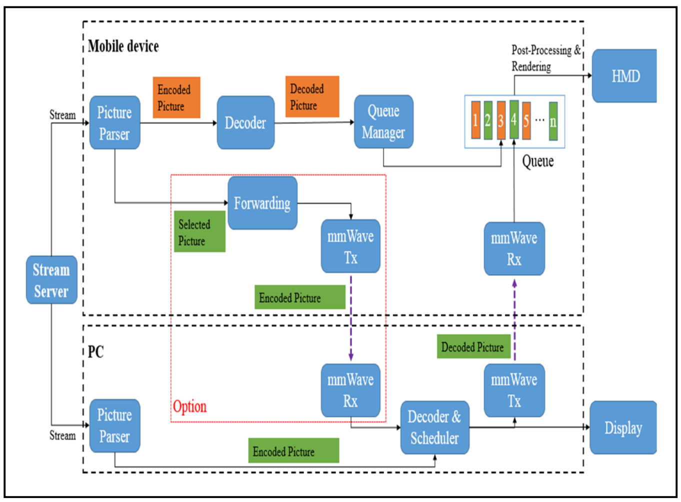

Fig. 6. PC Offloading mechanism

PC Offloading & Synchronization mechanism

Input: SHVC bitstream

N: {n} encoded picture in bitstream

Initial:

Picture parser (PP), Decoded Picture Buffer (DPB), Data Buffer (DB), Synchronizer with timer 0, max buffer size (MAXB), SHVC decoder.

while i lower (Max of N) do

1. Process input stream N by PP to get encoded picture n_i to check BL or ELs.
2. BL encoded picture n_i are written to DB
3. each EL encoded picture n_i is processed by SHVC decoder, then it's written to DPB
4. apply proposed data structure to picture ni by Synchronizer, picture ni become payload of new data
5. send out the new data to client
6. wait to ACK from client, check "pkt index" and decide re-transmission ni or moves to $n_{(i+1)}$ picture
7. open displaying picture from DPB, while client side's opening playing decoded picture ni

if (sizeof(DPB)> MAXB || sizeof(DB) > MAXB)

Release data n_0 to n_i on DPB, DB

end

end

Output: Decoded video

IV. Performance Evaluation

Here, real experimental-test on Wigig mmWave system is provided to demonstrate the performance of proposed scheme. The scenario gives the detailed parameters of proposed system in fact. The performance evaluation shows the results of real-time testing based on proposed system.

To evaluate the performance of real-time video streaming by proposed scheme, the scenario as shown in Fig.6 provides a real test-bed for demonstration. Instead of using a specified streaming server, we set a powerful PC as well as full functionality of streaming server. This means the powerful PC get encoded SHVC bitstream from the other sources. To perform the operation of offloading task, we considered two issues with the scenario as in Fig.7.

First, the BL inside the SHVC bitstream would be divided into a new bitstream, and then the BL bitstream's transmitted to mobile devices over Wigig mmWave or normal wireless network 802.11 AC. Thus, mobile device only handles BL processing and the performance of BL decoding is perfect. Therefore, the implementation focused on second issue. Second, the original SHVC bitstream's handled by powerful PC for decoding, post-processing and displaying of ELs, and then the raw output ELs video (YUV format 4:2:0) also will be sent to mobile device via mmWave link for displaying on mobile device's screen. Of course, in one time, the mobile device only displays one output YUV video from BL bitstream or ELs video, which is received from PC. This video transmission is named as raw video transmission.

Herein, many experimental-tests with Wigig mmWave devices was produced to detect issues, which are able to fix or optimize for implemented demonstration of real-time video streaming over mmWave. As illustrated in Fig. 7, we set up the experimental scenario to evaluate the performance. Fig. 8 and Fig. 9 show the real-performance of mmWave communication in indoor area. Moreover, the real-test for body blockage case confirmed that the throughput of mmWave link was going down when the human body is in position between transmitter and receiver, and then the link's be recovered immediately after the human body moved out the mmWave Line-of-Sight (LOS) area. . In addition, the parameters of scenario are fixable to maintain stably the operation of proposed system. Table I provides the parameter set of the scenario.

As shown in Fig. 8, the throughput of mmWave communication changes from 500 Mbps to 930 Mbps by distance between two UEs. The real-test further shows that by distance over 10 meters, the throughput will decrease to near zero. Through this test case, the selected distance for the demonstration of proposed scheme is 2 meters. We chose 2 meters value because of some reasons: 1) In fact, the mobile device can move around the powerful PC by many ways; 2) This distance also gives the highest throughput; 3) It seems to be good distance between human head-mounted-display and powerful PC's screen for playing video.

TABLE I. PARAMETER SET

Parameters	Value
mmWave MCS Level	7 (Physical Rate 1.9 Gbps)
mmWave Sector	7 (sector 0 – 15)
mmWave Antena	Radiation: type: Endfire; polarization: Linear
mmWave Frequency Channel	59.40 – 61.56 GHz
Distance (server-client)	2 meters
Video Time	30 seconds
SHVC bitstream	PeopleonStreet_3840x2048.bin; Traffic_2560x1600.bin

In "Fig. 9", the throughput of mmWave communication changes by obstacles between two UEs. The real-test further shows that if the barrier stay in fix location, the throughput will decrease to near zero. So on, in the test, all objects are moving pass through mmWave area. Through this test, to maintain high-speed for mmWave-connected link, the demonstration of proposed scheme handles all experimental cases without obstacle. Furthermore, the coverage for human head blockage will be handled as next step of proposed system.

Here, experimental results showed the performance of proposed scheme, compared with before applying the proposed scheme. The demonstration of proposed scheme was produced in reality-environment, and we have not seen any previous research for video transmission or demonstration like ours before. As shown in Fig.10, the result showed that the throughput of mmWave communication's near 300 Mbps, for both case 2K resolution and 4K resolution video. The quality of 2K resolution video on server side (powerful PC) and client (mobile device) figured out as shown in Fig.11 (a) and (b) For 2K resolution video streaming, we used raw video transmission over mmWave link. For 4K video, Fig.11 (c) and (d) confirmed that the display quality is quite good for 4K resolution video. The delay time is accepted QoS sensitive. Moreover, in case for long-time 4K video, the latency time is a little bit. This latency reflected that number of ACK packets increasing highly.

Fig. 7. Test-bed scenario for mmWave communications

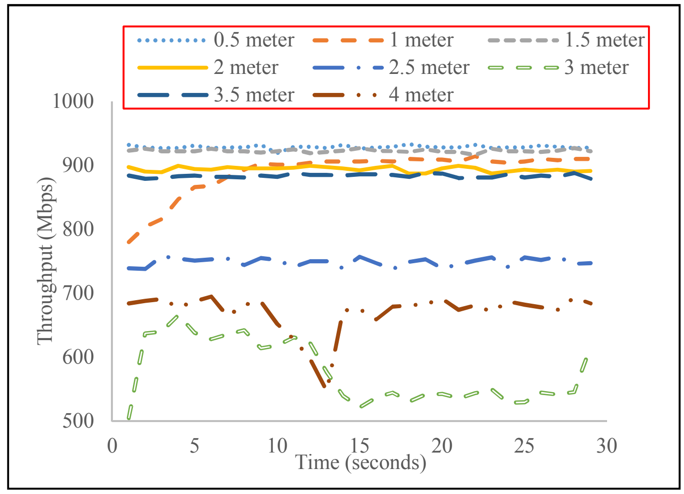

Fig. 8. The data rate of mmWave connection effected by distance

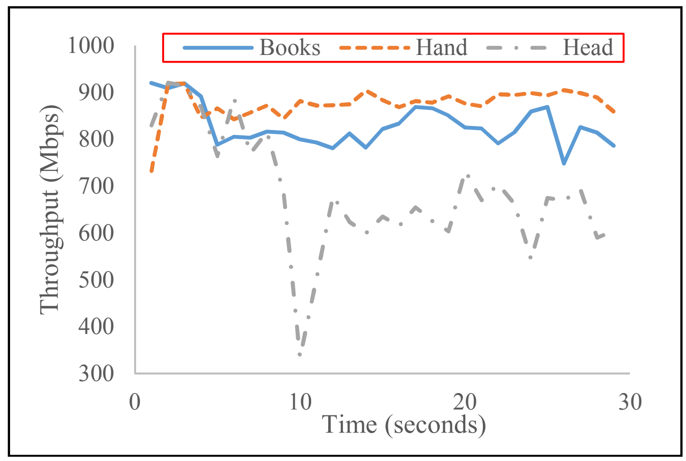

Fig. 9. The data rate of mmWave connection effected by obstacles

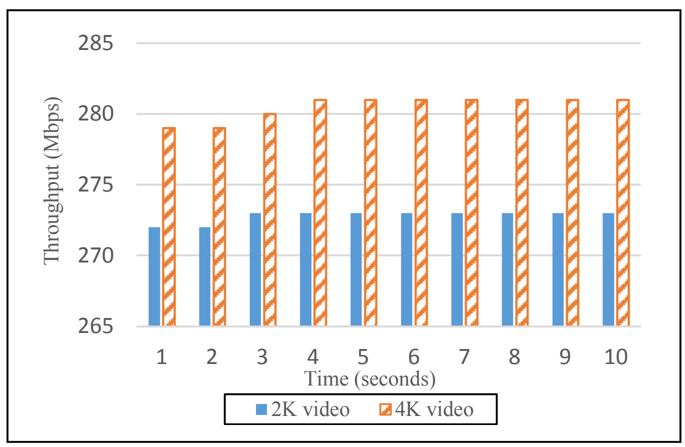

Fig. 10. Throughput of mmWave link for real-time video streaming

In addition, by using some optimized techniques to ensure enough power of mobile device. Through the implementation of our demonstration based on Wigig devices, we also confirmed that, Dongle Wigig devices are under developing, and some features of Wigig device are not perfect as we expected. However, these results encouraged us to take advanced missions in reducing limitations of video streaming over mmWave.

Fig. 11. (a) 2K decoded picture on server side; (b) 2K on client side ; (c) 4K decoded picture on server side; (d) 4K on client side

V. CONCLUSION

Herein, we studied the performance effects of deployment the video coding with mmWave communication. We showed that, while being feasible, mmWave communication could enhance the performance of real-time video streaming in indoor environment. Furthermore, the proposed scheme also proved that mmWave to ensure high-resolution video transmission in real-time model by applying its optimal mechanisms. First, the offloading mechanism provides the enhancement for loading of mobile device. Second, synchronization mechanism answers the question that how the proposed scheme can handle the video streaming in real-time.

Still more work is needed to improve the performance for 4K raw video transmission by enhancement of synchronization. Besides that, the offloading also need to be updated to play higher resolution video like 8K, 12K with SHVC coding. However, even the results we have so far can be used to inform the new design of video transmission system over mmWave communication.

ACKNOWLEDGMENT

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