Network Reputation-based Stereoscopic 3D Video Delivery in Heterogeneous Networks

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***Abstract*—The recent advances in both wireless technologies and mobile devices, fuelled by increased user interest, have driven the latest development of mobile 3D video services. However, the limited wireless bandwidth is one of the critical challenges for mobile 3D video delivery, especially as the 3D content requires higher bandwidth than the conventional 2D video. This paper proposes a network reputation-based stereoscopic 3D video quality enhancement scheme in heterogeneous networks. A network reputation module is proposed to report the network quality based on quality of service-related parameters (i.e. throughput, signal strength, delay, and loss) and price aspects. The proposed solution selects the best candidate networks for the smartphone using the network reputation module. IETF Multipath TCP (MPTCP) protocol is used for delivering the 3D video content to the mobile devices due to the higher throughput provided. Different 3D video components (i.e. color stream and depth stream) are delivered via separate sub-MPTCP flows and synchronized at the receiver. Simulation results show important quality of service benefits when using the proposed solution in comparison with multipath TCP approaches: the average throughput was with 5.5% higher and the average delay was with 9.3% lower.**

Keywords-3D video, multipath TCP, network reputation, heterogeneous networks.

I. INTRODUCTION

In the last decade, 3D video has been introduced to home through 3DTV, 3D gaming and 3D movies. Alternative codec solutions for the 3D video have been developed including [1]: i) two-view stereo video coding, ii) video and depth coding and iii) multi-view video coding (MVC) [2]. In general, a single 3D video stream consists of both color and depth information. This results in the 3D video delivery service requiring higher bandwidth than necessary for the traditional 2D video stream. The emerging LTE-A [3] and 802.11ac [4] standards provide significant improvements in terms of bandwidth and are very good for delivering 3D video sequences. Bandwidth resource allocation for 2D video streams in heterogeneous networks has been extensively studied [5], however, additional work is needed to propose efficient scheduling schemes for 3D video.

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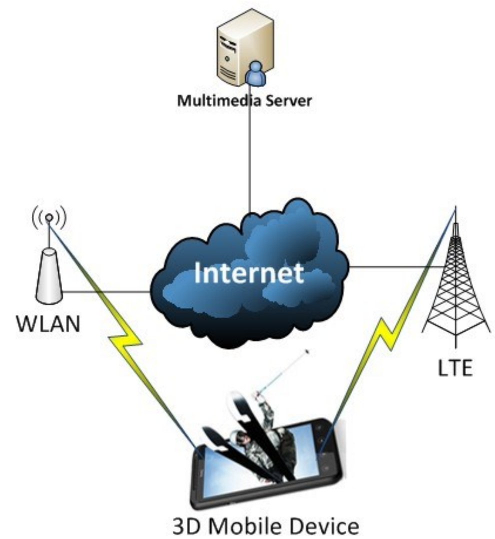

Figure 1. 3D Video Delivery Using LTE and WiFi

Currently, most mobile devices have access to different networks as they are equipped with multiple radio interfaces. By implementing the MPTCP [6] protocol, the mobile devices can concurrently utilize multiple interfaces. Regarding 3D video delivery, the 3D video stream can be decomposed into different components according to the coding methods employed for the 3D video [7]: left and right views, in the two-view stereo video coding; video and depth streams in video and depth coding; and several views plus depth information in MVC. In our previous works [8] [9], a network reputation mechanism was introduced to help enhance the content quality across various unscalable wireless networks.

In this paper, we make use of the reputation-based system to select the most appropriate set of networks. A Network Reputation-based Quality-aware 3D video delivery (NRQ-3D) scheme is proposed that makes use of the MPTCP protocol in order to balance the traffic among a set of networks and finds the best trade-off between QoS and monetary cost.

The structure of the paper is as follows: Section II discusses related works. Detailed information about the 3D video delivery scheme and system architecture is presented in section III, and the algorithms are described in section IV. Section V introduces the simulation scenarios and the analysis of results. Section VI presents the conclusions and future works.

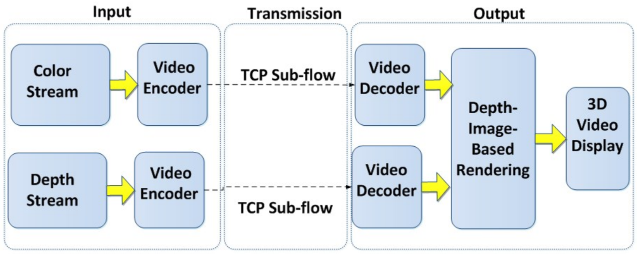

Figure 2 Overall 3D Video Delivery Scheme

II. RELATED WORKS

Currently, there are two categories of 3D video technologies: the stereoscopic 3D, as the first generation 3D video technology and the multi-view 3D video (MVV) as the second generation. Summarizing the previous works [1] [7] [10-14], Table 1 shows the comparison of the two technologies from different points of view.

At the moment, there are a limited number of mobile devices that support stereoscopic 3D due to the specific hardware requirements (i.e. 3D-enabled screen, advanced GPU, etc.).

The authors in [15] proposed a cross-layer adaptive stereoscopic 3D video streaming framework based on simulcast scalable video coding (SVC), combined with asymmetry coding. This framework reduces the loss rate for key packets by adapting the stereo video rate to the available network rate, to achieve the better perceived 3D quality with best scaling option depending on the bitrate/PSNR. A rate estimation method based on periodic packet loss feedback from the client is also present in the paper under the TCP/DCCP protocol. The emulation result shows that the adequate adaptation capability with scalable coding of only one view to match the network bit rate and gathering better perceived visual quality than scalable coding of both views.

The authors of [16] have proposed a transparent user-space module-Media Aware Network Element (MANE) which, different from the mechanism in [15], uses the 2D SVC adaption framework. MANE runs as a transparent proxy for low delay filtering of scalable video streams, and could work on any existing topology. MANE selects packets with enhancement information from both views to drop in order to adapt the transmission data rate. The double exponential smoothing method is using to forecast the transmission data rate. The performance evaluation involving the RTP protocol shows how the MANE scheme can gain 10 dB PSNR in comparison with non-MANE scheme.

The work in [17] focuses on the color plus depth 3-D video, and proposes a joint source channel coding scheme (JSCC) for depth image-based rendering (DIBR)-based 3D video coding. The proposed scheme works under the WiMAX based communication channel, and by investigating the optimum coding performance for various source and channel coding rates, the optimum bit allocation

TABLE 1 COMPARISON OF TWO 3D VIDEO TECHNOLOGIES

	Stereoscopic 3D	Multi-view 3D
Idea	1) Creating or enhancing the illusion of depth in an image and present two offset images separate for the left and right eyes. The two images are perceived by humans as 3D depth. 2) input layouts: side by side, top/down, alternating rows, etc.	1) Simultaneously encoding sequences captured from multiple cameras using a single video stream. 2) input layouts: multiple view streams
Strength	1) Compatible with conventional 2D 2) Save bandwidth and storage in comparison to Multi-view 3D 3) Good for broadcasting	1) Experiences natural depth perception 2) No glasses 3) Multiple angles
Weakness	1) Resolution of individual view is lower compared to 2D 2) Glasses needed in most cases 3) Lenticular sheet technology can avoid using glasses, but currently provides narrow spots. 4) Fixed viewing angle, no	1) challenge for broadcasting due to limited bitrate channel
Adaptation	Bitrate scaling e.g. 1) assign lower bitrate for chrominance than for luminance component; 2) reduce bitrate by discarding enhancement layer for either/both left and right eye(s).	View scaling e.g. 1) Discard certain views which might be outside of the user's field of view. 2) Depth based rendering is always adopted to enhance the experience with low added bitrate.
Codec	MPEG4/H.264 AVC for 2D+MPEG4/H.264 for depth; MPEG4/H.264 AVC for 2D+MVC for depth as enhancement; Multi-view Video Coding (MVC)	Multi-view Video Coding (MVC)
Delivery	MPEG-2 transport stream, e.g. Blue-ray disc IETF RTP, e.g. real-time transport via IP ISO base media file format, e.g. progressive download in video-on-demand, HTTP streaming	

combination of color plus depth stream sequences can be found. The simulations show that the quality of 3D video is dominated by the quality of the color stream.

In [18] the authors proposed an unequal error protection scheme (UEP) based on hierarchical quadrature amplitude modulation (HQAM) for 3-D video transmissions. The proposed UEP scheme follows the result of [24], which suggests that in order to achieve high quality 3D video, more protection has to be assigned to the color component rather than the depth. By comparison with the conventional equal error protection scheme (EEP), the simulation result shows that UEP can gain up to 5dB in terms of PSNR.

In conclusion, the previous works on stereoscopic 3D video transmission focus on two mechanisms: one might drop not-important packets from one or both views of the stereoscopic 3D video to adapt the transmission data rate to

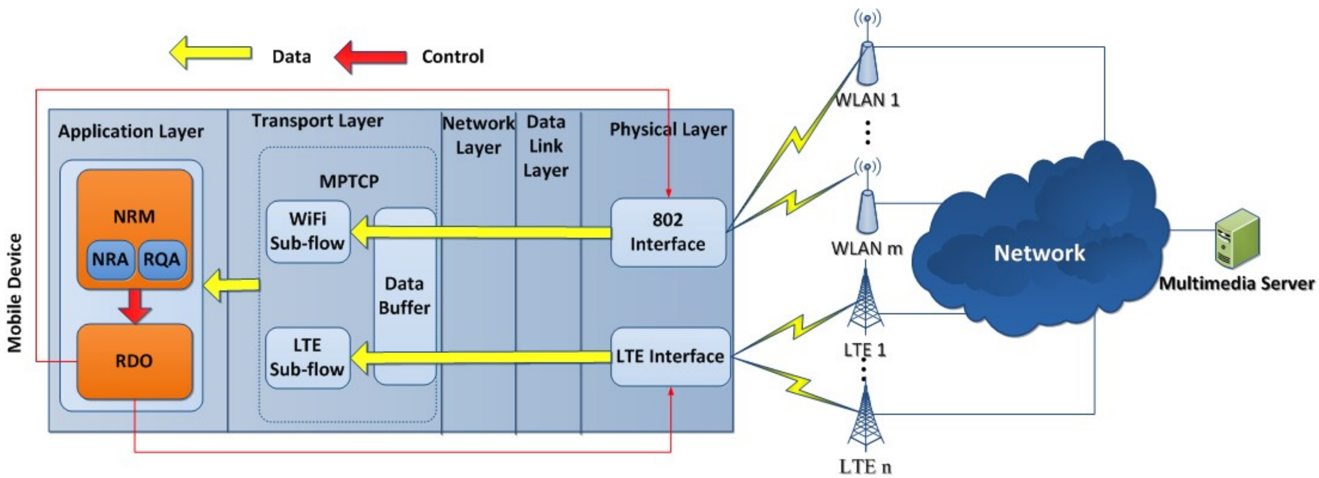

Figure 3 NRQ-3D Block Structure

the target rate, the other gives different protection levels on different content from the stereoscopic 3D video to maintain the transmit result at higher quality. All the transmission process of stereoscopic 3D video was single path and the 3D video quality is evaluated by PSNR. This work considers multipath transmissions and involves a 3D-specific quality metric to evaluate the 3D video stream quality level.

III. SYSTEM ARCHITECTURE

A. 3D Video Delivery using MPTCP

Fig. 2 shows the overview architecture of NRQ-3D. It uses the depth-enhanced based 3D video representation, whose detailed coding format can be found in [19]. The input data consists of two components: the color stream and the depth stream. Both color stream and depth stream are encoded by using a standard video encoder (i.e. H.264/MPEG-4 AVC). During the transmission, each stream will be transmitted via separate MPTCP sub-flow. Two streams will be sent to the video decoder and processed using the Depth-Image-Based Rendering (DIBR) [20] methodology. Finally, the 3D video will be generated and displayed on the 3D mobile device screen.

B. Reputation-based 3D Video Delivery

The block architecture of the proposed NRQ-3D is illustrated in Fig. 3. Two wireless network technologies, LTE and WLAN, are considered. The proposed scheme is implemented at the application layer providing high flexibility to the existing video delivery protocols and mobile devices. The NRQ-3D consists of two main components in the application layer: *Network Reputation Monitor (NRM)* and *Reputation-based Data Offloading* (RDO).

1) NRM consists of two sub-modules: *Network Reputation Algorithm (NRA)* and *Reputation-based 3D Video Delivery Quality Enhancement Algorithm (RQA)*. The principle behind the functionality of these two modules are decsribed next.

- NRA generates the candidate network list and selects the network with the best reputation for each interface based on historical and updated reputation data.
- RQA compares the reputations of the two interfaces and selects the better one to transmit the higher bitrate stream (i.e. color stream).
- During the transmission, NRM continuously monitors the QoS parameters (i.e. throughput, signal strength, delay) for each active network.
- RQA sends control commands (i.e. idle, handover, transmit) to RDO.

2) RDO works in steps, as follows.

- Sends *idle* command to either the LTE or WLAN interfaces when needed. Sends *handover* command and alterative Network ID to the WLAN or LTE interface.
- Sends *transmit* command to both interfaces to transmit content when RQA set or changed the transmission link.

Once the system is initialized, NRM starts to monitor the available networks and selects the best candidate network for each interface, by sending the transmit command through RDO to connect to the multimedia server. The interface with higher and lower reputation network is used to transmit the video and the depth streams, respectively. The video and depth streams received from their respective network interfaces will be sent to the data buffer module in the MPTCP structure. Both streams will be synchronized using the DIBP module at the receiver and displayed at the 3D-enabled device.

During the transmission, NRM keeps monitoring the available networks and the current networks to compute the variable network reputation level. Once the reputation of the LTE network is lower than the minimum threshold, the NRM sends an idle command through RDO to stop the multipath transmission. If the reputation of the available WLAN network is higher than the differential threshold plus the reputation of the current working WLAN network, then NRM sends a handover command through RDO to the WLAN interface. Exchange command will be sent through RDO to both interfaces when the reputation of the WLAN network is lower than that of the LTE network.

IV. ALGORITHMS AND DECISION PROCESS

This work extends the NRA in [8] by using the utility function of quality and cost in [21]. As the QoS requirement of 3D video delivery application is much higher than for normal multimedia applications [22], the minimum throughput and cost of the available network needs to be considered. So we include these two parameters into the NRA algorithm.

At initialization, NRA generates the candidate network list and selects the best reputation network for each network interface. The pseudo-code of the decision process handled by NRA is presented in Algorithm 1.

Once NRM gets the candidate network list and the network with the highest reputation for each interface, RQA starts to enhance the quality of 3D video delivery. The pseudo-code of the decision process handled by RQA is described in the Algorithm 2.

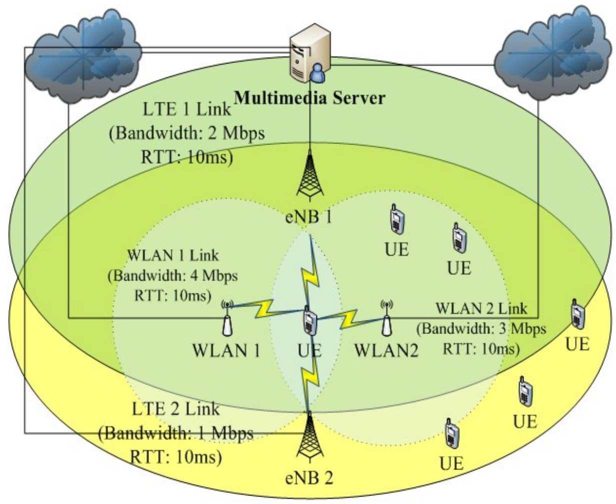

Figure 4 Network Topology Used in Simulation

Algorithm 1: Network Reputation Algorithm (NRA)

Input:

Wq - quality weight;
Wc - cost weight;
Wss - signal strength weight;
Th_{min} - the minimum acceptable throughput;
C_{Max} - the maximum of user budget;
Signal $strength_i$ –signal strength of network i measured on mobile device;
$Cost_i$ – the monetary cost of network i;
D_i – the distance between mobile device and base station of network i;
RTT_i – the round trip time of network i;
$Throughput_i$ – the available throughput of network i;
N_a - number of available networks in list $[A_i]$;

Procedure:

i=0;

Candidate Network List Initialization
for (i=0 **to** N_a **) do**
{
  if ($Throughput_i$ $\leqslant$ Th_{min} **or** $Cost_i$ $\geqslant$ C_{Max})
  {
    delete $Network_i$ **from** Available Network List $[A_i]$;
    N_a--;
  }**end if**
}**end for**

$N_c = N_a$; // N_c - number of candidate network list $[C_i]$

Calculate Reputation
for (i=0 **to** N_c **) do**
{
  compute utilities: Uq_i, Uc_i, Uss_i;
  compute reputation: R_i ;
  add ($Network_i$, R_i) **to** Candidate Network List $[C_i]$;
}**end for**

Output:
Candidate Network List $[C_i]$ **and**
The $Network_i$ with highest reputation (R_i)

Algorithm 2: Reputation-based 3D Video Delivery Quality Enhancement Algorithm (RQA)

Input:

$[Cl_i]$- candidate network list for LTE interface;
$[Cw_i]$- candidate network list for WiFi interface;
Rl_{max}- highest reputation in LTE networks;
Rw_{max}- highest reputation in WiFi networks;
N_l - number of candidate network in list $[Cl_i]$;
N_w - number of candidate network in list $[Cw_i]$;
f – frequency of schedule to update reputation;
t – current time;

Procedure:

t=0;
while (t = 0 **or** t%f = 0) **do**
{
  if(N_l != 0 and N_w != 0)
  {
    if(Rw_{max} $\geqslant$ Rl_{max})
    {
      set $Link_v$ =0; // color link using WiFi
      set $Link_d$ =1;// depth link using LTE
    }**else**{
      set $Link_v$ =1;// color link using LTE
      set $Link_d$ =0; // depth link using WiFi
    }**end if**
  }**else{**
    if(N_l = 0 and N_w = 0**)**
    {
      wait f;
    }else{
      if(N_l = 0)
      {
        set idle = 0;// idle the LTE interface
      }else{
        set idle = 1;// idle the WiFi interface
      }end if
    } end if
  }
  run NRA;
}

V. SIMULATION-BASED TESTING AND RESULT ANALYSIS

The performance of the proposed NRQ-3D was evaluated using NS version 3.17 with the Direct Code Execution (DCE) [23] package. The performance of the 3D video delivery in heterogeneous networks was assessed in terms of average throughput, delay, Peak Signal-to-Noise Ratio (PSNR) and Non-intrusive 3D Video Quality Metric (NVQM) [24].

The test-bed is based on NS-3.17 and DCE provides the possibility to directly execute real applications running over the NS-3 with actual network protocols [23]. MPTCP used is released by the Linux kernel Multi-Path TCP project [25] and is based on Linux 3.5.7 version of kernel.

A. Simulation Test-bed Setup

The network topology used in this simulation is presented in Fig. 4. It involved six nodes: one node is used as the multimedia server, two are LTE eNB nodes, two are WLAN base stations and one is a wireless user equipment (UE). The distance between UE and the first LTE (denoted LTE 1) eNB node was 3000 meters, with 2Mbps bandwidth and RTT was 10ms. The distance between UE and the second LTE (denoted LTE 2) eNB node was 4000 meters, with 1Mbps bandwidth and RTT was 10ms. The distance between UE and the first WLAN (denoted WLAN1) base stations was 10 meters, with 4Mbps bandwidth and RTT is 10ms. The distance between UE and the second WLAN (denoted WLAN 2) base stations is 50 meters, with 3Mbps bandwidth and RTT was 10ms.

Based on this topology, four test cases were considered with different available communication links between UE and the multimedia server, as follows:

- Case 1: LTE 1 and WLAN 1 links were established between UE and multimedia server.
- Case 2: LTE 1 link and WLAN 2 link were established between UE and multimedia server.
- Case 3: LTE 2 link and WLAN 2 link were established between UE and multimedia server.
- Case 4: LTE 2 link and WLAN 1 link were established between UE and multimedia server.

B. Test Scenarios

Two scenarios were designed in this simulation for NRQ-3D performance assessment:

- Scenario 1: Both LTE and WLAN links were established between UE and multimedia server. One constant bit-rate (CBR) 4 Mbps data stream, which aggregates all 3D video components, was sent from multimedia server to UE using MPTCP as the transport layer. Simulation lasts for 50 seconds in all four cases.
- Scenario 2: Two CBR data streams were sent from the multimedia server to the UE: a 3.2 Mbps color stream and a 0.8 Mbps depth stream. The simulations consider cases 2 and 3 only, as case 1 achieves very good quality and little additional improvement can be obtained and case 4 is similar to case 2. The other

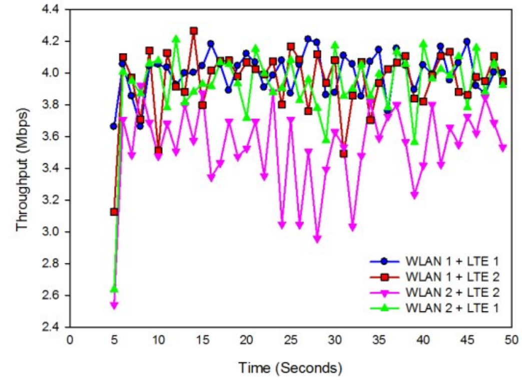

Figure 5 Throughput of 4 Cases with Scenario 1

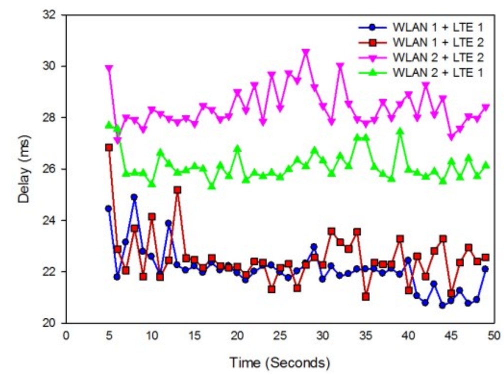

Figure 6 Delay of 4 Cases with Scenario 1

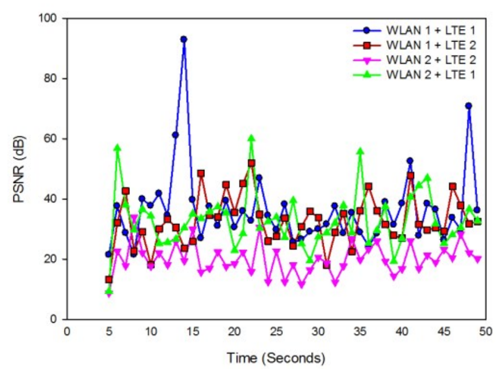

Figure 7 Estimated PSNR of 4 Cases with Scenario 1

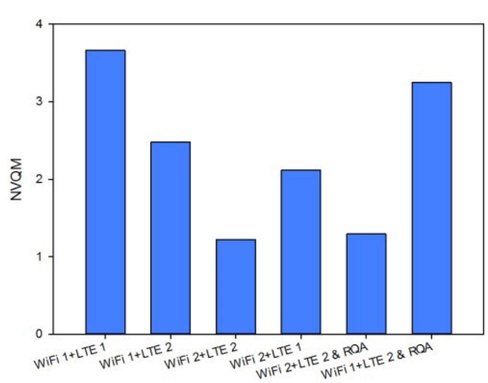

Figure 8 NVQM of all simulation cases and scenarios

settings were the same as in Scenario 1.

The ratio between the two streams bitrates in scenario 2 is 4:1, following [17], which shows that for the depth map bitrate is required nearly 20% of the total source coding bit rate for H.264/AVC format.

C. *Quality Assessment*

To assess the user-perceived quality of the videos, this paper uses an estimation of PSNR [26]: based on throughput and loss, as shown in equation (1).

$$PSNR = 20\log_{10}\left(\frac{Max\_Bitrate}{\sqrt{(Exp\_Thr - Crt\_Thr)^2}}\right) \quad (1)$$

In equation 1, *Max_Bitrate* is the maximum data rate of the transmitted stream, *Exp_Thr* is the expected throughput and *Cre_Thr* is the actual average throughput.

The 3D video might be associated with different human perception in terms of quality than the 2D video. NVQM, proposed in [24] and shown in equation (2), is an objective metric to estimate the 3D video quality by considering the bitrate and packet loss

$$V_{3D_q} = a1 + a2 * e^{\left(-\frac{Ppl_v}{a3 + a4 * e^{-\frac{Br_v}{a5}}}\right)} \quad (2)$$

In equation 2, Ppl_v is the packet loss ratio, and Br_v is the stream bitrate. *a1, a2, a3, a4* and *a5* are constant coefficients determined from subjective testing.

D. *Result Analysis*

Scenario 1 investigated the effect of using NRA under the data transmission with MPTCP protocol. Based on NRA, by computing the utilities of four networks which sets at the network topology, the reputation of four networks were generated and listed like this: $R_{WLAN1}>R_{WLAN2}>R_{LTE1}>R_{LTE1}$.

From the four cases: case 1 (WLAN1+LTE1), case 2 (WLAN1+LTE2), case 3 (WLAN2+LTE2), case 4 (WLAN2+LTE1), by running NRA, case 1 will be selected for the mobile device to receive the video traffic.

As shown in Fig.5, the average throughput of case 1 is 1.3%, 13.2% and 2% better than case 2, case 3 and case 4, respectively. Fig.6 shows that the average delay of case 1 is 2.2%, 22.3% and 15.4% lower than that in case 2, case 3 and case 4, respectively.

Fig.7 shows how PSNR of case 1 is 11% better than that of case 2, 79.7% better than that of case3 and 10.1% better than the value in case 4. Fig.8 shows how the NVQM in case 1 is with 1.2 points higher than in case 2, with 2.4 points higher than in case3 and with 1.5 points higher than in case 4.

Scenario 2 investigated the effect of RQA when the 3D video can be transmitted divided into color and depth streams. As the reputation of WLAN link is better than LTE link, from RQA, the color stream with higher bitrate will be transmitted via WLAN and the depth stream via LTE.

The performance of case 2 and case 3 is compared to that in Scenario 1.

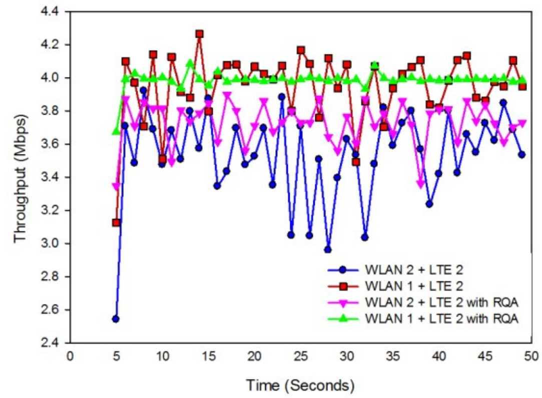

Figure 9 Throughput of Case 2 and 3 on both Scenario 1 and 2

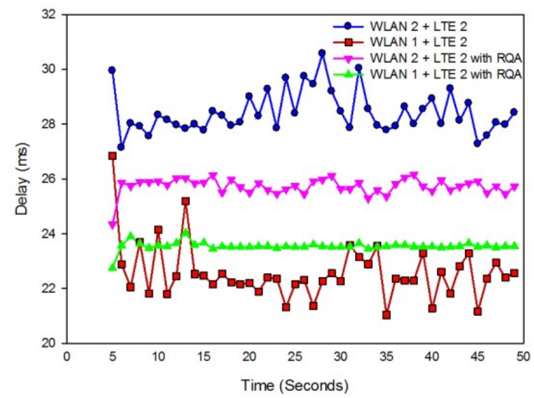

Figure 10 Delay of Case 2 and 3 on both Scenario 1 and 2

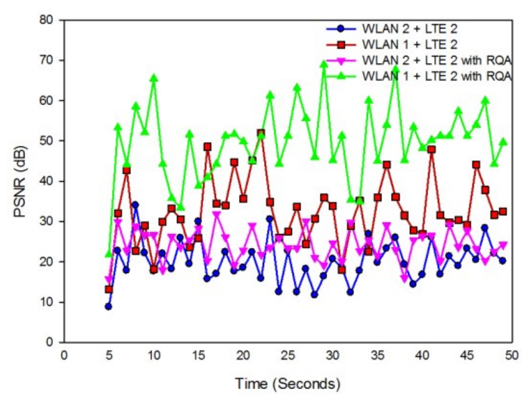

Figure 11 Estimated PSNR of Case 2 and 3 on both Scenario 1 and 2

As shown in Fig.9, the average throughput of case 2 is 5.5% higher when RQA is employed than without RQA. The average throughput of case 3 is also 0.9% higher when RQA is used than otherwise. Fig.10 shows that the average delay of case 2 with RQA is 9.3% lower than without, but at the same time, the average delay of case 3 with RQA is 4.3% higher than without RQA.

In terms of user perceived quality Fig.11 shows how in case 2 PSNR with RQA is 20.4% higher than without RQA and case 3 52.5% higher with RQA than without RQA. Fig.8, shows similar trend for NVQM which is 5.6% higher in case 2 with RQA than when no RQA is employed, and 53.4% higher in case 3 with RQA than without RQA.

VI. CONCLUSIONS AND FUTURE WORKS

This paper proposed NRQ-3D in heterogeneous networks. Simulation-based testing shows how the proposed solution improves the throughput, delay and estimated 3D video quality in different delivery situations.

Currently, the simulations are using constant bit-rate (CBR) as video and depth traffic. Future work will use 3D video trace files such as the ones in [27] in the simulations. The RDO with handover and transmit command also needed to be demonstrated with mobility device handover with different networks. In [18], authors proposed an UEP scheme for 3D video transmission will consider as the comparison scheme. The quality evaluation as described in [28] will be performed.

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REFERENCES

[1] G.-M. Su, Y.-C. Lai, A. Kwasinski, H. Wang, “3D video communications: Challenges and opportunities,” International Journal of Communication Systems, vol. 24, no. 10, Oct. 2011.

[2] ITU-T and ISO/IEC JTC 1, "Advanced video coding for generic audiovisual services," ITU-T Recommendation H.264 and ISO/IEC 14496-10(MPEG-4 AVC), 2010.

[3] LTE-Advanced Rapporteur, “RP-090939: 3GPP Submission Package for IMT-Advanced,” www.3gpp.org, 3GPP TSG RAN, meeting 45, Seville, Spain, September 2009.

[4] IEEE P802.11ac. “Specification framework for TGac”, IEEE 802.11-09/0992r21. January 2011.

[5] Z. Yuan and G.-M. Muntean, "A Prioritized Adaptive Scheme for Multimedia Services over IEEE 802.11 WLANs," IEEE Transactions on Network and Service Management, no.4, vol.10, pp.340 - 355, Dec. 2013.

[6] O. Bonaventure, M. Handley, C. Raiciu. “An Overview of Multipath TCP,” USENIX login, 17–23, Oct. 2012.

[7] K. Muller, P. Merkle, T. Wiegand, “3-D video representation using depth maps,” Proceedings of the IEEE. Proceedings of the IEEE, 99(4), 43 – 656, April. 2011.

[8] T. Bi, R. Trestian, G-M. Muntean, “Reputation-based Network Selection Solution for Improved Video Delivery Quality in Heterogeneous Wireless Network Environments,” IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB 2013), June 2013.

[9] T. Bi, R. Trestian, G-M. Muntean, “RLoad: Reputation-based Load-balancing Network Selection Strategy for Heterogeneous Wireless Environments,” IEEE International Conference on Network Protocols (ICNP 2013) PhD Forum, October 2013.

[10] Emerging Technologies for 3D Video: Creation, Coding, Transmission and Rendering, John Wiley & Sons, March 2013.

[11] A. Vetro, T. Wiegand, G. J. Sullivan, “Overview of the Stereo and Multiview Video Coding Extensions of the H.264/MPEG-4 AVC Standard,” Proceedings of the IEEE, 99(4), 626–642, 2011.

[12] A. Smolic, K. Mueller, “Coding algorithms for 3DTV—a survey. Circuits and Systems for Video Technology,” IEEE Transactions on. 17(11), 1606–1621, 2007.

[13] D. V. Coding, A. Payman, M. Hannuksela, D. Rusanovskyy, M. Gabbouj, “Nonlinear Depth Map Resampling for Depth-Enhanced 3-D Video Coding,” IEEE Signal Process. Lett. 20(1), 87–90, 2013.

[14] A. Hamza, M. Hefeeda, “Energy-efficient multicasting of multiview 3D videos to mobile devices,” ACM Transactions on Multimedia Computing, Communications, and Applications, 8(3s), 1–25, 2012.

[15] G. Gurler, K. Bagci, A. M. Tekalp, “Adaptive Stereoscopic 3D Video Streaming,” Proc. IEEE Int. Conf. Image Processing, Hong Kong, China, Sept. 2010.

[16] A. Kordelas, I. Politis, A. Lykourgiotis, T. Dagiuklas, S. Kotsopoulos, (2013). “An media aware platform for real-time stereoscopic video streaming adaptation,” 2013 IEEE International Conference on Communications Workshops (ICC), 687–691, 2013.

[17] B. Kamolrat, A.C. Fernandoand, M. Mrak, A. Kondoz, "Joint source and channel coding for 3D video with depth image - based rendering,” IEEE Transactions on Consumer Electronics. vol. 54, no. 2, pp. 887-894, May 2008.

[18] K.M. Alajel, X. Wei, "Color plus depth 3-D video transmission with hierarchical 16-QAM," 3DTV-Conference: The True Vision - Capture, Transmission and Display of 3D Video (3DTV-CON), 2012 , vol., no., pp.1,4, 15-17 Oct. 2012.

[19] A. Smolic, K. Muller, K. Dix, P. Merkle, P. Kauff, and T. Wiegand, “Intermediate view interpolation based on multiview video plus depth for advanced 3d video systems,” in Image Processing, 15th IEEE International Conference on, pp. 2448–2451. San Diego, California, USA, October 2008.

[20] C. Fehn, “Depth-image-based rendering (DIBR), compression and transmission for a new approach on 3D-TV,” Proc. of SPIE Stereoscopic Displays and Virtual Reality Systems XI, pp. 93–104, Jan. 2004.

[21] R. Trestian, O. Ormond, G-M. Muntean, “Power-friendly Access Network Selection Strategy for Heterogeneous Wireless Multimedia Networks”, IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB), pp. 1–5, 2010.

[22] Netflix, Internet Connection Speed Recommendations [online]. Available: https://help.netflix.com/en/node/306 access on: 25/04/2014

[23] NS-3 Direct Code Execution [online]. Available: https://www.nsnam.org/overview/projects/direct-code-execution/

[24] Y. Han, Z. Yuan, G-M. Muntean, “An Objective Quality Metric for Stereosecopic 3D Video,” IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB 2014), June 2014.

[25] The Linux kernel MultiPath TCP project [online]. Available: http://multipath-tcp.org/pmwiki.php?n=Main.HomePage

[26] S.-B. Lee, G.-M. Muntean, A. F. Smeaton, “Performance-Aware Replication of Distributed Pre-Recorded IPTV Content,” *IEEE Transactions on Broadcasting,* vol. 55, no. 2, pp.516-526, Jun. 2009.

[27] A. Pulipaka, P. Seeling, M. Reisslein, L. J. Karam. “Traffic and Statistical Multiplexing Characterization of 3D Video Representation Formats,” IEEE Transactions on Broadcasting, 59(2): June 2013.

[28] C.T.E.R. Hewage, S.T. Worrall, S. Dogan, S. Villette, A.M. Kondoz, “Quality evaluation of color plus depth map-based stereoscopic video,” IEEE J. Selected Topics in Signal Process., vol. 3, no. 2, pp.304-318, Apr. 2009.