IEICE Communications Express, Vol.12, No.12, 587–590

ComEX

Special Cluster in Conjunction with IEICE General Conference 2023

LETTER

QoE provisioning system for VoIP and video streaming using software-defined networking and IOTA micropayment

Jiayang Chen [1], **Hideya Masaki** [1], **Kien Nguyen** [1, 2, a)], **and Hiroo Sekiya** [1]

Abstract This paper presents a novel QoE provisioning system with micropayment for Voice of Internet Protocol (VoIP) and video streaming services (QmV^2). QmV^2 leverages Software Defined Networking (SDN) to provide guaranteed QoE and the distributed ledger IOTA technology micropayment. More specifically, QmV^2's SDN controller has an innovative QoE calculation mechanism utilizing Mean Opinion Score (MOS) that considers service flow monitoring parameters, including packet loss rate and delay. Upon a QoE request and receiving the IOTA payment, QmV^2 can provide the requested QoE for the service flow. We have implemented and evaluated QmV^2 using the POX SDN controller, the network emulator Mininet-WiFi with VoIP and video streaming. The results confirm QmV^2 delivers satisfactory user experiences (i.e., aligned with the guaranteed MOS values) for VoIP and video streaming applications with the confirmed IOTA payment.

Keywords: QoE provisioning, SDN, IOTA, MOS, VoIP, video streaming
Classification: SDN

1. Introduction

In recent years, we have seen wireless technologies' advancement and increasing popularity, including Wi-Fi, 5G, etc. Notably, there have been significant improvements in network speed or latency reduction, which will likely satisfy various applications' current and future quality of service (QoS) demands. In such a context, a crucial aspect in evaluating these networks and applications is the individual user experience, especially for the two popular services VoIP and video streaming. While many QoS metrics, including throughput, latency, and packet loss, primarily emphasize technical performance, they can not capture the user experience directly. In contrast, QoE-related metric (e.g., MOS) has been proposed to reflect the individual user experience [1]. On the other hand, the users are expected to have a pay-as-you-go system, where they can only pay for the VoIP or video streaming service/traffic they use. Motivated by those issues, it becomes necessary to construct a guaranteed QoE provisioning system with an efficient payment method.

To achieve such a QoE provisioning system, first, the challenge lies in effectively monitoring and controlling the entire network at a fine granularity level. SDN is a feasible solution since it provides centralized network control and empowers network programmability to monitor and analyze traffic flows. The controlling functions of SDN are normally realized in an SDN controller, which makes decisions for resource allocation to optimize QoE provisioning for the applications' flows. The second challenge is the payment method that can deal with high-frequency, small-value transactions associated with each guaranteed flow. This challenge can be solved using lightweight cryptocurrency that facilitates fast and cost-effective transactions [2].

This paper addressed the mentioned challenges and introduced a novel **Q**oE provisioning system with **m**icropayment for **V**oIP and **V**ideo streaming services (QmV^2) as a solution. QmV^2 inherited the micropayment method for each network flow using the feeless, fast, cryptocurrency IOTA from our previous work [3]. QmV^2 leverages the capabilities of SDN to ensure guaranteed QoE for each flow of VoIP and video streaming services. The SDN controller in QmV^2 introduced novel functions of calculating and updating MOS that considered monitored VoIP and video streaming flow parameters. The controller also has an IOTA client to process the micropayment for a request from a network user. Upon receiving the appropriate QoE request and IOTA payment, QmV^2 can provide the guaranteed QoE for the corresponding service flow while closely monitoring and analyzing to assess the QoE provisioning based on MOS. To validate the effectiveness of QmV^2, we implemented and evaluated the system using the open-source SDN controller POX, the network emulator Mininet-WiFi, and IOTA, along with traffic generators for VoIP and video streaming. Our evaluation results confirmed QmV^2 successfully delivered satisfactory user experiences for VoIP and video streaming flows after a verified IOTA micropayment transaction.

The remainder of this paper is as follows. Section 2 includes related works. Section 3, and Section 4 presents our proposed system and evaluation results, respectively. Finally, Section 5 concludes the paper.

2. Background and related works

SDN has gained significant popularity in recent years due to its capability to manage the entire network and implement programmatic networks centrally. With SDN, it becomes feasible to achieve end-to-end QoS control, such as delay and throughput, through switching flow to appropriate bottleneck queues based on estimation results [4].

[1] Graduate School of Science and Engineering, Chiba University, Japan
[2] Institute for Advanced Academic Research, Chiba University, 1-33 Yayoi-cho, Inage-ku, Chiba-shi, Chiba, 263-8522 Japan
a) nguyen@chiba-u.jp

DOI: 10.23919/comex.2023COL0002
Received June 23, 2023
Accepted July 31, 2023
Publicized November 21, 2023
Copyedited December 1, 2023

Table I Comparison with previous works

Network	QoE Provisioning Type		Payment	Ref.
	VoIP	Video Streaming		
wired	Yes	No	No	[5]
wired	No	Yes	No	[6]
wireless	Yes	Yes	No	[7]
wireless	Yes	Yes	Yes	Our work

IOTA is a unique distributed ledger technology (DLT) introduced in 2016 by the IOTA Foundation. Unlike traditional DLT (i.e., blockchain), in the IOTA network, every participating node maintains a copy of the Tangle, which is a directed acyclic graph of transactions. Moreover, a new IOTA transaction has only required approvals from two previous transactions. Hence, IOTA eliminates the need for a central authority or miners, achieving high-frequency and feeless micropayments.

QoE is a vital parameter for user-oriented applications, particularly VoIP and video streaming. To further enhance individual user experiences, a QoE provisioning system at the fine-grained level (e.g., network flow) is crucial. Accordingly, there has been previous research on QoE provisioning. For instance, [5] proposed a solution to realize QoE provisioning for VoIP in a campus network. In [6], the authors introduced an evaluation system focusing on MOS assessment for video streaming applying SDN; however, they only considered wired networks. To expand the QoE model into wireless, in [7], a QoE evaluation for VoIP and video streaming was presented. However, the work lacks a micropayment method. Our work is unique in terms of aggregating QoE provision and micropayment. A comparison between other works and ours is provided in Table I.

3. QoE provisioning for VoIP and video streaming

3.1 Overview

Figure 1 shows an overview of our proposed QoE provisioning system with micropayment for VoIP and video streaming services (QmV^2). QmV^2 consists of an SDN controller, a cryptocurrency platform, and SDN-capable devices such as routers, switches, base stations and access points. QmV^2 aims to provide network monitoring and QoE provisioning for VoIP and video streaming across user terminals within the SDN-based network. The cryptocurrency platform manages user requests, handing menu offerings, and processing payment transactions.

The QoE provisioning process for a client is as follows. Assuming the client starts using VoIP or video streaming, forming a network flow to a server, which is then allocated a default networking resource. If the client wants better user satisfaction (i.e., QoE level), a QoE request with a specific service period will be issued. After receiving the menu from the network provider, the client makes the micropayment through cryptocurrency. The information exchange process is between the client and an SDN controller. After that, the SDN controller will perform control rules to direct the network flow to a path with sufficient resources, resulting in a higher QoE value for the targeted flow service. We adopt the micropayment method with IOTA from our previous

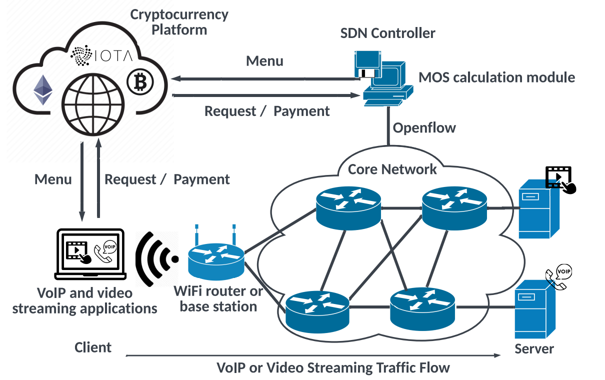

Fig. 1 System overview

work [3], which focuses on QoS provisioning. Different to [3], this work realizes QoE provisioning rather than QoS.

3.2 QoE provisioning

QoE is typically assessed subjectively by multiple human participants to reflect user satisfaction. However, we can evaluate with the Mean Opinion Score (MOS) metric. The MOS values are typically in the range from 1 to 5. To estimate the MOS of a service flow, the SDN controller relies on the ITU-T QoE estimation model [8]. The model incorporates various parameters such as voice and video codecs, packet loss, and delay to estimate the QoE level for VoIP and video streaming. We use the VoIP with codec G.729 to describe the MOS estimation.

VoIP MOS is expressed using the evaluation factor R as follows.

$$MOS = \begin{cases} 1, (R < 0) \\ 1 + 0.035R + \\ R(R-60)(100-R)*7.0*10^{-6}, \\ (0 \le R \le 100) \\ 4.5.(100 < R) \end{cases} \quad (1)$$

From [7], R can be represented via the impairments introduced by the equipment and random packet loss parameters I_{ef} and delays introduced from the end-to-end signal traveling I_d as

$$R = R_0 - (I_d + I_{ef}), \quad (2)$$

where $Ro = 94.2$ is the fundamental transmission rating factor in ideal condition, ignoring the equipment or network impairments, packet loss and delay.

I_d can be calculated with the delay parameter d (ms):

$$I_d = 0.024d + 0.11(d - 177.3)H(d - 177.3), \quad (3)$$

where

$$H(x) = \begin{cases} 0, (x < 0) \\ 1.(x \ge 0) \end{cases} \quad (4)$$

Since the codec G.729a is used, I_{ef} can be calculated using the packet loss rates p as follows:

$$I_{ef} = 11 + 40ln(1 + 10p). \quad (5)$$

As a result, R is expressed using p and d as:

$$R = 83.2 - 0.0024d - 0.11(d - 177.3)H(d - 177.3) - 40ln(1 + 10p). \quad (6)$$

Table II Relationship between MOS and user satisfaction

MOS	User Satisfaction
4.34	Very satisfied
4.03	Satisfied
3.60	Some users dissatisfied
3.10	Many users dissatisfied
2.58	Nearly all users dissatisfied

Video streaming The QoE estimation for video applications can be expressed as follows:

$$MOS = 1 + I_{coding} \cdot I_{transmission}, \tag{7}$$

where I_{coding} is the basic video quality considering coding distortion; $I_{transmission}$ means the video quality affected by the transmission process. I_{coding} is calculated as

$$I_{coding} = I_{Ofr} \cdot exp\left\{\frac{(ln(Fr_v) - ln(Ofr))^2}{2D_{FrV}^2}\right\}, \tag{8}$$

where I_{Ofr} is the maximum video quality at each bit rate; Fr_v is the video frame rate (fps); Ofr, D_{FrV} are the optimal frame rate that maximizes video quality at each bit rate, and the robustness of video quality with frame rate, respectively. $I_{transmission}$ is calculated from the video packet loss rate P_{plv} and the robustness of video quality due to packet loss D_{Pplv} as

$$I_{transmission} = exp\left\{-\frac{P_{plv}}{D_{Pplv}}\right\}. \tag{9}$$

On the other hand, Ofr, I_{Ofr}, D_{FrV}, and D_{Pplv} are expressed using 12 constant coefficients (v_1, v_2, $\ldots v_{12}$) depending on codec types, video formats, keyframe intervals, and video display sizes when the video frame rate, Fr_v and video bit rate, Br_v are known, as follows:

$$Ofr = v_1 + v_2 \cdot Br_v, \tag{10}$$

$$I_{Ofr} = v_3 - \frac{v_3}{1 + \left(\frac{Br_v}{v_4}\right)^{v_5}}, \tag{11}$$

$$D_{FrV} = v_6 + v_7 \cdot Br_v, \tag{12}$$

and

$$D_{Pplv} = v_{10} + v_{11} \cdot exp\left\{\frac{-Fr_v}{v_8}\right\} + v_{12} \cdot exp\left\{\frac{-Br_v}{v_9}\right\}. \tag{13}$$

If the video type is determined, $v_1, v_2, \ldots, v_{12}$, Fr_v and Br_v can be treated as constant coefficients. Consequently, based on (8) and (10) - (12), Ofr, I_{Ofr}, D_{FrV}, and D_{Pplv} can all be computed and considered as constant values, leading to a constant value I_{coding}. Considering (7), the only variable is P_{plv} in $I_{transmission}$, which is closely associated with the packet loss rate. Thus, the MOS of video streaming can be regarded as a function of packet loss rate. Analyzing (7), It is evident that as the packet loss rate increases, the MOS value will invariably decrease, resulting in a worse user experiment. Besides, according to [8], user satisfaction can be reflected by MOS, as shown in Table II.

In QmV^2, we rely on the above MOS calculation to achieve QoE provisioning for VoIP and video streaming. With the centralized view of the SDN controller, we monitor a network flow and update the associated MOS value in a real-time manner. In the implementation, we refer to the OpenNetMon module [9] for monitoring network packet loss deployed in the SDN controller. This module can obtain flow statistics by periodically polling SDN switches with FlowStat messages, one of the OpenFlow messages. The module calculates packet loss by calculating the difference between the number of packets in the switch where the flow first passed. The flow delay is measured using the method described in the [10], by inserting probe packets and measuring the difference in timestamps. With the monitoring values, we write an additional module to compute MOS for VoIP and video streaming. When there is a QoE request for a specific flow (typically, MOS reduces), QmV^2 drives the flow traffic to a reserved path with better capability. Specifically, we use Linux traffic control (tc)'s Hierarchy Token Bucket (HTB) to virtually divide the potential bottleneck link's inputs to have multiple queues (default and guaranteed queues). When MOS reduces and diminishes user satisfaction, the client sends a QoE request. After confirming the micropayment, the system configures the HTB filter settings so that the packets of the target flow are moved from the default queue to the guaranteed one, resulting in a guaranteed MOS value.

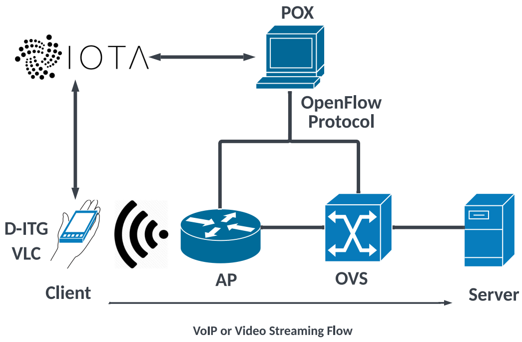

Fig. 2 Evaluation topology

4. Evaluation

The evaluation network topology is illustrated in Fig. 2, in which a client connects to an access point (AP) using IEEE 802.11n. The AP is also connected to an Open vSwitch (OvS) version 2.16.0, which also connects to an application server. We use a POX controller version 0.7.0 to facilitate the interconnection and management of the AP and OvS through TCP port 6633. We selected POX since it has a Python implementation that can be integrated into Python's IOTA client (i.e., PyOTA). The client and the controller connect with IOTA to form the Tangle. We use Distributed Internet Traffic Generator (DITG) to generate VoIP traffic with H.729.2 codec with a transmission packet rate of 200 per second. Moreover, we use a VLC media player (3.0.9.2 Vetinari) to send and receive video streaming. The parameters of streaming video are listed in Table III.

The evaluation scenarios are as follows. Initially, the client starts using its VoIP or video streaming applications, assuming a good QoE. About twenty seconds after the beginning, we simulated a loss event for the link failure

Table III Parameters of streaming video

Frame rate	29.97
Bit Rate (kbps)	2774
Video Codec	H.264
Video Format	1920 x 1080
Video key frame interval	1

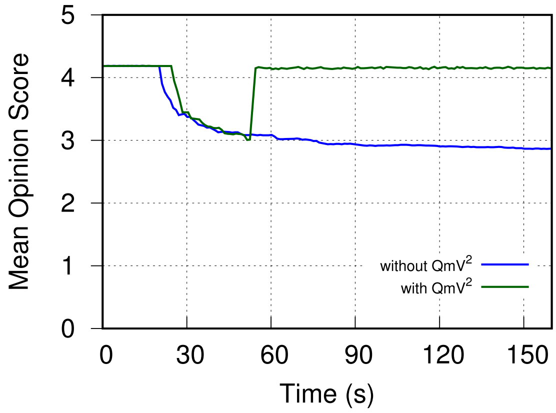

Fig. 3 Guaranteed MOS of VoIP

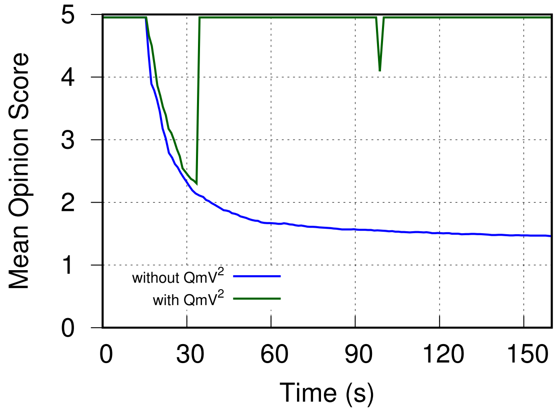

Fig. 4 Guaranteed MOS of video streaming

between the AP and OvS, resulting in a 10% packet loss. Shortly after the packet loss is initiated, the client sends a QoE request to have the service's initial QoE level and continues to use the VoIP or video streaming service. Once the client and POX have completed the micropayment process, POX proceeds with the QoE provisioning. Since the micropayment method is similar to the one in [3], we omit the results of confirmation payments here. The recorded QoE provision data for the VoIP and video streaming flows are presented in Fig. 3 and Fig. 4, respectively. We have also shown the cases without QmV^2 in the figures. As shown, without the guaranteed mechanism, the user experience has degraded (i.e., the deduction of MOS). Meanwhile, with QmV^2, throughout the QoE provisioning period, the flows have been maintained with high MOS values. That is because they are enqueued into a dedicated queue, ensuring a packet loss ratio of 0%. In the case of VoIP, MOS is always higher than 4, similar to the one before the event happened. The MOS values for video streaming are close to 5 but with a drop value. The reasons might be the enqueued speed of video streaming flow or the miscalculation from the SDN controller. These results indicate that QmV^2 can provide guaranteed QoE for VoIP and video streaming flows.

5. Conclusion

In this paper, we proposed the QmV^2 system, which provides guaranteed QoE with IOTA micropayments for VoIP and video streaming. QmV^2 actively monitors various network parameters and converts them into MOS in the SDN controller. When a QoE request is issued, QmV^2 dynamically allocates network resources to ensure the guaranteed QoE. We have implemented and assessed the QmV^2 system using Mininet-WiFi, POX, IOTA, and traffic generators. The evaluation results confirm that QmV^2 effectively provides flow-level QoE for VoIP and video streaming. These findings indicate the system's ability to deliver sufficient resources that meet users' QoE requirements.

Acknowledgments

This work was supported in part by the Japan Society for the Promotion of Science (JSPS) under Grant 20H0417, 23H03377 in part by the Japan Science and Technology Agency (JST) through the establishment of university fellowships towards the creation of science technology innovation, Grant Number JPMJFS2107.

References

[1] J. Wang and W. Cheng, "Heterogeneous quality of experience guarantees over wireless networks," *China Communications*, vol. 15, no. 10, pp. 51–59, Oct. 2018. DOI: 10.1109/cc.2018.8485468

[2] E. Vieira, P.C. Bartolomeu, S.M. Hosseini, and J. Ferreira, "IOTA-pass: Enabling public transport payments with IOTA," Proc. IEEE WF-IoT, pp. 1–6, 2020. DOI: 10.1109/wf-iot48130.2020.9221224

[3] H. Masaki, K. Nguyen, and H. Sekiya, "Fine-grained QoS provisioning with micropayments in wireless networks," *NOLTA*, vol. 14, no. 1, pp. 50–65, 2023. DOI: 10.1587/nolta.14.50

[4] M. Haiyan, Y. Jinyao, P. Georgopoulos, and B. Plattner, "Towards SDN based queuing delay estimation," *China Communications*, vol. 13, no. 3, pp. 27–36, March 2016. DOI: 10.1109/cc.2016.7445500

[5] T. Bakhshi and I. Nadir, "On MOS-enabled differentiated VoIP provisioning in campus software defined networking," Proc. ICET, pp. 1–6, 2019. DOI: 10.1109/icet48972.2019.8994425

[6] M. Wang, Y. Wang, and Y. Liu, "SDN-based QoE evaluation methods for HTTP adaptive video streaming," Proc. IEEE IC-NIDC, pp. 220–224, 2021. DOI: 10.1109/ic-nidc54101.2021.9660473

[7] D. Ciambrone, S. Tennina, D. Tsolkas, and L. Pomante, "A QoE performance evaluation framework for LTE networks," Proc. IEEE WoWMoM, pp. 14–19, 2018. DOI: 10.1109/wowmom.2018.8449757

[8] J.A. Bergstra and C.A. Middelburg, "Itu-t recommendation g. 107: The e-model, a computational model for use in transmission planning," 2003.

[9] N.L.M. van Adrichem, C. Doerr, and F.A. Kuipers, "Opennetmon: Network monitoring in openflow software-defined networks," Proc. IEEE NOMS, pp. 1–8, 2014. DOI: 10.1109/noms.2014.6838228

[10] D.T.T. Hien, T.D. Ngo, D.-D. Le, H. Sekiya, V.-H. Pham, and K. Nguyen, "A software defined networking approach for guaranteeing delay in Wi-Fi networks," Proc. ACM SoICT, pp. 191–196, 2019. DOI: 10.1145/3368926.3369710