# New Cross-Domain QoE Guarantee Method Based on Isomorphism Flow

Zaijian Wang[1(✉)], Chen Chen[1], Xinheng Wang[2], Lingyun Yang[1], and Pingping Tang[1]

[1] Anhui Normal University, Wuhu, Anhui, China
wzj0553@foxmail.com, Alice-Cr@ahnu.edu.cn, {lingyun716,pphysicstpping}@126.com
[2] University of West London, London W5 5RF, UK
Xinheng.Wang@uwl.ac.uk

**Abstract.** This paper investigates the issue of Quality of Experience (QoE) for multimedia services over heterogeneous networks. A new concept of "Isomorphism Flow" (iFlow) was introduced for analyzing multimedia traffics, which is inspired by the abstract algebra based on experimental research. By using iFlow, the multimedia traffics with similar QoE requirements for different users are aggregated. A QoE evaluation method was also proposed for the aggregated traffics. Then a new cross-domain QoE guarantee method based on the iFlow QoE is proposed in this paper to adjust the network resource from the perspective of user perception. The proposed scheme is validated through simulations. Simulation results show that the proposed scheme achieves an enhancement in QoE performance and outperforms the existing schemes.

**Keywords:** Diffserv networks · Quality of experience · Multimedia traffic

## 1 Introduction

With the increasing demands of high quality personalized services and large number of smart devices such as smartphones and smart TVs being used for Internet of Things (IoT), a large volume of multimedia data is delivered over the heterogeneous networks, such as WiFi networks, Differentiated Services (DiffServe) networks, Long Term Evolution (LTE) networks and Bluetooth networks [1–4]. Each user/device within these heterogeneous networks requires very different Quality of Experience (QoE), and the services could be delivered through the routes with different features to meet their QoE requirements with the lowest costs [6]. However, bandwidth constraints and the resulted delay and packet loss may have an adverse impact on the delivered multimedia quality [1]. To guarantee the QoE of multimedia traffic still remains a challenge for multimedia communications.

Existing research efforts on QoE are focusing on three aspects: (1) development of QoE-driven frameworks for multimedia applications [1, 5, 6]; (2) QoE evaluation [7–9]; and (3) the influence of QoE features on the user's QoE level [10–13]. However, little work is done for cross-domain QoE guarantee, and very little efforts are made on differentiated traffics from QoE perspective. At the same time, the existing QoE


H. Gao et al. (Eds.): CollaborateCom 2018, LNICST 268, pp. 432–447, 2019.
https://doi.org/10.1007/978-3-030-12981-1_30

evaluation methods still need to be improved to effectively provide cross-domain QoE guarantee. The reason is the user' preferences are missed in evaluating the QoE.

Figure 1 demonstrates a typical application scenario of multimedia communications via a heterogeneous network, where multimedia traffics will tranverse three typical networks (WiFi, DiffServe, and LTE). Among these three networks, each network will provide its own service guarantee mechanisms to guarantee the quality of services. For example, the WiFi network prioritizes the multimedia traffic by adopting four Access Categories (AC): voice (AC_VO), video (AC_VI), best effort (AC_BE), and background (AC_BK). The DiffServ network, on the other hand, guarantees the quality of traffics by processing different traffic classes according to their DiffServ Code Point (DSCP) values. The LTE network, however, guarantees the quality of traffics based on traffic differentiation and prioritization of data flows. In this case, the users are exposed to a complex and diverse heterogeneous network environment. When these three networks cannot effectively interconnect with each other, the user's QoE cannot be guaranteed. The effectiveness of the network is greatly weakened.

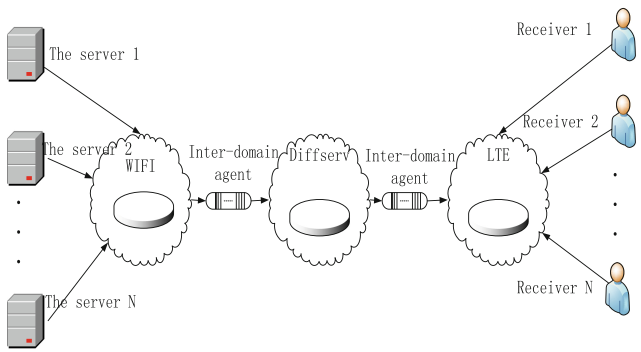


**Fig. 1.** A typical scenario of multimedia communication

As mentioned above, the recent developments on QoE can't solve the problem to provide cross-domain QoE guarantee for multimedia traffics over heterogeneous networks. In order to tackle this problem, a new cross-domain QoE guarantee method is proposed in this paper, in which users obtain their personalized services by differentiating multimedia traffics at a fine-grained QoE level. To differentiate appropriately multimedia traffics from QoE perspective, a new concept of "Isomorphism Flow (iFlow)" is introduced in this paper after analyzing four types of QoE features of multimedia traffics from real world applications. Based on the QoE features, the multimedia traffics with similar QoE requirements are aggregated into a same iFlow category. Meanwhile, an improved QoE evaluation method is proposed, which considers user's preference. To the best of our knowledge, this is the first work on exploiting QoE related features to provide cross-domain QoE guarantee for multimedia traffics over heterogeneous networks.

The key contributions of this paper are as follows:

(1) A new concept: this paper, for the first time, introduces a new concept of iFlow based on the QoE features, by which the multimedia traffics are appropriately classified to provide differentiated services for users from the perspective of user perception.
(2) A new model: according to our experiment, a typical QoE evaluation model was improved to make its evaluation results closer to the real value.
(3) A new method: we propose a new cross-domain QoE guarantee method based on iFlow and improved QoE evaluation method, in which the network resource is allocated according to user's QoE requirements.

The rest of this paper is organized as follow. The related work is described in Sect. 2. Section 3 introduces typical QoE features and iFlow concept. Section 4 describes a new cross-domain QoE guarantee method based on iFlow. In Sect. 5, the simulation results are presented. Finally, Sect. 6 concludes this paper and also provides suggestions for future work.

## 2 Related Work

QoE includes two main aspects [14]: Quality of Service (QoS) and human perception. QoS mechanism is mainly responsible for the business management from the viewpoint of network and is to provide business diversity. Human perception is subjective in nature and is internal to the user, thus not directly observable to the experimenter, which generally exhibits the effects of hysteresis and recency.

The main features of QoE depend on the user's emotion, hobbies, etc. The aim of our future multimedia network communications is to meet the personalized user satisfaction with the needs and expectations.

As mentioned before, QoE guarantee frameworks and QoE evaluations are the most important aspects of QoE research. In this section, the state-of-the-art research work in these two areas is described.

### 2.1 QoE Guarantee Method

For multimedia communications in IoT, authors in [1] introduce a new concept of Quality of Things (QoT), and propose a new quality aware IoT architecture based on QoT for multimedia applications to ensure the quality of multimedia content to be collected, processed and delivered appropriately in such applications. authors in [5] propose a QoE-driven framework named Smart Media Pricing (SMP) to price the QoE for IoT multimedia services, which is translated to a game theoretical QoE maximization problem. Authors in [6] propose a novel vehicle network architecture for the smart city scenario, in which a joint resource management scheme is proposed to mitigate the network congestion with the joint optimization of caching, networking and computing resources.

Based on the centrality of nodes, authors in [7] propose a suboptimal dynamic method that is suitable for the IoT with frequent content delivery, and a green resource allocation algorithm based on Deep Reinforcement Learning (DRL) to improve the accuracy of QoE in an adaptive manner. The model proposed in [7] can capture the network cost and the influencing factors of IoT user services according to the conditions of the IoT, and pay attention to the issues of cache allocation and transmission rate. Under this content-centric IoT, the goal is to allocate cache capacity between content-centric computing nodes and process transmission rates within the total network cost and Mean Opinion Score (MOS) limits for the entire IoT. A 5G QoE system capable of extracting video metadata and stream QoS metrics is proposed in [8]. Authors in [9] present an IoT-based architecture for multi-sensorial media delivery to TV users in a home entertainment scenario. In [10] a computational offloading scheme is formulated to model the competition among IoT users and allocate the limited processing power of fog nodes efficiently. Each user aims to maximize its own QoE, which reflects its satisfaction of using computing services in terms of the reduction in computation energy and delay. Through numerical studies, it evaluates the users' QoE as well as the equilibrium efficiency. It reveals that by utilizing the proposed mechanism, more users benefit from computing services in comparison with an existing offloading mechanism. It further shows that the proposed mechanism significantly reduces the computation delay and enables low-latency fog computing services for delay-sensitive IoT applications.

These papers all indicate that there are some unreasonable or waste of resources in the process of network resource scheduling. We need to propose new schemes to make the network more optimized and the QoE higher.

### 2.2 QoE Evaluation Method

According to different classification standards, the QoE evaluation methods can be classified into three different categories, according to a comprehensive survey [15], including:

(1) subjective evaluation method: QoE is obtained from subjective test, where human viewers evaluate the quality of tested traffics under a controlled environment;
(2) objective evaluation method: objective quality models are developed to predict QoE based on objective QoS parameters; and
(3) data-driven QoE analysis method: this method adopts measurable QoE metrics, e.g., viewing time, probability of turns, etc.

Subjective evaluation method refers to the evaluation given in a specific and controlled environment according to people's feeling, and a Mean Opinion Score (MOS) of multiple testers is finally obtained as the benchmark for the quality of each sequence. At present, ITU-T has launched a corresponding subjective quality assessment standard for different video services [16]. Typical subjective evaluation methods include Double Stimulus Continuous Quality Scale (DSCQS), Double Stimulus Impairment Scale (DSIS) and Single Stimulus Continuous Quality Scale (SSCQE) [17]. Objective evaluation method is mainly to establish the mapping relation between the objective QoS parameters and user QoE by using the relevant information of multimedia, so as to make the result as close as possible to the subjective. In addition, objective evaluation methods based on input parameter types can be divided into: parameter planning model, packet layer model, bitstream layer model, mixed layer model, and media layer model [18]. These models are applicable to different situations. Data-driven QoE analysis method carries out large-scale measurement studies in various services.

A QoE predictive assessment scheme that can be applied to real-world network environments with real-time processing requirements is proposed in [8]. A model of user's QoE is given in [9]:

$$QoE_Q = \alpha e^{-\beta QoS} + \gamma \tag{1}$$

where $\alpha$, $\beta$ and $\gamma$ are the parameters constraining the quantization of QoE, $QoS$ represents the QoS a user can obtain. It mainly evaluates the user's QoE based on various network parameters.

Paper [10] studies the influence of odor type on the user's QoE level, and suggests adding olfactory sense to improve the user's QoE. Paper [11] defines the user satisfaction level of video streaming through the function formula, which utilizes emotions to predict the user's QoE and puts forward to customize the personalized content through the viewer's emotional feedback so as to improve the method of video QoE user experience. Paper [12] discusses some environmental factors parameters of user QoE modeling.

In our works, user's preferences and tags are very important in real-time communications. Our focus is not only on all network parameters, but also the user's preferences for either whether to change the user experience or whether the scheme we built based on this can meet the requirements of user evaluation or not. Therefore, users' geographical location, gender, network parameters and preferences will be taken into account in our real-time communication software.

## 3 Typical QoE Features and Isomorphic Flow Concept

To consider QoE features in QoE evaluation and garantee is still at its infancy, and there is still great room for development. The selected QoE features should be a good indicator of user experience or engagement, and easy to track and monitor in real-time [15]. By surveying 50 volunteers, we obtain the distributions of age and gender, shown in Fig. 2. It is obvious that the users' age and gender will affect their preference for traffics. Furthermore, their further preference for different traffics are obtained as shown in Table 1. Meanwhile, we also investigate hobbies and business categories, which affect user's preference for traffics. This paper mainly focuses on four typical QoE features and provides some meaningful results.

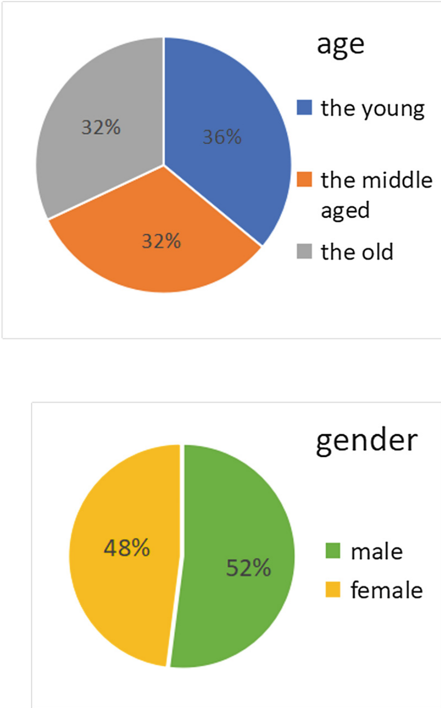


**Fig. 2.** Distribution of age and gender

**Table 1.** The effect of interest on the degree of business preference

| Traffic | Medical (%) | Game | Household | Message |
|---|---|---|---|---|
| Traveling | 36% | 14% | 22% | 30% |
| Reading | 18% | 22% | 36% | 22% |
| Drawing | 22% | 38% | 18% | 20% |
| Music | 24% | 36% | 24% | 28% |

**Typical QoE Features**
The four typical QoE features are as follows.

(1) Gender: the gender difference of users is one of the primary factors to be considered in our personalized service since there are obviously gender difference in physical characteristics and hobbies between male and female in most cases. The percentage of gender preference for four kinds of traffics is shown in Fig. 3.

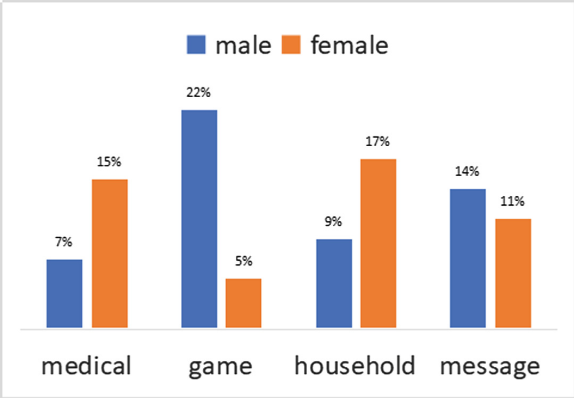


**Fig. 3.** The percentage of gender preference for four kinds of traffics

(2) Age group: as far as users are concerned, human beings love different things at different age. A person will change and develop his/her preferences when growing older, so we also consider them.
(3) Hobbies: users' hobbies largely determine their favorite businesses. They are closely related to users' personalities. If we can assign priority of different businesses according to users' interests before evaluation, the evaluation results will be more accurate. Table 1 shows that different traffic preferences caused by different users' hobbies. It indicates that users with different hobbies have different uses for social software.
(4) Traffic categories: the traffics with similar QoE requirement can be classified into the same category from QoE perspective, which has a globally unique label with corresponding scheduling priority.

After surveying 50 volunteers, it shows that the QoE requirements are not completely stochastic. The users with similar age generally have similar preference on traffic categories. Furthermore, the users with similar age and gender generally have more similar preference on traffic categories. For example, women prefer to use video and text services, while men are more likely to enjoy voice services and pictures.

Figure 4 indicates that the frequency of old users enjoying medical traffics is higher than that of young people, however, the young and middle-aged users prefer online gaming and household traffics than old users.

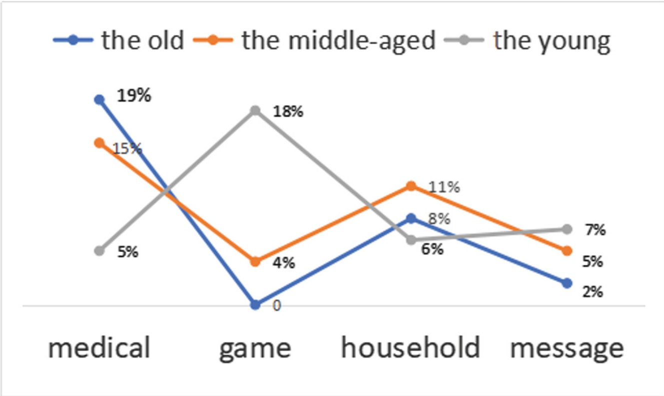


**Fig. 4.** The effect of age on the degree of traffic preference

The results of above observation and analysis inspired us that similar QoE requirements may mean similar geometric spatial structure in higher-dimensional QoE space, which is comprised of QoE metrics. In other words, multimedia traffics may be represented by QoE metrics in higher-dimensional QoE space. The multimedia traffics with similar QoE requirements can be aggregated, and provided with differentiated services by similar network operator to guarantee end-to-end QoE for different users.

**Isomorphic Flow Concept**

According to the concept of graphic isomorphism in abstract algebra, this paper introduces a new concept of "Isomorphism Flow" (iFlow) for evaluating multimedia traffic, which is generated by aggregating the multimedia traffics with similar QoE requirements.

Different from typical traffic/QoS classes or aggregation flow, the iFlow is generated according to QoE metrics. The multimedia traffics belonged to the same traffic/QoS classes may be different iFlow categories. Even if the same multimedia traffic may be divided into different iFlow categories when users with different background have different QoE requirements. For the same user, the same multimedia traffic may be divided into different iFlow categories when the users' preference changes with circumstance. Meanwhile, different multimedia traffics may be divided into the same iFlow category when the users' preferences are identical. It is obviously that multimedia traffic is divided into corresponding iFlow from the perspective of QoE.

To express easily, a higher-dimensional QoE space is comprised of QoE metrics. In QoE space, the multimedia traffics belonged to the same iFlow categories have similar geometric structures. However, for different users, the same traffics may have different geometric structures with different preference. Each of iFlow categories has a sole label. Based on users' QoE, the traffics with the same users' QoE and different users have the same priority and network operations. Therefore, the iFlow can reflect users' preference and help utilize the network resources efficiently by classifying the network multimedia traffics into different iFlow categories according to users' QoE. For example, when user A prefers to gaming and user B is inclined to choose household, if

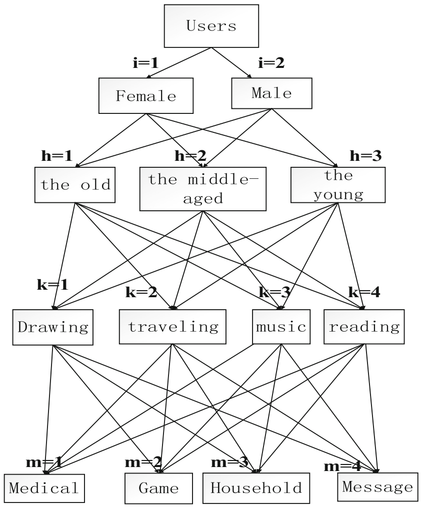


**Fig. 5.** User characteristics and traffic association diagrams

**Table 2.** Definitions of various parameters

| Characteristics | Meaning |
|---|---|
| Gender | i = 1 stands for female, i = 2 stands for male |
| Age | h = 1 stands for the old, h = 2 stands for the middle age, h = 3 stands for the young |
| Hobby | k = 1 stands for drawing, k = 2 stands for traveling, k = 3 stands for music, k = 4 stands for reading |
| Traffic | m = 1 stands for medical, m = 2 stands for game, m = 3 stands for household, m = 4 stands for message |

users A and B have priorities for their traffics, the gaming traffic of user A and the household traffic of user B belong to the same iFlow category. Otherwise, if users A and B have different priorities for their traffics, the gaming traffic of user A and the household traffic of user B belong to the different iFlow category. In this paper, the selected traffics are divided into four categories (from 1 to 4) to easily explain, for which the value is larger and the priority is higher, the iFlow with higher priority will be assigned with a higher label value.

As shown in Fig. 5 and Table 2, users can be divided into two genders, respectively, and each of the genders can be further divided into three categories in different age groups (the old, the middle and the young). Each age category has different hobbies. Through investigating typical Chinese families, we select four typical activities (drawing, traveling, music and reading) for hobbies. Users with different hobbies have different preference for different traffics (medical, game, household and message).

The priority of traffic is different among users with different tags, the equation of traffic priority is given as follows.

$$D_j = [A_h^i, T_k^m] \tag{2}$$

where $D_j$ denotes the $j^{th}$ priority, $A_h^i$ denotes a user with different gender $i$ and age $h$, for which the meaning are shown in Table 2, and $T_k^m$ denotes the traffic with $m$ and $k$. The detailed finding from 50 volunteers is provided in the appendix A, from which the highest priority group $D_1$ is provided as follows.

$$D_1 = \{A_1^1, T_1^2; A_1^1, T_3^1; A_1^1, T_3^4; A_1^1, T_4^3; A_2^1, T_1^2; A_2^1, T_2^1; A_2^1, T_3^4; A_2^1, T_4^3; A_3^1, T_1^2; A_3^1, T_1^3; A_3^1, T_2^3; A_3^1, T_3^1; A_1^2, T_1^3, A_1^2 T_4^1; A_1^2, T_4^2; A_1^2, T_4^4; A_2^2, T_1^2; A_2^2, T_3^4; A_2^2, T_4^1; A_2^2, T_4^3; A_3^2, T_1^2; A_3^2, T_1^3; A_3^2, T_3^1; A_3^2, T_3^4\}$$

From $D_1$, the same traffics have different priorities for different groups of users. For example, $(A_1^1, T_3^1)$ and $(A_3^2, T_3^4)$ belong to the same iFlow with same priority in this proposed method. However, $(A_1^1, T_3^1)$ represents that the older female with music preference like medical of home traffics; $(A_3^2, T_3^4)$ represents that the young men who like music preferred real-time messaging of home traffics.

## 4 A New Cross-Domain QoE Guarantee Method Based on iFlow

As shown in Fig. 6, the whole process of the proposed method can be divided into three modules. In module A, multimedia traffics are transmitted. In module B, the multimedia traffics are classified according to QoE characteristics. According to the users' preference from our survey, the corresponding traffics in the queue should be sorted and prioritized. According to the definition of iFlow, homogeneous flow scheduling process is started by setting roughly 50 users and 4 priorities for 4 types of traffics over heterogeneous networks. Since the users have different preferences, the users are divided into different priorities. The user with higher preference degree has higher priority by providing the queue with higher priority. Then the corresponding mapping is provided according to the order of priority access to the queue in the network.

The module C is the evaluation module, in which an improved model is utilized to calculate the corresponding user's MOS value. The evaluation includes subjective and objective evaluations, in which the MOS value from objective evaluation model is compared with that from subjective evaluation model. After the comparison, the results are used to verify the accuracy of our improved model.

The proposed method comprises of two sections including isomorphic flow scheduling process and QoE evaluation. In isomorphic flow scheduling process sections, the isomorphic flow is introduced. In QoE evaluation section, an improved QoE evaluation process is described. The following figure shows the scenario assessment framework under our architecture.

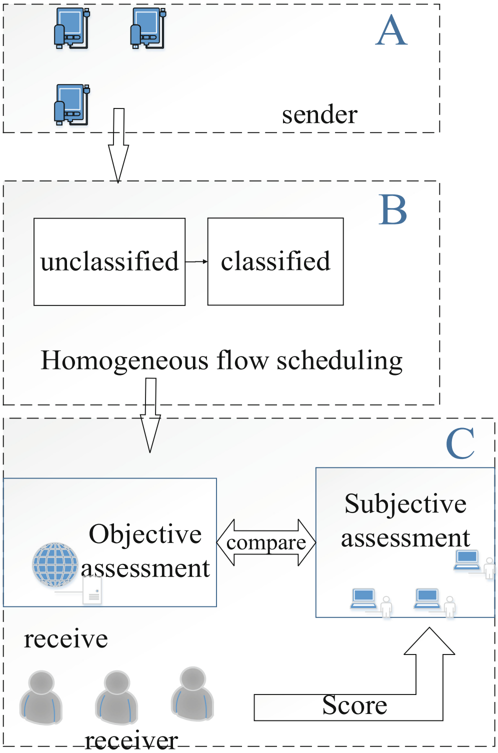


**Fig. 6.** Experience of quality assessment process

**Isomorphic Flow Scheduling Process**

The detailed isomorphic flow scheduling process is provided in this section. As shown in Fig. 7, within each network of heterogeneous networks there have different QoS/traffic classifications for different multimedia traffics. $D_i(i = 1, 2, \cdots, n)$ represents the priority of the corresponding queue $i$. When the traffics with different priorities are scheduled into different queues in heterogeneous networks, the queue with higher priority has higher probability to be transmitted. The traffics belonging to the same iFlow category are scheduled into the same queue as shown in Fig. 7.

**QoE Evaluation**

A typical QoE evaluation model [9] shown in Eq. (1) considers the influences of various network parameters, however, neglects user's preferences so that users' perception can't be reflected. Therefore, this paper tries to improve this model by introducing preference impact factor to increase the weight of user's interest and enhance the precision of this typical model. $M'$ is selected as the range of preference influencing factors (0, 1), for which the smaller the value is, the more consistent with the use of traffic of the user's interest is.

This paper assigns different weights and normalized the QoS parameters (resolution, delay and packet loss rate). $Q$ represents the normalized network influence parameter, which is the x-coordinate of the model proposed as follows.

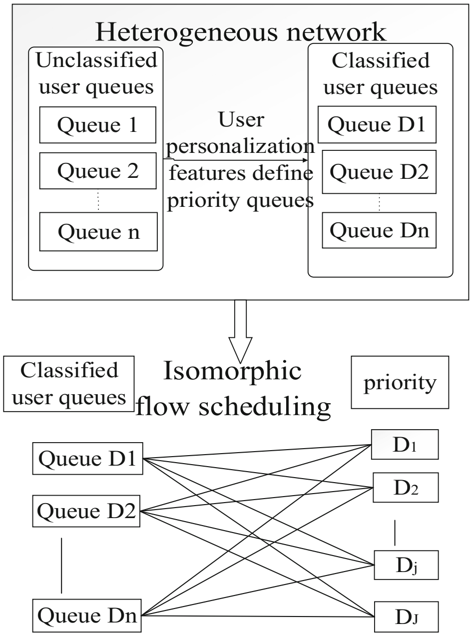


**Fig. 7.** The effect of age on the degree of business preference

$$Q = \text{resolution} * C1 + \text{delay} * C2 + \text{loss rate} * \text{C3} \quad (\text{Q} = 0 \sim 1) \tag{3}$$

where C1 $\approx -0.00017$, C2 $\approx 0.01220$. C3 $\approx -0.0000001$.

The improved model is as follows:

$$QoE = a - M\text{QoE}_{QoS} \tag{4}$$

where $\text{QoE}_S$ denotes the QoE value from Eq. (1), $M = M^{'} + b$, where $b$ is the corrected parameter. This paper classifies the preferences of the volunteers and identified four preference factors $M'$, which are defined as M′ = 0.1, 0.3, 0.6 and 0.9. In order to show it more visually, $M$ is calculated by adding an influence factor and a parameter $b$.

## 5 Experiments

In order to demonstrate the effectiveness of the proposed method, the proposed method is compared with existing schemes in bandwidth utilization performance. Meanwhile the improved QoE evaluation model is analyzed by whether to consider the preference influencing factors or not.

$B$ represents the bandwidth utilization as follows.

**Table 3.** The values of different coefficient

| β | α | γ | a | b | M |
|---|---|---|---|---|---|
| −2.02 | −0.32 | 0.6 | 8.65 | 8.42 | M′ + 8.42 |

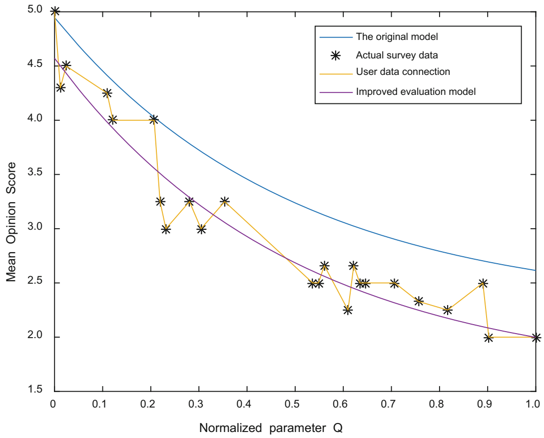


**Fig. 8.** The comparison between the original model and the present model and our research results

$$B = Y1/Y2 * 100\% \tag{5}$$

where $Y1$ is the bandwidth loss of the user and $Y2$ is the total bandwidth of the user. In this paper, the bandwidth utilization is used to calculate the improvement of this proposed scheme compared with the traditional ones.

In the simulation environment, 50 volunteers are selected. According to their preferences, the multimedia traffics are divided into medical, gaming, household, and massage.

According to Eq. (4), the values of different coefficient are obtained as shown in Table 3. The value range of $M^{'}$ is at [0, 1].

To verify the effectiveness of the improved QoE evaluation method, the proposed QoE model is evaluated when $M^{'} = 0$ and $M^{'} = 1$, respectively. $M^{'} = 0$ means that the preference influencing factor isn't considered; $M^{'} = 1$ means that the preference influencing factor is considered. The definition of x coordinate parameter Q is given in formula (3). The results of comparison are shown in Fig. 8. Based on Eq. (4), Table 3 and subjective evaluation, the QoE level can be obtained as follows:

$$\begin{cases} QoE = 2.688\mathrm{e}^{-2.02QoS} + 6.3916 & M^{'} = 0 \\ QoE = 2.9664\mathrm{e}^{-2.02QoS} + 1.60478 & M^{'} = 1 \end{cases} \tag{6}$$

After normalizing the network parameters, this paper compares the results of evaluation among three models. To facilitate observation, the average MOS value is utilized in x-coordinate. As shown in Fig. 8, it is observed that the results of subjective evaluation are closer to the improved model than that of typical model. The simulation results indicate that the MOS value of typical model is higher than that of subjective evaluation since the typical model neglects users' preferences.

When $M'$ selects 0.1, 0.3, 0.6 and 0.9, respectively, Eq. (7) is obtained according to Eq. (4) as follows.

$$\begin{cases} QoE = 2.71872e^{-2.02QoS} + 2.19304 & M' = 0.1 \\ QoE = 2.77376e^{-2.02QoS} + 2.06232 & M' = 0.3 \\ QoE = 2.85632e^{-2.02QoS} + 1.86624 & M' = 0.6 \\ QoE = 2.93888e^{-2.02QoS} + 1.67016 & M' = 0.9 \end{cases} \tag{7}$$

The computing result of Eq. (7) is shown in Fig. 9. It indicates that those different traffics have different influence degrees for the same user. The user has higher preference to medical traffic, the MOS value is higher.

To verify the effectiveness of the new cross-domain QoE guarantee method, the proposed QoE guarantee method is compared with Aggregate flow method and mapping table [19] in bandwidth utilization performance. Based on iFlow, the simulation is carried out and the results are shown in Fig. 10. Figure 10 indicates that the broadband utilization ratio of the new cross-domain QoE guarantee method is significantly higher than that of the other method.

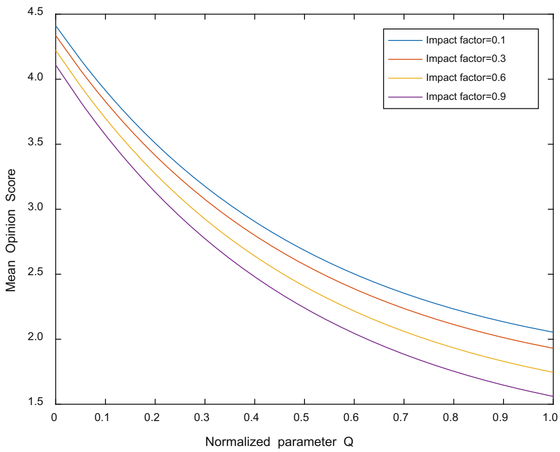


**Fig. 9.** Shows the curves obtained by the four preference factors of the present model

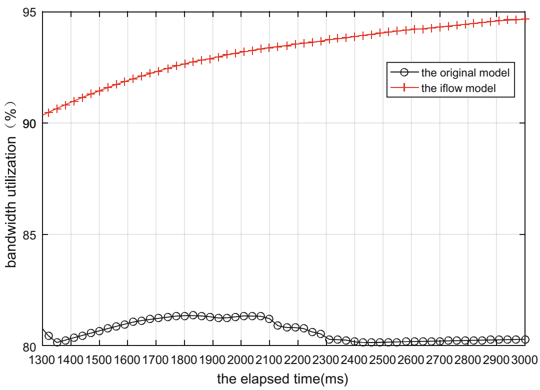


**Fig. 10.** Bandwidth utilization comparison chart

## 6 Conclusions

In this paper, a new cross-domain QoE guarantee method based on iFlow is presented to provide user with good perception and acquire high utilization ratio of network resources for multimedia traffic in IoT. After investigating the behavior of multimedia traffic and analyzing typical QoE features of multimedia traffics, a new concept of Isomorphism for multimedia traffic, iFlow, is introduced. iFlow is generated by aggregating different traffics with similar QoE requirements. Furthermore, an improved QoE evaluation method is proposed, in which the user's interests have the very high weight. The simulation studies are given to demonstrate the effectiveness of the proposed method.

**Acknowledgment.** This work was supported in part by National Natural Science Foundation of China (No. 61401004).

## References

1. Karaadi, A., Sun, L., Mkwawa, I.-H.: Multimedia communications in Internet of Things QoT or QoE. In: 2017 IEEE International Conference on Internet of Things (iThings) and IEEE Green Computing and Communications (GreenCom) and IEEE Cyber, Physical and Social Computing (CPSCom) and IEEE Smart Data (SmartData), pp. 23–29 (2017)
2. Wang, Z., Dong, Y., Mao, S., Wang, X.: Internet multimedia traffic classification from QoS perspective using semi-supervised dictionary learning models. IEEE/CIC China Commun. **14**(10), 202–218 (2017)
3. Wang, Z., Mao, S., Yang, L., Tang, P.: A survey of multimedia big data. IEEE/CIC China Commun. **15**(1), 155–176 (2018)
4. Naserian, E., Wang, X., Dahal, K., Wang, Z., Wang, Z.: Personalized location prediction for group travellers from spatial-temporal trajectories. Future Gener. Comput. Syst. **24**(1), 1–15 (2018)
5. Wang, W., Wang, Q.: Price the QoE, not the data: SMP-economic resource allocation in wireless multimedia Internet of Things. IEEE Commun. Mag. **56**(9), 74–79 (2018)

6. Li, M., Si, P., Zhang, Y.: Delay-tolerant data traffic to software-defined vehicular networks with mobile edge computing in smart city. IEEE Trans. Veh. Technol. (Early Access) **67**, 1–14 (2018)
7. He, X., Wang, K., Huang, H., Miyazaki, T., Wang, Y., Guo, S.: Green resource allocation based on deep reinforcement learning in content-centric IoT. IEEE Trans. Emerg. Top. Comput. (Early Access), 1 (2018)
8. Nightingale, J., Salva-Garcia, P., Calero, J.M.A., Wang, Q.: 5G-QoE: QoE modeling for ultra-HD video streaming in 5G networks. IEEE Trans. Broadcast. **64**(2), 621–634 (2018)
9. Charonyktakis, P., Plakia, M., Tsamardinos, I., Papadopouli, M.: On user-centric modular QoE prediction for VoIP based on machine-learning algorithms. IEEE Trans. Mob. Comput. **15**(6), 1443–1456 (2016)
10. Murray, N., Lee, B., Qiao, Y., Miro-Muntean, G.: The impact of scent type on olfaction-enhanced multimedia quality of experience. IEEE Trans. Syst. Man Cybern.: Syst. **47**(9), 2503–2515 (2017)
11. Tao, X., Dong, L., Li, Y., Zhou, J., Ge, N., Jianhua, L.: Real-time personalized content catering via viewer sentiment feedback: a QoE perspective. IEEE Netw. **29**(6), 14–19 (2015)
12. Scott, M.J., Guntuku, S.C., Lin, W., Ghinea, G.: Do personality and culture influence perceived video quality and enjoyment. IEEE Trans. Multimed. **18**(9), 1796–1807 (2016)
13. Mitra, K., Zaslavsky, A., Åhlund, C.: Context-aware QoE modelling, measurement, and prediction in mobile computing systems. IEEE Trans. Mob. Comput. **14**(5), 920–936 (2015)
14. Chen, B.-W., Ji, W., Jiang, F., Rho, S.: QoE-enabled big video streaming for large-scale heterogeneous clients and networks in smart cities. IEEE Access **4**(1), 97–107 (2016)
15. Chen, Y., Kaishun, W., Zhang, Q.: From QoS to QoE: a tutorial on video quality assessment. IEEE Commun. Surv. Tutor. **7**(2), 1126–1165 (2015)
16. ITU-T Recommendation P.913. Methods for the subjective assessment of video quality, audio quality and audiovisual quality of Internet video and distribution quality television in any environment (2014)
17. ITU-R Recommendation BT.500-11. Methodology for the subjective assessment of the quality of television pictures (2002)
18. Takahashi, A., Hands, D., Barriac, V.: Standardization activities in the ITU for a QoE assessment of IPYV. IEEE Commun. Mag. **46**(2), 78–84 (2008)
19. Wang, Z.J., Dong, Y.N., Wang, X.: A dynamic service class mapping scheme for different QoS domains using flow aggregation. IEEE Syst. J. **9**(4), 1299–1310 (2015)