Resource Allocation Method Based on QoE for Multiple User Types

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***Abstract*—Both of Quality of Service (QoS) and Quality of Experience (QoE) are defined to specify the degree of service quality. In some sense, QoE includes subjective evaluation from the users as an extension of QoS. Therefore, feedback from QoE to QoS control might realize user-oriented resource allocation in network services. Utility functions are sometimes used to assign a bridging role between QoS and QoE. Although the user characteristic has variety, a single utility function was used in previous studies in most cases. Moreover, the QoS control, i.e., the resource allocation, by making use of the utility functions are hardly studied yet. In this paper, multiple user types which have respective utility functions are considered. Respective utility functions are acquired from real experiments. Then a resource allocation method is proposed to reflect each user type satisfaction based on the utility functions. The simple case is studied and the resource allocation method is derived analytically.**

***Keywords*—Quality of Experience, Quality of Service, utility function, resource allocation, user type.**

I. INTRODUCTION

Network infrastructure is a requisite for our business and ordinary life and it provides us Web service, video streaming, Social Network Service (SNS), video meeting, and so on. Available network throughput is increasing owing to the progress of technologies, while user demand for network capability is also growing year in and year out. Therefore, adequate network resource allocation is one of the problems that network operators consider [1], where maximization of the user satisfaction with minimum cost is a goal.

In order to attain this goal, a quality of experience (QoE) based approach is regarded as a promising way to introduce the user satisfaction [2]-[4]. Compared with quality of service (QoS), QoE includes more subjective factor and presents more comprehensive evaluation. In other words, concept of QoE is suitable to reflect the degree of user satisfaction, since it is defined as “the overall acceptability of an application or service, as perceived subjectively by the end-user” in [5]. A popular way to obtain QoE evaluation is a subjective experiment such as the mean opinion score (MOS).

Several studies use utility functions in order to implement QoE factors [2]-[4],[6],[7]. The term “utility” is initially defined as the total satisfaction received from consuming a good or service in economics. Its concept can be extended to the network service and it is used to allocate resources in connection with economic approaches from the viewpoint of the users. Schroeder *et al.* [4] used the game theory, where they proposed an auction algorithm to determine the resource allocation. Ogino *et al.* [6] defined user terminal utility functions and allocated terminal resources by negotiation regarding QoS. These previous studies, however, assume the same utility function for all of the users and the application case of this assumption is considered to be rare.

Reference [3] categorized the users into three types and proposed the utility function that estimates the user satisfaction for different applications. Simulations were carried out to compute the user satisfaction. Application of the utility function to the resource allocation problem is still an open issue. Yamazaki *et al.* [8] also presented categorization of the users into four groups. The categorization seems to be realistic and credible because it is based on the real experimental data. The QoS control, i.e., the resource allocation, by the utilization of QoE factors remains as a future study.

In this paper, it is assumed that there are multiple user types, which have respective utility functions for a particular service. QoE evaluation differs from each other for different utility functions. A novel resource allocation method is proposed to reflect each user type satisfaction based on the utility functions. The simple case is studied and the resource allocation method is derived analytically.

The rest of this paper is organized as follows. Section II introduces the notation used in this paper and the problem setting. In Section III, the utility function is defined as the function mapping QoS parameters to the degree of user satisfaction and concrete utility functions are presented. In Section IV, two types of users are considered as a simple case and analyzed solutions are derived for such a case study. Section V presents computation results in order to evaluate the analyzed solutions and Section VI concludes this paper.

II. NOTATION AND PROBLEM STATEMENT

The symbols and variables used hereafter are explained in this section.

The situation considered in this paper is that the users are at the same task requiring the same traffic on a network segment. The number of all users is N_{ALL} and the users can be categorized into N_{TYPE} ($1 \leq N_{TYPE} \leq N_{ALL}$) user types. N_n ($n = 1, 2, \ldots N_{TYPE}$) is the number of users who belong

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to the user type n. N_{ALL}, N_{TYPE} and N_n are integers.

$$N_{ALL} = \sum_{n=1}^{N_{TYPE}} N_n. \quad (1)$$

The ratio of the user number in the user type n to the number of all users is defined as R_n.

$$R_n = N_n/N_{ALL} \quad \text{for} \quad n = 1, 2, \ldots N_{TYPE}. \quad (2)$$

The utility function is specified for each user type. The utility function is the function that maps a QoS parameter or QoS parameters to the degree of user satisfaction. For the task, each user downloads a file of size S_{DATA} (bits) and the users have to utilize the same network link of bandwidth B_{ALL}, which is the bottleneck of communication in the problem. Hereinafter, the network bandwidth is considered as the QoS parameter and it is related with the waiting time of data download that affects QoE evaluation. B_n is introduced to denote the bandwidth allocated to one user in the user type n. Hence, the waiting time of data download for a user in the user type n is defined as T_n,

$$T_n = S_{DATA}/B_n \quad \text{for} \quad n = 1, 2, \ldots N_{TYPE}. \quad (3)$$

It is also assumed that there is a bandwidth allocation function in the network segment using, for instance, the software defined networking (SDN) technology such as OpenFlow [9]. Namely the network can assign a necessary network capacity for each user. The problem is how to determine the network resource allocation B_n using the utility functions related with user QoE evaluation.

III. Utility Functions

As above-mentioned, the utility function is considered to be the function mapping a QoS parameter or QoS parameters to the degree of user satisfaction. In general, the utility functions are difficult to obtain.

Regarding the problem concerned, the bandwidth allocation B_n influences the user satisfaction. The smaller B_n , the longer the download waiting time becomes. Since human beings are sensitive to time [10], the user satisfaction might be ruled by the waiting time. Therefore, the experiments to measure the user QoE are executed to get the utility functions under the controlled delay time.

The outline of the experiments is as follows. The experimental respondents are asked to solve simple four arithmetic operations (hereafter, they are called questions) on PC. A Web application presents the questions in sequence. After the respondent solves one question, random time delay ranging between 0 and 12 seconds is set before the next question is presented. The time delay is set as integer.

The respondents are classified into two groups. One group is instructed to solve the questions as fast and correctly as possible. It is assumed that the respondents are in busy or emergent situation, so this group is called the busy user group.

A movie playing window is provided for the other group on each PC. They are instructed to be relaxed and permitted to watch the movie during the resolution of the questions. It is assumed that the respondents in this group are in relaxed situation, so this group is called the relaxed user group.

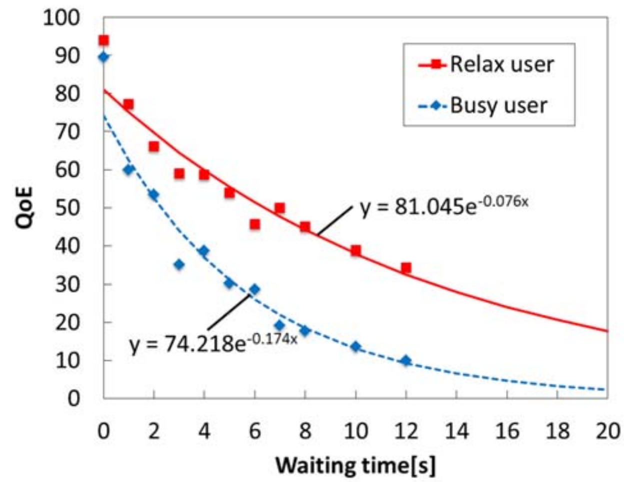

Fig. 1. The utility functions obtained by the user QoE measurement experiments.

After the calculation, the respondents are requested to answer the question “how long did you feel the transition period from one question to the next question?”. The answer is recorded by means of the visual analog scale (VAS) method which uses a continuous scale in conformity with ITU-R Recommendation. BT.500-11 [11]. In the VAS method, there are five equidistant ranks of degrees on the definite length of line on the inquiry score sheet. The respondent answers his/her evaluation by marking a point on the line and the evaluation measurement of length is converted to normalized scores in the range 0 to 100. The number of respondents whose ages ranged from 18 to 23 was 31 (4 women and 27 men).

Fig. 1 is the utility functions that shows relations between the loaded time delay (waiting time) and the average values of VAS (QoE) for the busy user and relaxed user groups. From Fig. 1, different tendency is observed between two groups apparently.

Khan and Toseef proposed more generic user utility functions for real-time and non-real-time applications with respect to both technical and non-technical attributes [3]. Their utility functions were computed based on simulations. On the contrary, the more realistic utility functions are obtained through the experiments in this paper. Analysis of the utility functions in [3] and this paper is futher study.

IV. Case Study: Two User Type Analysis

In order to deduce a bandwidth allocation method, a simple case of two user types is considered. The bandwidth allocation method utilizes the utility functions to attain adaptive resource allocation. Simplification of the problem statement is just to limit the user types as two, that is all users are categorized into N_1 or N_2. To make it clearly understandable, two user types are assumed to be the busy user and relaxed user types. Thus N_1 and N_2 are denoted as N_B (the busy type) and N_R (the relax type) respectively. All of the notation in Section II are the same otherwise expressing B as the busy type and R

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as the relax type. Moreover, the utility functions in Section III can be applied for the busy and relax types.

The utility functions in Fig. 1 are expressed as follows,

$$U_B(t) = C_B e^{-Q_B t}, \quad (4)$$

$$U_R(t) = C_R e^{-Q_R t}, \quad (5)$$

where C_B, Q_B, C_R and Q_R are the constant values shown in Fig. 1. Using (3) that is the relationship between the waiting time and the allocated bandwidth, (4) and (5) is transformed as follows,

$$U_B(B_B) = C_B e^{-Q_B \frac{S_{DATA}}{B_B}}, \quad (6)$$

$$U_R(B_R) = C_R e^{-Q_R \frac{S_{DATA}}{B_R}}. \quad (7)$$

Then the average utility of all users is described as $\overline{U_{ALL}}$.

$$\overline{U_{ALL}} = U_B(B_B)R_B + U_R(B_R)R_R, \quad (8)$$

where R_B and R_R are the ratios of the busy and relaxed user numbers to the number of all users respectively.

A parameter k is introduced to control balance of the utility values of two user types.

$$U_R(B_R) = k \times U_B(B_B). \quad (9)$$

When $k = 1$, both the busy and relaxed users experience the same degree of satisfaction. If k is set as 0.8, it means the relaxed users receive 20% less degree of satisfaction than the busy users.

From (5) and (9), the followings are derived.

$$kC_B e^{-Q_B \frac{S_{DATA}}{B_B}} = C_R e^{-Q_R \frac{S_{DATA}}{B_R}}. \quad (10)$$

Finally,

$$\frac{Q_B}{B_B} - \frac{Q_R}{B_R} = \frac{1}{S_{DATA}} \ln(k\frac{C_B}{C_R}). \quad (11)$$

On the other hand, summation of the bandwidth shared by each user becomes the total bandwidth.

$$B_B \cdot N_B + B_R \cdot N_R = B_{ALL}. \quad (12)$$

From (11) and (12), B_B is deduced by eliminating B_R,

$$\frac{Q_B}{B_B} - \frac{N_R \cdot Q_R}{B_{ALL} - B_B \cdot N_B} = \frac{1}{S_{DATA}} \ln(k\frac{C_B}{C_R}). \quad (13)$$

The right side of (13) can be regarded a constant value and it is replaced as C',

$$C' = \frac{1}{S_{DATA}} \ln(k\frac{C_B}{C_R}). \quad (14)$$

Using (14), (13) is regarded as a quadratic equation of B_B. Then the following equation is derived for B_B,

$$B_B = \frac{V(N_B) \pm \sqrt{V(N_B)^2 - 4C'N_B Q_B B_{ALL}}}{2C'N_B} \quad (N_B \neq 0), \quad (15)$$

where

$$V(N_B) = (Q_B - Q_R)N_B + Q_R N_{ALL} + C'B_{ALL}. \quad (16)$$

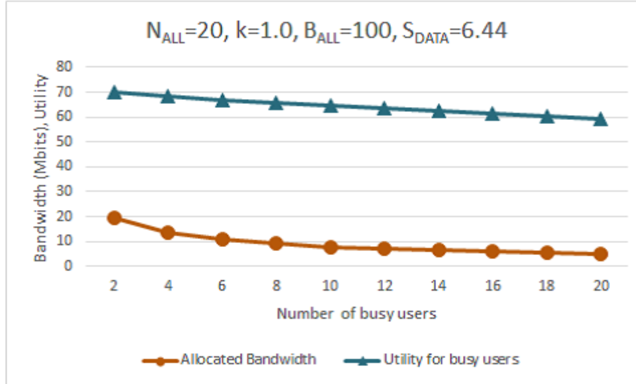

Fig. 2. Computation results ($N_{ALL} = 20, k = 1.0, B_{ALL} = 100, S_{DATA} = 6.44$).

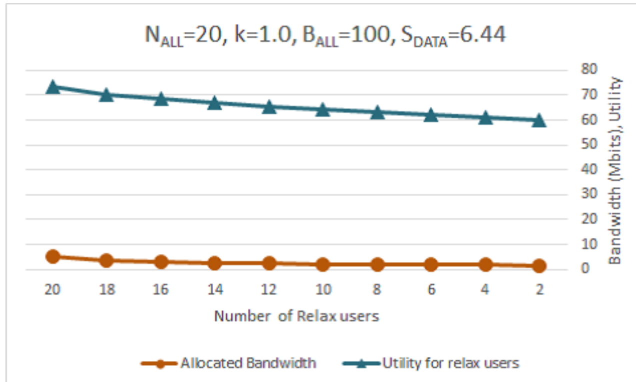

Fig. 3. Computation results ($N_{ALL} = 20, k = 1.0, B_{ALL} = 100, S_{DATA} = 6.44$).

In the same way, B_R is derived as

$$B_R = \frac{-W(N_R) \pm \sqrt{W(N_R)^2 + 4C'N_R Q_R B_{ALL}}}{2C'N_R} \quad (N_R \neq 0), \quad (17)$$

where

$$W(N_R) = (Q_R - Q_B)N_R + Q_B N_{ALL} - C'B_{ALL}. \quad (18)$$

From (15) and (17), the amounts of allocated bandwidth are calculated for the busy and relaxed user types. k is the parameter to control the QoE degrees of two user types.

V. RESULTS

This section evaluates the analyzed results obtained in Section IV.

In the first place, the case of $N_{ALL} = 20$ is presumed. The task is that each user downloads a Web content whose size is 6.44 Mbits. The size is an average value of five contents actually retrieved from a news Web site. It is also presumed that $B_{ALL} = 100.0$ (Mbits/s) and $k = 1.0$. It means a small office is assumed and the same utility is assigned to all users in the busy and relaxed user types.

Figs. 2 and 3 present allocated bandwidths and attained user utilities when the rates of busy and relaxed users change. In Fig. 2, the allocated bandwidths and the utilities for the busy users are shown, where the horizontal axis indicates the

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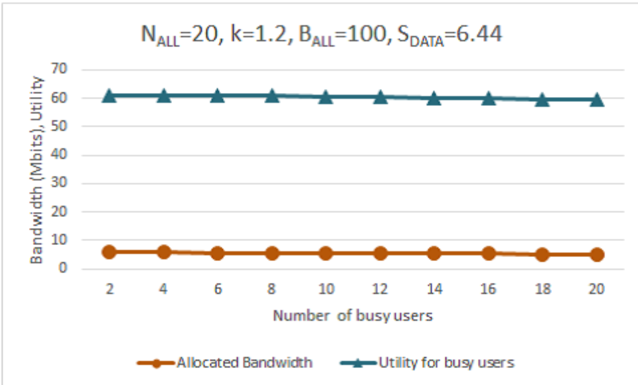

Fig. 4. Computation results ($N_{ALL} = 20, k = 1.2, B_{ALL} = 100, S_{DATA} = 6.44$).

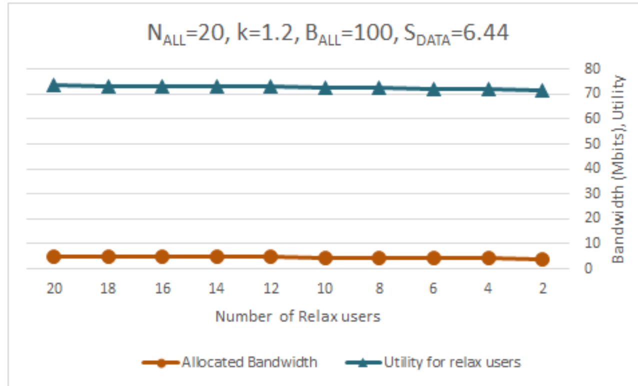

Fig. 5. Computation results ($N_{ALL} = 20, k = 1.2, B_{ALL} = 100, S_{DATA} = 6.44$).

number of the busy users and the vertical axis indicates both the allocated bandwidth in Mbits and the utility simultaneously. Fig. 3 presents the same results but from the viewpoints of the relaxed users. The horizontal axis indicates the number of the relaxed users in descending order, because it is corresponding to the ascending order of the horizontal axis in Fig. 2. The indications of the axes are set in the same way for the following figures.

From Figs. 2 and 3, it is shown that the same utilities are attained at any rate of the users since the utility balance control parameter k is set to 1.0. The bandwidth allocated to the relaxed users is rather stable, while the busy users are somewhat greedy since a small number of busy users tend to occupy the bandwidth.

Under the same conditions, the utility balance control parameter k is changed into 1.2, that is the utility for the relaxed users is set 20% more than the busy users. The results are shown in Figs. 4 and 5. Actually the utilities are always set higher for the relaxed users. Still the utilities for the busy users are kept around 60 which is not so bad value for waiting. It is noted that these conditions are very stable for any rate of the users. Fairness might be attained at these conditions.

Regarding fairness, Jain *et al.* [12] studied the fairness definition widely and expressed that fairness implies equal allocation of resources. It should be noticed that they dealt with QoS-level resource allocation fairness and an allocation metric differs among researchers. At QoE-level, the definition of fairness can be extended and the user utility is selected as the allocation metric.

Next, the parameters are set as more considerable values to evaluate the larger scale case in the user number and the network size. The scale is extended as $N_{ALL} = 100$, $B_{ALL} = 100.0$ (Mbits/s) and $S_{DATA} = 200.0$ (Mbits).

Figs. 6 and 7 present the results of $k = 1.0$, that is the case of equally-balanced utilities. Note that scaling of the vertical axes is different, because the busy users are greedy. The utilities of two user types are, however, kept to be even.

Next, the utility balance is changed as $k = 1.2$. The relaxed users' utilities are increased by 20% and the results are shown in Figs. 8 and 9. The allocated utilities are stable in spite of the user type ratios, while the allocated bandwidths decrease

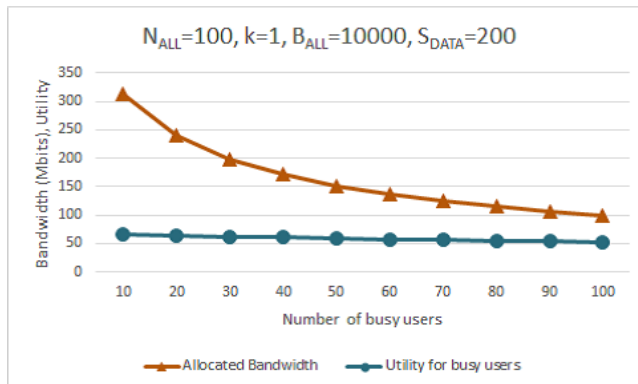

Fig. 6. Computation results ($N_{ALL} = 100, k = 1.0, B_{ALL} = 10000, S_{DATA} = 200$).

as the number of the busy users increases. Although it can be said that fairness is kept for two user types, the characteristics of the user types are not considered so well.

Finally, the computation results for $k = 0.8$ are presented in Figs. 10 and 11. These results tell that the priviledged utilities for the busy users are protected compared with the other results. The utilities are provided from 52.4 to 70.4 for the busy users, though it might be difficult to read the values from Fig. 10. One critical point is that too much bandwidth

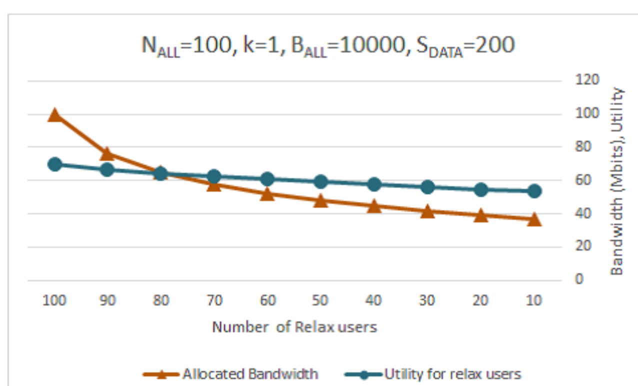

Fig. 7. Computation results ($N_{ALL} = 100, k = 1.0, B_{ALL} = 10000, S_{DATA} = 200$).

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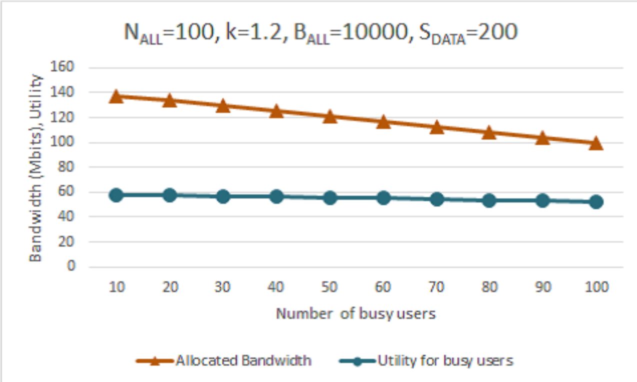

Fig. 8. Computation results ($N_{ALL} = 100, k = 1.2, B_{ALL} = 10000, S_{DATA} = 200$).

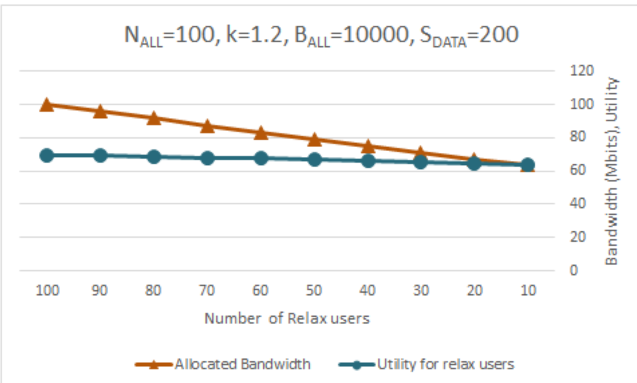

Fig. 9. Computation results ($N_{ALL} = 100, k = 1.2, B_{ALL} = 10000, S_{DATA} = 200$).

allocation might occur in the case of small number of the busy users.

VI. Conclusion

The utility functions should be different for each user type, where the utility function is defined as the function mapping QoS parameters to the degree of user satisfaction (QoE). Based on this premise, a novel resource allocation method using QoE factors is proposed in this paper. The detailed analysis is carried out for the case of two user types. By making use of the analyzed solutions, the resource allocation is derived for each user type and the utilities attained for the users are correctly derived. The analysis uses the user utility functions obtained from real user experiments. Several computation results are presented to prove the correctness of the solutions.

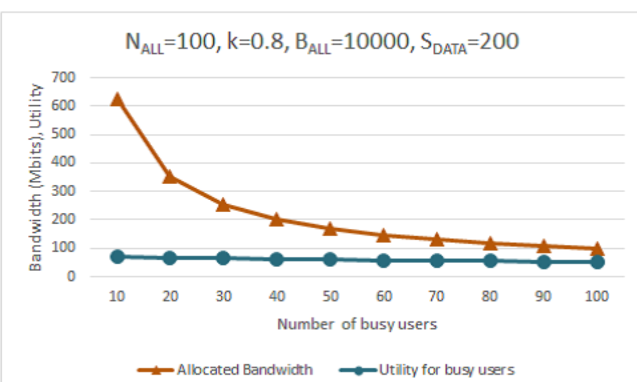

Fig. 10. Computation results ($N_{ALL} = 100, k = 0.8, B_{ALL} = 10000, S_{DATA} = 200$).

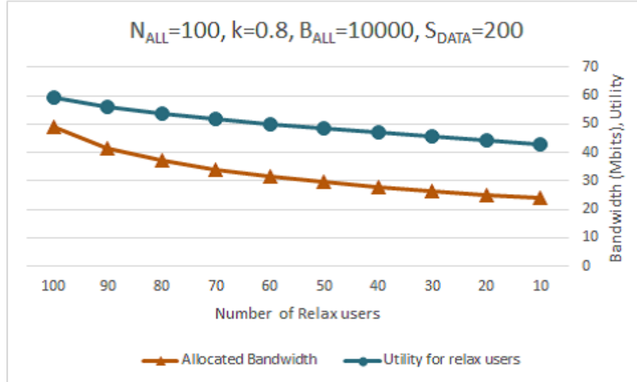

Fig. 11. Computation results ($N_{ALL} = 100, k = 0.8, B_{ALL} = 10000, S_{DATA} = 200$).

Future works include introduction of more general analysis for the cases of various user types. Moreover, implementation of the proposed method by e.g. the SDN technology is needed to evaluate adaptability of the proposed method to real situations.

References

[1] T. M. Stoenescu and D. Teneketzis, ”Decentralized resource qllocation mechanisms in networks: realization and implementation,” in Advances in Control, Communication Networks, and Transportation Systems, pp. 225-263, Birkhauser, Boston, 2005.

[2] P. Ameigeiras, J. J. Ramos-Munoz, J. Navarro-Ortiz, P. Mogensen, and J. M. Lopez-Soler, ”QoE oriented cross-layer design of a resource allocation algorithm in beyond 3G systems,” Computer Communications, 33, pp. 571-582, March 2010.

[3] M.A. Khan and U. Toseef, ”User utility function as Quality of Experience (QoE),” the Tenth International Conference on Networks (ICN 2011), pp. 99-104, Jan. 2011.

[4] D. Schroeder, A. El Essaili, E. Steinbach, Z. Despotovic, and W. Kellerer, ”A Quality-of-Experience driven bidding game for uplink video transmission in next generation mobile networks,” IEEE International Conference on Image Processing (ICIP 2012), Orlando, Florida, USA, Sept. 2012.

[5] ITU-T Recommendation P.10/G.100 Amendment 1, ”New appendix I - definition of Quality of Experience (QoE),” Jan. 2007.

[6] N. Ogino, M. Kosuga, T. Yamazaki, and J. Matsuda, ”A model of adaptive QoS management platform based on cooperation of layered multi-agents,” GLOBECOM’99 (Global Telecommunications Conference), pp. 406-413, Rio de Janeiro, Brazil, Dec. 1999.

[7] V. Gazis, N. Houssos, A. Alonistioti, and L. Merakos, ”On the complexity of ”always best connected” in 4G mobile networks”, IEEE Semiannual Vehicular Technology Conference (VTC Fall 2003), Orlando, Florida, USA, 2003.

[8] T. Yamazaki, M. Eguchi, T. Miyoshi, and K. Yamori, ”A service quality coordination model bridging QoS and QoE,” 20th International Workshop on Quality of Service (IEEE/ACM IWQoS 2012), Coimbra, Portugal, June 2012.

[9] P. Georgopoulos, Y. Elkhatib, M. Broadbent, M. Mu, and N. Race, ”Towards network-wide QoE fairness using OpenFlow-assisted adaptive video streaming,” Proc. of the Workshop on Future Human-Centric Multimedia Networking (FhMN 2013) (an ACM SIGCOMM workshop), Hong Kong, Aug. 2013.

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[10] O. Huber and U. Kunz, ”Time pressure in risky decision making: effect on risk defusing,” Psychology Science, vol. 49, no. 4, pp. 415-426, 2007.

[11] ITU-R Recommendation: BT.500-11, ”Methodology for the subjective assessment of the quality of television pictures,” 2002.

[12] R. Jain, D. Chiu, and W. Hawe, ”A quantitative measure of fairness and discrimination for resource allocation in shared systems,” DEC, Tech. Rep., 1984.

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