doi:10.3772/j.issn.1006-6748.2014.03.009

Non-cooperative game for network access selection in heterogeneous integrated networks①

Guo Hongyao (郭洪尧)*, Zhang Xin②**, He Yunlu**, Jiang Rui*, Xie Jiangbo**
(* School of Telecommunication and Information Engineering, Xi'an University of Posts and Telecommunications, Xi'an 710061, P. R. China)
(** School of Electronic Engineering, Xi'an University of Posts and Telecommunications, Xi'an 710061, P. R. China)

Abstract

The integration of different heterogeneous access networks is one of the remarkable characteristics of the next generation network, in which users with multi-network interface terminals can independently select access network to obtain the most desired service. A kind of unified quantification model of non-monotone quality of service (QoS) and a model of non-cooperative game between users and networks are proposed for heterogeneous network access selection. An optimal network pricing mechanism could be formulated by using a novel strategy which is used in this non-cooperative game model to balance the interests of both the users and the networks. This access network selection mechanism could select the most suitable network for users, and it also could provide the basis when formulating QoS standards in heterogeneous integrated networks. The simulation results show that this network selection decision-making algorithm can meet the users' demand for different levels service in different scenes and it can also avoid network congestion caused by unbalanced load.

Key words: heterogeneous network integration, access selection, non-cooperative game, non-monotone quality of service (QoS)

0 Introduction

With the rapid development of wireless communication technology, the integration of different heterogeneous access networks is being gradually transformed toward the trend of system integration and collaboration. The integration of a variety of wireless access technologies is an inevitable trend of network of the next generation, so the emergence of user terminals that support multiple network interfaces will make the access form more flexible and convenient. In heterogeneous integrated networks, the user terminals that support multiple network interfaces can obtain services through a variety of different access networks. In order to obtain the satisfying quality of service, more reasonable decision-making algorithms should be taken in access network selection. In recent years, the study of heterogeneous wireless network access selection has made some valuable results. Ref. [1] proposed a novel network selection approach using improved multiplicative multi-attribute auction (MMA). In this way, the best suitable network can be selected according to the user's performance-cost-ratio. Ref. [2] provided a novel unified framework for defining decision criteria weights relying on the variance of network measurements. Ref. [3] introduced a wireless network access selection algorithm using non-cooperative game theory. The algorithm takes competition in resources between users into account. Ref. [4] proposed a novel dynamic network selection mechanism in cooperative heterogeneous wireless networks. The strength of this approach is its ability to allow users to dynamically change their preferences achieving better quality of service (QoS) whereas the network operator can also vary their controlling parameters. However, the above papers are made on the assumption that the network attribute is monotonous, in some certain scenarios, it's not real[5]. In addition, in most of the above papers, the interests of the user side or network side are taken into account unilaterally, and the balance of interests of both sides when selecting network is ignored. In view of these, a kind of a unified quantification model of non-monotone QoS is proposed based on sigmoid func-

① Supported by the National Natural Science Foundation of China (No. 61272120) and the Science and Technology Project of Xi'an (No. CXY1117(5)).
② To whom correspondence should be addressed. E-mail: zhx@xupt.edu.cn
Received on June 14, 2013

tion in robot learning mechanism and grey relational analysis. Thus users' demand for different levels of quality of service can be achieved by this model. Then a model of non-cooperative game between the user and the network is proposed and a strategy balancing the interests of both the user and the network is used in this non-cooperative game model. An optimized network pricing mechanism could be made by solving the Nash equilibrium solution.

1 Unified quantification model of non-monotone QoS

1.1 Offset degrees of network attributes

Access network selection is one of the key steps to achieve seamless integration of the terminals in heterogeneous integrated networks, and it is an important factor that affects system performance and satisfaction of users for the quality of service. The heterogeneity and complexity of heterogeneous integrated networks makes it very difficult to evaluate users' demand for quality of service. In order to fairly quantify the quality of service in heterogeneous integrated networks, this paper proposes a method of normalizing network attributes. Firstly, network attributes are divided into two categories according to their different impact on QoS. The first class is called the beneficial attributes by which users could improve the QoS, such as bandwidth, throughput, and so on. The second class is called the cost attributes that users wish to minimize them, such as delay, jitter, and packet loss rate. This paper defines two classes of network attributes normalized formula:

Beneficial attributes normalized formula:

$$V_i = \frac{X_{\max}^i - X^i}{X_{\max}^i - X_{\min}^i} \tag{1}$$

Cost attributes normalized formula:

$$V_i = \frac{X^i - X_{\min}^i}{X_{\max}^i - X_{\min}^i} \tag{2}$$

In the above equations, X^i is the actual value of the network attribute. $X_{\max}^i$ and $X_{\min}^i$ are the maximum value and minimum value of attribute i respectively. Eq. (1) and Eq. (2) show that V_i is the normalized value of the network attribute, $V_i \in [0,1]$. As the value is smaller, the network can provide a better quality of service for the users. When $V_i = 0$, that means that the beneficial attributes are maximun values and the cost attributes are minimum values. When $V_i = 1$, that means that the beneficial attributes are minimum values and the cost attributes are maximum values. Users can obtain the best quality of service when $V_i = 0$ and worst quality of service when $V_i = 1$.

1.2 Grey relational analysis

When selecting access networks according to the network attributes, we generally assume that each network attribute is monotonic. In other words, we assume that the smaller cost attributes the better the QoS will be and the bigger beneficial attributes the better the QoS will be. However, users in different occasions tend to choose different levels of quality of service[6]. For example, in business occasions, users are mainly considerate of the performance of the network. In such place, the shorter delay the better, the higher bandwidth the better, and the price becomes a secondary factor. In casual occasions, users are mainly considerate of the price as long as the quality of service could be maintained within a tolerable range, and the QoS became a secondary factor. When different levels of QoS are demanded, the questions caused by non-monotonic occurr. In order to solve this question, we need to find a reference solution, then the access network whose QoS is most associated with the reference solution will be selected as the most appropriate network. Grey relational analysis is the best way to solve such questions[7].

Fig. 1 shows a simple decision making scenario with one attribute, for example, the delay. This scenario contains two networks, the delay of network 1 is smaller than the delay of network 2. Both networks offer three kinds of business, such as VoIP, streaming media and web browsing. Traditionally, the measure of users' satisfaction associated with the delay is monotonic, in other words, users' satisfaction decreases monotonically with increasing delay. In this case, network with the least delay value, such as network 1, will be selected for all service types. However, in some casual occasions, the most important factors to be considered is the price, as long as the quality of service can be maintained within a tolerable range. At this time, the measure of users' satisfaction associated with the delay is non-monotonic. In other words, users' satisfaction doesn't increase or decrease monotonically with increasing delay. In this case, the user would like to use the network closest to the service's delay requirements but not necessarily the network with the least delay. For example, 3 parabolas in this figure correspond to three different types of business, the highest point of the parabola corresponding to the most suitable delay. In view of the users' non-monotonic satisfaction, network 1 will be selected for VoIP and network will be selected for streaming media and web browsing services. It is inclined to make a decision that this type of optimization for policy reasons such as load balancing across access networks or for keeping the best networks for services and sessions with higher QoS requirements that it can expect to have. It would be similar to the policy of an airline that decides to fly with some first or business class seats empty and not upgrade people from economy class with the knowledge or the hope that it would be able to get full fare business or first class customers at the next stop.

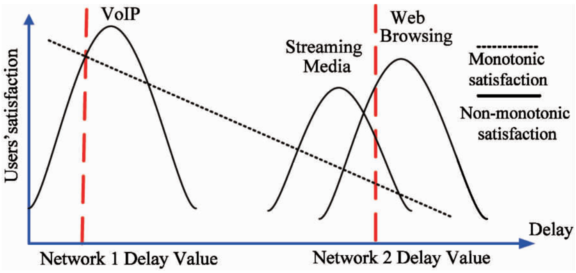

Fig. 1 Simple decision making scenario with one attribute

1.3 The unified quantification model of non-monotone QoS

It's difficult to quantify the QoS, because of the diversity and complexity of heterogeneous integrated networks. Sigmoid function based on machine learning mechanism[8] is a good method, but it can hardly achieve the users' demand for non-monotonic quality of service. Therefore the paper provides an improved Sigmoid function based on machine learning mechanism to quantify non-monotonic QoS in heterogeneous integrated networks. New model is made of the original model that is cascade of a normal distribution function. The mean of distribution is μ, and the variance is 1 in this normal distribution function

The unified quantification model of non-monotone QoS:

$$Q = \frac{C_1 \sum_{i=1}^{k} \exp[-S_2(V_i - \mu)^2]}{1 + \exp[-S_1 \sum_{i=1}^{k} w_i(T_i - V_i)]} \qquad (3)$$

where C_1, S_1, S_2 are constant, k represents the number of network attributes, $w_i(0 < w_i < 1)$, and T_i respectively represents the users' sensitivity and tolerance of network attribute i, μ indicates the level of QoS. For simplicity the levels of QoS is divided into five levels, respectively 0, 0.25, 0.5, 0.75 and 1.

The unified quantification model of non-monotone QoS not only quantifies QoS fairly, but also meets the users' demand for different levels service in different scenes. In this model, μ is the level of QoS, it is determined by users' demand. The closer the values of V_i and μ, the greater the value of Q. So that users' demand for quality of service in different occasions can be satisfied.

2 Access network selection based on non-cooperative game

2.1 Non-cooperative game model

The interests between network providers and users are conflicting. In networks' perspective, they wish to obtain the maximum benefit with minimum cost, meanwhile, network providers have to provide users with better service to avoid users switching networks. However, in users' perspective, they trend to take up more bandwidth, higher throughput and lower delay, and pay as little as possible. Therefore, the model provided by this paper is a non-cooperative game model[9].

The basic elements of the model are as follows:

(1) Players: access network $i(i = 1, 2, \cdots, N)$ and a user.

(2) Strategies: the access network i's strategy is to formulate a price of per quality of service $P_i(P_i \geqslant 0, i = 1, 2, \cdots, N)$; users' strategy is to select a network.

(3) Payoffs: when accessing network i whose price of per quality of service is P_i, user's payoff function is defined as follows:

$$R_i = Q_i - \alpha Q_i P_i \qquad (4)$$

In the above equation, α is the weighting factor, Q_i is the quantified QoS of network i, P_i is the price of per quality of service provided by the network i. The payoff function can help user select network with higher performance/price ratio. And it also can avoid network congestion caused by unbalanced load[10]. Because the non-monotonic quality of service can avoid too many users to choose the same network. In view of this, this paper selects the payoff function as the decision function which can help users selecte the most suitable network. Therefore, we can ensure the both interests of user and network, and ultimately achieve a win-win goal.

2.2 The utility function

This paper refers to utility function of different networks[11]. to describe the relationship between quality of service and price of per quality of service.

The utility function $U(Q)$:

$$U(Q) = \sum_{i=1}^{N} Q_i e_i - \frac{1}{2}\Big(\sum_{i=1}^{N} Q_i^2 + 2\rho \sum_{i \neq j}^{N} Q_i Q_j\Big) - \sum_{i=1}^{N} P_i Q_i \qquad (5)$$

where $Q = (Q_1, \cdots, Q_i, \cdots, Q_N)$ are quality of services of N networks. P_i is the price of per quality of service provided by the network i, $\rho(0 \leqslant \rho \leqslant 1)$ is competitive factor between different networks. $\rho = 0$ means network competition is intense, and the services they provide can not be replaced. When $\rho = 1$, there is no competition between networks, and services provided by the networks can be replaced. $0 \leqslant \rho \leqslant 1$ means different degrees of competition between different networks.

Users' demand for quality of service can be maximized by Eq. (5):

$$\frac{\partial U(Q)}{\partial Q_i} = e_i - Q_i - \rho \sum_{i \neq j} Q_j - P_i = 0 \qquad (6)$$

The demand function: $Q_i(P)(i = 1, 2, \cdots, N)$ can be solved by Eq. (5):

$$Q_i(P) = \frac{(e_i - P_i)[\rho(N-2)+1] - \rho \sum_{i \neq j}(e_j - P_j)}{(1-\rho)[\rho(N-1)+1]} \qquad (7)$$

2.3 Nash equilibrium solution of non-cooperative game

In the game $G = \{S_1, \cdots, S_n : u_1, \cdots, u_n\}$, S is the strategy space and u is the utility space, if a strategy group $(S_1^*, \cdots, S_n^*)$ is consist of strategies of every player in the game, and every player's strategy in the strategy group is the best solution for the rest of the strategy groups, that $u_i(S_1^*, \cdots, S_{i-1}^*, S_i^*, S_{i+1}^*, \cdots, S_n^*) \geqslant u_i(S_1^*, \cdots, S_{i-1}^*, S_j^*, S_{i+1}^*, \cdots, S_n^*)$ for any $S_j \in S_i$ is true, then $(S_1^*, \cdots, S_n^*)$ is a Nash equilibrium solution. In this paper, the Nash equilibrium solution is expressed as pricing strategies $(P_1^*, \cdots, P_i^*)$.

Access network decision function (Eq. (4)) and demand function Eq. (7) show that the access network decision function can be expressed as a function of price:

$$R_i(P) = (1-\alpha)P_i[(e_i - P_i)F_1 - \sum_{i \neq j}(e_j - P_j)F_2] \qquad (8)$$

In the above equation:

$$F_1 = \frac{\rho(N-2)+1}{(1-\rho)[\rho(N-1)+1]}$$

$$F_2 = \frac{\rho}{(1-\rho)[\rho(N-1)+1]}$$

Derivative of the Eq. (9):

$$\frac{\partial R_i(P)}{\partial P_i} = (1-\alpha)e_iF_1 - \sum_{i \neq j}(1-\alpha)(e_j - P_j)F_2 - 2(1-\alpha)P_iF_1 = 0 \qquad (9)$$

Best price function:

$$P_i^* = \frac{e_iF_1 - \sum_{i \neq j}(e_j - P_j)F_2}{2F_1} \qquad (10)$$

Best price function P_i^* of user i can be solved by Eq. (10), so as the $P_j^*, \cdots, P_N^*$. The Nash equilibrium solution of the access network selection model can be obtained by simultaneously solving $P_j^*, \cdots, P_N^*$. Due to that the best price function of every access network is linear, the Nash equilibrium solution is determined and have only one value[12]. In this case, the interests of users accessing different network can be balanced.

Nash equilibrium is applied to predict the selection results of users with the goal that maximize their payoffs. It is a state of non-cooperative game and gives a strategy profile with the property which no player can improve his payoff by choosing a different action given the actions of other players . When selecting access network, users should set up a suitable level of quality of service according to their occasions first. Then network's QoS could be quantified by the unified quantification model of non-monotone QoS. Finally, according to the value of payoff function, hereafter called decision value, users could select the network in which user's payoff reaches a maximum value.

3 Experimental simulation and analysis

We assume that the heterogeneous integrated networks are consist of two different access networks, the parameters are set as follows: $C_1 = 1$, $S_1 = 10$, $S_2 = 100$, $T_i = 0.6$, $w_i = 0.5$, $N = 2$, $k = 2$, $\alpha = 0.1$, $0.3 \leqslant e_i \leqslant 0.8$, $0.3 \leqslant \rho \leqslant 0.6$, $i = 1, 2$.

Fig. 2 shows the comparison of traditional quality of service and non-monotone quality of service, where the level of QoS $\mu = 0.5$. From the figure, we can see the differences between traditional quality of service and non-monotone quality of service: non-monotone QoS shows a non-monotone increase with an increase in attribute value and QoS reaches the maximum value when attribute 1 and attribute 2 are 0.5.

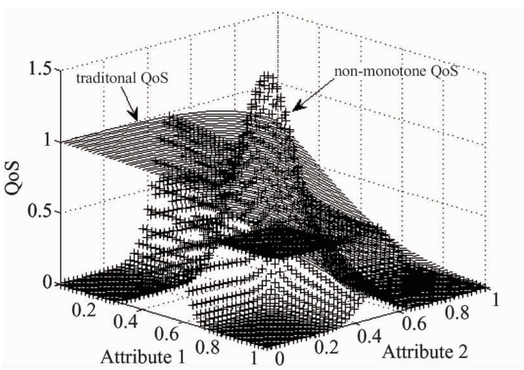

Fig. 2 Comparison of traditional quality of service and non-monotone quality of service

Its non-monotonic features can meet the users' different demand for different levels of QoS in different occasions.

Fig. 3 shows the relationship between price and decision value of network 1. Price 2 is the price of network 2. We get that the decision value of network 1 increases with the increase of price 1, and then decrease at a certain price which is the optimal price of network 1. From the figure we can also get the decision values of network 1 will increase with the increase in the price of the network 2. Thus, the possibility of the user access network 1 will increase. The reason is that users are more likely to choose a low-priced network.

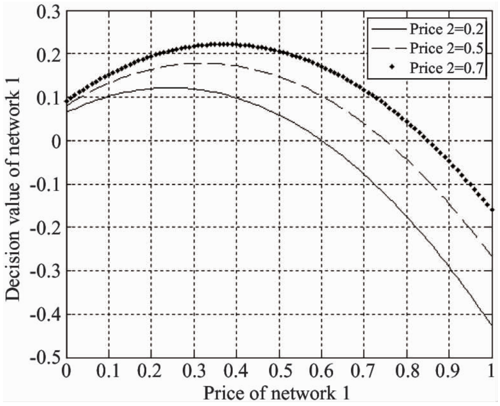

Fig. 3 Relationship between price and decision value

Fig. 4 shows the relationship between decision value of network 2 and price of network 1. When price of network 2 is determined, users' payoff will increase with the increase of network 1's price, which means users will have more opportunity to selecte the network 2. The reason is that users always tend to choose the network with low price. It also can be observed that compared with high price (0.7) and low price (0.1), user's payoff is higher when price of network 2 is appropriate (0.3).

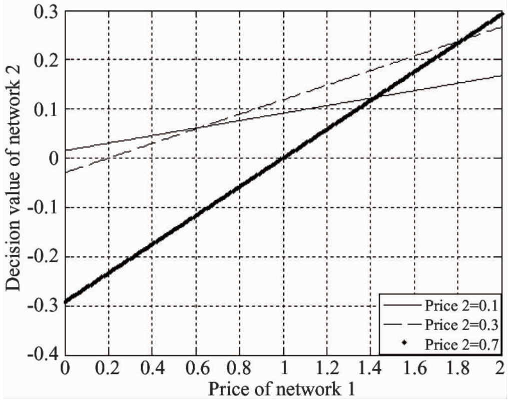

Fig. 4 Relationship between price and decision value

Fig. 5 shows the Nash equilibrium solution of two different networks in a non-cooperative game mode. At the Nash equilibrium solution, both networks have equal probability to select the network 1 or network 2. Therefore, network load can be balanced to avoid network congestion.

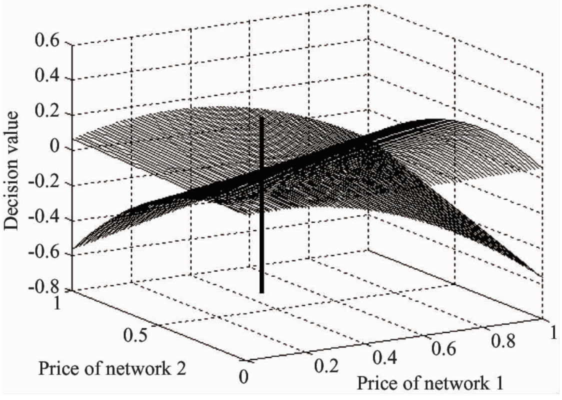

Fig. 5 Nash equilibrium solution in a non-cooperative game mode

Fig. 6 shows decision values in different levels of quality of service. From this figure we come to the conclusion that the proposed decision function can effectively meet users' demand for different levels of quality of service.

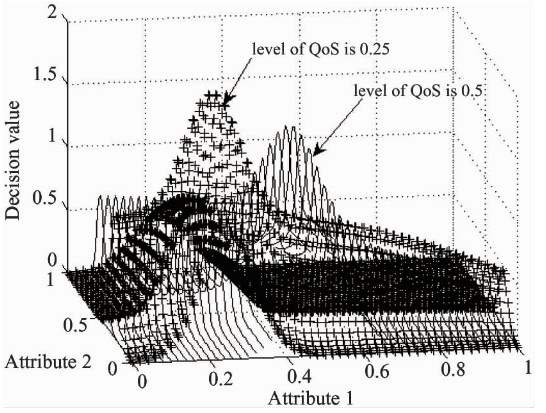

Fig. 6 Decision values in different levels of QoS

4 Conclusion

A kind of unified quantification model of non-monotone QoS based on sigmoid function in robot learning mechanism and grey relational analysis is proposed by which the users' demand for different levels of quality of service can be achieved. Then a model of non-cooperative game between the users and the networks is proposed and a strategy balancing the interests of both the users and the networks is used in this non-cooperative game model. The simulation results show that the unified quantification model of non-monotone QoS and the network selection balancing the interests of the networks and the users can effectively meet users' demand for quality of service in different occasions. It also shows that when networks' price meets the price in Nash equilibrium solution, network load will be balanced and utilization of networks will be maximized.

References

[1] Zhai L J, Ji H, Li X, et al. Multiplicative multi-attribute auction based optimal network selection for heterogeneous wireless networks. *Journal of China Universities of Posts and Telecommunications*, 2012, 19(4):1-5

[2] Dimitris D E, Panagopoulos A D, Markaki O I. A unified network selection framework using principal component analysis and multi attribute decision making, *Wireless Personal Communications*, 2012:1-19

[3] Cui Y, Xu Y B, Xu R Q, et al. A heterogeneous wireless network selection algorithm based on non-cooperative game theory. In: Proceedings of 2011 6th International ICST Conference on Communications and Networking in China (CHINACOM), Harbin, China. 2011. 720- 724

[4] Pervaiz H, Ni Q. User preferences-adaptive dynamic network selection approach in cooperating wireless networks: A game theoretic perspective. In: Proceedings of the 11th IEEE International Conference on Trust, Security and Privacy in Computing and Communications, Liverpool, UK, 2012. 1609-1616

[5] Bari, F, Leung V. Use of non-monotonic utility in multi-attribute network selection. *Lecture Notes in Electrical Engineering*, 2007, 44 LNEE: 21-39

[6] Chai R, Zhou W G, Chen Q B, et al. A survey on vertical handoff decision for heterogeneous wireless networks. In: Proceedings of the IEEE Youth Conference on Information, Computing and Telecommunication, Beijing, China, 2009. 279-282

[7] Liu S F, Forrest J. Advances in grey systems theory and its applications. In: Proceedings of 2007 IEEE International Conference on Grey Systems and Intelligent Services, Nanjing, China, 2007. 1-6

[8] Mitchell T M. Machine Learning. New York: McGraw Hill , 1997

[9] Maillé P, Tuffin B. Price war in heterogeneous wireless networks. *Computer Networks*, 2010, 54 (13): 2281-2292

[10] Yan J H, Zhang H C, Jing Y Z. Load balancing of the distributed system based on multi-agent, *Journal of South China University of Technology* (*Natural Science*), 2004, 32(12):74-79

[11] Chen Q B, Zhou W G, Chai R, et al. Game theoretic approach for network access selection in heterogeneous integrated networks. *Chinese Journal of Computers*, 2010, 33 (9):1644-1652

[12] La R J, Anantharam V. Network pricing using game theoretic. In: Proceedings of the 38th IEEE Conference on Decision and Control, A Z, USA, 1999. 4008-4013

Guo Hongyao, born in 1988. He received his master's degree in Xi'an University of Posts and Telecommunications. He received his bachelor's degree in Xi'an Technological University in 2011. His research interests include network computing, network management, etc.