A Noncooperative Game-Theoretic Vertical Handoff in 4G Heterogeneous Wireless Networks

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Abstract—**Proactive handoff is expected to be one of the distinct feature of 4G heterogeneous wireless systems, which is obviously different from the passive handoff commonly existed in traditional cellular systems. Users with multi-network interface terminals can actively and easily handoff to access network for better QoS satisfaction at a minimum expense, on the other hand, service providers (SPs) will have to face more intense competition for attracting more users to maximize their profits. In this paper, the relationship between competitive SPs and users is modeled as a noncooperative game, and the Nash equilibrium solutions corresponding to the best response price offered by SP are obtained. Based on the optimal prices, a novel vertical handoff algorithm for maximizing user performance-price-ratio is proposed. Numerical results demonstrate that all SPs can attain maximal profits from the Nash equilibrium results, and both of the network utilization efficiency and user QoS can be guaranteed.**

Keywords-heterogeneous wireless network; proactive vertical handoff; noncooperative game; Nash equilibrium

I. INTRODUCTION

In traditional cellular systems, passive handoff is commonly employed in which network collects handoff-related information and makes handoff decision while users have no control over the handoff process. The basic purpose of the handoff in these systems is to maintain the continuity of the communication link. In the case that user is not satisfied with the service quality or the expenses of the access network, he/she may have to change his/her SIM (Subscriber Identity Module) card or carry out WLNP (Wireless Local Number Portability) to switch to another access network or another service provide, which is both inconvenient and time-consuming in general. This problem is expected to be solved in 4G heterogeneous wireless systems, in which a potentially large number of different heterogeneous wireless network technologies is integrated together to support users seamless communications. An example of 4G system model is shown in Fig.1. In this system, user terminal with multi-network interfaces is capable of accessing the variety of different network services provided, and is able to make handoff decision of handoff instance and handoff destination network based on the network performance and user characteristics. In contrary to passive handoff, this type of handoff is referred to as proactive handoff, which is expected to be one of the radical features of 4G [3].

During the proactive handoff, users are able to actively and conveniently handoff to more satisfied or low-cost access network and SPs will compete more intensely with each other for attracting more users accessing to their systems. On the one hand, the time of want-and-do is significantly decreased when the user wants to switch to another SP, and instinctively self-regard behavior of user will increase the total handoff numbers because users are inclined to choose the “best” network access service in 4G heterogeneous wireless systems. On the other hand, SPs will face more intensely competition in order to gain more profits in launching actively or passively the price or quality competition to attract more users. Therefore, the competitive relationship in nature among the SPs and user can be modeled as a noncooperative game. In this game scenario, the problem of obtaining the equilibrium solutions such that both of SPs and users are able to achieve best profits is an important issue worthy of study.

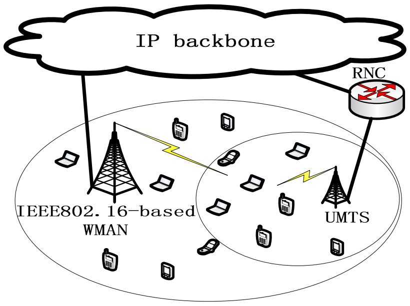

Fig.1.Heterogeneous system model of 4G

In this paper, we propose a unified quantification model for evaluating the access service of heterogeneous networks and a vertical handoff model based on noncooperative game-theory for 4G heterogeneous systems. The Nash equilibrium solution corresponding to optimal prices offered by SP are obtained and a novel vertical handoff algorithm is proposed. Numerical results are presented to demonstrate that all SPs can attain maximal profits from the Nash equilibrium result, which will be beneficial to enhance the utilization efficiency of whole network resource and the user QoS. In this paper, the terms “access network” and “service provider” will be used interchangeably.

II. PREVIOUS WORK

Vertical handoff is one of the most important issues in 4G heterogeneous wireless systems and has been studied extensively in the literatures [1,2]. Extended from traditional horizontal handoff, RSS-based vertical handoff algorithm is proposed in [6, 8], the performance of this type of algorithm is limited due to the lack of comprehensive consideration on

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network performance and user characteristics. In [9], a handoff decision algorithm based on signal to interference and noise ratio (SINR) is proposed. The vertical handoff procedure is modeled as a Markov decision process and the reward function of each target network is defined based on network bandwidth and delay conditions in [10], the optimal candidate network with satisfied bandwidth and delay conditions is chosen as the handoff destination network. In [12], a network selection algorithm based on analytic hierarchy process is discussed for providing the best user QoS support. In [13], grey relational coefficient is applied to calculate the correlation between each candidate network and user current network, under the consideration of seamless handoff, the candidate network with the highest correlation is chosen as the handoff destination network. The handoff algorithm proposed in [20] aims to provide an efficient resource utilization of heterogeneous networks through balancing the traffic load among all the APs/BSs and maximizing the battery lifetime of mobile terminals at same time. Fuzzy logic method can be designed to design vertical handoff algorithm with fuzzified parameters in [16,17]. The resource management framework based on policy is proposed in [18] and all sorts of network resources can be utilized under the framework of the load balancing policy.

Game theory, which was widely proposed to explain complicated economic behavior, has been applied in resource management of wireless networks. In [11], power control mechanism of CDMA system is modeled as a noncooperative game among users competing with the power to obtain SIR requirements and a feasible power assignment is formed. An integrated admission and rate control for CDMA system is proposed based on noncooperative game to reach Nash equilibrium with pure or dominant strategy in [4]. In [19], the problem of spectrum sharing in cognitive radio networks was formulated as a potential game, and the Nash equilibrium of this game was obtained by a distributed sequential play. In [14], the market-based modeling to manage network resources is discussed based on repeated noncooperative game and the existence of a unique Nash equilibrium is proved.

In a heterogeneous wireless network, owing to the fact that users desire to maximize their satisfaction according to the quality of access service and service costs while SP wants to maximize their revenue, pricing and quality of access service in resource allocation of SP are closely related and are major consideration issues for both SP and user. In this paper, we focus on these two issues and propose a noncooperative game model to optimize the service pricing and the vertical handoff performance.

The rest of the paper is organized as follows. In section III, a unified quantification model for evaluating the access service of heterogeneous networks is described. A vertical handoff model based on noncooperative game-theory for heterogeneous wireless access network is proposed and discussed in section IV. The simulation results are given in section V. Finally, the summary is drawn in Section VI.

III. NETWORK ACCESS SERVICE MODELING

Heterogeneous system architectures and complicated system performance parameters of access networks result in the difficulties in evaluating the quality of service (QoS) offered by different access networks, which in turn give rise to the difficulty in design efficient network selection and vertical handoff algorithm. In this section, taking into account both network performance and user characteristics, we propose a unified quantification model for evaluating the access service of heterogeneous networks.

A. Normalization of Parameters Offset Ratio

During the process of vertical handoff, different network and user parameters may affect the performance of vertical handoff in 4G systems [7]. On the one hand, the handoff network needs to be chosen based on the performance comparison of different candidate networks. The difference of performance parameters resulted from different structures and characteristics of different wireless access system leads to difficulties in network parameter comparison and performance evaluation. On the other hand, due to the loss of actual wireless link transmitting circumstance or designed resource allocation of SPs, those parameters are impossible to achieve ideal value all the time. To deal with those problems, the normalization of parameters' offset ratio for fairly quantify the quality of heterogeneous wireless access service can be applied properly.

The parameters for QoS evaluating can be classified into two categories, i.e., reward parameter, and cost parameter. Reward parameter is expected to be as large as possible, with bandwidth and RSS being typical examples. On the contrary, cost parameter is expected to be as small as possible, for instance, power consumption of user terminal and connection delay etc. The normalization formula of parameter offset ratio for two types of parameters are defined as below, respectively:

$$V_i = \frac{p_{\max} - p_c}{p_{\max} - p_{\min}} \tag{1}$$

$$V_i = \frac{p_c - p_{\min}}{p_{\max} - p_{\min}} \tag{2}$$

where, $p_{\max}$, $p_{\min}$ denote respectively, the maximum and minimum value of the i th parameter required by user access service and p_c denotes current system parameter offered by the access network. Therefore, V_i indicates the actual offset ratio of the i th parameter. It is clear that, $0 \le V_i \le 1$ and the smaller V_i, the better QoS can be offered by the access system.

B. Quantifying the Quality of Network Access Service

Given the normalized parameter offset ratio calculated in part A and taking into consideration of the affects of parameters on the QoS, we formulate in this section a unified quantification model of the quality of access service based on the Sigmoid function which is originally introduced in Machine Learning[5]. Denoting Q as the quality of access service, we define:

$$Q = C_1 \Big/ (1 + \exp(-S \sum\nolimits_{i=1}^{K} w_i (T_i - V_i))) \tag{3}$$

where, w_i denotes the sensitivity factor of the i th parameter, $0 < w_i \le 1$, T_i denotes the tolerable offset ratio of parameter i for user, C_1 and S are both scale constants. S and T_i determine the steepness and the inflection point of the curved surface, respectively.

As examples, Fig. 2 and Fig, 3 show the variation of QoS versus sensitivity factor and tolerable parameter offset ratio, respectively. In ploting both figures, the number of parameters are chosen to be 2, i.e., $K = 2$, the two scale constants are chosen as $C_1 = 1$ and $S = 10$, respectively. It can be seen from Fig.2that the value of w_i determines how fast the QoS decreases with the increase of the parameter offset ratio. The larger w_i, the faster QoS decreases, representing more sensitive QoS to parameter offset ratio. Fig.3 shows that T_i determines when the QoS decreases at the inflection point of the curved surface.

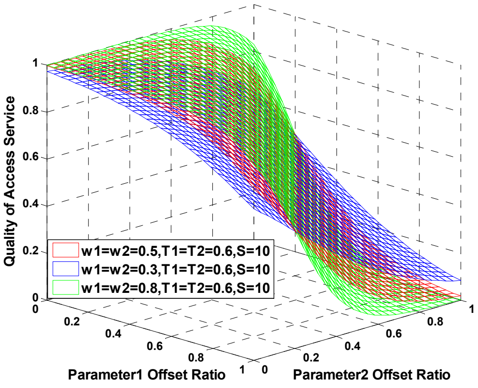

Fig.2. Variation of QoS versus different w_i with offered S

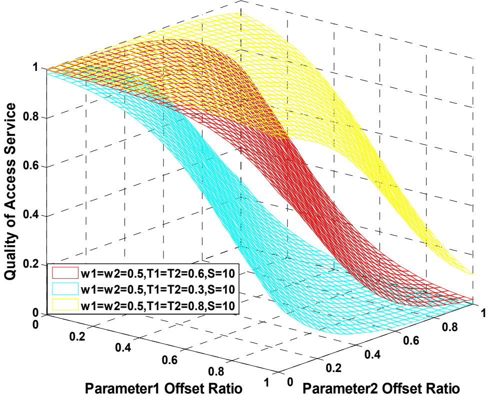

Fig.3. Variation of QoS versus different T_i

IV. NONCOOPERATIVE GAME MODELING

In 4G system, a variety of access networks are expected to integrate together to support user service with different connection requirements (corresponding to different $p_{\max}$ and $p_{\min}$ defined in (1) and (2)). These access networks which may belong to different SPs will launch actively or passively the service quality and price competition to attract more users and maximize their revenue. In this section, the competitive relationship among the SPs is modeled as a noncooperative game. The Nash equilibrium solution, i.e., the optimal service price offered by each SP is obtained and a novel vertical handoff algorithm to maximize user performance-cost-ratio is proposed.

A. Noncooperative Game Model

The basic elements of noncooperative game theory include players, the strategy of players and the payoff of players for choosing corresponding strategies. In the noncooperative game model of vertical handoff in heterogeneous networks, these elements are summarized in Table I:

TABLE I. ELEMENTS OF NONCOOPERATIVE GAME MODEL OF VERTICAL HANDOFF

Players	***Strategy***	***Payoff***
Access network i $(1 < i \le M)$	Service price P_i of QoS	$R_i(\mathbf{P})$
Users (N)	Choosing the best network	Performance-Cost-Ratio

The payoff of access networks and user can be defined as follows:

$$R_i(\mathbf{P}) = n_i(P_i D_i - c_i e_i D_i) \qquad (4)$$

$$\text{Performance-Cost-Ratio} = De/P \qquad (5)$$

where, $R_i(\mathbf{P})$ denotes the revenue function of access network i. Denoting c_i as the cost factor of access network i and D_i as the desired amount of QoS toward access network i (Assume SP is willing and able to offer the user demand) and denoting e_i as the transmission efficiency of D_i in access network i. e_i can be obtained from $e_i = C_2(1 - \sum_{i=1}^{K} w_i V_i \Big/ \sum_{i=1}^{K} w_i)$ with C_2 being a constant, n_i denotes the user number of access network i, $\sum_{i=1}^{M} n_i = N$.

B. Utility Function

In this paper, we apply the quadratic utility function [15] which was originally introduced in economics theory and model network utility function to quantify user QoS demand:

$$U(\mathbf{D}) = \sum_{i=1}^{M} D_i e_i - \frac{1}{2}\left(\sum_{i=1}^{M} D_i^2 + 2\rho \sum_{i \ne j} D_i D_j\right) - \sum_{i=1}^{M} P_i D_i \quad (6)$$

where, $\mathbf{D} = \{D_1, ..., D_i, ..., D_M\}$ denotes the demand vector from all the access networks, P_i denotes the access service price of access network i, ρ denotes competition factor, $0 \le \rho \le 1$. While $\rho = 0$ denotes the one network access service has no substitutability (for instance, one user moves out from UMTS to WMAN or there are only one network that achieves the minimal QoS requirement of the user), $\rho = 1$

indicating the quality of two network access service is identical, $0<\rho<1$ denotes the competitive degree of substitutable access service among SPs.

The optimal D_i corresponding to maximal $U(\mathbf{D})$ can be obtained by differentiating $U(\mathbf{D})$ with respect to D_i, and set the ratio to zero:

$$\frac{\partial U(\mathbf{D})}{\partial D_i} = e_i - D_i - \rho\sum_{i\neq j} D_j - P_i = 0 \tag{7}$$

Jointly solve (7) for D_i, i=1, 2..., M, we obtain the demand function:

$$D_i(\mathbf{P}) = \frac{(e_i-P_i)[\rho(N-2)+1]-\rho\sum_{i\neq j}(e_j-P_j)}{(1-\rho)[\rho(N-1)+1]} \tag{8}$$

C. *Solving Nash Equilibrium of Noncooperative Game*

The Nash equilibrium of a noncooperative game is the strategy profile with this property that no player can increase his payoff by choosing other action while other players' action remains unchanged. The Nash equilibrium price can be obtained by using the best response function in the noncooperative game proposed in this paper.

As SP expects to sell the quality of access service to user for maximal revenue, based on the relationship between revenue function in (4) and demand function in (8), the revenue issue of each SP can be expressed as the function of price. Differentiating $R_i(\mathbf{P})$ with respect to P_i, and set the ratio to zero:

$$\begin{aligned}&\frac{\partial R_i(\mathbf{P})}{\partial P_i} = 0 \Rightarrow \\ &P_i^* = \frac{1}{2}(e_i + c_i e_i) - \frac{\rho}{2\rho(N-2)+2}\sum_{i\neq j}(e_j - P_j)\end{aligned} \tag{9}$$

We obtain the best response price function P_i^* of the access network i, P_j^* of the access network j can be obtained similarly, which are exactly the Nash equilibrium prices of the two networks, that is each SP can achieve the maximal revenue in the Nash equilibrium price.

D. *Network Selection Scheme of User Noncooperative Game*

In 4G system, users tend to choose the access network with best QoS, however, the higher QoS requirement; the higher service costs are required in general. As a rational player in the game model, user will choose the access network i with best performance-cost-ratio (PCR). The best response function for users choosing a candidate network is defined in (10) and user is able to achieve the best PCR on the Nash equilibrium price.

$$\begin{aligned}&i^* = \arg\max_i \left(\frac{D_i e_i}{P_i^*}\right) = \\ &\arg\max_i \left\{ e_i \frac{(e_i - P_i^*)[\rho(N-2)+1] - \rho\sum_{i\neq j}(e_j - P_j^*)}{(1-\rho)[\rho(N-1)+1]P_i^*} \right\}\end{aligned} \tag{10}$$

V. NUMERICAL STUDY

A. *Parameter Settings*

In our simulation experiment, a heterogeneous wireless network with two access systems is assumed. The parameters in the simulations are chosen as $C_2 = 1, M = 2, n_i = n_j = 100,$ $c_i = 0.1, 0.3 \le \rho \le 0.6, 0.3 \le e_i \le 0.7, i = 1, 2$.

B. *Numerical Results*

Fig.4 shows the revenue of SP for different offered price of SP1 and SP2. In Fig. 4(a), the revenue of SP1 is plotted as a function of its offered price for three particular prices offered by SP2. It can be observed from Fig. 4(a) that the revenue of SP1 first increases with the increase of the price, however, after one certain price (This price is best response price of SP1 when the price of SP2 is offered), the revenue of SP1 decreases. This is because high price will lead to the loss of user. It can also be seen that for higher price offered by SP2, more revenue can be obtained by SP1, for more users may choose or switch to SP1 due to high price offered by SP2.

In Fig. 4(b), the revenue of SP2 is plotted as a function of the offered price by SP1. It is shown in Fig. 4(b) that for particular offered price of SP2, the revenue of SP2 increases with the increase of the price offered by SP1. This result can be explained as higher price offered by SP1, less users choose to access to it, which in turn provides the possibility for SP2 to attracting more users. Moreover, it can also be observed that comparing to a higher (0.35) and lower price (0.15) and 0.25, respectively, a medium price, i.e., p2=0.25 offers better performance in terms of the total revenue.

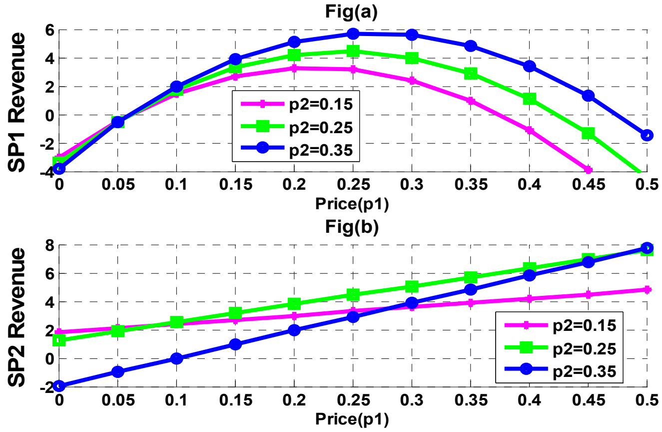

Fig.4. Revenue of SP versus offered price

Fig.4 has illustrated that what price is best response price of one SP to obtain the maximal revenue while the price of other SP is offered. When two SPs will adjust their anticipatory price for maximal profit in game, and the Nash equilibrium price benefited to both can be found.

Fig. 5 shows the best response price (BRP) functions of two SPs and corresponding Nash equilibrium price for different combinations of e_i and ρ .The Nash equilibrium price is corresponding to the intersection of the BRP functions of two SPs. As the BRP functions of two SPs are linear functions, the

Nash equilibrium price under any particular network scenario exists and is unique. Comparing to Case 1 and 2 in Fig. 5, we can see that when e_i increases, i.e., better QoS can be offered by the network, the price offered by the network increases correspondingly. The comparison of Case 2 and Case 3 shows the price decreases due to intensive competition (larger ρ) between the access networks, for lower price is offered by the SPs to attract more users. The increment of service cost of one SP will push the equilibrium price up, thus the price of the SP with lower cost is more competitive due to its relative low price for offering the same user QoS, as shown in Case 3 and Case 4.

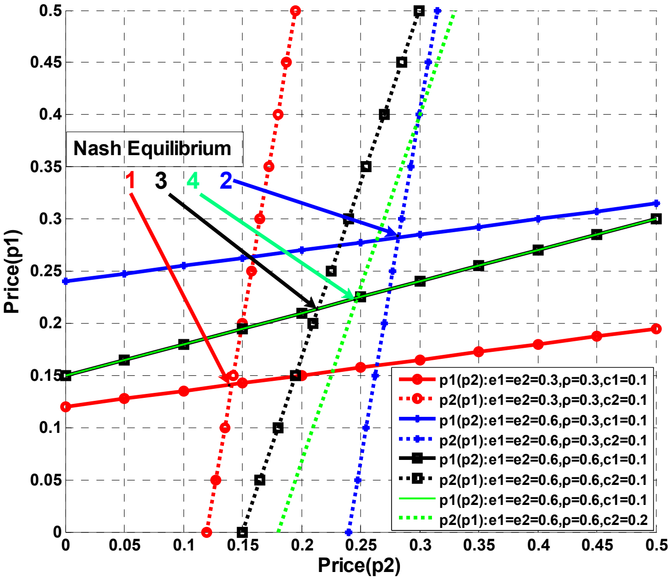

Fig.5. Best response price function and Nash equilibrium

VI. SUMMARY AND OUTLOOK

In this paper, we present a noncooperative game-theoretic vertical handoff and network selection model for heterogeneous wireless access network, and the Nash equilibrium price and user network selection scheme are obtained. Numerical results are presented to demonstrate that both SPs and user can attain maximal profit from the Nash equilibrium result, which will be beneficial to enhance the utilization efficiency of whole network resource. In our future work, the dynamic characteristics of the price competition and the simulations of heterogeneous network parts in the game model will be analyzed and the stability of the Nash equilibrium solution will be further discussed.

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