MULTIPLE ATTRIBUTE NETWORK SELECTION ALGORITHM BASED ON EVOLUTIONARY GAME THEORY IN WIRELESS NETWORK

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Abstract – Abstract‑ In a heterogeneous wireless network, multiple networks are available to provide end to end mobility and service to mobile users. So in heterogeneous wireless network, selection of the optimal network becomes an important task, which is a key technology to realize fair resource allocation and load balancing for converged multi-radio heterogeneous networks. In this paper, we combine the grey relational analysis and evolutionary game theory (GREGT) to solve the network selection problem in the constrained heterogeneous networks. In GREGT, utility functions are designed appropriately to compute user QoS satisfaction of the candidate network. User preferences and network condition that are considered in this paper are computed by fuzzy analytic hierarchy process (FAHP) and grey relational analysis (GRA), then the dynamics of the population's behavior are explicitly described by EGT. At last, the validity of the proposed scheme is verified by numerical and simulation results.

Keywords - Evolutionary game theory; Heterogeneous wireless networks; Replication dynamics; Grey relational analysis; Utility functions

I. INTRODUCTION

In the past few years, there is an impressive growth in wireless communication systems due to the popularity of smart phones and other mobile devices, the rapid development of smart multimode terminals and mobile Internet applications have raised a great challenge to service provisioning paradigm. While the converged multi radio access technologies (RATs) such as long term evolution (LTE) networks, universal mobile telecommunications systems (UMTS), wireless metropolitan area network (WMAN), and Wireless Local Area Networks (WLAN), would alleviate this problem[1]. Network selection is a key technology to enable the multi-RAT convergence, by selecting network, users could obtain high quality of services (QoS) and ubiquitous network access opportunities.

Many algorithms have been developed to address this problem such as algorithms based on fuzzy logic, algorithms based on utilities, algorithms based on game theory and algorithm based on multiple attribute. The various multi attribute decision making (MADM) algorithms which include simple additive weighting (SAW), multiplicative exponential weighting (MEW), grey relational analysis (GRA) and technique for order preference by similarity to an ideal solution (TOPSIS) etc. can be used for selection of efficient network, the MADM algorithms use utility to measure the satisfaction that a network could provide to the mobile user. In [2], the selection of network via AHP and TOPSIS is given, AHP is used to get attributes weight and TOPSIS is used to get best network. In [3], combined fuzzy AHP and elimination et choix tradulsant la realtite (ELECTRE) algorithm are discussed where fuzzy AHP is used to assign the weight to the criteria and ELECTRE is used for ranking the candidate networks.

Network formation games and coalition structures [4] have also been studied in standard game theory. Non-cooperative network formation game proposes an explicit representation of the coalition formation between players [5]. Coalitional formation game which investigates players have interacted with their neighbours in a network. In such games, players usually have some discretion to connect each other, hence the network structure both influences the result of the interactions and is influenced by the decisions of the players. In [6], the selection technique of network using AHP and Game theory (Bankruptcy Game Model) is provided and it is done in case of three available networks. In [7], the issues of spectrum share strategy and precoding strategy selection are formulated as a non-cooperative game. The Nash equilibrium is considered as the solution. But classical Nash game theory may have more than one equilibrium. In general, it is difficult to obtain all the solutions, let alone the best one. And the Nash game could not describe the dynamic strategy change of players. To account for the above problem, evolutionary game theory is used to deal with the network selection in heterogeneous networks.

The main purpose of this paper is to develop an effective network selection scheme to ensure that the allocation of the finite radio resources to each user in the constrained heterogeneous network as fair as possible. So in this paper, we integrate FAHP, GRA and EGT (GREGT) to address the network selection issue. Both user centric requirements as bandwidth and network centric concerns as load balancing are taken into account. The utility function is carefully designed to precisely quantify the relationship between the QoS and these attributes, in which the preference weights are calculated by FAHP and GRA is calculated to rank the candidate networks. Its convergence and adaptation properties are demonstrated by numerical and simulation results.

The remainder of this paper is organized as follows. The system model is described in Section 2. The details of our proposed GREGT network selection scheme are presented in

Section 3. Section 4 are the discussions of the numerical and simulation results. The conclusion is stated in Section 5.

II. SYSTEM MODEL

We consider a constrained heterogeneous wireless access network consists of a long term evolution (LTE), an IEEE 802.11-based wireless local area network (WLAN) and an IEEE 802.16-based world interoperability for microwave access (WiMAX). We denote LTE, WLAN and WiMAX by $i \in \{1, 2, 3\}$ respectively. We use $a \in \{1, 2, 3, 4\}$ to mark the different service area in Figure 1. The user number in area a is N^a. As shown in Figure 1, in order to provide diverse and ubiquitous services to consumers, the coverage areas of multiple radio access networks are overlapped.
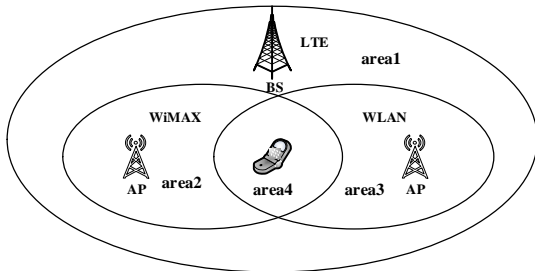

Fig. 1 Multimode terminal network selection in heterogeneous wireless networks

In general, LTE network has a wide coverage and would provide the mobile users with guaranteed QoS in a high price. While in the hotspot like the resting place users would prefer WLAN due to its lower price and higher data rate. As an enhancement, WiMAX performs better in terms of data rate and security. Therefore, a user equipped with multi-interface device would select the best access network according to its own QoS requirements, its preferences and network conditions.

III. THE PROPOSED ALGORITHM SCHEME

Game theory is used to make decision in complex situation where decision of an agent is affected by other agents. Basic ingredients of non-cooperative games are almost the same. They include a set of players which are the decision makers competing for network access opportunities. A set of strategies associated with each player which is the competitive action taken by the player, the payoff of each player given a chosen strategy and the solution. However, an evolutionary game extends the formulation of a non-cooperative game by including the concept of population. Further, in an evolutionary game model, there is a single or multiple populations. The players of one population may choose strategies against players in another population. As an alternative to the classical Nash equilibrium approach, dynamic evolutionary game is a very promising tool for describing competitions in large scale systems or strategic interactions among large number of players [8]. It makes the predictions of the player's dynamic behavior and outcome of the game be possible. At the same time, MADM is also a common method in network selection. Therefore, the specific GREGT algorithm is introduced as follows.

Step1 Weight Calculation

In this paper, for assigning the weight to each attribute involved in the selection, we use FAHP and standard deviation (SD) method to compute the subjective and objective attribute weights respectively.

The network selection problem is decomposed into a hierarchy of easy to solve sub-problems. The network selection is on the top level, the multiple attributes are on the second level and the solution networks are at the bottom. We make pair-wise comparison of these attributes and construct a FAHP matrix F based on their contributions to the final utility. $f_{ij} \in F$ is a scale from 0.1 to 0.9 which denotes the dominance ratio of attribute i to attribute j. f_{ij} is obtained according to user experience. The calculation of subjective weights using FAHP is given in detail in [9]. The subjective weights can be expressed as,

$$w^s = [w_1, w_2, \text{L}, w_n] \qquad (1)$$

where n is the number of attributes considered. The calculation of objective weight using SD is given in detail in [10], and can be expressed as,

$$w^O = [w_1, w_2, \text{L}, w_n] \qquad (2)$$

Then the comprehensive weight is,

$$w = [w_1, w_2, \text{L}, w_n] \qquad (3)$$

Step2 Rank networks

Score of each network involved in the selection is to be calculated. This rank depends on network parameters and attributes weight. In this paper, score calculation for selection is done using GRA and Game Theory's Evolutionary Game Model. At first, the GRA is used to get the initial network selection results. According to the user's preferences and network parameters to get the grey relational degree $GRC(i), i \in m$ of each network [11] by formula 4,

$$GRC(i) = \frac{1}{n} \sum_{j=1}^{n} w_j \xi_{ij}(j), j = 1, 2, \text{L} \ n, i = 1, 2, \text{L} \ m \quad (4)$$

where n is the number of attributes considered, m is the number of candidate networks, ξ_{ij} is the correlation coefficient. The original GRA method does not involve load balancing. However, load balancing is of vital importance to wireless resource management. In general, the capacity of an access network is limited. When the accommodated traffics exceed a certain threshold, the network performance will decline dramatically. Moreover, in network operator's opinion, load balancing is an effective approach to improve resource utilization and avoid network congestion. Then, to ensure that the allocation of the finite radio resources to each user in the constrained heterogeneous network as fair as possible, EGT is used to achieve the load balancing.

Step3 Evolutionary Game Model of the Network Selection

With the concepts mentioned above, the evolutionary game for the network selection problem in a heterogeneous wireless network can be described as follows.

- *Players:* For a particular service class, each user in each service area who can choose among multiple wireless access networks is a player of the game. For example, in Figure 1, considering a particular service class, the players are the users in that service class in areas 2, 3 and 4 who compete for bandwidth from LTE, WiMAX, and WLAN.

Note that the users in area 1 are not involved in the game since the LTE is the only wireless access network available to these users. But in this paper, we only consider the users in area 4.

- *Strategy:* in this paper, {LTE, WLAN, WiMAX} is the set of strategies for the players in area 4.
- *Payoff:* The payoff of a player is quantified by the achieved bandwidth and the price for it.
- *Population:* As shown in Figure 1, in the area 4, different business types belong to different populations.

For different business types, the sensitivity of different QoS parameters is different, so the corresponding utility function will also be different. In this paper, sigmoid functions are used to describe the utility,

$$U(x) = \frac{1}{1 + e^{-s(x-l)}} \qquad (5)$$

where the parameter s reflects the sensitivity of the user to the QoS parameter, and l is the minimum requirement of the user to the QoS parameter. By adjusting the value of s and l, we can obtain the utility function of different business.

We assume that $u_k(i)$ is the utility function when the business type k access the network i. We also assume that the allocated bandwidth of the user choosing network i is equal, the $u_k(i)$ can be expressed as,

$$u_k(i) = u_k^b(C_i / N_i) \qquad (6)$$

where u_k^b is the utility function to the bandwidth when the user's business type is k, C_i is the available bandwidth of the network i, N_i denote the total user number of network i in the service area 4, i.e.

$$N_i = \sum_{a=1}^{p} N^a x_i^a \qquad (7)$$

where N^a is the number of population in area a, x_i^a is the proportion of users in the population a to select the network i, p is the number of population. The access price function is defined as,

$$P(i) = p_i N_i \qquad (8)$$

where p_i is the price coefficient when access to the network i, N_i denote the total user number of network i in the service area 4. Then the net utility function can be defined as follows:

$$\pi_i^a(x) = GRC(i) * (u_k(i) - P(i)) \qquad (9)$$

where $GRC(i)$ is the grey relational degree of the user to select the network i.

Step4 Replicator Dynamic

The replicator dynamic equations are proposed to describe the players' behavior in an evolutionary game [12].The replicator equations can be expressed as follows,

$$\dot{x}_i^a = \sigma x_i^a (\pi_i^a - \bar{\pi}^a) \qquad (10)$$

where σ is a parameter that used to control the rate of the dynamics. The average payoff of the users in population a is computed from,

$$\bar{\pi}^a = \sum_i x_i^a \pi_i^a \qquad (11)$$

Based on this replicator dynamics of the users in population a, the number of users choosing network i increases if their payoff is above the average payoff. It is impossible for a user to choose network j, which provides a lower payoff than the current payoff. This replicator dynamics satisfies the condition,

$$\dot{x}_i^a = \sigma x_i^a (\pi_i^a - \bar{\pi}^a) = 0 \quad i = 1, \mathrm{L}, m; a = 1, \mathrm{L}, p \quad (12)$$

The GREGT algorithm can be summarized as shown in Table 1.

TABLE I GREGT ALGORITHM

1. *All users select a wireless access network with maximum grey correlation coefficient according to the GRA.*
2. *Loop:*
3. *user computes his payoff π_i^a by using (8) and compare it with $\bar{\pi}^a$*
4. *if $\pi_i^a < \bar{\pi}^a$*
5. *if $rand() < (\pi_i^a < \bar{\pi}^a) / (\bar{\pi}^a)$*
6. *choose network j where $\pi_j^a > \pi_i^a$ and $j \neq i$*
7. *end if*
8. *end if*
9. *end Loop.*

IV. NUMERICAL AND SIMULATION RESULTS

In this paper, three business types are considered, which are conversation, streaming and background service. The utility function parameters of three types of business are shown in Table 2, and the parameters of the networks and user QoS requirements are listed in Table 3[13].

TABLE 2 THE FUNCTION PAREMETERS WITH DIFFERENT TYPES OF BUSINESS

Business type	parameter s	parameter l	Minimum bandwidth requirement (kb/s)	Maximum bandwidth requirement (kb/s)
Conversation	76.005	64.5	64	65
Streaming	0.643	128	80	176
Background	0.05	25	0	50

TABLE 3 QOS PARAMETERS

Network	Parameters			
	Bandwidth /MHz	Load rate/ %	Delay/ ms	Cost/Mbps
LTE	7	80	40	1
WLAN	11	70	200	0.2
WiMAX	15	60	100	0.7

For the constrained heterogeneous network considered in this paper as shown in Fig. 1, we assume that the channel rates of LTE, WLAN and WiMAX are 7Mb/s, 11Mb/s and 15Mb/s

respectively. The number of users with each business type in area 4 is $N^4 = 120$. For the payoff function, we set the parameter $p_i = 0.01$. For the replicator equations, we set $\sigma = 1$. The evolutionary equilibrium process of each business type is shown in Figure 2.
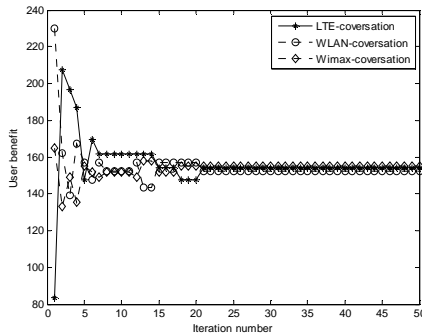

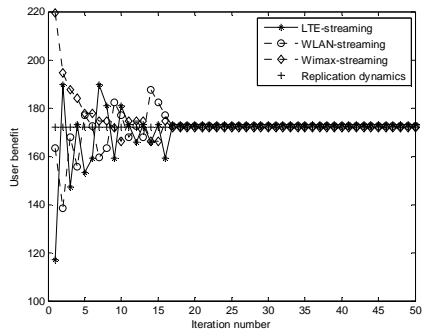Fig. 2(a). The evolution equilibrium process of conversation class service

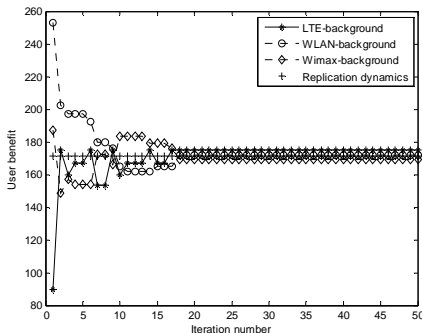Fig. 2(b). The evolution equilibrium process of streaming class service

Fig. 2(c). The evolution equilibrium process of background class service

The user benefit of different types of wireless access networks are depicted in Figure 2. The horizontal coordinate is the number of iterations, the vertical coordinate is the user benefit. From the figure, it can be seen, with the continuous network selection, the user benefit changes constantly. When the number of iterations reach about 20 times, the all user benefit are close to the average, and then stay the same. At last the populations converge to the equilibrium where the utility in different kinds of networks is the same.

In order to show the superiority of our proposed algorithm GREGT, WLAN priority algorithm is compared in network load and user satisfaction, only conversation business considered, and the simulation results are shown in Figure 3 and Figure 4.
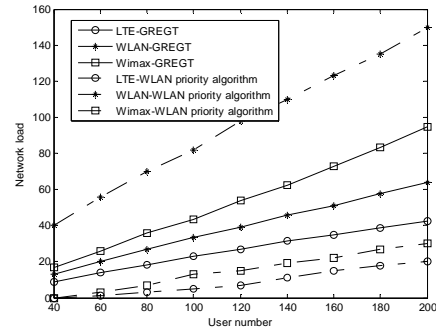

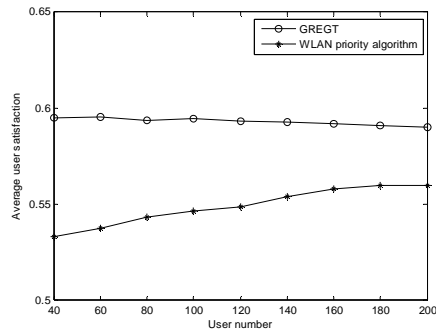Fig. 3 The network load of the conversation business

Fig. 4 User average satisfaction of the conversation business

The user average satisfaction versus the number of users is depicted in Fig. 4. As we all know, the conversation business has a high demand for time delay, so the LTE with minimum network delay will be the best choice to access. But using the WLAN priority algorithm, more users access to WLAN network. So the user average satisfaction of GREGT algorithm is always higher than that using the WLAN priority algorithm.

V. CONCLUSIONS

In this paper, the GREGT network selection scheme has been proposed in this paper to address the network selection problem for heterogeneous wireless networks, in which each user can gradually change its strategy to select a network with a higher payoff by observing other users' behavior. And User preferences and network load are considered in the utility functions design. The users in different service areas compete for bandwidth from different wireless networks. The numerical and simulation results show that load balancing can be achieved through our proposed evolution algorithm GREGT, and can greatly improve the user satisfaction.

REFERENCES

[1] S. Andreev, M. Gerasimenko and O. Galinina, "Intelligent access network selection in converged multi-radio heterogeneous networks," IEEE Wireless Communications, pp.86-96, Dec. 2014.

[2] F. Bari and V. Leung, "Automated Network Selection in a Heterogeneous Wireless Network Environment," IEEE Network, vol.21, no.1, pp.34-40, Jan/Feb.2007.

[3] D. E. Charilas, O. I. Markaki, J. Psarras, and P. Constantinou, "Application of Fuzzy AHP and ELECTRE to Network Selection," Mob. Light. Wirel. Syst., vol.13, pp.63–73, 2009.

[4] R. Aumann and J. Dreze, "Cooperative games with coalition structures," Int. Journal of Game Theory, vol.3, pp.317-237, 1974.

[5] M. O. Jackson, "A survey of models of network formation: Stability and efficiency," In Group Formation in Economics: Networks, Clubs and Coalitions, New York Cambridge University Press, 2004.

[6] Bin Liu, Hui Tian, Bin Wang and Bo Fan, "AHP and Game Theory based Approach for Network Selection in Heterogeneous Wireless Networks," The 11th Annual IEEE CCNC-Wireless Communications Track, 2014.

[7] Wei Zhong, Youyun Xu, Tianfield Huaglory, "Game-Theoretic Opportunistic Spectrum Sharing Strategy Selection for Cognitive MIMO Multiple Access Channels," IEEE Transactions on Signal Processing, vol.59, no.6, pp.2745-2759, June, 2011.

[8] Khan, M.A., Tembine, H., "Evolutionary coalitional games in network selection," Wireless Advanced (WiAd), pp.185-194, June 2011.

[9] Kaiyuan J. "Research on radio resources management method in heterogeneous wireless networks," Harbin Institute of Technology, pp.84-87, Jul. 2014.

[10] Zhang, S. and Zhu, Q, "Heterogeneous wireless network selection algorithm based on group decision," Journal of China Universities of Posts & Telecommunications, vol.21, no.3, pp.1-92, 2014.

[11] Zhao, S., Shi, W. and Fan, S, "A GRA-based network selection mechanism in heterogeneous wireless networks," Computer Mechatronics Control and Electronic Engineering (CMCE), 2010 International Conference, pp.215-218, 2010.

[12] Dusit Niyato, Ekram Hossain and Zhu Han, "Dynamics of Multiple-Seller and Multiple-Buyer Spectrum Trading in Cognitive Radio Networks:A Game-Theoretic Modeling Approach," IEEE Transactions On Mobile Computing, vol.8, no.8, August 2009.

[13] Ma, S. and Zhang, J, "Network selection algorithm by using AHP and entropy theory," Xi'an University of Posts and Telecommunications, vol.3, pp.162-167, 2014.