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A Game Theory Based Vertical Handoff Scheme For Wireless Heterogeneous Networks

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***Abstract*—Next-generation wireless networks integrate multiple wireless access technologies to provide seamless wireless connectivity for mobile nodes (MNs). When MNs move in wireless heterogeneous networks, they may suffer from the great degradation of received signal strength (RSS) and further quality of services (QoS), if randomly selecting an access point (AP). We address vertical handoff with game theory to enable MNs to trigger the handoff and select an appropriate network from multiple wireless access technologies. On the other hand, the existing vertical handoff schemes lack of jointly considering the behaviors of MNs and APs for approaching the reality. To solve this problem, we propose a repeated game based scheme for vertical handoff. Each sub-game is formulated as a non-cooperative strategic game between a MN and an AP in which the Nash equilibrium is the solution of each strategic game. The proposed repeated game is to optimize the utility functions of the whole network by finding an equilibrium point. We perform the performance analysis, which shows that proposed scheme can achieve better bandwidth utilization and throughput of the network compared to the AP random selection scheme.**

Keywords—Vertical handoff, wireless heterogeneous networks, game theory, Nash Equilibrium.

I. Introduction

As the development of wireless communication systems, heterogeneity has been introduced to be one of the most important features in the next generation wireless network [1]. In heterogeneous wireless networks, different wireless access technologies are integrated to complement each other in terms of coverage area, mobility support, bandwidth, and price. Based on such heterogeneous networks, some works have been proposed for extending the coverage of service availability and offering a range of connectivity alternatives, in terms of QoS support, coverage areas and service cost. For the characteristic of different wireless technologies integrated in networks, it is necessary to develop a vertical handoff scheme so that access points (APs) always provide best connections to mobile nodes (MNs) [2].

A typical architecture of wireless heterogeneous networks integrates different technologies of wireless communication including wireless local area networks (WLANs), cellular network and worldwide inter-operability for microwave access (WiMax). A base station (BS) of cellular network provides wide service coverage with low performance compared with WLAN access points (APs). Covering limited areas APs implement high-speed wireless communication. WiMax supports the performance with balancing between communication speed and service coverage by radio access station (RAS). And all of them can communicate with wired core network which is responsible for data processing. When the mobile nodes (MNs) , etc. PC or mobile phone, move in such wireless heterogeneous networks, it has high possibility to switch from one access technology to another. It results that the RSS and QoS of MNs degrade. Vertical handoff problem is how to select a suitable AP for MNs from different wireless technologies. A high performance scheme make MNs keep seamless connectivity. In the paper we address the problem of vertical handoff for wireless heterogeneous networks. We analyze the competitions among MNs in different service areas to share the limited resources by using game theory and propose a game theoretic vertical handoff scheme for wireless heterogeneous networks.

Most of existing works focus on one MN selecting from different APs. Several of them solve the problem by taking the competition among MNs into consideration. Even though few of them consider the competition between MN and AP, by which APs maximum the utilization of resources at the same time, when MNs make decisions. Taking the behaviors of MNs and APs into consideration, we formulate vertical handoff scheme for wireless heterogeneous networks as a non cooperative strategic game. By taking part in the game, APs and MNs perform the handoff decisions iteratively and repeatedly, to achieve the best performance with minimum cost. Nash Equilibrium (NE) is the solution of the problem. At equilibrium point, utility functions of both APs and MNs can not be increased by choosing other strategies unilaterally given the decisions of all the others. And utility functions can be defined according to user preferences and network capacity so that we can develop an adaptive vertical handoff schemes. In the numerical analysis, we analyze the scheme under different cases of network scenarios for approaching to reality. The simulation results suggest that our scheme increases the mean throughput of network and the bandwidth utilization of each AP.

The main contribution of this paper can be summarized as follows.

- We formulate vertical handoff problem in wireless heterogeneous networks as a repeated game, each sub-game of the repeated game is a non-cooperative strategic game.
- We propose a best-response based algorithm for finding Nash Equilibrium
- We show some numerical analysis for the proposed

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scheme and compare with other schemes

The organizations of reminding parts are we summarize some related works in section 2. In section 3 we describe the system model. We formulate the problem and show how to find Nash equilibrium in section 4. And then in section 5 we use some numerical analysis to inspect the performance of the proposed scheme. In last section we conclude the paper and list several future works to do.

II. Related Work

As the development of wireless communication integrating multiple technologies, vertical handoff problem becomes an important issue in wireless heterogenous communication. It has been extensively studied in recent years.

Traditional handoff algorithms are usually based on utility function. Every MN in network computes a value of utility function of each AP and selects the AP with the best value. Due to the different possible strategies and the numerous parameters involved in the process, researchers have tried many different techniques in order to construct cost functions. The Simple Additive Weighting Method (SAW) [4] and the Multiplicative Exponential Weighting Method (MEW) [5] are the most popular cost function based schemes. The work proposed an effective parameter measurement scheme for vertical handoff. Thus the studies reporting these algorithms lack enough details for implementation [2].

Several proposed schemes are focusing on keeping QoS level for vertical handoff. Kim, Sang-wook Han, and Young-nam Han [6] proposed a QoS-aware vertical handoff algorithm based on service history information. Another QoS based scheme are proposed by Lee, Han, and Hwang [7]. They calculate the QoS score for network by an utility function. The AP with highest QoS score is selected by MN.

The above schemes usually cannot efficiently make decisions for interactive MNs. Different selection of a user influences decisions of others. Also, user's selection results different resource allocation of networks. Game theory is an analysis tool for making decision interactively. By taking this kind of competition between users and networks into consideration, some game theoretic schemes for selecting suitable APs are proposed . Trestian, Ormond, and Muntean [3] survey the works briefly. In these works, different game models are used for achieving various goals or based on different network scenarios. Cesana, Malanchini, and Capone [8] proposed a congestion game for decreasing the interference among users. Kun, Dusit, and Ping [9] formulate the problem as a Bayesian game with incomplete information. Liu, Fang, Chen, and Peng [10] simulate the handoff decision problem into a bidding. Antoniou et al. in [11] look at the network selection problem and model the user-networks interaction as a cooperative repeated game.

To solve the problem for approaching to reality, we investigate a network scenario taking more reality parameters into consideration. The system model is described in the next section.

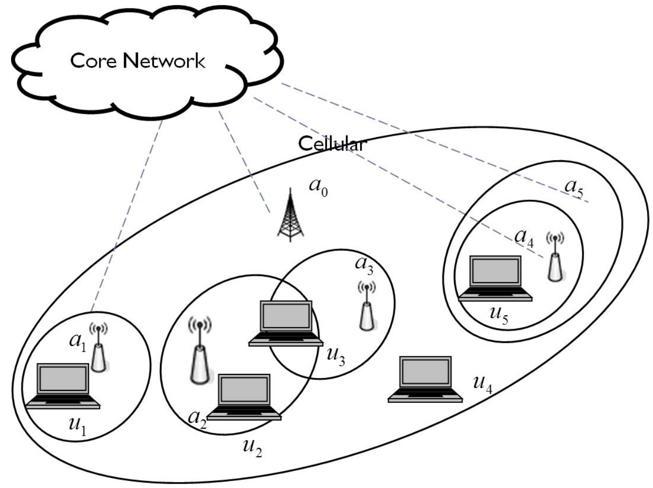

Fig. 1: A network scenario

III. System Description and Problem Formulation

A. System Description

In order to show the vertical handoff problem, we consider a typical scenario integrating cellular networks, WiMax and Wi-Fi LAN interwork to form a heterogeneous wireless networks. As shown in Fig.1, the network scenario consists of one cellular network, several WiMax RAS (radio access station) and Wi-Fi LAN APs, whereby the cellular system provides communication services in a larger coverage area with a relatively lower data rate at a higher cost whereas WiMax and Wi-Fi LAN can offer a relatively higher data rate in a shorter range with a lower cost. WiMax can be considered as a kind of Wi-Fi LAN AP with high coverage by WiMax BS. The BS and APs can communicate with the core network.

Fig.1 shows the three different cases.

- Case1: There is no overlapping part among the service areas of APs, e.g., the service area of AP a_1 in Fig. 1.
- Case2: There exist overlapping service areas between two APs, e.g., the service area of AP a_2 and a_3 in Fig. 1
- Case3: One AP is completely under the service area of another one, e.g., the service area of WiMax BS covers several WLAN APs, such as AP a_4 covered by AP a_5 in Fig. 1

Consider that there are m MNs moving in the area. The set of MNs is represented by $U = \{u_1, ..., u_i, ..., u_m\}$. The set of APs are represented by $A = \{a_0, a_1, ..., a_j, ..., a_n\}$, a_0 represents the BS of cellular network, $a_1, a_2, ..., a_n$ represent APs of WLAN.

For convenience the definitions of variable notations used in the paper are provided as follows.

- B_j maximum bandwidth which an AP a_i can provide
- r_i the bandwidth requested for handoff by MN u_i

- b_{ij} effective bandwidth of MN u_i when it is attached to AP a_j
- c_{r_i} the cost of MN u_i for obtaining requested resources
- C_{r_j} the cost of AP a_j for satisfying the requested resources for MN u_i
- F_{u_i} pay-off function of MNs
- F_{a_j} pay-off function of AP or BS
- RSS_{ij} received signal strength (RSS) of MN u_i from AP a_j
- θ_{a_j} RSS threshold of AP a_j

As we know, handoff process is divided into 3 steps: handoff initiation, network selection and handoff execution. Firstly handoff is triggered by an external condition such as signal degradation. And then based on always best connection (ABC) principle, MN makes network selection. Handoff execution is how the mobile device performs the transition from one network to another. In the system, , we assume that the handoff is triggered when the AP can not provide the requested performance from MN. When one MN moves in the area if the received signal strength (RSS) RSS_{ij} of an AP starts decreasing rapidly and falls below a RSS threshold θ_{a_j} for a specific period of time, or the allocated bandwidth to MN decreases to a low level, the handoff of MNs is triggered. All APs and the BS periodically broadcast advertisement messages announcing their availability and the cost of data transfer. According to the broadcast messages, each MN will establish a connection to an attachment point with highest efficiency by lowest cost. Then the handoff is executed by exchanging information between MNs and APs. We focus on handoff triggered and network selection.

The model used in the paper are based on the assumptions as follows.

- APs are responsible to collect the information for handoff including bandwidth, power consumption, cost and so on.
- MNs get the information of neighbor APs from current AP.
- Both APs and MNs are intelligent and rational. That means one side they can deal with the information by computing, another side they can make decisions according to others' behavior.
- Each MN attached to the same APs or BS uniformly share the resources allocated by the access points.
- No MN can know the decision of other nodes.

The first assumption means that AP has enough power to calculate so that MN with limited storage can save power. The other three assumptions are based on game theory. The rational players with no information of other players choose the best actions selfishly. It results the game can reach a Nash Equilibrium in which each player can not increase his pay-off by changing his decision.

We model a repeated game between MNs and APs. Each sub-game of the repeated game is a non-cooperative strategic game between composed by one MN and one candidate AP. MNs and APs selfishly make decisions to increase their profits. In one side, access points provide connections to the MNs for increasing its resource utilization. In the other side, the MNs select the access point that can provide the highest quality of service with lowest cost in the handoff process.

B. Problem Formulation

Game theory is a study of strategic decision making. The vertical handoff problem is a decision making problem. MNs determine when to trigger handoff and which AP to select. APs determine whether provide service to MNs and which quality of service to provide. The interaction between MNs and APs in vertical handoff can be formulate as a game.

Consider that there exist lots of MNs and APs. Initially a MN communicates with an AP. In one time, the degradations of received signal strength (RSS) and quality of service (QoS) trigger the handoff for some MNs. These MNs select a suitable AP from candidate ones. One MN and one AP construct a game. Then for a MN, there are lots of candidate APs. For an AP, there are lots of MNs sending handoff requests at the same time. The incentive of MN and AP is maximizing their utility function, denoted by F_{u_i} and F_{a_j}, respectively. AP just provide service to the MNs for optimizing its resource allocation. MN just select the AP with best QoS. So for MN and AP, it is possible not to obtain best results. After the first selection, some MNs handoff to a new AP. It results that new handoff are triggered due to new resource allocation. The processes continue until the whole network reach to an equilibrium point. In the point, the utility functions of MNs and APs is a social optimal.

1) Repeated Game for Vertical handoff: We formulate vertical handoff as a repeated game. The sub-game in each round is a non-cooperative strategic game between one player pair (u_i, a_j) in one stage. Repeated game is concerned about the sum of payoff (or utility) for every sub-game. There are lots of candidate APs (or BS) for a MN, and in the same time there are different MNs selecting an AP as candidate. As the actions change in every sub-game, the network topology and obtain payoffs change for each MN and AP. Due to the truth, it is necessary to repeat game until the network reaches a balancing point at which each MN and AP can not increase its payoff by changing their actions.

We assume that one stage strategic game is denoted by $G = \{P, S, U\}$ for T periods. P, S and U represent players, strategies and the corresponding utility respectively. At each period, the outcomes of all past periods are observed by all players. And we consider the case in which T is finite. That is, in each period t, $u_p(s_p^t, s_{-p}^t)$ is the stage payoff to player p when strategy profile $s^t = (s_p^t, s_{-p}^t)$ is played.

So the payoff to player p in the repeated game is

$U_p(s) = \sum_{t=0}^{T} u_p(s_p^t, s_{-p}^t)$.

Definition 1. (Nash Equilibrium) Let N be the number of players in a game and i be an index of a player such that $0 < i \leq N$. Let S_i denote a set of available mixed strategies for player i with $s_i \in S_i$ being any possible strategy of player i. The Nash Equilibrium satisfies the condition given in the following equation.

$\pi_i(s_i^*, s_{-i}^*) \geq \pi_i(s_i, s_{-i}^*), \forall 0 < i \leq N \forall s_i \in S_i$

Where $\pi_i()$ is the payoff function of player i, s_i^* denotes a Nash Equilibrium strategy of player i, and s_{-i}^* denotes the Nash Equilibrium strategies of all players other than player i.

For every stage game, if there exists a Nash equilibrium (NE), the NE is a sub-game perfect NE.

Definition 2. (Sub-game perfect Nash Equilibrium) A strategy profile is a sub-game perfect equilibrium if it represents a Nash equilibrium of every sub-game of the original game.

In the ideal condition, players can obtain highest payoff in each stage game.

Given the definition

$$c_{ij=} \begin{cases} 1, & \text{if } a_j \text{ is a candidate AP for MN } u_i, \\ -1, & \text{if } a_j \text{ is the current AP serving MN } u_i. \\ 0, & \text{if else} \end{cases}$$

The maximum payoff the players can obtain is represented as follow.

$$maxU_p(s) = \sum_{t=0}^{T} u_p(s_p^t, s_{-p}^t) \qquad (1)$$

subject to

$$\sum_{j=1}^{n} c_{ij} = -1 \qquad (2)$$

The purpose of the game is to obtain higher value of the utility functions for both MN and AP. Constraint promises that each MN can connect with one and only one AP at the end of the game. Every stage game is formulated as a non-cooperative strategic game, denoted by G. Game G consists of some components including players of the game, competing resources among players, strategies of players and utility/payoff functions.

- Players The agents who are playing the game: users or/and networks
- Strategies A plan of actions to be taken by the player during the game: available/ requested bandwidth, subscription plan, offered prices, available APs, etc.
- Payoffs The motivation of players represented by profit and estimated using utility functions based on various parameters: monetary cost, quality, network load, QoS, etc.
- Resources The resources for which the players involved in the game are competing: bandwidth, power, etc.

Concrete to the vertical handoff problem, players are MN and AP. Based on some actions, MN and AP select the strategy by which they can obtain more payoffs. The purpose is to compete resource in the networks. In the next subsection, we propose a non-cooperative strategic game between MN and AP, and give the description to the components of the game.

2) A Non-cooperative Strategic Game for Vertical Handoff: The incentives of MNs and APs in vertical handoff are different. An MN selects the best AP from candidate ones for obtaining high performance service. On the other side APs connect with MNs as many as possible for increasing the resource utilization. MNs and APs selfishly make decisions to increase their utility functions and do not know others' decisions. So we formulate the problem as a non cooperative strategic game. Firstly we construct the components of the game including players, resources, strategies, and utility functions.

- **Players** We have a set of MNs U, $U = \{u_1, ..., u_i, ..., u_m\}$, and a set of APs (or BS) A, $A = \{a_0, ..., a_j, ..., a_n\}$. a_0 represents the BS of cellular network. One MN u_i and one candidate AP (or BS) a_j construct a player pair. We denote player pair by (u_i, a_j). For constructing player pairs, we define an association matrix X consisting of x_{ij}. There are two conditions for MN (u_i and AP a_j) to construct a player pair. One is that the MN u_i requests to handoff, and another one is that the MN u_i is under the coverage of AP a_j. For computing X, in further, we give definitions as follows.

  $$s_i = \begin{cases} 1, & \text{if the handoff of MN } u_i \text{ is triggered} \\ 0, & \text{otherwise.} \end{cases}$$

  s_i suggests whether the MN u_i requests to handoff. c_{ij} show the relationship between MN u_i and AP a_j. So in further x_{ij} can be calculated as $x_{ij} = s_i c_{ij}$. If and only if $x_{ij} = 1$, MN u_i and AP (or BS) a_j can construct a player pair.
- **Resources** For competing some resources the players involved in the game. In vertical handoff, considering one player pair, to a MN, it requests handoff to a potential AP for obtain high performance or some special application, such as increasing bandwidth or QoS. To different an AP (or BS), under the constraint of owned resources such as maximum bandwidth B_{a_j} it provides services to MNs for increasing its utilization of resources while decreasing the cost for connecting one MN.
- **Strategies** Considering one player pair, there are two players in the game, MN u_i and AP (or BS) a_j. We use $S = \{S_u, S_{AP}\}$ denoting strategies of players, S_u and S_{AP} represent strategies of MN and AP, respectively. Assuming that the set of requests from MNs is represented by $R = \{r_1, r_2, ..., r_i, ...r_m\}$. MN u_i can stay connected with current AP (or BS) denoted by st or handoff to potential target APs (or BS) denoted by ho. For AP, there also exist two strategies. When MN u_i requests to handoff based on some necessary, AP a_j can select connecting with MN by promising satisfying the requests or not, denoting by P_h and P_l respectively.
- **Utility function** Utility is the ability of something to satisfy needs or wants. MNs request handoff to potential APs for obtaining high performance by low cost. APs provide services to MNs and increase utilization of resources. We define two utility functions, one is for MNs and another one is for APs denoting by F_{u_i} and F_{a_j}, respectively.
  The utility function of MNs are composed by two terms. One is a function related to the handoff request r_i. It indicates that the capacity of an AP to satisfy

the request. Another one is the cost of obtaining the requested resources. So the utility function of a MN u_i is the function:

$F_{u_i}(S_{u_i}) = f(r_i) - c(r_i)$ where $f(r_i)$ represents the utility of requested and $c(r_i)$ represents the cost for obtaining the request resources.

$f(r_i)$ is a monotonous increasing function as the satisfaction to resource allocated increases and the value of $f(r_i)$ belongs to $(0, 1)$.

Corresponding to resource requests, each AP can allocate resource to MNs connecting with it. The utility of AP is the sum of utility from each MN connecting with it. AP can select to provide service satisfying the request or not. The utility function of AP a_j is the function as follow.

$F_{a_j}(S_{a_j}) = g_{a_j} + c(r_i) - C(r_i)$ where g_{a_j} is the utility function before connecting with MN, $c(r_i)$ is the benefit obtain from connecting with MN, and $C(r_i)$ is the corresponding cost.

F_{a_j} is a piecewise function with the facts that before reaching to the maximum solving capacity, AP can always increasing its utility function by connecting with new MNs, after that the utility function decreases obviously.

Based on the components of the game, we model a non-cooperative strategic game $G = \{P, S, U\}$. The set of players are one MN and one AP, denoted by $P = \{MN, AP(orBS)\}$. The strategies of the game are $S = \{S_{MN}, S_{AP}\}$. S_{MN} is the set of strategies for MN, denoted by $S_{MN} = \{st, ho\}$. S_{AP} is the set of strategies for AP, denoted by $S_{AP} = \{P_h, P_l\}$. Given the definition of utility functions, each player can increase the utility function themselves until reach an equilibrium point. Then the repeated game is composed by several stage non-cooperative strategic games. The game is end until each player can not increase the pay-off by changing its action.

We formulate the vertical handoff as a repeated game and every sub-game is a non-cooperative strategic game and. The solution of the game is Nash equilibrium (NE). In the next section, we show an algorithm how to find NE.

IV. Proposed Algorithm

Both mobile node (MN) and access point (AP) can select two different strategies. F_{u_i} and F_{a_j} are utility functions. And $F_{u_i}(ho), F_{u_i}(st), F_{u_i}(P_h), F_{u_i}(P_l)$ are corresponding to the utility functions under different strategies. Based given the utility functions, they can calculate the utility under different strategies. The game between AP and MN can be represented by the following table.

	AP a_j provide P_h	AP a_j provide P_l
MN u_i ho	$f, F_{a_j}(P_h)'$	$F_{u_i}(ho), F_{a_j}(P_l)'$
MN u_i st	f_c, g_{a_j}	$F_{u_i}(st), F_{a_j}(P_l)$

For formulating the problem, we choose bandwidth as the competed resources in the network. MNs request handoff for satisfying bandwidth requirement. Bandwidth requested $r_i \in (0, max(B_{a_j}))$ and B_{a_j} is the maximum bandwidth of AP a_j. The utility function of MN is $F_{u_i}(S_{u_i}) = f(b_{u_i})$, where b_{u_i} is allocated bandwidth. The utility function of AP a_j is the sum of utility function for MN connecting with it.

$F_{a_j} = \sum_{\forall u_i \ c_{ij}=-1} f_{u_i}$

The values of utility functions are determined by bandwidth allocation. Considering in each player pair (u_i, a_j), both MN u_i and AP a_j selfishly chooses the strategies to increase the utility functions themselves until reach Nash Equilibrium which is defined as follows.

However, some games might not have a Nash Equilibrium or they can have more than one Nash Equilibrium.

Theorem 1. (Nash Equilibrium Existence) If we allow mixed strategies, then every game with a finite number of players in which each player can choose from finitely many pure strategies has at least one Nash equilibrium.

Now we use a two players game to prove it. There are two players A and B. There are two possible strategies for each of them. The pay-off of the game is shown as the following table.

	1	2
$1'$	a, a'	b, b'
$2'$	c, c'	d, d'

For pure strategic game, it is easy to find NE based on best responds. We consider the cases that there exists no pure strategic NE.

- $a < c$ and $c' < d'$ and $d < b$ and $b' < a'$, or
- $a > c$ and $c' > d'$ and $d > b$ and $b' > a'$

In these two cases, there exists no pure strategic NE. Now we prove there exist NEs if mixed strategies are allowed.

Definition 3. (Mixed strategy) A mixed strategy is an assignment of a probability to each pure strategy.

We suppose that player A select strategy 1 with probability x and player B select strategy $1'$ with probability y. So for player A the probability of strategy 2 is $1-x$. for player B the probability of strategy $2'$ is $1 - y$. The mixed strategy makes each player have same payoff from select the two strategies. From equality of the expected payoffs for player A.

$$ay + b(1 - y) = cy + d(1 - y)$$

$$y = \frac{b-d}{(c-a)+(b-d)}$$

From equality of the expected payoffs for player B.

$$a'x + c'(1 - x) = b'x + d'(1 - x)$$

$$x = \frac{c'-d'}{(b'-a')+(c'-d')}$$

In both of two cases, we get $0 < x, y < 1$. We can find a probability of pure strategy for each player. In another word, each player have a mixed strategy with a fixed probability to each pure strategy. Either a pure NE exists, or a fully mixed one exists in the general two-player game.

According to the theorem 1, in proposed game, two players MN u_i and AP a_j have finite strategies denoted by strategy set $S = \{S_{MN}, S_{AP}\}$. So at least one Nash equilibrium exists in the game. In the next we propose an algorithm for finding Nash Equilibrium based on the best-response principle.

	AP a_j provide P_h	AP a_j provide P_l
MN u_i ho	$f_{ho}-c_h, g_{a_j}+c_h-C_h$	$f_{ho}-c_l, g_{a_j}+c_l-C_l$
MN u_i st	f_{st}, g_{a_j}	f_{st}, g_{a_j}

For finding Nash Equilibrium, we substitute defined utility functions into table 1, then obtain a game between one MN and one AP as the following table.

Vertical handoff for heterogeneous wireless network is formulated as a noncooperative strategic game between MN u_i and AP a_j. The utility functions can be calculated as table 2. When MN u_i perceives the current quality of service (measure by f_{st}) degradation, MN sends handoff requests to potential APs. The utility function to handoff for MN is $f_{ho}-c_h$ and $f_{ho}-c_l$. When MN do not know the action of AP, MN makes decision selfishly to increase its utility function. Taking two cases into account, a best respond based algorithm is proposed.

- Case 1: If $f_{ho}-c_h > f_{st}$ and $f_{ho}-c_l > f_{st}$
- Case 2: If $f_{ho}-c_h < f_{st}$.

A. Case 1

In case 1, no matter what actions AP makes, MN selects handoff to the new AP. Even if the new AP provide low performance service to MN, MN can obtain more payoff compared with the current one. This is represented by $f_{ho}-c_h > f_{st}$ and $f_{ho}-c_l > f_{st}$. Based on best responds principle, strategy ho is dominant strategy for MN.

Definition 4. (Dominant strategy) In game theory, strategic dominance (commonly called simply dominance) occurs when one strategy is better than another strategy for one player, no matter how that player's opponents may play.

For finding Nash Equilibrium (NE), in further we compare the payoffs of AP, denoted by c_h-C_h and c_l-C_l. AP selects the strategy to increase its utility function. If $c_h-C_h > c_l-C_l$, strategy P_h is best responds to the dominant strategy of MN, and strategies set $\{ho, P_h\}$ is the Nash equilibrium. Otherwise if $c_h-C_h < c_l-C_l$, strategy P_l is best responds to the dominant strategy of MN, and strategies set $\{ho, P_h\}$ is the Nash equilibrium.

B. Case 2

In case 2, MN can not improve its quality of service by handoff to a new AP. But MN can increase its utility function by receiving low quility service from new AP. This case is described by $f_{st} < f_{ho}-P_l$. Strategies set $\{ho, P_l\}$ is Nash equilibrium. Otherwise, MN selects stay connecting with current AP, and the utility function of candidate AP do not increase. Both of two strategies set $\{st, P_h\}$ and $\{st, P_l\}$ are Nash equilibrium.

We describe the best response based algorithm for finding Nash equilibrium between one play pair as follows. Input is the game including players, strategies and utility functions. Output is Nash equilibrium of the game.

Algorithm 1 Finding Nash Equilibrium

Initialization Construct the game (P, S, U)
$P = \{u_i, a_j\}$, $S = \{\{ho, st\}, \{P_h, P_l\}\}$, $U = \{f_{st}, g_{a_j}; f_{ho}-c_h, g_{a_j}+c_h-C_h; f_{ho}-c_l, g_{a_j}+c_l-C_l\}$
if $f_{ho}-c_h > f_{st} || f_{ho}-c_l > f_{st}$ **then**
  Compare c_h-C_h and c_l-C_l
  if $c_h-C_h > c_l-C_l$ **then**
    return $\{ho, P_h\}$
  else
    return $\{ho, P_l\}$
  end if
else $\{f_{ho}-c_h < f_{st}\}$
  if $f_{st} < f_{ho}-P_l$ **then**
    return $\{ho, P_l\}$
  else
    return $\{st, P_h\}$ and $\{st, P_l\}$
  end if
end if

V. Numerical analysis

A. Parameter settings

In this section, we give the numerical analysis to the repeated game model for vertical handoff in wireless heterogeneous networks. Simulation tool is Matlab 2010b. We set one base station of cellular network and the number of WLAN APs increases from 4 to 49 as the network topology expands. All of WLAN APs are under the coverage of BS. The available bandwidth of WLAN network and cellular network are 54Mbps and 20Mbps, respectively. The BS allocates bandwidth to MN uniformly. APs allocate bandwidth according to bandwidth requests from MN. The overlapping areas changes according to different cases discussed above.

The number of MNs is changed from 100 to 1000. The number of APs increases as the number of MNs increases. Initially, each MN is allocated to some bandwidth randomly. And the set of bandwidth requests from a MN is $(1Mbps, 2Mbps, 3Mbps)$. If the allocated bandwidth of a MN is smaller than the request one, the handoff of the MN is triggered. For each kinds of network topology, we repeat simulation for 100 times. The parameter settings are described as the following table.

Parameter setting	
Number of APs	$5 \sim 50$
Number of MNs	$100 \sim 1000$
Maximum bandwidth of WLAN	54Mbps
Maximum bandwidth of BS	20Mbps
Bandwidth requests from MNs	1Mbps,2Mbps,3Mbps
Number of runs of simulation	100

The utility function we used is defined by Rakocevic [13]. They define three utility functions corresponding to different class applications. We choose the one that can indicate the relationship between allocated bandwidth to MN and maximum bandwidth of AP. The utility function is shown as follow.

$$f_{b_{u_i}} = 1 - e^{-\frac{\alpha b_{u_i}}{B_{max}}}$$

α is a scaling parameter which determines the shape of the function. We choose $\alpha = 1$. B_{max} is the peak rate of

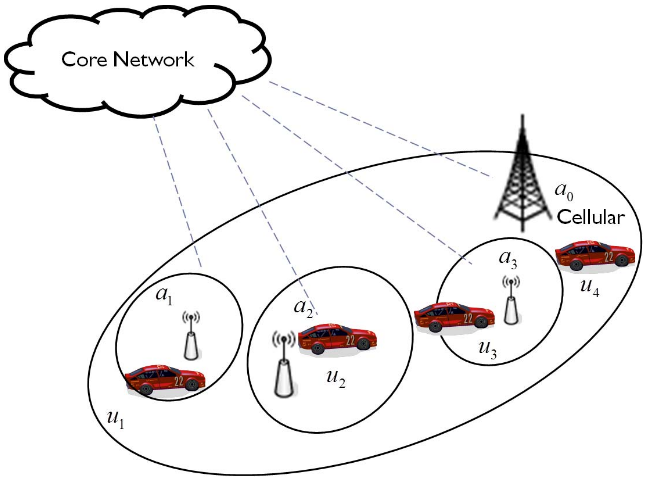

Fig. 2: The network topology in case 1 that there are no overlapping areas between nodes

allocated bandwidth by AP. We set B_{max} equals the maximum bandwidth of AP a_j, denoted by B_{a_j}. That means AP can allocate all bandwidth with best effort.

B. Analysis to results

As described above, we consider three cases of different network topology. In the numerical analysis, we implement the first case of network topology. The topology is randomly generated by a program.

In this case, the network are composed by 1 cellular network BS and several WLAN APs, among which there are no overlapping areas. That means for nodes within coverage of each AP, they can just select the AP or cellular BS to connect with. This is the simplest situation and the network topology are shown as Fig 2.

The network topology is randomly generated and represented by the association matrix c as described above, in which each item represents corresponding relationship between 1 MN and 1 AP. If the value equals 1, the corresponding MN is under the coverage of the AP, else if the value equals -1, that means the MN is connecting with the AP, else the MN can not connect with the AP. For case one, just the MN under the coverage of AP can select handoff between one AP and the BS. The bandwidth allocation strategies are different for the BS and AP. BS allocates its bandwidth to each MN uniformly. AP allocates the bandwidth based on the principle of first come first served. That means the AP allocates bandwidth to MN sending request firstly until there is no available bandwidth. We analyze meaning bandwidth utilization and mean throughput for AP. The value based on random selection is used to compare with the value after several stage games.

The red line represent the value after several stage games. The black line is the value of random selection for comparing with repeated game.

Fig 3 shows the change of mean bandwidth utilization for all the APs in the network. As network topology expands,

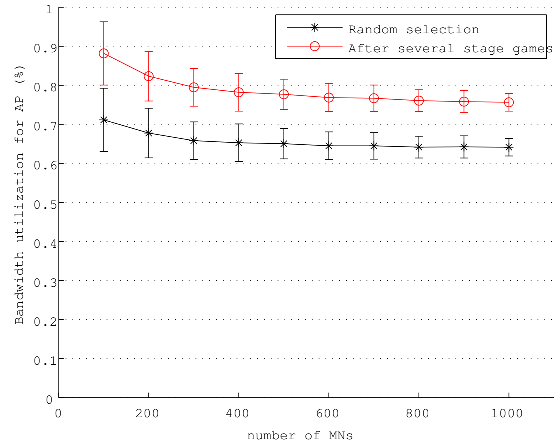

Fig. 3: The mean bandwidth utilization of an AP changed as the topology expansion

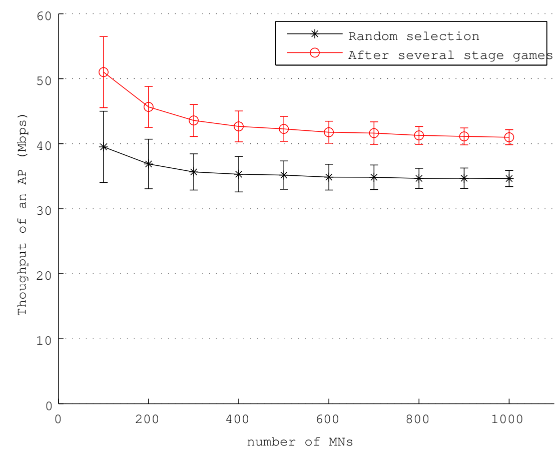

Fig. 4: The mean throughput of an AP changed as the topology expansion

the mean bandwidth utilization decreases. After handoff based on proposed repeated game, bandwidth utilization increases compared with the value based on random selection.

Fig 4 shows the change of throughput for AP as the network topology expansion. The proposed scheme increases the throughput of AP. But as the number of MN increases, the mean throughput decreases. Until the number of MN reaches to a value, the mean throughput tends to a stable value.

VI. Conclusion

The paper proposed a game theory based network selection scheme for wireless heterogeneous networks. One mobile node (MN) and one access point (AP) construct one player pair. The MN and AP repeated a strategic game. Every strategic game has a sub-game perfect Nash Equilibrium. And as the interaction among MNs and APs the game is repeated according to selection result of last stage game. The numerical analysis suggested that by repeated game the bandwidth utilization and throughput of AP is increased compared with random selection. After several stage games the payoff for MNs and APs is approaching to the result of social optimal.

In the future, we should give more numerical analysis to verify the conclusion. And the paper just consider a game between MN and AP. If taking behaviors among MNs into consideration, the problem are more complex. By considering competition among MNs a scenario is referenced as vehicular heterogeneous networks (VHNs) including vehicles to infrastructure (V2I) and vehicles to vehicles (V2V). And vehicles are mobile node in the scenario. V2I communication can be solved by proposed repeated game. And V2V communication can be formulated as a coalition game or cluster based architecture instead. We will consider a complete vertical handoff scheme for VHNs including both V2I and V2V communication.

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