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PERFORMANCE ANALYSIS OF HETEROGENEOUS NETWORKS USING COALITIONAL GAMES

Rajesh L.[1] and Bhoopathy Bagan K.[2]
Madras Institute of Technology, Anna University, Chennai, India
E-Mail: virudhairaj@gmail.com

ABSTRACT

A network which is best suited for a user in a heterogeneous wireless environment is selected by using a Game Theory technique. A statistical game theoretical model is developed by positioning the users randomly, setting-up the base stations of WiMAX and 3G as per standards of ITU and defining the Grade of Service (GoS) for each type of network respectively. Several parameters such as Received signal strength (RSS), Reputation factor, Energy utility, Cost utility and Mobility support are considered. With these parameters the Utility function payoffs are estimated for all the users. With the calculated Payoffs, an algorithm is designed for a best network selection by implementing Coalitional Game Theory principles. Performance estimation is done to demonstrate the Game Theory principles stand and compare with conventional network selection schemes.

Keywords: coalitional games, heterogeneous networks, WiMAX

1 INTRODUCTION

Next generation wireless networks are expected to exhibit heterogeneity in terms of wireless access technologies, services and application requirements. Modern wireless communication systems consist of cellular, WLAN and WiMAX access networks coexisting and are termed heterogeneous wireless networks. Technological advancements in the evolution of portable devices have made possible the support of different radio access technologies. This has raised much interest in the integration and interworking of WLAN, WiMAX and 3G cellular networks. It is expected that mobile users could enjoy seamless mobility and can stay Always Best Connected (ABC) anywhere and at anytime.

Every Radio Access Network (RAN) was designed independently, targeting different service types, data rates, and user's .The integration and inter-operation of these heterogeneous networks pose several challenges. One of the important issues the integration and inter-operation of these heterogeneous networks is to choose the optimal network depending upon the type of the demanding application. In general the network selection problem is part of the HO decision process and is modelled using either a centralized or a decentralized approach. Most centralized approaches are network-centric, and consist of a centralized, operator-controlled policy that decides the users' distribution among the networks. These network-centric approaches are based on the cooperation of subscribed user devices in obeying the decision made by the controller. For the decentralized approach the decision is made at the user side either by the user or automatically by the user's device.

2. GAME THEORY

Game theory can be defined as the study of mathematical models of conflict and cooperation between intelligent rational decision-makers. It is useful in analyzing situations in which two or more individuals make decisions that will influence one another's welfare. A game is described by a set of rational players, the strategies associated with the players, and the payoffs for the players. A rational player has his own interest, and therefore, will act by choosing an available strategy to achieve his interest. Coalitional game theory focuses on groups of agents, rather than individual agents. A coalitional game (*N,v*) consists of A set of players *N,* a *coalition* S is a group of cooperating players subset of N Worth (utility) of a coalition *v.* In general, payoff v (S) is a real number that represents the gain resulting from a coalition S in the game (N, v), v (N) is the worth of forming the coalition of all users, known as the grand coalition User payoff $x_{i:}$ the portion of *v(S)* received by a player *i* in coalition S. Once the utility parameters are estimated in the coalitional game, the solution to the game is found using shapely, core and nucleolus are [1, 2, 3, 4] used.

3. HETEROGENOUS NETWORK ENVIRONMENT ANALYSES

A heterogeneous environment is modelled in such a way that a WiMAX base station is located in the centre of a geographical area of 300 m × 300 m span. Hundred users are randomly located in the area considered. The coverage radius of a WiMAX base station is set as 50 km while the coverage radius of a conventional 3G base station is set as 5 km. Four Wi-Fi access points are deployed over the area with an overlapping coverage. Initially, 70% of the users are accessing Wi-Fi network; 15% of the users are provided with WiMAX connectivity and 15% users are connected to 3G network. The base station to which each user is connected can be identified by the BSIDs (Base Station Identification numbers) assigned ranging from 1 to 6.Wi-fi access points are assigned BSIDs from 1 to 4 to indicate to which access point, the users are connected. WiMAX and 3G base stations are referred by the BSIDs 5 and 6, respectively.

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3.1 Utility parameters formulation

From the above environment modelled, the utility parameters are estimated for each user. The utility parameters are Coverage and RSS, Reputation factor, Energy Utility, Mobility support, and Cost Utility.

i) Coverage and RSS

Each user position is checked to know whether it lies within the coverage of Wi-Fi WiMAX and 3G networks. The area under consideration is just 300m×300m, so all the users will be connected to any one of the networks. If the i^{th} user lies within the coverage radius of one or more networks, then the received signal strengths corresponding to each network is estimated as,

RSS = fn (distance, EMI, fading) (1)

If free space Propagation model is considered thus,

RSS = fn (distance) (2)

ii) Reputation factor

A database is maintained in such a way that it stores the details of service given by the service provider. Reputation factor of a particular network pertaining to a particular user is calculated as,

$$Reputation\ factor = h_i(r)/_{n} \tag{3}$$

Where, i= user index, r = network index, $h_i(r)$ = Number of call requests and packet data transfers handled by a candidate network 'r' for a particular user 'i, n = Total number of call requests and packet data transfers handled by all the candidate networks for a particular user.

iii) Energy utility

Energy utility for i^{th} user (e_i) is calculated as,

$$e_i = t_i\left(r_t + Th_{req} r_d\right) + c \tag{4}$$

Where, t_i = transaction time(s), r_t = mobile device's energy consumption per unit of time (W), Th_{req} = required throughput (kbps), r_d = energy consumption rate for data/received stream (J/Kbyte), e_i = total energy consumed (J) and c = constant

Also,

$$E_i = \begin{cases} 1 & , E < Emin \\ \dfrac{Emax - E}{Emax - Emin} & , Emin \le E < Emax \\ 0 & , otherwise \end{cases} \tag{5}$$

Where, E_{max} and $_{Emin}$ are the maximum and minimum energy utilities obtained from equation (4).

iv) Mobility support

The mobility support of each type of network is taken into account. This parameter indicates the level of user's mobility, and the network seamless connectivity. It's obvious that the order of mobility support is WiMAX>3G>Wi-Fi. So mobility support factor is chosen based on data rates of each candidate network and scaled accordingly.

v) Cost utility

The cost utility value for i^{th} user is calculated as:

$$cost_i = \begin{cases} 1 & , C < Cmin \\ \dfrac{Cmax - C}{Cmax - Cmin} & , Cmin \le C \le Cmax \\ 0 & , otherwise \end{cases} \tag{6}$$

Where, C = monetary cost for the current network C*min* = minimum cost that the user is willing to pay C*max* =maximum possible cost that the user can afford to pay.

3.2 Coalition formation process

Coalitions can be formed in two ways such as i)step by step process or Hierarchical model and ii) simultaneous process or Non-Hierarchical model.

i) Step by step process

Two parties negotiate and will reach an agreement if users are of same interest i.e., their maneuvering spaces overlap. Negotiation positions are denoted with x_1 and x_2, when a third party joins the negotiation. Players 1 and 2 operators proto coalition (1, 2) in agreement with 3 is only reached if maneuvering spaces of 1, 2 and 3 overlap. This process continues with adding new parties until a majority coalition (S) with position x_s has been reached. Number of coalitions (L) in step by step procedure (L) is calculated as,

$$L = C_n^2 + C_n^2 * (n-2) + \dots + C_n^2 * (n-2) * \dots * (n-(n-2)) * (n-(n-1))$$

$$= \frac{n!}{2} * \sum_{k=2}^{n} \frac{1}{(n-k)!} \tag{7}$$

ii) Simultaneous process

All parties of a coalition sit round the table to negotiate simultaneously. If the parties 1, 2 and 3 form coalition {1, 2, 3} their coalition position is $X_{\{1,2,3\}}$. A coalition forms if the maneuvering space overlaps. Number of coalitions is calculated as,

$$K = C_n^2 + C_n^3 + \dots + C_n^n = \sum_{k=2}^{n} C_n^k = 2^n - (n+1) \tag{8}$$

For three players, Number of coalitions formed will be six in case of step by step process and four in case of simultaneous process. For real time scenario systems, Simultaneous process is used. The users tend to form coalitions among themselves depending on the type of network currently connected. So the possible set of coalitions are {Wi-Fi, WiMAX, 3G, (Wi-Fi and WiMAX), (Wi-Fi and 3G), (WiMAX and 3G), (Wi-Fi and 3G and

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WiMAX). The solution to coalitional Game is obtained via Shapley Value Estimations and Nucleolus concepts.

3.3 Shapley value estimation

i) Shapley value calculation: Given a coalitional game (N, v), the Shapley value of player i is given by,

$$\phi_i(v) = \sum_{\substack{S \subseteq N \\ i \in S}} \frac{(|S|-1)!\,(n-|S|)!}{n!}\left[v(S) - v(S-\{i\})\right] \quad (9)$$

Equation (9) can be viewed as capturing the “average marginal contribution” of agent *i*, where the average over all the different sequences according to which the grand coalition could be built up from the empty coalition. More specifically, imagine that the coalition is assembled by starting with the empty set and adding one agent at a time, with the agent to be added chosen uniformly at random. Within any such sequence of additions, look at agent *i*’s marginal contribution at the time is added. If it is added to the set S, his contribution is [v(S ∪ {i}) - v(S)]. Now multiply this quantity by the |S|! Different ways the set *S* could have been formed prior to agent *i*’s addition and by the (|*N*| - |*S*| - 1)! Different ways the remaining agents could be added afterward. Finally, sum over all possible sets *S* and obtain an average by dividing by |*N*|!, the number of possible orderings of all the agents.

ii) Dissatisfaction estimation

For a user ‘i’, the dissatisfaction factor on a network to which it is currently connected is given by,

Dissatisfaction factor= 1/RSS+1/Mobility support +1/Reputation factor +Energy +cost (10)

The goal is to minimize the total dissatisfaction factor i.e., sum of dissatisfaction factor of all the users in a particular network of each network there by ensuring fairness in user distribution among the networks based on the extent to which a particular network can serve.

3.4 Nucleolus

As a measure of the inequity of an imputation *x* for a coalition *S* is defined as the excess,

$$e(x, S) = v(S) - \sum_{j \in S} x_j \quad (11)$$

Which measures the amount (the size of the inequity) by which coalition *S* falls short of its potential *v*(*S*) in the allocation *x*. Since the core is defined as the set of imputation such that $\sum_{i \in S} x_i \geq v(S)$ for all coalitions *S*, we immediately have that an imputation is in the core if and only if all its excesses are negative or zero. On the principle that the one who yells loudest gets served first, we look first at those Coalitions S whose excess, for a fixed allocation *x*, is the largest. Then we adjust *x*, if possible, to make this largest excess smaller. When the largest excess has been made as small as possible, we concentrate on the next largest excess, and adjust *x* to make it as small as possible, and so on.

Similarly excess in terms of networking domain refers to the excess load carried by the candidate network. The user who is having excess dissatisfaction will be served first and the one with second lowest will be served next and so on. By using Shapley value as limiting value iteratively the network load is decreased on the candidate network which has at most network load.

3.5 Super additivity property verification

For three candidate networks the characteristic function must be introduced with vector A= [v1 v2 v3 v12 v13 v23 v123]. A game is additive if v(S ∪ T) ≥ v(S) + v (T), for all disjoint coalitions S, T ⊂ N. This clearly states that the gain from coalition is always greater than or equal to sum of the gain of the individual users of various networks.

4. SIMULATIONS AND DISCUSSIONS

A heterogeneous wireless environment is simulated using MATLAB GUI (Graphical User Interface). A WiMAX base station is located in the centre of a geographical area of 300 m × 130 m span. Hundred users (100) are randomly located in the area considered. A 3G base stations is also setup in that area. In addition, Four Wi-Fi access points are also located in that area.

For simulations, the following assumptions are made, 70 % of the users are given access to Wi-Fi, 15% of the users are provided WiMAX connectivity and 15% of the users are connected to 3G.

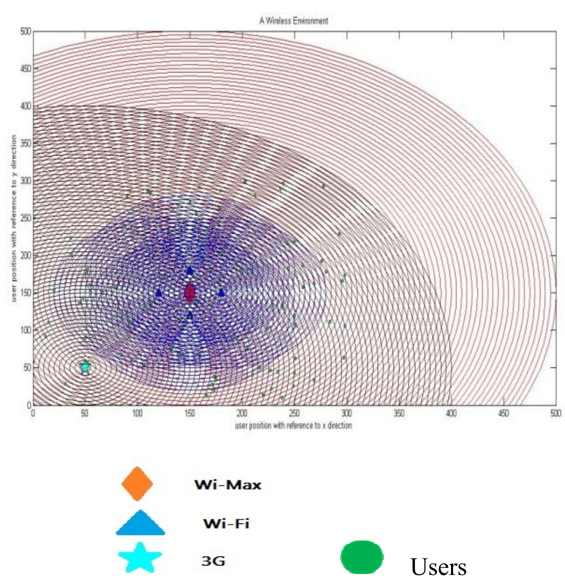

Figure-1. Heterogeneous wireless environment.

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For each user, user positions (X and Y co-ordinates) are generated. Each user has a BSID value which represents the base station to which it is connected currently. Utility parameters such as Reputation, Cost, RSS, Mobility and Energy are calculated. Shapley value is estimated for the possible set of coalitions {Wi-Fi, Wi-Max, 3G, (Wi-Fi and WiMAX), (Wi-Fi and 3G), (WiMAX and 3G), (Wi-Fi and 3G and WiMAX)}. Dissatisfaction factor is estimated for all the users and is minimized using nucleolus concept. The Figure-2 and Figure-4 show the GUI of random User position and utility parameter estimation.

Table-1. Initial user distribution.

	BSID	USERS
Wi Fi-AP1	1	23
Wi Fi-AP2	2	18
Wi Fi-AP3	3	9
Wi Fi-AP4	4	17
Wi-Max	5	16
3G	6	17

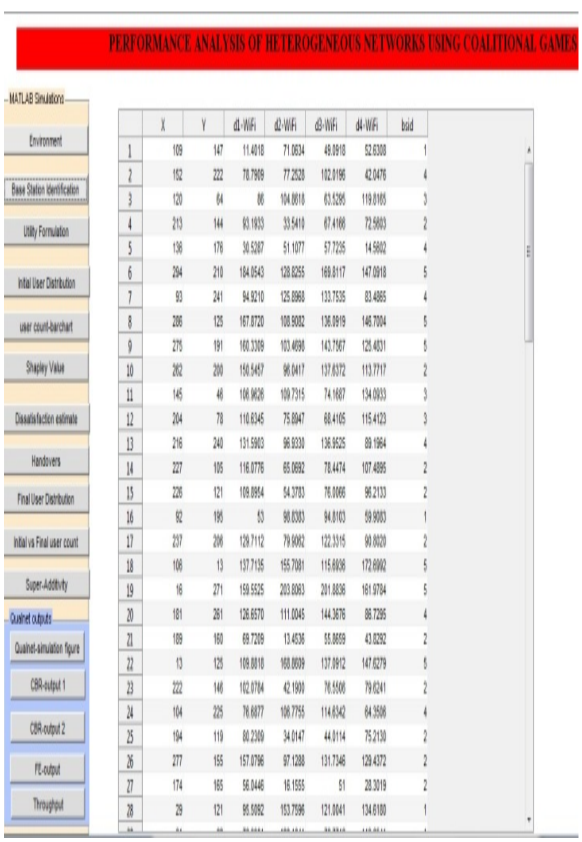

Figure-2. Random user position generation.

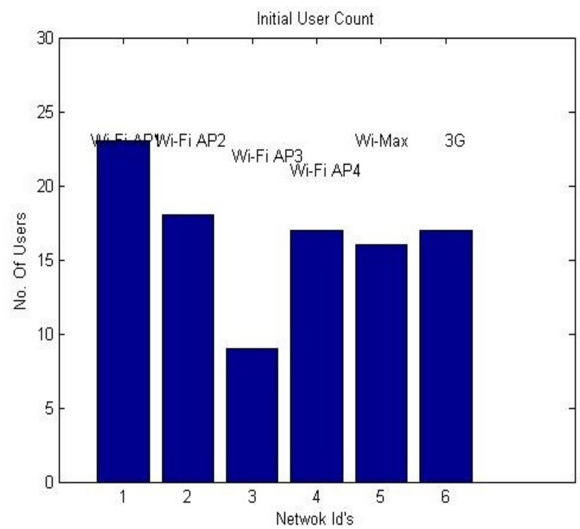

Figure-3. Initial user count.

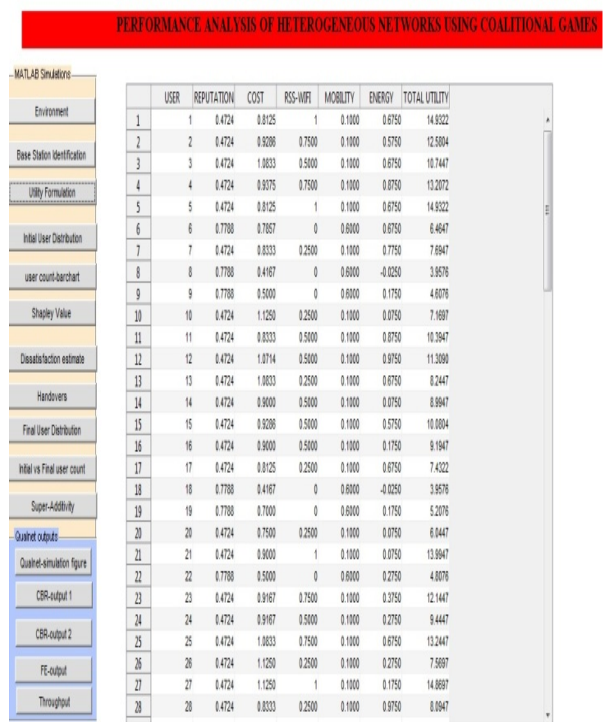

Figure-4. Utility parameters estimation.

Table-2. Shapley value estimated for coalition game.

	Shapley value suggestion
Wi Fi users	50.1667
Wi-Max users	24.6667
3G users	25.1667

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Figure-2 shows the random user positions (different X and Y co-ordinates) generated for various users. The distance between each user and all the Access Points (d1-WiFi, d2-WiFi, d3-WiFi, d4-WiFi) are calculated. For each user, bsid is found. bsid corresponds to the Base Station (Network dependent) to which he is currently connected. BSID for Wi-fi AP ranges between 1 and 4. The bsid of WiMAX network is 5. BSID is set to 6 if he is connected to 3G. Figure-4 shows the estimation of utility parameters such as Reputation factor, cost utility, RSS, Mobility support factor and Energy utility for various users.

Figure-3 shows the number of users in each type of network. The network id's from 1 to 6 represent Wi-Fi AP1, Wi-Fi AP2, Wi-Fi AP3, Wi-Fi AP4, WiMAX and 3G.

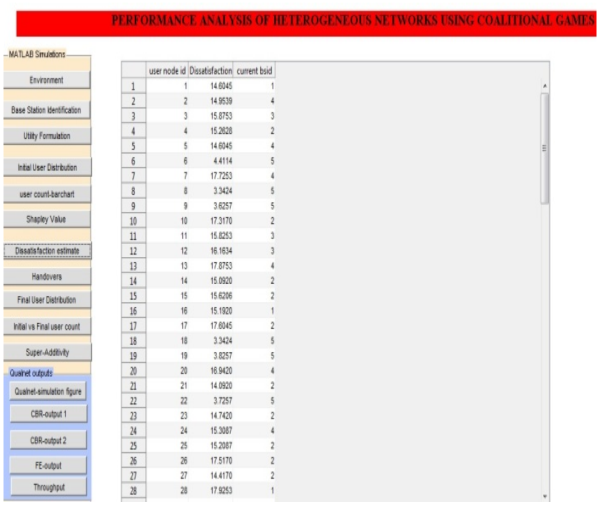

Figure-5. Dissatisfaction factor estimation.

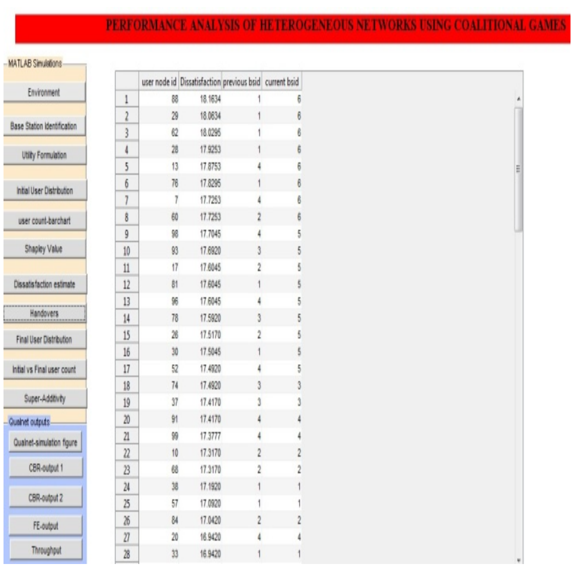

Figure-6. Handover visualization.

Table-3. Final user distribution.

	Network id	Initial user count	Final User count
Wi Fi-AP1	1	23	16
Wi Fi-AP2	2	18	15
Wi Fi-AP3	3	9	7
Wi Fi-AP4	4	17	12
Wi-Max	5	16	25
3G	6	17	25

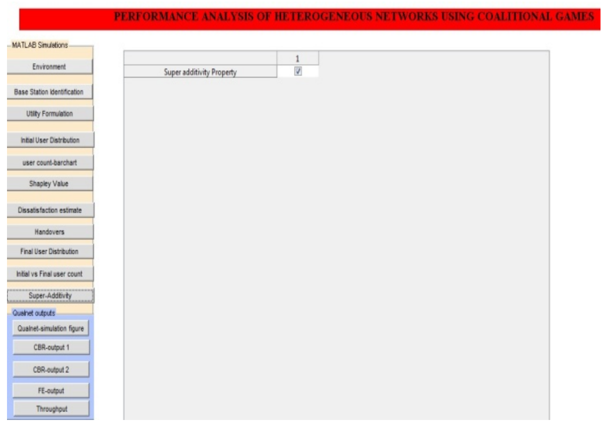

Figure-7. Super additivity property verification.

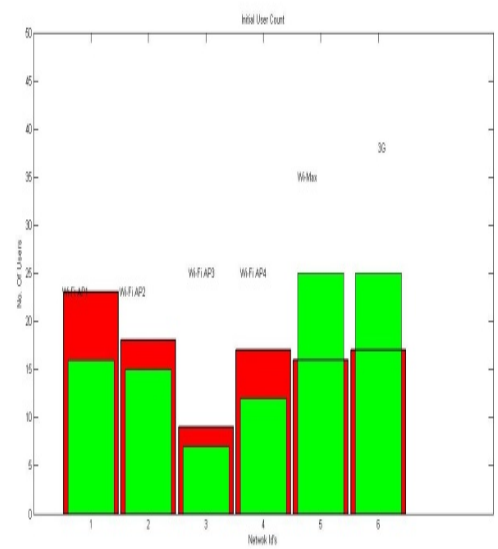

Figure-8. Network scenario after coalition formation.

For all the users, dissatisfaction factor is estimated based on utility parameters like Reputation factor, cost utility, RSS, Mobility support factor and Energy utility is shown in Figure-7. The Call request/ Packet Data Transfer requests from users with highest dissatisfaction factor are handed over to another Candidate Networks based on RSS and network load shown in Figure-8. The number of users in each type of network before Coalition formation are indicated by Red bars while the number of users in each type of network after Coalition formation. The excess users in the Wi-fi network whose dissatisfaction factor is fairly large are handed over to Wi-Max and 3G networks based on RSS is shown in Figure-5. The super additively property states that the gain of coalition is greater than or equal to sum of the individual players is shown in Figure-8.

5. CONCLUSIONS

In this paper a 4G heterogeneous wireless environment (WiMAX and 3G networks in particular) is modeled and the best ranked networks for the user are listed by employing a game theoretical technique which falls under the category of co-operative games. Various parameters such as Received Signal Strength(RSS) of WiMAX and 3G networks, Bandwidth availability, Data rate compatibility, Energy Utility, Link quality(QoS) and Cost utility for all the users are calculated. Based on these parameters the utility payoffs for all the users are estimated. The users are clubbed in a pair of two and then the solution to the game is found after examining the symmetry property over the region R. Coalitional Game Theoretical Technique can also be used to model the game. In Coalitional games, the modeling unit is groups or coalitions formed among the players instead of using individuals as modeling unit. In order to find solution to the game, non emptiness of the core is checked and Shapley value estimations are done. Using the coalitional games, the number of computations in MSC (Mobile switching center) can be greatly reduced and hand over can occur with minimum delays and QoS of the services is improved.

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