Network Selection in Heterogeneous Wireless Network: Evolution with Incomplete information

Pritesh Nandgaonkar 11D070004, Guide:- Shabbir Merchant

1. Abstract:-

In this report, we formulate the network selection problem in heterogeneous wireless networks with incomplete information as a Bayesian game. In general, the preference (i.e., utility) of a mobile user is private information. Therefore, each user has to make the decision of network selection optimally given only the partial information of the preferences of other users. To study the dynamics of such network selection, the Bayesian best response dynamics and aggregate best response dynamics are applied. Bayesian Nash equilibrium is considered to be the solution of this game, and there is a one-to-one mapping between the Bayesian Nash equilibrium and the equilibrium distribution of the aggregate dynamics. The numerical results show the convergence of the aggregate best response dynamics for this Bayesian network selection game. This result ensures that even with incomplete information, the equilibrium of network selection decisions of mobile users can be reached.

2. Introduction:-

The mobile users always want congestion free services. The mobile users are always in an area where there are many users and limited network providers. The idea presented in this project is to optimally decide which network the mobile users should select based on the inputs such as price of the network, bandwidth provided by the provider and the number of users in an area. This project formulates Network selection problem as Bayesian game and tries to maximize the utility of the users in an area. The analysis done in this paper gives the final result as the equilibrium distribution of the users in available networks given the information such as no. of users available networks and their bandwidth and pricing details. The motivation for formulating the network selection problem as game theoretic problem lies in the fact that in game theoretic approach the users always try to maximize their utility and this also happens in our case where users want to maximize their utility in the form of good service at low price.

The papers which are used as references are discussed in section 3.1. Actual formulation of the heterogeneous network selection as Bayesian game theoretic problem is done in section 3.2. The simulation results and observations are explained in section 3.3. This section is followed up with conclusion(4) , future work(5) and references(6).

3.1. Work Related:-

The paper which were used as a references are as follows

- Game Theory Based Implementation:- Solutions and Challenges Ramona Trestian, Olga Ormond, and Gabriel-Miro Muntean, Member, IEEE,2012

- Network Selection in Heterogeneous Network Kun Zhu , Dusit Niyato and Ping Wang IEEE communication Society 2010
- A survey on game theory applications in wireless networks Dimitris E. Charilas, Athanasios D. Panagopoulos
- Game theory by Osborne edition 2

The paper on game theoretic implementation by Ramona Trestian, Olga Ormond, and Gabriel-Miro Muntean gave different ideas as how we can transform the heterogeneous network based selection problem into game theoretic formulations . Examples in the form of modeling this problem as user vs network non cooperative game was explained where users compete against networks, each seeking to maximize their own utility. On one side, the users try to maximize their benefits from the service for the price they pay. On the other side, the networks try to maximize the profit for the provided services. One can even model this problem as cooperative game were network and users cooperate to achieve mutual satisfaction. Such game theoretic formulation helped me to understand and formulate the problem at hand in Bayesian game.

The paper by Dimitris E. Charilas, Athanasios D. Panagopoulos gave the general ideas about the game theory and how one can formulate the payoffs of the users considering different scenarios. One can take the payoff of the player to be Signal-to -Interference- and -Noise ratio. One can even model the game for network providers as how to distribute the limited spectrum to multiple wireless devices, for this the obvious utility function is based on the idea of Shannon capacity.

The paper by Kun Zhu , Dusit Niyato and Ping Wang explained the formulation of network selection as Bayesian game which will be explained in the coming sections.

3.2. Formulation of a Bayesian game:-

In game theory, a Bayesian game is one in which information about characteristics of the other players (i.e. payoffs) is incomplete.A Bayesian game can be modelled by introducing Nature as a player in a game. Nature assigns a random variable to each player which could take values of types for each player and associating probabilities or a probability density function with those types. The type of a player determines that player's payoff function and the probability associated with the type is the probability that the player for whom the type is specified is that type. In a Bayesian game, the incompleteness of information means that at least one player is unsure of the type (and so the payoff function) of another player. Players have initial beliefs about the type of each player (where a belief is a probability distribution over the possible types for a player) and can update their beliefs according to Bayes' Rule as play takes place in the game, i.e. the belief a player holds about another player's type might change on the basis of the actions they have played. The lack of information held by players and modelling of beliefs mean that such games are also used to analyse imperfect information scenarios.

The Bayesian game formulation for our problem statement is as follows:-

- *Players: N* active users in service area *a*.
- *Action*: Actions available to the users are the probabilities through which they select the particular network

  $\Delta = \{\boldsymbol{y} = [y_1, y_2, \dots \dots y_K]\}$ where $y_1 + y_2 + \cdots y_K = 1$
- Type of player i is the minimum bandwidth requirement ($b_i \in \sigma$). We have assumed that all users have same probability distribution of type and the probability density function of which is denoted by f(b_i).
- Strategy of a player i , $s_i: \sigma \rightarrow \Delta$ such that $s_i(b_i) = [s_i^1(b_i) s_i^2(b_i) \dots\ s_i^K(b_i)]$ represents the probability distribution over actions given the Bayesian strategy *si* and the minimum bandwidth requirement *bi*, where $s_i^k(b_i)$ is equal to y_k. To simplify the presentation, in the following we will use $s_i(b_i)$ and s_i interchangeably.
- Payoff the players are defined as

$$\pi_i^k = U(\tau_i^k) - P_k \quad \text{if } \tau_i^k > b_i$$
$$= -P_k \quad \text{if } \tau_i^k < b_i$$

Where $U(\tau_i^k) = \alpha \log(1 + \beta \tau_i^k)$, in particular, $U(\tau_i^k)$ is a concave function representing the bandwidth utility of user *i* given its allocated bandwidth τ_i^k from network *k* and P_k is the price charged by network *k* (i.e., connection fee).

Now we would analyze the Bayesian game that we just formulated above. Let *δ = {s*1*, s*2*, . . . , s$_N$}* denote the strategy profile in Bayesian network selection game which is the set of strategies adopted by *N* players. To ease the presentation, the strategy profile can be represented as *δ = {s$_i$,* **s**$_{-i}$*}*, where s_i is the strategy of user *i* and **s**$_{-i}$ is a vector of strategies of all users except user *i*. Similarly, the set of types of all users can be denoted as *{b$_i$,* **b**$_{-i}$*}* where **b**$_{-i}$ is a vector of types of all users except user *i*. The expected number of users choosing network *k* given all other users' strategies **s**$_{-i}$ and types **b**$_{-i}$ can be obtained from

$$I_k(s_{-i}, b_{-i}) = \sum_{j=1\ j \neq i}^{N} s_j^k\ (b_j)$$

And the expected number of users choosing network *k* containing all possible type combinations is expressed as follows:

$$I_k(s_{-i}) = \int .. \int .. \int .. \int I_k(s_{-i}, b_{-i}) \prod_{j=1}^{N} f(b_j) db_N \dots db_j \dots db_1$$

for $j \neq i$

Therefore, if user *i* chooses to access network *k*, the total expected number of users choosing network *k* becomes

$$L(N_k) = 1 + I_k(s_{-i})$$

Given all other users' strategies, the bandwidth allocated to user *i* by network *k* is

$$\tau_i^k(s_{-i}) = \frac{B_k}{L(N_k)}$$

Let $\varphi_i^k(s_{-i}, b_i)$ denote the probability of satisfying the minimum bandwidth requirement of user *i* by choosing network *k* given all other users' strategies $\boldsymbol{s_{-i}}$. If user *i* chooses network *k*, the expected payoff of user *i* is expressed as

$$\pi_i^k(s_{-i}, b_i) = \varphi_i^k(s_{-i}, b_i)(U(\tau_i^k) - P_k) - (1 - \varphi_i^k(s_{-i}, b_i))P_k$$

We have obtained the expected payoff of users for the underlying static Bayesian network selection game. For the Nash equilibrium of the underlying Bayesian network selection game, the expected payoff of user *i* considering the action distribution **y** and the strategy s_i are derived. $\pi_i(\mathbf{y}, \mathbf{s}_{-i}, b_i)$ can be obtained from

$$\pi_i(\boldsymbol{y}, s_{-i}, b_i) = \sum_{k=1}^{No.\,networks} \pi_i^k(s_{-i}, b_i) y_k$$

$$\pi_i(s_i, s_{-i}, b_i) = \sum_{k=1}^{No.\,networks} \pi_i^k(s_{-i}, b_i) s_i^k(b_i)$$

Therefore, the expected payoff of user *i* given strategy profile $\{s_i, \mathbf{s}_{-i}\}$ can be expressed as follows

$$\pi_i(s_{-i}, b_i) = \int \pi_i(s_i, s_{-i}, b_i) f(b_i) db_i$$

Let $K(s_{-i})$ denote the best response for player i given strategy profile $\{s_i, \mathbf{s}_{-i}\}$

$$K(s_{-i}) = \arg\max_{y \in \Delta} \pi_i(y, s_{-i})$$

The Bayesian strategy profile $\delta*$ is a Bayesian Nash equilibrium if and only if no user can benefit by unilaterally changing his strategy even just an action under a certain type.

Definition 1: A strategy profile $\delta* = \{s_i^* \boldsymbol{s}_{-i}^*\}$ is a Nash equilibrium if and only if $\forall s_i \in \Omega$, $\pi_i(s_i^* \boldsymbol{s}_{-i}^*) > \pi_i(s_i^* \boldsymbol{s}_{-i}^*)$ for all $i \in \{1, 2, . . ., N\}$, and for every i and bi, $s_i^*(bi) = K_i(s_i^*, bi)$.

The Bayesian best response dynamics is described by the law of motion on the space of Bayesian strategies as follows:

$$\dot{\boldsymbol{s}} = (K(E(\boldsymbol{s})) - \boldsymbol{s}$$

where K is the best response for player i ,the subscript i is omitted as it is symmetric for all players.

$$E(s)=(E(s)_1, E(s)_2, \dots, E(s)_K)$$
$$E(s)_k = \int s^k(b)f(b)db\ ,\ k \in C$$

Due to the complexity in analyzing the Bayesian best response dynamics in the $L1$ space, aggregate best response dynamics is applied. According to, the definition of aggregate best response dynamics for Bayesian network selection game is given as follows:

$$\dot{x_t} = \gamma(E(K(x_t)) - x_t)$$

where $\mathbf{x}_t$ is the aggregate network selection distribution at time t and y is the learning rate which represents the proportion of users adjusting their strategies towards best response to the current network selection distribution at each selection epoch. We let $\mathbf{x}(m)$ denote the social network selection distribution at selection epoch m. Notice that $\mathbf{x}(m)$ is different from $\mathbf{x}_t$. $\mathbf{x}(m)$ is a network selection distribution point which is the weighted best response (i.e., considering the learning rate) to $\mathbf{x}(m-1)$, while $\mathbf{x}t$ describes the path from $\mathbf{x}(m-1)$ to $\mathbf{x}(m)$.

$$\mathbf{x}(m) = \gamma E\,(K(\mathbf{x}(m-1))) + (1-\gamma)\mathbf{x}(m-1)$$

3.3. Results:-

The parameters required to define this problem are no. of players, no. of network providers along with their bandwidth and pricing value. In this simulation no. of players are taken to be 20 and no. of network providers are taken to be 3. The typical scenario will be as shown in Fig. 2. Gradient descent algorithm is applied for solving the ODE . We can observe from Fig.1 that the distribution converges. Also the graph of distribution vs price change in network 3 is plotted in Fig.3. The bandwidth of Network 1, Network2 and Network 3 under consideration for Fig.1 are 20,30 and 25 respectively. The pricing for different networks are 0.25,0.3 and 0.35 for network 1,network 2 and network 3. The initial distribution of the users are 0.3,0.4 and 0.3 for network1 ,nework2 and network3 respectively. Thus ideally we would expect the final distribution to be higher in network 3 as the available bandwidth is more and the price is not that significantly high. This trend is clearly observed in Fig.1.We can observe that after 140 iterations the final distributions has achieved the equilibrium. Also it will be interesting to note as what will be the trend of final distribution as we vary price of network 3.

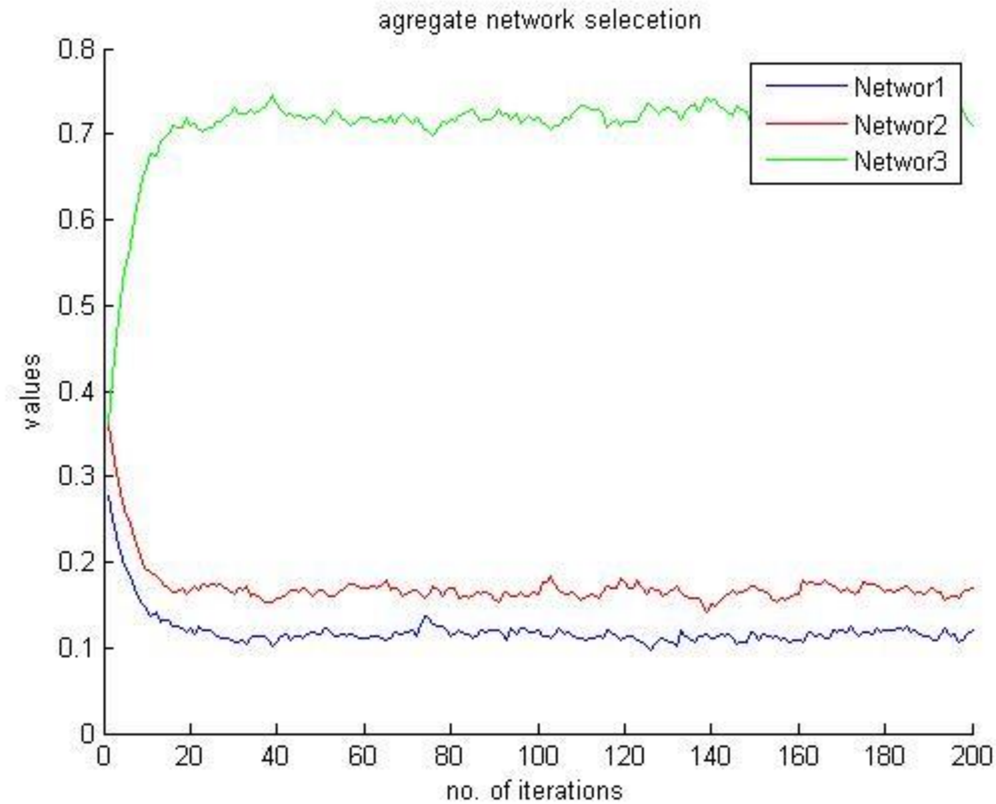

Fig1:-Final distribution of users in three networks

Network 3 provides more bandwidth as compared to other networks but if we increase its price it will not be beneficial for the players /users to keep continuing with the network3. Fig.3 provides the plot which clearly displays that as we increase the price of the network 3 the distribution of users in network3 decrease and correspondingly distribution of network1 increase. Distribution of network1 increase because its price is less and bandwidth available is not too bad as compared to network2.

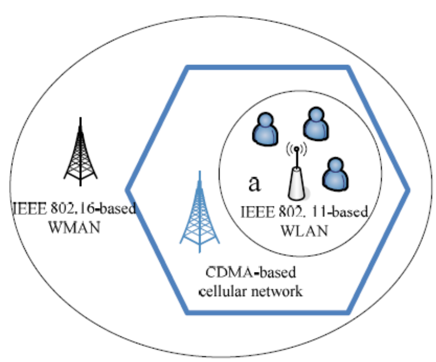

Fig.2:-Users and network displayed in an area

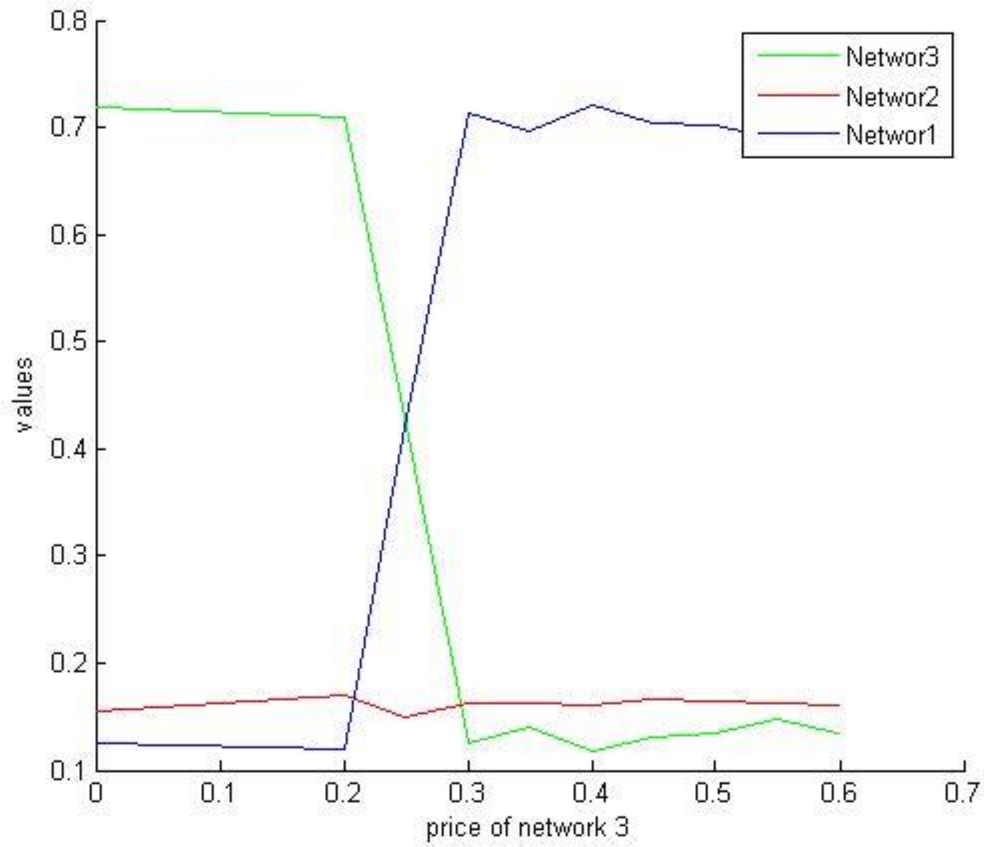

Fig 3.:- Distribution of the users vs price of network 3

4. Conclusion:-

Formulating Heterogeneous network selection problem as game theoretic Bayesian game problem gives satisfactory results for the scenarios under consideration. One can still improve on learning rate to get the desired result for less number of iterations. Through the above formulation one can easily predict what will be the distribution of the users in different networks. This data would be helpful to many companies in order to improve their services and revenues.

5. Future work:-

One can incorporate the feature of user selecting multiple networks simultaneously ,basically can incorporate the green symbiotic framework with this. One can improve this analysis by relaxing the assumption that that all users have same probability distribution of type and the probability density function of which is denoted by f(b_i).

6. References:-

- Network Selection in Heterogeneous Network Kun Zhu , Dusit Niyato and Ping Wang IEEE communication Society 2010
- Game Theory Based Implementation:- Solutions and Challenges Ramona Trestian, Olga Ormond, and Gabriel-Miro Muntean, Member, IEEE,2012
- A survey on game theory applications in wireless networks Dimitris E. Charilas, Athanasios D. Panagopoulos
- Game theory by Osborne edition 2