A Network Selection Mechanism for Fourth Generation Communication Networks

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***Abstract*— It has been widely agreed that there will be a co-existence of different radio access technologies in fourth generation communication networks. So there will be a problem of choosing the best access network at a particular time. The selection of the best access network will depend on a number of factors. This work aims to take into account their influence in the selection of the network using a Game theoretical modeling to solve the network selection problem. The paper introduces the concepts of Strategy Space, Quality Points in the Game theoretical context and gives a mathematical mechanism for network selection. Finally it is shown that only the best network serves the service request of the user.**

***Index Terms*—4G communication networks, network selection, Game Theory, quality points, strategy space, weighting factors.**

I. INTRODUCTION

Up to the third generation (3G) communication networks homogenous networking has been mainly used to serve the subscribers. The basic idea behind the evolution of fourth generation (4G) networks is to give the user the opportunity to be always best connected [1] as described by E. Gustafsson and A.Jonsson. This will enable the subscribers to take advantages of networks having different architectures and varying capabilities. Therefore the networking scenario is a heterogeneous one. For example, WCDMA & WLAN (Wireless Local Area Network) networks can be combined in a converged networking framework. Interoperability [2], Interworking [3], Convergence [4] of different access networks are going to be some of the key issues in the 4G environment. Therefore, in such a situation it has to be decided why and how one access network is preferred to a different access network to provide service. Such a converged networking scenario has been modeled with the aid of Game Theory [5] by J. Antoniou and A. Pitsillides. This paper models the 4G environment from a Game theoretical point of view too but introduces additional concepts and a different mechanism for network selection. This work will demonstrate the process by which network selection mechanism will work. It will also be proven that only the best access network will serve the subscriber when this mechanism is implemented. The rest of this paper is structured as following: Section II introduces related works in the field, Section III gives brief overview of the approach taken in this paper and the basic assumptions, Section IV and V discusses Game Theory, explains related concepts and illustrates the mathematical mechanism for network selection in detail. Section VI discusses ways by which networks try to maximize their payoff, Section VII explains service and access provider's role in network selection, Interconnection pricing and network congestions issues. Section VIII demonstrates the concept and shows how the user will be assigned the best network if this mechanism is used. Finally, section IX provides conclusions and future plans.

II. RELATED WORKS

Game theory has been used extensively in wireless networking. In the recent years there have been a number of publications which deal with best access network selection in 4G communication networks. Reference [5] used a Game Theory based model for 4^{th} generation communication networks and they introduced a game played in stages allocating service requests to competing access networks. In this paper, the authors have acknowledged the user centric paradigm of 4G by making user satisfaction a goal for the competing access networks. They have also described the user utility and preferences which are related to Quality of Service (QoS) parameters such as delay, jitter and packet loss. They have rightly explained the different effects of real time and non real time services on user utility or satisfaction. However, like some other works only QoS parameters have been considered. According to our argument other factors for network selection should be taken into account. In [6] however, the authors proposed an algorithm to predict the transfer completion time, utility and consumer surplus. In addition they have ensured that the user is connected to the cheapest network given that the data transfer completion time of that network is less than a threshold which can be set by the user. However,

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in this paper the authors used two networks of same technology (WLAN) to evaluate their concept. But in 4G there will be access networks belonging to different radio access technologies. Reference [7] has also described a utility based model for heterogeneous networks. They have shown that their algorithms not only ensure user utility but also help in distributing network load evenly. The paper of Ronald van Ejik et al [8] explains the roles of service platform and terminals on the network selection decision. The authors of this paper are in favor of a mobile terminal controlled handover approach. But, this approach might not be suitable for a handheld device because the overhead signaling will drain the battery power of the terminal at a rapid rate. Another paper of Rinta-Aho [9] identifies a variety of factors which can be taken as inputs for making the network access selection decision. But a mathematical mechanism to tie up these factors is missing. In [10], the authors modeled access network selection in next generation networks as an optimization problem. They proposed a system to maximize the user satisfaction or utility which will depend on the data rate and possibly other parameters. The network resources were defined as main constraints for the optimization problem. E. H. Ong and J.Y.Khan. [11] have come up with a network selection algorithm. In this paper the authors state that network QoS parameters are highly dynamic, existent static optimization based solution to network selection might not be as effective. Therefore they proposed a network selection mechanism based on sequential Bayesian estimation which takes into account dynamic QoS factors. The authors of these papers did not clearly identify other parameters (for example speed of users, user preferences, cost which can act as possible constraints) for access network selection. Ref. [12], On the other hand identified the differences between a network assisted and terminal based network selection approach. They also proposed a network assisted selection mechanism which is compatible with our approach. However, in this paper the authors did not provide an algorithm for network selection. If we look deeply into the existing literature it is evident that a balanced approach which ensures proportional impact of input factors on network selection decisions and which precisely explains why that particular approach is worth implementation is absent.

III. Our Assumptions and Proposal

We have defined and classified a variety of factors which influence the network selection decision. In this work we have been able to formulate a mathematical mechanism of network selection under the non co-operative Game theoretical framework as explained by the authors of Ref. [13] but here we consider that the game to win service requests will be played between three access networks namely:WCDMA(Wideband Code Division Multiple Access),WLAN(Wireless Local Area Network) and WiMAX(Worldwide Interoperability for Microwave Access). Additionally concepts like “strategy space”, “quality points” and “weighting factors” will be described to illustrate the possible 4G scenario and to make the network selection decision. In this work we will consider a possible 4G scenario where each of the three access networks has the coverage of a particular area. In addition, the subscriber will have a mobile device which is capable to operate in WCDMA, WLAN and WiMAX mode. This networking scenario will lay the platform for a competitive game being played among the three access networks. In the next section Game Theory based modeling has been described.

IV. Modeling 4G Scenario based on Game Theory

Game theory is the study of a mathematical model of conflict and co-operation between intelligent rational decision makers [14]. The critical components of a game are:

(A) A well defined set of two or more players.

(B) A set of actions or strategies for each player.

(C) A set of payoff functions for each player for each possible strategy.

We will consider the following game which has similarity with the model of [5] but also has differences which will become evident later in this section:

$G = \{N, K, P_i\}$ where

N=the set of players (here three access networks: WCDMA denoted by 1, WLAN denoted by 2 and WiMAX denoted by 3).

K=the set of strategies (Service requests that access networks choose to serve with the aim of achieving the highest payoff).here we consider three types of service requests: streaming video denoted by 1, internet surfing denoted by 2 and voice call denoted by 3.

Pi=the payoff for each player i for choosing a strategy from the set of strategies K.

Now the strategy space based modeling of the 4G networking environment will be introduce. The strategy space in this work is just a three dimensional modeling of a possible 4G converged network scenario. Following are the elements that make up the strategy space:

A. Individual Access Networks

According to a Game theoretical model [5], the players of the game are the individual access networks (here WCDMA, WLAN, WiMAX) each of which competes to win a service request. Here we have positioned these networks along X, Y and Z axis respectively.

B. Strategies of Access Network

In a Game theoretical model each player can choose a strategy from a set of strategies. In network selection game the strategies are the service requests. At a particular time each player makes choice of a strategy with the aim of achieving highest payoff. Here each access network makes choice of a service request with this aim. Therefore there are varying combinations of these strategies which give the strategy space co-ordinates. Accordingly this strategy space is given in figure1.

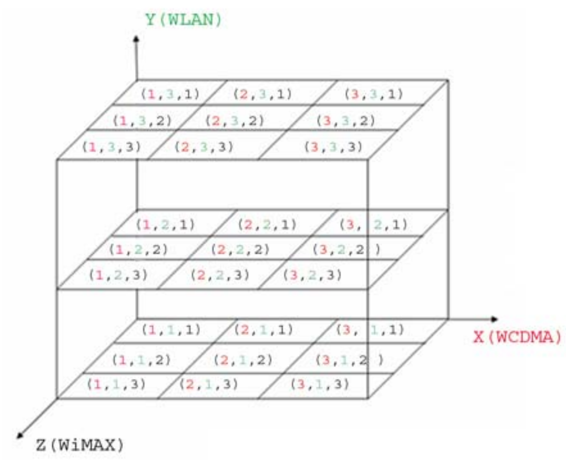

Figure1. Strategy space

For example the strategy space co-ordinate (1, 1, 2) means that WCDMA network has chosen strategy 1(streaming video),WLAN has chosen strategy 1 too and WiMAX has chosen strategy 3(Voice call).In general three competing access networks along 3 co-ordinate axis together with varying combinations of their chosen strategies make up the strategy space. We would like to clarify that in reality the 4G environment will be made up of a number of access networks (players) not only the three players we mentioned above. There will also be a wide variation in service types (here we have considered 3 service types: streaming video, internet surfing, voice call).The services can also be classified as real time and non real time services. Therefore, the actual 4G scenario will be multidimensional with varying combinations of the service requests (strategies).For example, if m players (access networks) are competing to serve n service requests, there will be n^m strategy space co-ordinates in the m dimensional strategy space. Here, we considered three players (WCDMA,WLAN,WiMAX) to illustrate the possible multidimensional 4G scenario in a simple three dimensional representation. So, in our example strategy space with 3 players and 3 service types, m=3, n=3. Here we have chosen these access networks because we have observed that user prefer WCDMA network for voice calls while they are more comfortable with WLAN when they are running high bandwidth applications at a nominal cost. WiMAX also seems to be a promising access technology for next generation internet access. Each of these three technologies have different capabilities to offer to the subscribers which make them ideal to be modeled as players in a competitive 4G network selection game.

V. Calculating the Payoffs

A possible 4G scenario has been modeled from a Game theoretical point of view in the previous section. The next step is to calculate the payoffs of each competing access network. The payoffs will not only depend on the choice of strategy of the access networks but also on other factors which are denoted by A to E in this paper. Each factor will have an associated condition at a particular time which is denoted by an integer for clarity and demonstration purpose. These factors or inputs are identified as following:

A. The type of service: streaming video (1), internet surfing (2), voice call (3).

B. User preference: Cost (1), Quality (2).

C. Traffic state and signal strength of the network: bad (1), medium (2), good (3).

D. Speed of the user: High speed (1), Low speed (2), Stable (3).

E. Drainage rate of battery in each mode: (1), (2), (3), (4), (5), (6).

Here, the fifth input factor will now be clarified. This factor is kept dynamic in this work. In case of the fifth factor (factor E), input condition 1 means that in a three mode (WCDMA, WLAN, WiMAX) enabled mobile device in the 4th generation communication networks, WCDMA is draining battery power at the least rate, WLAN is draining the battery power at a worse rate than WCDMA and WiMAX is draining the battery power at the worst rate among the three modes. Therefore the conditions are given as following:

1 means that WCDMA>WLAN>WiMAX
2 means that WCDMA>WiMAX>WLAN
3 means that WLAN>WCDMA>WiMAX
4 means that WLAN>WiMAX>WCDMA
5 means that WiMAX>WCDMA>WLAN
6 means that WiMAX>WLAN>WCDMA

The information regarding these input factors and their associated conditions will be collected by the 4G core network with the aid of individual access networks and the user(for example the user will set his cost/quality/bandwidth preference in his mobile device and this information will be collected by the 4G core network). Upon the collection and processing of this information the 4G core network will give the network selection decision using the following mathematical manipulations.

A. *Assignment of Quality Points*

Earlier it has been stated that, the payoff of each competing network depends on a number of factors (namely A to E),again each factor or input has a number of specific conditions which are denoted by a number (1, 2 and so on).Based on these conditions the competing networks will receive a certain amount of quality points. That is the quality point translates the relative 'advantage' of one access network over another into an integer value based on the conditions of the factors. For example, we can assume that for a high speed user, WiMAX or WCDMA is a better option than WLAN since WLAN has a small coverage area and overwhelming number of handovers may occur when a high speed user uses WLAN. Therefore the quality points for WLAN under this condition (high speed user) will be less than that of WiMAX or WCDMA. We also acknowledge the fact that, since the technology of the mentioned access networks are evolving even now, the quality points obtained by a network in a particular condition will not necessarily be the same as what we have assigned in this paper. But the inclusion of quality points shows that, a measure like 'quality points' can be used to account for the relative advantage of one access network over another in a particular condition. There will be a mapping from wireless parameters, user preferences, speed of the users, power consumption of battery, available bandwidth to the quality points. Thresholds can be defined for this mapping. For example, a user speed of 80km/h may map to a quality point of 0 for WLAN network because it will not be efficient to provide WLAN service to such a high speed user. If the data transfer rate of an access network drops below a predefined threshold (for example 500 Kbps) it might map to a low quality point for that network which will make the network less likely to win the service request. Similarly, other mappings will be done. There has to be across layer information exchange, design and signaling to ensure that these mapping is done accurately.

B. An illustration of Assigning Quality Points

As we mentioned before, the quality points will not necessarily be the same as what we have assigned in this paper. The quality points are assigned below just for illustration purpose:

A. Quality points based on type of service

A1.When factor A=1(streaming video)

Quality points for three networks are

$Q_{1\text{ (WCDMA), factor A=1}} = 3$

$Q_{2\text{ (WLAN), factor A=1}} = 5$

$Q_{3\text{ (WiMAX), factor A=1}} = 6$

A2.When factor A=2(internet surfing)

Quality points for three networks are

$Q_{1\text{ (WCDMA), factor A=2}} = 3$

$Q_{2\text{ (WLAN), factor A=2}} = 4$

$Q_{3\text{ (WiMAX), factor A=2}} = 4$

A3.When factor A=3(voice call)

Quality points for three networks are

$Q_{1\text{ (WCDMA), factor A=3}} = 7$

$Q_{2\text{ (WLAN), factor A=3}} = 4$

$Q_{3\text{ (WiMAX), factor A=3}} = 4$

B. Quality points based on user preference

B1.When factor B=1(Cost: i.e. the user prefers cost to quality)

Quality points for three networks are

$Q_{1\text{ (WCDMA), factor B=1}} = 3$

$Q_{2\text{ (WLAN), factor B=1}} = 7$

$Q_{3\text{ (WiMAX), factor B=1}} = 4$

B2.When factor B=2(Quality: i.e. the user prefers quality to cost)

Quality points for three networks are

$Q_{1\text{ (WCDMA), factor B=2}} = 3$

$Q_{2\text{ (WLAN), factor B=2}} = 5$

$Q_{3\text{ (WiMAX), factor B=2}} = 6$

C. Quality points based on state of the network and signal strength

C1.When factor C=1(network traffic is high and signal strength is low)

Quality points for three networks are

$Q_{1\text{ (WCDMA), factor C=1}} = 0$

$Q_{2\text{ (WLAN), factor C=1}} = 0$

$Q_{3\text{ (WiMAX), factor C=1}} = 0$

C2.When factor C=2(network traffic and signal strength are medium)

Quality points for three networks are

$Q_{1\text{ (WCDMA), factor C=2}} = 7$

$Q_{2\text{ (WLAN), factor C=2}} = 3$

$Q_{3\text{ (WiMAX), factor C=2}} = 5$

C3.When factor C=3(network traffic is low and signal strength is high)

Quality points for three networks are

$Q_{1\text{ (WCDMA), factor C=3}} = 4$

$Q_{2\text{ (WLAN), factor C=3}} = 7$

$Q_{3\text{ (WiMAX), factor C=3}} = 4$

Similarly quality points for the other two inputs will be assigned depending on the condition of those inputs.

C. Weighting Coefficients

In this work we have considered five factors (A to E) which effect the payoff of the three competing access networks. But it should also be noticed that these factors do not effect the payoff in the same way, some factors have greater impact while others have less impact, in other words some factors are more important for network selection decision while others are less important for network selection decision. Therefore, we suggest a system of weighting to account for the varying effects of these factors or inputs. For example we assign the following weighting coefficients (which can be an integer number) to the five factors (A to E):

W_A=Weighting coefficient for factor A

W_B=Weighting coefficient for factor B

W_C=Weighting coefficient for factor C

W_D=Weighting coefficient for factor D

W_E=Weighting coefficient for factor E

For instance, if we assume that Factor E is ten times more important in network selection than factor A, we can assign $W_E = 50$ and $W_A = 5$.In the same way the importance of the other factors may be quantified by assigning an integer number.

D. Equation for Calculating payoff of the networks

The total payoff of each network is the weighted sum of quality points it receives from each factor depending on the specific condition of the factor. Therefore, we introduce the following "payoff equation" which gives the payoff of the competing access networks:

$$P_i = W_A Q_{Ai} + W_B Q_{Bi} + W_C Q_{Ci} + W_D Q_{Di} + W_E Q_{Ei} \quad (1)$$

In (1), Pi is the payoff of player i, W_A to W_E are weighting coefficients for factor A to E respectively and Q_{Ai} is the Quality point that player i obtains from factor A depending on a specific condition (denoted by a number as shown previously), Q_{Bi} to Q_{Ei} bear the similar meaning (for example, Q_{Ei} is the Quality point that player i obtains from factor E depending on a specific condition).Equation(1) for 3 players can be written separately as:

$$P_1 = W_AQ_{A1} + W_BQ_{B1} + W_CQ_{C1} + W_DQ_{D1} + W_EQ_{E1} \quad (2)$$

$$P_2 = W_AQ_{A2} + W_BQ_{B2} + W_CQ_{C2} + W_DQ_{D2} + W_EQ_{E2} \quad (3)$$

$$P_3 = W_AQ_{A3} + W_BQ_{B3} + W_CQ_{C3} + W_DQ_{D3} + W_EQ_{E3} \quad (4)$$

E. The Network Selection Decision

Using Equation(2),(3) and (4) we can get the payoffs for each network and the network with the highest payoff will serve a particular service request of the user in case two or more networks (players) make choice of the same service request (strategy) at the same time**.**

F. Flowchart for Network Selection Process

We have illustrated how this network selection mechanism will work with the help of the flowchart shown in Fig. 2.

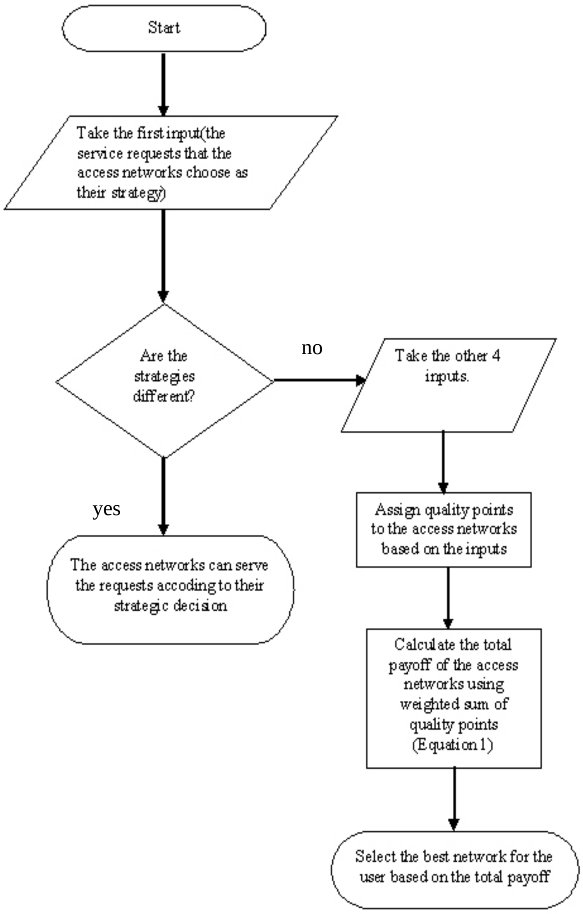

Figure2. Network selection process

VI. MAXIMIZING THE PAYOFFS

In a Game, the intelligent rational players always try to maximize their payoff. To do so they might take different strategies. Since we have used a Game Theoretical model for the 4G converged environment, the players of this game, which are the access networks (WCDMA,WLAN,WiMAX) also try to maximize their payoff. Earlier in this work a strategy space based model has been introduced where the three access networks reside according to their chosen strategy. If an intelligent access network finds out that with its current co-ordinate point in strategy space it can not receive high enough payoff to win the network selection race it tries to move to a different point in the strategy space and thus tries to maximize its payoff by choosing a different strategy.

VII. OTHER ISSUES RELATED TO NETWORK SELECTION

A. Service and Access Provider's Role in Network Selection

According to the model we describe here, the access network providers will always try to maximize their payoff and financial benefit by winning service requests. In this model, they reside in a strategy space which is made of varying combination of strategies of all the networks competing to provide network access to the user. This work gives some hints to the service/access providers in selecting a strategy from the strategy space which gives a platform for intelligent network monitoring on the part of the network providers. Details on such strategy may be explored in future work. Here with intelligent network monitoring, the current position of the access network in the strategy space can be observed. On the basis of this observation, the provider can decide to serve those requests which will give them the highest benefit but will cause least resource (i.e. bandwidth) consumption.

On the other hand, the application and content service providers will have an indirect influence on network selection. This is the case because the nature of the application has associated bandwidth requirements. The quality of service required for an application might cause the user to prefer a particular access network. In fact, the current Quality of Service that can be provided by the access network for an application will be known by the Input C (section 5).So, based on the QoS required for the application and QoS that can be provided by the access network the, user preferences will be given to weighted payoff equation

B. Interconnection Pricing

There will be prior agreements between the access providers which will include interconnection pricing when the network selection changes. The interconnection pricing will also depend on the service level agreements between the subscriber and the individual access networks. The interconnection pricing will work in collaboration with a common Authentication, Authorization and Accounting (AAA) scheme for the access networks. In this work, the interconnection pricing is assumed equal for all cases. So, it has no impact on selection strategy here.

C.Network Congestion Issues

Network congestion is a very important issue in today's communication networks and no doubt it will remain a problem in the 4G network as explained in [15]. Throughput and Quality of Service (QoS) can degrade due to network congestion which will dissatisfy users. In the recent years, there has been significant rise in the resource consumption by subscribers. The subscribers are using services which require more bandwidth (For example streaming video and peer to peer (P2P) applications).When too many subscribers in a particular access network demand such services in a resource constrained access network, congestion occurs. Signaling overhead will also contribute to network congestion by consuming bandwidth resources.

However, in this paper, we have kept a provision to deal with this problem especially from the 4G user's point of view. For instance, the input C will be based on state of the network and signal strength. Here, state of the network practically means the network traffic and congestion state. The quality points obtained from factor C by a particular access network will depend on the network congestion. This essentially can knock out a congested network out of the network selection game and connect the user to a better access network in terms of network congestion.

VIII. Demonstration and Proof of Concept

Now we would illustrate how this mechanism of selecting the best access network will actually work. We will provide a variety of inputs (which are actually the conditions of the five factors for network selection decision) to a computer program that implements the mechanism described above. This program will process the input information and ultimately decide which access network will best serve the subscriber at a particular time.Though here it has been designed as a straightforward module for the clarification of our concept, we presume that this module will lay the basis for an intelligent agent which will always ensure that the user is connected to the best network according to his context.In practice, this agent will have many interfaces with a number of other entitities and modules(i.e. AAA servers,access routers,Mobile Switching Centers,etc). It will exchange information with differetn layers (for example, application layer, network layer, link layer) in order to make the network selection. Here we will consider and compare the following two cases.

A. First set of Inputs(Case 1)

Fig. 3 shows the conditions of the factors and the network selection decision based on these conditions.

B. Second set of Inputs(Case 2)

Fig. 4 shows a different set of inputs have been provided and the result is also different.

C. Discussion of the Results

The two different sets of inputs and the associated results are shown in the table-I.

The table shows the inputs provided to the network selection module for two cases. It also demonstrates the decisions for both cases.

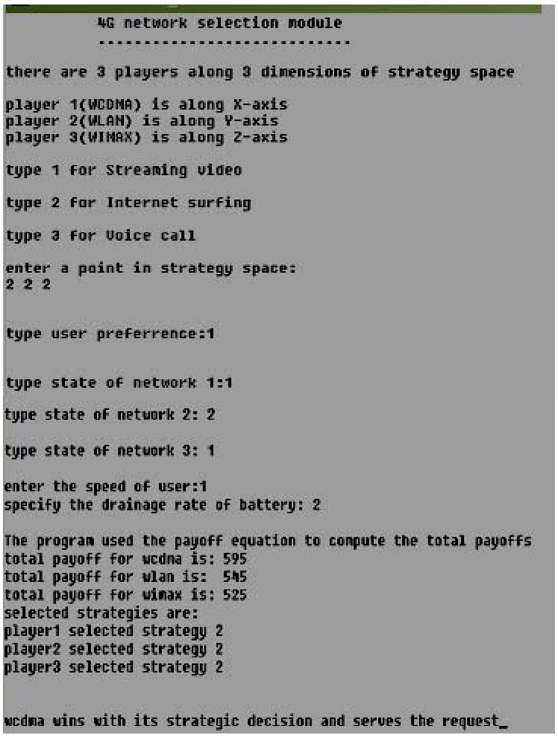

Figure3. Case-1

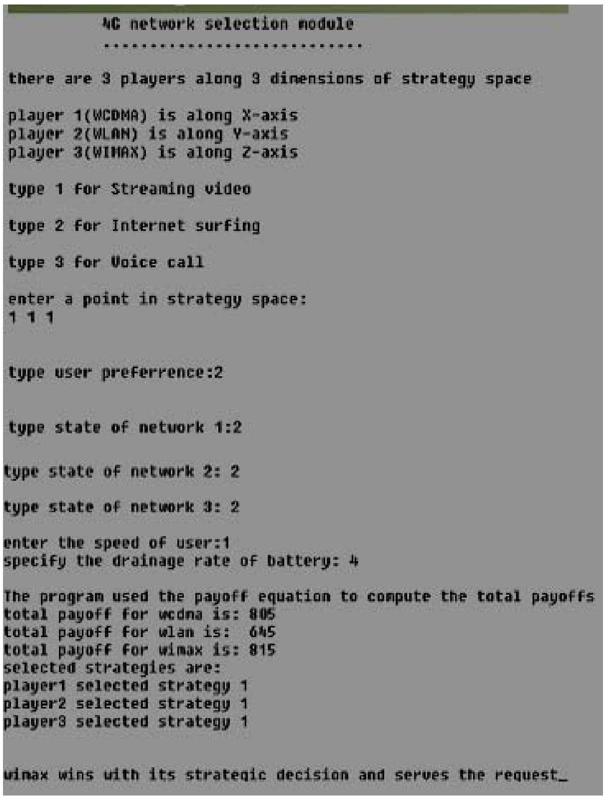

Figure4. Case-2

TABLE I
INPUTS AND RESULTS FOR CASE-1 AND CASE-2

	I/P A	I/P B	I/P C	I/P D	I/P E	Best network
Case 1	2 2 2	1	1 2 1	1	2	WCDMA
Case 2	1 1 1	2	2 2 2	1	4	WiMAX

In case-1 all of the three networks competed with each other to win a service request of internet surfing. In this case Input B was 1 which means that the user preferred a cheaper service rather than high bandwidth and better quality. Input C signified the traffic state and signal strength for three networks. Input D was 1 which meant that the service request was from a high speed user. Input E was 2 giving WCDMA a better position in terms of drainage rate of battery. Detailed conditions signified by integers are already discussed in section 5.When we analyze the results we see that WCDMA had the highest payoff (595).Therefore WCDMA was the network eventually used for internet surfing.

Similarly, in case-2 WiMAX managed to come up with the highest payoff and served the streaming video. Therefore, this new mechanism of network selection ensures that only the best network having significant advantages for all the factors or inputs over other networks will be chosen to serve the user.

IX. CONCLUSION AND FUTURE WORK

In this work, we have introduced a new Game theory and strategy space based modeling of the 4G converged environment. Additionally important concepts for network selection like 'quality points', 'weighting factors' have been introduced. Finally, a new equation called the "payoff equation" has been established to tie up the quality points and weighting factors in a transparent manner and calculate the total payoff of the access networks competing to provide service to the user in a 4G converged environment. This is the equation which ultimately determines which access network will provide the service to the user. In section VIII the method of network selection is illustrated. The goal of this paper was to propose a network selection mechanism which will give the users of 4G network an opportunity to be 'always best connected'. In this paper we have explained a mathematical approach which takes into account the most influential factors for network selection from user's perspective. It also gives the platform for intelligent network monitoring and resource allocation on the part of the access network by the inclusion of strategy space as we have explained in section VII. We can see from the demonstration that only the access network with the highest quality points can serve the user. In other words, the access network which is most appropriate for a user at a particular moment considering the context of the user and the state of the network will be selected to serve him. Therefore, the module demonstrates and evaluates that the user will be best connected if the proposed mechanism is implemented.

However, we have not investigated the implementation details of the proposed mechanism in this paper. Currently, we are working to come up with an intelligent agent for network selection which will ensure best connectivity to the subscriber of the 4G network based on the concepts discussed in this paper. A 4G test bed incorporating different radio access technologies and network selection agent is also planned for the future. Further investigation of the assignment of quality points under various conditions is required. In addition, the relationship between mobility, handoff issues and the network selection decision in 4G communication networks will be examined in future works.

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