A Game Theoretic Approach for a Service-Based Selection of Radio Access Network in a Heterogeneous Environment

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ABSTRACT

One of the first decisions that need to be made in a heterogeneous network is how to select the access network most suitable to serve each wireless/mobile user seeking admission. We refer to this decision as network selection decision and propose a game-theoretic, service-based approach to resolve it. This is based on the requirements imposed by the user and the service, but also considers the operator and the technology. The model is a game played between the network components achieving a user friendly system, since the network selection process is made transparent to the wireless/mobile user.

Categories and Subject Descriptors
C.2 [Computer-Communication Networks]: Network Architecture and Design – Wireless Communication

General Terms
Design, Performance, Reliability

Keywords
Heterogeneous Networks, Network Selection, Game Theory, Multi-service network

1. INTRODUCTION

Recent years have revealed a considerable amount of interest and effort, both in industry and academia, towards the performance modelling, evaluation and convergence of multi-service networks of diverse technologies in an effort to meet the requirement for connectivity “anytime, anywhere and anyway”.

Wireless/mobile networks (WLAN/Wi-Fi, Ad-hoc/Sensor networks as well as GSM, GPRS, UMTS and beyond 3G mobile systems) have become a major part of modern data communication networks. Demand for these systems continues to grow as applications involving both voice and data expand beyond their traditional service requirements. In order to meet the increasing demand in data rates that are currently being supported by high speed wired networks composed of electrical cables and optical links, it is important to fully utilize the capacity available in wireless/mobile networks, as well as to develop robust strategies for integrating these systems into a large scale, heterogeneous data network.

The unifying technology proposal is currently a solution of an all-IP network layer. This is based on a popular model for heterogeneous networks where there is a common core network that deals with all network functionality and operates as a single network, but different access networks. Communication between access networks belonging to a common core is based on lower network layers such as link or network layer (i.e. all IP network layer), which reduces communication overhead, improving performance. New issues, however, arise with this solution. One of the first decisions that need to be made in a heterogeneous network is how to select the access network most suitable to serve each mobile/wireless user seeking admission.

We refer to this decision as network selection decision and we propose a game-theoretic, service-based approach to resolve it. The proposed approach evaluates each access network in terms of Quality of Service (QoS) support per service, by considering metrics such as bandwidth, loss, delay, coverage area, mobility support, and others. It is based on the requirements imposed by the user and the service, but considers the operator and the technology as well.

We currently consider two mobile technologies, UMTS and Wi-Fi, to form elements of an example heterogeneous network. We model the proposed approach as a game between the two different networks, which compete over the resources of the game, in this case the set of mobile users. The players aim to gain “satisfaction” (directly related to each network’s capacity). The use of game theory adds further confidence to the solution, as it shows that equilibrium can always be reached. Furthermore, the applicability of this solution is discussed through an example using a realistic set of services and a sensitivity analysis evaluates to what extend small alterations in the input set of services affects the results of the game.

Section 2 discusses the motivation for this work; Section 3 presents the proposed approach as an extensive game, Section 4 demonstrates convergence, fairness and efficiency for the proposed approach; Section 5 analyzes a real-world example to support the theory and Section 6 provides a sensitivity analysis of the input parameters to investigate how input variations affect the results. Finally, Section 7 offers some conclusions and discusses future work.

2. MOTIVATION

The area of resource management in wireless/mobile heterogeneous networks is a very young research area. In the past few years the research community has been showing an increasing interest in this emerging wireless technology [1], which soon was named the 4th Generation (4G) of wireless networks [2]. Several new technological challenges need to be addressed in order to support 4G networks. Resource
Management and Performance issues of heterogeneous networks have been addressed in [3][4][5][6] but the area is far from exhausted. Specifically the area of radio network selection in 4G wireless networks, addressed in this work, has only just appeared in research works [7][8]. The selection of access network is a very important issue, a consequence of the 4G technology; each mobile user should be served by the best network component of the heterogeneous environment. We address this important issue in this work using a game theoretic, service-based approach.

Game Theory has scarcely been used in the area of heterogeneous networks [9] and has not yet been used to model the network selection process. However, Game Theory has been used in the general area of networks in several works to address issues such as bandwidth allocation and pricing [10], modeling of peer-to-peer and ad-hoc networks [11][12][13], power control and resource management in general [14][15]. A collective and detailed survey of games in the telecommunications area is presented in [16]. Experiences from using game theory as a modeling and analysis methodology as well as allocation rules may be found in [17][18].

Game Theory is actually a most appropriate methodology to use for modeling this new heterogeneous system. 4G systems are made up of different components each seeking to gain as a unit (since each component may be operated by a different authority). All these different components share the same resources (in this case by “resources” we refer to the mobile users participating in the heterogeneous system). Each resource may only participate in one network component at a time. The issue that needs to be resolved is to find the best way to distribute the “resources” among the different system components in order for each component to be “satisfied”. As a consequent goal we need to achieve overall system efficiency. This may be easily translated into a game. Although network/telecommunication games have always been defined in a specific way (the network users are defined to be the players of the game and the network itself to be the resources, e.g. links), our game is defined in a novel way. The traditional definition is a good model for homogeneous networks but cannot work for heterogeneous networks, where the system is made up of independent components and each component has different properties that need to be considered in the overall model. Our approach is therefore, to model the network components as the players of the proposed game and the mobile users as the resources that the game players compete for.

Our work follows the paradigm of personal computing, i.e. the user of the heterogeneous system should, in an easy and straightforward manner, have quality access to numerous real-time and non real-time services. The modeling approach successfully strips the mobile user off the infrastructure complexity and leaves the decision-making to the network itself as the game is played between the network components, and not the actual mobile users. What a mobile user simply does is indicating the service to use. This model achieves a user friendly system, where the network selection process is made transparent to the user.

3. THE NETWORK SELECTION APPROACH AS AN EXTENSIVE GAME

The heterogeneous environment we are studying is an infrastructure of different access networks (two in the following model) connected to the same backbone infrastructure, using the same transport technology to carry information. A mobile terminal in this environment has access capabilities to the different access networks simultaneously, however, is served by only one of them at a time.

As mentioned above, we try to simplify any decisions that the user has to make. The heterogeneous network should, transparently, select one of these access networks to support the terminal and the requested service at a time. This selection should provide the biggest gain to the heterogeneous network as a unified infrastructure and to its constituents separately (we assume that each access network will be operated by a different authority). Network selection is the mechanism appropriate to allow the terminal to use a certain access network (similar to admission control in a homogeneous wireless network). The most appropriate access network has to be selected by this mechanism to handle each terminal requesting service support.

This is modeled as an extensive game [23], where the players of the game are the various homogeneous networks comprising the heterogeneous environment under study. We have selected the extensive form to model this game in order to capture the time factor which is important in this case as it will provide a precedence of events. Extensive form games satisfy an additional condition named “perfect recall”. Whenever a player moves, he remembers all the information that he knew earlier in the game, including all of his own past moves.

Each network-player tries to get mobile users (services) to participate in the network functions. The participation of a user affects the network, in terms of capacity, i.e. payoff for the network-player. Overall, the participation of a mobile user is beneficial to the heterogeneous network because it increases the capacity of the network (QoS constraints need to be satisfied for each participating service).

Let H be the heterogeneous network. Consider H to be a set of n homogeneous components such that H = (0, 1, 2 … n), where n = 2. Zero (0) denotes chance nodes, 1 and 2 are the two constituent networks. This is a two-player game, i.e. H = (0, 1, 2).

Let S be the set of all services to be served by H, containing a finite number of m services such that S = (0, 1, 2 … m).

Each member of H is characterized by a number, c0, indicating its available capacity. Let C be a 1xn matrix where each entry indicates the c0 number for each member of H except chance nodes, i.e. C = (c1, c2).

Each member of S is characterized by a number, d0, indicating its maximum data-rate. Let D be a 1xm matrix where each entry indicates the d0 number for each member of S, D = (s0, s1, s2… sm).

Assume that each service has a preference towards one of the networks. Let P be the set of m preferences where each entry corresponds to the same entry of set S, i.e. the mth entry of set P is the network preference of the mth service in set S, e.g. P = (1,2,2… 1).
A service is randomly picked from the finite set of services. The network favored by the preference of the picked service, found from the corresponding entry in P, plays first (in the tree this is shown by the pass strategy).

Next, strategies are defined according to information states (inf) per player. A pure strategy for player h \( H \) is a function \( s_{h}: \text{INF} \rightarrow A \), where A is the set of possible actions, such that \( s_{h}(\text{INF}) \in A_{h}(\text{INF}) \). We use only pure strategies for this game. The possibility of mixed strategies will be explored in future work.

Each strategy may bring a particular “player” a certain satisfaction, represented as a utility function that maps a given strategy to a numeric gain \( U: \text{STR} \rightarrow \mathbb{R} \).

The extensive game itself is defined as \( I^{*} = \{H, S, P, (X, >), (\ell), A(\cdot), \text{INF}, U, C, D\} \) where,

\( H, S \) and \( P \) are the sets of players, services and preferences as defined above.

\( (X, >) \) is a tree, a finite collection of nodes \( x \in X \) where \( x > x' \) means \( x \) “is before” \( x' \). Each node \( x \) has exactly one immediate predecessor. \( (X, >) = \{(x_0 > x_1, x_2), (x_1 > x_3), (x_2 > x_4), (x_3 > x_5, x_6), (x_4 > x_7), (x_5 > x_8, x_9), (x_6 > x_{10}, x_{11}), (x_7 > x_{12}, x_{13}), (x_8 > x_{14}, x_{15})\}. \) Any extensive game may be represented in the form of a tree. Figure 1 illustrates the tree for this game.

\( (\ell) \) denotes the mappings from a tree node to a player \((\ell: X \rightarrow H)\). Terminal nodes do not map to a specific player as they need to indicate payoffs for all players in the game.

\( A(\cdot) \) denotes the set of feasible actions for each node \( A(x) \) or each information state \( A(\text{INF}) \). The set of feasible actions for all nodes (excluding the root which is a chance node) is \( A = \{\text{Pass, Pick Up, Admit, Reject}\} \).

\( \text{INF} \) is the set of all information states \( \text{inf} \), such that \( \text{inf} \in \text{INF} \). Each node may have only one information state. An information state is what a player knows at a certain instance of the game. The information states are as follows: a: service prefers current player, b: service prefers other player, c: service prefers other player but was rejected.

\( U_{h} \) is the set of payoffs per player \( h \) for all terminal nodes of the tree such that \( U_{h}: (\text{terminal node}) \rightarrow \mathbb{R} \). In our game we choose arbitrary constants to be the payoffs for each terminal node and each player to show the relativity of the different payoffs rather than anything else. The game has six terminal states and each has a payoff constant for each of the two players as follows:

\( x_5: [10, 0], x_11: [-2, 5], x_12: [-2, 0], x_5: [0, 10], x_{14}: [5, -2], x_{15}: [0, -2] \). A payoff of 10 (the highest payoff) is gained by a network-player who admits a service that indicated preference for the specific network-player and a payoff of 5 is gained from any other admission. When a network-player rejects a service that preferred it has a negative gain (-2) and any other rejection has no effect on the network-player (0).

Finally, \( C \) and \( D \) are the single-row matrices representing the capacities of the constituent networks (C) and the services’ maximum data-rates (D).

Each round of the game ends with the admission or rejection of a specific service request by one of the access networks. The game ends when all the requests have been handled or when the maximum capacity of the network is reached. At each terminal node of the tree the payoffs for each player are indicated. At the end of the game, the total payoff for each user is the summation of the payoffs in all rounds.

The mobile user is not, at any point in the game, aware of the selection process (of the “game” between the different access networks). What the mobile user simply does is to indicate the service requesting support. Each service has certain requirements that may be translated as a preference of the mobile user to each of the available access networks (since each access network has different capabilities). Based on this preference the game is played according to a set of rules presented next.

The most important rule of this game is that somehow each service requesting admission has a preference towards one of the homogeneous networks in the heterogeneous environment under study. For simplification purposes let’s assume for now that all the services requesting admission have a 50% probability of preferring network 1 and a 50% probability of preferring network 2. In the next section we will show how this preference is derived and that this percentage is a realistic assumption.

The game is represented as a tree and Figure 1 is a graphical representation of a round of the game, i.e. to admit/reject one mobile user. Time progresses as we move from the root of the tree to the leaves. The root is a chance node, i.e. it does not belong to either player but represents a random event. Therefore, in the root of the tree we have two edges, one with a 0.5 preference of network 1 and the second with a 0.5 preference for network 2.

Suppose player 1 plays first (the order does not matter in this game). The player “looks” at the service. At this point player 1 may have two information states (it learn's that the service prefers 1 or 2).

If the service prefers 1 (information state 1.a), it “picks it up” and looks at it in more detail to decide whether it has the capability to support it. If yes, it admits it. This is done by matching the service maximum data-rate to its available capacity. If no, it rejects it and then player 2 gets to play and “pick the service up”. In turn it can decide to admit or reject it.

On the other hand, if the service picked prefers 2, then player 1 will pass and player 2 will play this round first.

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**Figure 1: Access Control Game in tree format**
A round of the game is played as follows:

**Player 1**: plays first. The player may have 3 information states, \( a \rightarrow \text{service prefers 1}, \ b \rightarrow \text{service prefers 2}, \ c \rightarrow \text{service prefers other player but was rejected.} \) The strategies for information state \( a \) are: pick up and admit, pick up and reject. The only strategy for strategy for information state \( b \) is: pass, and the strategies for information state \( c \) are: pick up and admit, pick up and reject.

**Player 2**: plays second. The player may have two information states, \( b \rightarrow \text{service prefers 2}, \ c \rightarrow \text{service prefers other player but was rejected.} \) The strategies for information state \( b \): pick up and admit, pick up and reject, and the strategies for information state \( c \): pick up and admit, pick up and reject.

4. CONVERGENCE, FAIRNESS AND EFFICIENCY

In order for the game to be successful it needs to achieve three fundamental goals of game theory: (a) Convergence (Existence/Uniqueness of equilibrium), (b) Efficiency (Pareto, Best Possible Performance), and Fairness (resources should be shared equitably).

The extensive form allows for an equilibrium concept that refines Nash equilibrium. This concept is called subgame perfection. A subgame is every subset of the tree that looks like a game (i.e. it has an initial node and following nodes). A subgame perfect equilibrium is a profile of strategies that are a Nash Equilibrium [19] in every subgame (including the game as a whole).

In order to be able to deduce equilibriums from a game in extensive form, we need to convert its representation to the strategic form, a simpler form that can be analyzed more easily. It is important in this conversion not to lose any information that is important to our game (e.g. timing, information states etc). A way to achieve a reliable conversion is to use the multi-agent representation. It should not matter if a given player in an extensive game were represented by a different agent in each of his possible information states, provided that these agents all share the same preferences and information of the original player. In our game we have 5 players in our multi-agent representation (1a, 1b, 1c, 2b, 2c).

We may refer to these players as temporary agents. A way to achieve a reliable conversion is to use the multi-agent representation. It should not matter if a given player in an extensive game were represented by a different agent in each of his possible information states, provided that these agents all share the same preferences and information of the original player. In our game we have 5 players in our multi-agent representation (1a, 1b, 1c, 2b, 2c).

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In the multi-agent representation of this game we have five new players-agents: 1a, 1b, 1c, 2b, 2c. Agent 1a represents player 1 at information state a and so on for the rest of the agents. Now, there is a new set of strategies for each player-agent. These are the following: 1a {pick.admit, pick.reject}, 1b {pass}, 1c {pick.admit, pick.reject}, 2b {pick.admit, pick.reject}, 2c {pick.admit, pick.reject}. According to these a round of the game has only six possible paths i.e. sequences of possible actions:

1a/pick.admit (1),
1a/pick.reject \( \rightarrow \) 2c/pick.admit (2),
1a/pick.reject \( \rightarrow \) 2c/pick.reject (3),
1b/pass \( \rightarrow \) 2b/pick.admit (4),
1b/pass \( \rightarrow \) 2b/pick.reject \( \rightarrow \) 1c/pick.admit (5),
1b/pass \( \rightarrow \) 2b/pick.reject \( \rightarrow \) 1c/pick.reject (6)

Examining this game even further, we may deduce that there are only two possible routes the game could take depending on whether the mobile terminal (through the service request) “prefers” network 1 or network 2. Figure 2 illustrates the tree in the first case (preference for network 1) and Figure 3 illustrates the tree in the second case (preference for network 2). The two routes are distinct in the sense that once one is selected the other will not be visited in the specific round.

Figure 2 clearly shows that in the case the service has a preference for network 1, then the game is played between two agents only: 1a and 2c (each representing one of the original two players: 1 and 2). Each player has a choice of two strategies: {pick.admit, pick.reject}.

We may visualize the players, their strategies and payoffs in the following table:

<table>
<thead>
<tr>
<th>Table 1: Equilibrium when preference is network 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
</tr>
<tr>
<td>-------------</td>
</tr>
<tr>
<td>admit</td>
</tr>
<tr>
<td>reject</td>
</tr>
</tbody>
</table>

The shaded cell indicates the equilibrium state. Equilibrium in a game is reached when neither of the players will gain by changing their strategy. This is known as Nash equilibrium. We have to note here that once 1a admits the service then it doesn’t really matter what the other player does, since the game terminates at that point. However, for modeling purposes we assume that even if player 2 moves the gain is zero.
Figure 3: Sub-tree of preference to network 2

Figure 3 presents the same path of play as Figure 2, with a different set of agents: 2b and 1c. Agent 1b playing first can be ignored in the analysis. The reason is that agent 1b only has one strategy and plays first; therefore it will always play the strategy whenever the game takes this route. Ignoring this has no real consequence on the analysis because his strategy is taking no action and has no effect on the payoffs of any of the other players.

The following table illustrates the payoffs for each of the two players.

<table>
<thead>
<tr>
<th></th>
<th>admit</th>
<th>reject</th>
</tr>
</thead>
<tbody>
<tr>
<td>2b</td>
<td>(10,0)</td>
<td>(10,0)</td>
</tr>
<tr>
<td>1c</td>
<td>(3,2)</td>
<td>(3,0)</td>
</tr>
</tbody>
</table>

Again, we can detect Nash equilibrium for the strategy 2b.admit → 1c.reject. As we indicated previously agent 1c’s move does not really make a difference but we consider it for modeling purposes. Whatever the preference is in the beginning of the game, the equilibrium strategy is admitting the service by the player who is favored by the service preference.

This is obviously more beneficial for each player separately as the individual player’s capacities (considered for the determination of the relative payoffs) are increased (by terminals that will be “satisfied” by the admission). This generic two-player network selection game assumes equal capacities of the two network players. In the Sensitivity Analysis section we further consider varying network capacities. Let’s also assume that each network component has enough capacity to admit all service requests and that all services will be admitted to their preferred network. The final payoffs of the game for each player will be N/2 times the payoff shown above (=10), where N is the number of services. This will result in a fair resolution of the game and each player will be “satisfied”, since equilibrium was reached in every round (the equilibrium strategy will always be picked in the case of infinite capacity).

The game demonstrates convergence and fairness; hence we further need to determine whether it is efficient. A way to determine whether the game is efficient for the overall system is by testing whether it demonstrates Pareto Efficiency. A situation is Pareto efficient, if there is no way to make any player better off without hurting anyone else [24]. Examining the proposed approach of selecting, when possible, for each service the network it prefers, we identify that the game results in Pareto-efficiency. Any more gain for either of the players will immediately result in a decrease of payoff for the other player (gain is directly related to the number of admitted users). Furthermore, this approach is beneficial for the overall welfare because of a uniform distribution of resources (= mobile users/services) among the competing networks (50% of mobile users are served by each of two equal-capacity networks).

The question that arises, however, is whether it is realistic to assume that the preference of a random service will be 50% towards each of the two competing networks. The section below considers an indoor environment that supports UMTS and Wi-Fi and a set of services is selected based on recent literature. Assigning usage probabilities to the services in the scenario shows that indeed the assumption of a 50% preference of a service to the networks is a realistic one.

This brings additional confidence to the game equilibriums presented above and to the proposed service-based approach itself. Future work will investigate different sets of services that will show more preference to one of the two networks participating in the game, and also the effect of other environments e.g. outdoor.

5. SERVICE PREFERENCE ESTIMATION: AN EXAMPLE

As we mentioned in the introduction of this report, the idea of supporting heterogeneous networks aims to achieve the Always Best Connected (ABC) concept. In reality the different wireless/mobile technologies separately cover a wide range of location needs for a mobile user.

Figure 4 presents different wireless networks with different coverage capabilities, from which we selected the two players of our access control game (UMTS & Wi-Fi). The coverage may be separated into four categories: Personal Area Network (PAN), Local Area Network (LAN), Metropolitan Area Network (MAN) and Wide Area Network (WAN). This also affects the kind of user mobility that each network may support. Future work aims to extend the two-player game to a multi-player game and use players from all coverage categories.

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5. SERVICE PREFERENCE ESTIMATION: AN EXAMPLE

As we mentioned in the introduction of this report, the idea of supporting heterogeneous networks aims to achieve the Always Best Connected (ABC) concept. In reality the different wireless/mobile technologies separately cover a wide range of location needs for a mobile user.

The question that arises, however, is whether it is realistic to assume that the preference of a random service will be 50% towards each of the two competing networks. The section below considers an indoor environment that supports UMTS and Wi-Fi and a set of services is selected based on recent literature. Assigning usage probabilities to the services in the scenario shows that indeed the assumption of a 50% preference of a service to the networks is a realistic one.

This brings additional confidence to the game equilibriums presented above and to the proposed service-based approach itself. Future work will investigate different sets of services that will show more preference to one of the two networks participating in the game, and also the effect of other environments e.g. outdoor.
The following table provides a general comparison of the two network players [20].

**Table 3: Comparison of 3G (UMTS) and WiFi**

<table>
<thead>
<tr>
<th></th>
<th>3G (UMTS)</th>
<th>WIFI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Standard</strong></td>
<td>WCDMA (CDMA 2000)</td>
<td>1EEE 802.11b</td>
</tr>
<tr>
<td><strong>Maximum Speed</strong></td>
<td>2Mbps</td>
<td>54Mbps</td>
</tr>
<tr>
<td><strong>Operators</strong></td>
<td>Cell-phone companies</td>
<td>Individuals, WISP</td>
</tr>
<tr>
<td><strong>Use of Licensed Spectrum</strong></td>
<td>YES</td>
<td>NO (shared spectrum)</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td><strong>QoS Management</strong></td>
<td>YES</td>
<td>NO</td>
</tr>
<tr>
<td><strong>Coverage Area</strong></td>
<td>Several Km</td>
<td>About 100m</td>
</tr>
<tr>
<td><strong>Mobility Support</strong></td>
<td>High User Speeds</td>
<td>Limited to None</td>
</tr>
<tr>
<td><strong>Security Support</strong></td>
<td>Good</td>
<td>Poor</td>
</tr>
</tbody>
</table>

The preference of a service towards a specific network is deduced based on five major network parameters. Each of these parameters may be supported to a different extent by each network. The importance of each parameter for a specific service is different (this is also affected by the mobile user’s needs and the environment itself, i.e. indoor, outdoor etc.). The five parameters are: Cost, Mobility, QoS, Data-rate and Coverage. Furthermore, each service may have special needs that the network needs to support, e.g. telephone channels for voice-based services or location estimation capabilities for location-based services. Therefore, a service will first check if a network fulfills these special requirements and consequently it will evaluate the five above-mentioned parameters to conclude which of the candidate networks it prefers. For the current example the parameter of cost is not taken into account, for simplification purposes (since the payoff is currently based on user capacity and not operator revenue).

We have selected a set of 17 services to form the realistic set of services for our games. These have been selected based on current literature [21][22] and general requirements for 4th Generation (4G) heterogeneous networks such as consideration for safety (tele-medicine, virtual navigation), location-based services (assistance in travel, tourist information), multicast/broadcast capabilities (micro-movies, electronic newspaper) and very high bit-rates (tele-education, control data). The proposed set of services was evaluated in an indoor environment (OFFICE), where users are mostly stationary. A probability usage (from 0 to 1) was given to each service that corresponds to the specific environment. The following table shows the set of services, their corresponding usage probabilities in the OFFICE environment, their maximum data-rate and their network preference.

**Table 4: Service Preference in an Office environment**

<table>
<thead>
<tr>
<th>Service</th>
<th>Usage Probability (0 – 1)</th>
<th>Max. Data-rate (kbps)</th>
<th>Network Preference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>VOICE</strong></td>
<td>0.15</td>
<td>12</td>
<td>UMTS</td>
</tr>
<tr>
<td><strong>VOICE OVER IP</strong></td>
<td>0.10</td>
<td>12</td>
<td>UMTS</td>
</tr>
<tr>
<td><strong>INTERACTIVE REMOTE GAMES</strong></td>
<td>0.01</td>
<td>128</td>
<td>UMTS</td>
</tr>
<tr>
<td><strong>MICRO MOVIES</strong></td>
<td>0.03</td>
<td>128</td>
<td>UMTS</td>
</tr>
<tr>
<td><strong>COLLABORATIVE WORKING</strong></td>
<td>0.11</td>
<td>128</td>
<td>UMTS</td>
</tr>
<tr>
<td><strong>TELE-ADVERTISING</strong></td>
<td>0.04</td>
<td>384</td>
<td>UMTS</td>
</tr>
<tr>
<td><strong>DATA FILE TRANSFER</strong></td>
<td>0.12</td>
<td>384</td>
<td>WI-FI</td>
</tr>
<tr>
<td><strong>TELE-MEDICINE</strong></td>
<td>0.04</td>
<td>384</td>
<td>WI-FI</td>
</tr>
<tr>
<td><strong>INSTANT MESSAGING FOR MULTIMEDIA</strong></td>
<td>0.08</td>
<td>1024</td>
<td>WI-FI</td>
</tr>
<tr>
<td><strong>REMOTE PROCEDURE CALL</strong></td>
<td>0.02</td>
<td>1024</td>
<td>WI-FI</td>
</tr>
<tr>
<td><strong>MOBILE TELE-WORKING</strong></td>
<td>0.03</td>
<td>1536</td>
<td>UMTS</td>
</tr>
<tr>
<td><strong>ASSISTANCE IN TRAVEL</strong></td>
<td>0.01</td>
<td>1536</td>
<td>WI-FI</td>
</tr>
<tr>
<td><strong>VIRTUAL NAVIGATION</strong></td>
<td>0.01</td>
<td>1536</td>
<td>WI-FI</td>
</tr>
<tr>
<td><strong>TOURIST INFORMATION</strong></td>
<td>0.01</td>
<td>1536</td>
<td>WI-FI</td>
</tr>
<tr>
<td><strong>ELECTRONIC NEWSPAPER</strong></td>
<td>0.05</td>
<td>1536</td>
<td>WI-FI</td>
</tr>
<tr>
<td><strong>TELE-EDUCATION</strong></td>
<td>0.04</td>
<td>2048</td>
<td>UMTS</td>
</tr>
<tr>
<td><strong>CONTROL DATA</strong></td>
<td>0.15</td>
<td>3840</td>
<td>WI-FI</td>
</tr>
</tbody>
</table>

**Voice**: The plain telephone service, using telephone channels. The preference between the two competing networks is obviously UMTS, since UMTS supports telephone channels but Wi-Fi does not.

**Voice over IP**: The process of transmitting voice traffic across an IP-based packet network. This service requires the use of telephone channels hence its preference is UMTS.

**Interactive Remote Games**: Online games that participants can play against other remote opponents on the same network (in this case could be in different networks that belong to the same heterogeneous system). This is a real time service and it is very important to keep low delays. The preference is UMTS because of the QoS guarantees.

**Micro Movies**: This is a video distribution service that operates in broadcast mode. The type of information broadcast is moving pictures and sounds (including
video clips). The preference of this service is UMTS because it is real time and requires QoS support. It has relative low data-rate demands and requires mostly delay guarantees.

**Collaborative Working:** Flexible way of working, which covers a wide range of work activities, all of them involve working remotely from an employer; may communicate with a collaborator through audio, video and data. The need to support real-time communication, leads to a preference towards UMTS for this service.

**Tele-advertising:** Interactive publicity based on the exchange of audio-visual information. Real-time service, need for QoS support, thus preference towards UMTS.

**Data File Transfer:** Usual FTP functionality; it allows the transfer of any type of data file between different types of computers or networks. The preference is for Wi-Fi because the high data-rate will ensure for a faster file transfer.

**Tele-medicine:** Access of medical records from a remote location. May be interactive; it is important to receive the information, less delay-sensitive. The choice of Wi-Fi is because it offers high data rates and it is more important to know that the appropriate data will be received.

**Instant Messaging for multimedia:** It allows the real-time transmission and storage of mixed documents containing text, graphics, voice and/or video components. A user starts a session and exchanges multimedia messages via a server, watching and listening to the messages and answering if required. Messaging needs high throughput. The network most appropriate to offer this high throughput is Wi-Fi.

**Remote procedure call:** A technology in which a program invokes services across a network by using modified procedure calls. It is a means of communication between two tasks running on separate machines, usually liked in a LAN setting. The preference is for the throughput guarantees, hence the Wi-Fi (the fast LAN setting ideal for this service).

**Mobile Tele-working:** Working from home or from anywhere (public transportation, airport waiting rooms) through the user’s mobile terminal. The ability of telecommunications to deliver video and sound as well as real-time data allows users to avoid costly and time-consuming travel. The real time demands and the coverage needs of this service lead to a preference of UMTS.

**Assistance in Travel:** This can be both real-time and non real-time. A tourist can have assistance to reach a certain location at the time of travel (city guidance), or can request information and comments about a location (traffic advice and road conditions). Since the mobile users in this game are stationary in an OFFICE environment, this service is for informative purposes, thus non real-time. The preference is for Wi-Fi because it may support high bit-rates.

**Virtual Navigation:** Physical characteristics of a certain location (indoor or outdoor) are contained in a database including graphical representations. The user may visualize the environment ahead through this information. The high bit rate requirement results in a preference for Wi-Fi.

**Tourist Information:** The system provides tourist information in the form of multimedia documents. Access to booking/reservation systems is also available. The service prefers Wi-Fi as this is not real-time information but it is important to support the high bit-rate demands to assure that the content is received successfully.

**Electronic Newspaper:** The newspapers are made available to users on their fixed/mobile terminal equipment. The news can be organized so that the users navigate according to their own interests. Special services such as personalized journals can be provided on demand for this kind of service. This service does not have any special QoS requirements but it is important that the multimedia content is supported by high bit-rates, thus the preference is for Wi-Fi.

**Tele-Education:** Remote learning and training based on audio-visual information. Virtual-school, online science labs, online library, online language labs and training are offered with this service. Although a high bit-rate service, this service is real time and requires QoS guarantees and support for telephone channels; hence its preference is for UMTS.

**Control Data:** A seamless exchange of production and equipment status information between end-users and production management/business systems to facilitate faster decisions, increased productivity and better management of plant and corporate assets. This service requires a very high maximum bit-rate and is thus better suited for Wi-Fi network.

Now, adding up all the usage probabilities of the services that prefer UMTS results in a total probability of 0.51. The summation of the usage probabilities for the Wi-Fi preferences equals to 0.49. These correspond to the two initial probabilities used at the chance node (the root) of our game tree. These results show that the assumption of 0.5 probability preference is quite realistic for the OFFICE environment. We are not concerned here with the capacities of the two networks since the purpose was to show that the assumption of a probability preference of 0.5 for each network is indeed a realistic assumption, at least in one environment, OFFICE.

Furthermore, our service-based approach for the selection of the appropriate access network may indeed result in high payoffs for the networks in terms of capacity and the resulting uniform distribution of mobile users is beneficial to the heterogeneous system as a whole. The high payoffs result from the fact that we do not consider capacity constraints in the game so far. We assume that the capacities of the two networks are equal and can sufficiently support all services requesting admission. This is not the case in real life, however, as the selected networks show.

Next, we need to show to what extent the proposed scheme is sensitive to the above assumptions. Would a differentiation in the probability preference change the outcome of the game? What would be the effect of changing the relationship between the network capacities? These questions are explored in the following section in a process called sensitivity analysis.

### 6. Sensitivity Analysis

The most important input in our network selection game is the network preference probabilities, i.e. what percentages of services prefer each of the two network-players. The original assumption, for simplicity purposes, was that 50% of the services prefer each network.

Another set of important inputs is the set of the capacities of the two network-players. Again, for simplicity purposes, the two capacities were assumed to be equal so far but this may not always be the case. We always assume that the set of services requesting admission is finite but large enough to fill the heterogeneous system to capacity. The last assumption is necessary to test the proposed scheme.
Let Pay 1 be the payoff of Player 1, and Pay 2 be the payoff of Player 2. Similarly, let C1 be the capacity of network 1 and C2 be the capacity of network 2. For comparison purposes we define Pay 1/Pay 2 as the payoff ratio and C1/C2 as the capacity ratio. Ideally, these two ratios should be equal or comparable, i.e. the payoffs of the players should be relative to their maximum capacities. Since the payoffs are capacity based, the above relationship would result in a uniform resource distribution (“resources” refer to mobile users). For example, in the case where the two capacities are equal, i.e. each network has half of the total capacity of the heterogeneous system, the payoffs are also equal. If the relationship no longer holds after varying the inputs away from ideal values, this is an indication that the payoffs are very sensitive to the input variations.

We need to investigate the sensitivity of our game to two inputs, the capacities and the preference probabilities. Let N equal to the total number of services. Let P1 and P2 be the preference probabilities of a service towards player 1 and player 2. We use four different alternatives for C1 and C2.

What we are interested in are not the actual capacity values but the relation between the two networks’ capacities. For each of the four alternatives we have three different probability sets (P1, P2): 50%-50%, 40%-60%, and 60%-40%.

We expect that these twelve cases can be sufficient for the sensitivity analysis, to show whether small but significant changes in the input parameters may affect dramatically the results of the game. Observations from the sensitivity analysis process are summarized in Table 5.

Let’s analyze Case 4 (randomly selected) to show how we deduce the specific results presented in Table 5.

**Case 4: C1/C2 = 2, P1 = 50%, P2 = 50%;**

For case 4, 50% of the services prefer network 1. Since network 1 is twice as big as network 2, it will admit all of the services preferring it, gaining maximum payoff (=10). Therefore for N services, network 1 will gain: (10)(50%)(N) = 5N. The rest 50% of the services prefer network 2. Network 2 is 1/3 of the total network capacity, therefore can only admit one third of the total services (assumption: N services fill heterogeneous network to capacity). Network 2 gains: (1/3)(10)(N) = 3.3N. The remaining services (1-1/2-1/3 = 1/6), prefer network 2 but will be admitted by network 1 (at payoff max/2 = 5), since network 2 is filled to capacity. The gain for network 2 is (1/6)(5)(N) = 0.83N. The total payoffs for each player are: Pay 1: 5N + 0.83N = 5.83N, Pay 2 = 3.3N (payoff ratio = 1.77).

We solve the rest of the cases in a similar manner. The capacity and payoff ratios remain comparable throughout the 12 cases.

The sensitivity analysis has shown that there is low risk in using the proposed scheme, since it will provide near optimal results even when the input parameters vary. This is achieved by the capacity constraints of the networks themselves, which keep the payoff values in the desired ranges even when the preference percentage diverts away from the ideal (the ideal would be to have a relationship between the preference probabilities equivalent to the relationship between the network capacities).

### Table 5: Sensitivity analysis results for 12 different sets of inputs.

<table>
<thead>
<tr>
<th>Case</th>
<th>Capacity Ratio</th>
<th>Preference Percentage</th>
<th>Payoffs for Player 1 &amp; Player 2 (N services)</th>
<th>Payoff Ratio</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>C1/C2 = 1</td>
<td>P1 = 50%, P2 = 50%</td>
<td>Pay 1 = 5N, Pay 2 = 5N</td>
<td>Pay1/Pay2 = 1</td>
<td>For all cases we observe that the variations in the preference distribution do not affect the tendency of the payoff ratio to be very similar to the capacity ratio. This implies that network capacities, and consequently system overall welfare, will not be affected by input variations</td>
</tr>
<tr>
<td>2</td>
<td>C1/C2 = 1</td>
<td>P1 = 40%, P2 = 60%</td>
<td>Pay 1 = 4.5N, Pay 2 = 5N</td>
<td>Pay1/Pay2 = 0.9</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>C1/C2 = 1</td>
<td>P1 = 60%, P2 = 40%</td>
<td>Pay 1 = 5N, Pay 2 = 4.5N</td>
<td>Pay1/Pay2 = 1.1</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>C1/C2 = 2</td>
<td>P1 = 50%, P2 = 50%</td>
<td>Pay 1 = 5.83N, Pay 2 = 3.3N</td>
<td>Pay1/Pay2 = 1.77</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>C1/C2 = 2</td>
<td>P1 = 50%, P2 = 60%</td>
<td>Pay 1 = 5.35N, Pay 2 = 3.3N</td>
<td>Pay1/Pay2 = 1.62</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>C1/C2 = 2</td>
<td>P1 = 60%, P2 = 40%</td>
<td>Pay 1 = 6.3N, Pay 2 = 3.3N</td>
<td>Pay1/Pay2 = 1.92</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>C1/C2 = 10</td>
<td>P1 = 50%, P2 = 50%</td>
<td>Pay 1 = 7N, Pay 2 = 1N</td>
<td>Pay1/Pay2 = 7</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>C1/C2 = 10</td>
<td>P1 = 40%, P2 = 60%</td>
<td>Pay 1 = 6.5N, Pay 2 = 1N</td>
<td>Pay1/Pay2 = 6.5</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>C1/C2 = 2</td>
<td>P1 = 60%, P2 = 40%</td>
<td>Pay 1 = 7.5N, Pay 2 = 1N</td>
<td>Pay1/Pay2 = 7.5</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>C1/C2 = 50</td>
<td>P1 = 50%, P2 = 50%</td>
<td>Pay 1 = 7.4N, Pay 2 = 0.2N</td>
<td>Pay1/Pay2 = 37</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>C1/C2 = 50</td>
<td>P1 = 40%, P2 = 60%</td>
<td>Pay 1 = 6.9N, Pay 2 = 0.2N</td>
<td>Pay1/Pay2 = 34.5</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>C1/C2 = 50</td>
<td>P1 = 60%, P2 = 40%</td>
<td>Pay 1 = 7.9N, Pay 2 = 0.2N</td>
<td>Pay1/Pay2 = 39.5</td>
<td></td>
</tr>
</tbody>
</table>

**7. CONCLUSIONS AND FUTURE WORK**

The integration of wireless/mobile networks into a large scale, heterogeneous network and developing mechanisms in order to fully utilize the capacity of the constituent networks is a new technology proposal that aims to address the demand...
for increasing data-rates and simultaneously the continuous evolution of services and applications for mobile/wireless environments.

One of the issues that need to be resolved in such a technology proposal is how to select the access network most suitable to serve each mobile/wireless user seeking admission. This paper proposes a novel game-theoretic approach for a service-based selection of radio access network in such a heterogeneous environment.

The approach is user-friendly, utilizes the constituent network capacities and demonstrates convergence, fairness and efficiency. The theoretical work is supported by a real-world example as well as a sensitivity analysis that investigates the effect of variations in the input parameters.

Future work involves using mixed strategies (a combination of probabilities of using the pure strategies) and extending the game from a two-player game to a multi-player one. We expect that the game will easily translate into the multi-player case with equilibriums supporting the service-based selection of radio access network as in the two-player game. Furthermore, different sets of services, environments and constituent networks will be taken into account to provide with a most realistic as well as efficient solution to the issue of radio access network selection in heterogeneous environments.

8. ACKNOWLEDGMENTS

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REFERENCES


