Game Theory-based Dynamic RRM for Reconfigurable WiMAX/WLAN System

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Abstract— **This paper proposes, analyzes and evaluates a novel user-oriented Radio Resource Management (RRM) strategies for coexisting WiMAX/WLAN reconfigurable system. The proposed strategies are based on game theory concepts, where games are dynamically played depending on the system condition with the applications on the terminal modeled as players. User's terminals have two interfaces, which can be used for enforcing reconfigurability by deploying RRM strategy that results in appropriate network selection for each application. The proposed RRM strategies are distributed and they map rationality behavior by adopting two game theory concepts: Nash and Quantal Response Equilibrium (QRE). These RRM strategies are compared with SNR based strategy. The effects of particular strategy are evaluated in terms of user's average throughput and the initiated application handovers. The results present guideline framework for distributed terminal management in reconfigurable systems.**

Keywords-Game theory; Reconfigurable systems; RRM

I. INTRODUCTION

In recent years, there are number of design and realization strategies for reconfigurable wireless systems due to their paramount importance in delivering 4G concepts [1]. Reconfigurable systems are envisioned as the future providers of rich multimedia content via various wireless links. The dynamic resource allocation strategies in such systems tackle crucial problems that lead to performance degradations in the wireless medium [2]. Furthermore, these strategies can be used to utilize particular network in the system by appropriate selection that will result in performance increase. The challenging task is the design of such strategies.

This paper proposes, analyzes and evaluates novel user oriented dynamic allocation strategy for user reconfigurability based on *game theory* concepts. The strategy is distributed at each user terminal and evaluated in a simulated WiMAX/WLAN reconfigurable system. User's terminals have two interfaces [3], one for each available network in the reconfigurable system. The result of the strategy is an appropriate network selection for the applications started on the terminal. This selection is made by game theory modeling, where players are the applications on the terminal and they can select WLAN or WiMAX. The result of the game differs due to the *degree of rationality* in the decision (Nash, QRE) and due to changes in the system (fluctuations of the received SNR from the networks). The general idea is to test how rationality of the distributed decision influences the overall user performances. Completely rational decision is modeled with the Nash equilibrium solution, whereas specific stochastic decision is modeled with QRE equilibrium. Furthermore, these two decisions (Nash based and QRE based) are compared with SNR based strategy.

The paper is organized as follows**.** Section II gives short background of game theory and explains the decision making for Nash and QRE equilibrium solutions. Section III explains the deployment of both game theory based RRM strategies (Nash and QRE) and the classical SNR based strategy. Section IV elaborates details of the system model with simulation setup, analytical definition of utility and presents the performance results in terms of application throughput and the application handover initiation. These results are used for comparison between the three decisions based on Nash, QRE and SNR. Finally, Section V concludes the paper.

II. GAME THEORY SCOPE

Game theory is a branch of applied mathematics. By using mathematical description and modeling, game theory concepts provide useful tool to analyze scenarios in which particular features can be modeled with games. The participants in the game are labeled as *players*. Each player has possible set of actions (*strategies*) that it can deploy and a *preference* that should be achieved during the game. The conflict of interest between the players implies that each player decision influences the preferences of the other participants in the game. Player's preferences are modeled with a *utility function* that depends on the scenario and the game model [4]. The main objective of the players in the game is to maximize their preferences by optimizing the utility function with appropriate deployment of their strategies. The solution concept in which referent player in the game is assumed to know the equilibrium strategies of the others and none of the players has any gain when unilaterally changes the strategy is Nash equilibrium [5]. The Nash equilibrium is a result of *totally rationality* of the players, meaning that each player behaves in utility maximizing manner by playing the *best possible response* to other player's strategies.

Alternative approach to solve a game is the concept of *bounded rationality*. When the player's behavior is modeled with bounded rationality they do not always play the best response to other player's strategies. This approach implies stochastic decision for the strategy deployment where better actions are played with higher probability than worse actions. Stochastic decisions with bounded rationality can be more effective in particular cases. Nash equilibrium is optimal for rational players, however it may not be optimal for irrational players. The reason for irrationality occurrence may be due to dynamic changes of the modeled system or due to incomplete knowledge of all parameters that may influence the game outcome. Quantal Response Equilibrium (QRE) [6] is a solution concept of a game based on bounded rationality in which each player strategy is a *stochastic best response* to other player's strategies. There is a *precision parameter* (λ) within the QRE choice function that defines the degree of rationality in the decision making process. When this parameter is set to zero, the decisions become totally random, whereas for infinity value of the precision parameter the QRE equilibrium converges to Nash equilibrium.

The Nash solution is optimal for total rationality of the players. This rationality requires selection of the optimal strategy. For two possible strategies (*A* and *B*) and *utility* function *u* that maps the strategies in preferences, the rational player will do the following:

- $u(A) > u(B)$, play *A*;
- $u(A) < u(B)$, play *B*;
- $u(A) = u(B)$, play random;

The QRE solution is based on stochastic choice, where for two possible strategies (*A* and *B*) the player will do the following:

- $u(A) + \xi a \; > \; u(B) + \xi b$, play *A*;
- $u(A) + \xi a \; < \; u(B) + \xi b$, play *B*;
- $u(A) + \xi a \; = \; u(B) + \xi b$, play random;

where ξ is a random variable with zero mean value that can be observed as *additional shock* in utility calculation (mistakes in mapping the strategies to the preferences). The following equation denotes the probability for a player to play strategy *A* with the QRE solution:

$$P(A) = \frac{e^{\lambda u(A)}}{e^{\lambda u(A)} + e^{\lambda u(B)}} \qquad (1)$$

The two game theory concepts map the degree of rationality in the decisions. The RRM strategies are based on this decision process, which is completely distributed. Hence, the obtained results evaluate the effect of rationality on overall user's performances (application throughput and handover initiation) in a reconfigurable system.

III. GAME THEORY BASED RRM

The user oriented RRM strategies proposed in this paper are based on Nash and QRE solution concepts. The implementation of the RRM strategies is for a terminal that has two interfaces (WiMAX, WLAN) that enable communication with the reconfigurable WiMAX/WLAN system. There are *two data applications* on each user terminal labeled as players in the game. This is done only for simplicity. The same approach can be used for more applications which can only lead to more complex computation of the equilibrium. Possible strategies for the players are to use WiMAX or WLAN network. The player's preferences in the game are defined with utility (application based metric) that depends on the application type and the specific PHY and MAC parameters of the component networks in the reconfigurable system. The general game setup is given in Table I, where P_1 and P_2 denote the players, *WiMAX/WLAN* are the possible strategies and with *U* as the appropriate utility for the particular strategy (e.g. $U_{wimax(1)}$ is the utility of P_1 for the *WiMAX* strategy).

TABLE I. Game notation

P_1 ; P_2	WiMAX	WLAN
WiMAX	$U_{wimax(1)}$; $U_{wimax(2)}$	$U_{wimax(1)}$; $U_{wlan(2)}$
WLAN	$U_{wlan(1)}$; $U_{wimax(2)}$	$U_{wlan(1)}$; $U_{wlan(2)}$

The outcome of the game is a network selection per application on each terminal. When *Nash based strategy* is deployed the decision for selecting network for the application is totally rational. In contrast, the QRE strategy deploys stochastic decision that depends on the precision parameter in the QRE choice function. The *QRE strategy* adopted in the paper deploys *opposite strategy* of the one selected with Nash. This can be achieved by adaptive tuning of the precision parameter that defines the probability for playing a certain strategy. To compare, if the Nash strategy selects the two applications to remain on one network, the modeled QRE strategy parts the applications on both networks. The game on each terminal is dynamically played and the decisions are updated, since the variations in the wireless channel and network availability change the utility perception of the mobile user.

The two game theory based RRM strategies are compared with classical *SNR based strategy*. This approach selects the interface with higher SNR for both applications. Additional intelligence in the SNR decision making is introduced by mechanism that parts the applications on both networks only when the SNR on the inactive interface exceeds the SNR value on current active interface (both interfaces have very high SNR). Comparing the SNR and the game theory RRM, the latter provides further intelligence by specifying why and which application should be run on particular network (since they are modeled as players).

IV. SYSTEM MODEL & PERFORMANCES

The following subsections elaborate the system model (simulation platform, utility functions) and present the evaluation of the decisions rationality within the game theory RRM. The results are compared with the SNR approach.

A. Simulation platform

The simulations are made in combined manner by utilizing three environments: *QualNet* [7], *Java* and *Gambit* [8]. The simulation platform is presented in Figure 1. Qualnet simulator is used to configure WiMAX/WLAN reconfigurable system and the terminals with two interfaces.

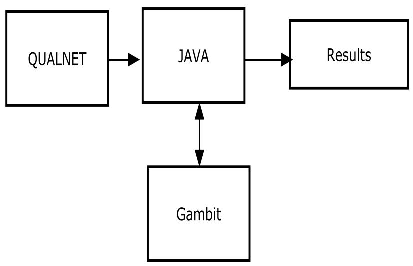

Figure 1.Simulation concept

The WiMAX cell has full coverage over the simulation area, whereas the WLAN has smaller coverage area which is completely within the WiMAX cell. As a result, the WiMAX network is always available for the users, whereas the WLAN is not because according to the mobility model the users can leave the WLAN coverage. The configuration parameters for the networks are given in Table II.

TABLE II. Parameters for WiMAX/WLAN

WiMAX	Antenna gain [dBi]	Tx power [dBm]	Antenna height [m]
BS	*18*	*43*	*35*
Channel	*3.3 GHz*		
WLAN	Antenna gain [dBi]	Tx power [dBm]	Antenna height [m]
802.11a	*8*	*15*	*1,5*
Channel	*5 GHz*		

When the simulation in QualNet is finished, the following parameters for every terminal (user) are transferred in Java environment:

- The time when an SNRwlan value is received
- The appropriate SNRwlan value in dB
- The time when SNRwimax value is received
- The SNRwimax value in dB

These values are used for definition of the user. The user is created from a defined *Java class*. Additionally, there are Java classes for the *applications*, *strategy deployment* and *results monitoring*. The strategy deployment in Java is done by coordination with the Gambit environment that provides Nash and QRE solution for the games. In Java, the parameters from QualNet and Gambit are combined and the results for average application throughput and the initiation of application handovers are obtained with event driven simulation.

B. Analytical utility model

The utility is application depended metric that shows how the application quality is perceived by the users. There are different approaches for estimating utility value for a particular application. References [9, 10] elaborate the concept of utility functions design and their application as metrics within RRM and optimization strategies in wireless systems. It shows that the utility function depends on the application type. For example, the on/off nature of the voice applications results in a steep utility function. References [11, 12] show approaches for estimation of the utility function for voice applications. The utility function for data application is a smooth curve due to the data elasticity. There are different utility functions designs depending on various technical parameters that "describe" the application flow in the wireless links.

This paper proposes RRM strategies for elastic data applications with *adaptive throughput* that can vary due to the conditions in the channel and available network resources. Such model can be used for variable data services corresponding to file download. In addition, they can be used within the game theory model since they do not have delay constrains. The utility depends only on the throughput. The adopted function for modeling the utility is given in [13, 14]:

$$u = a * \log[b * R * (1 - PER)] \qquad (2)$$

where R denotes the application throughput, PER is the packet error rate (predefined value 0,01) and a,b are dimensioning constants that depend on the maximum and minimum possible throughput in each network. The utility function depends only on the throughput and the specific modeling of the wireless system. The utility in WiMAX and WLAN is presented as follows, with a framework method that can be used for more complex approaches in utility based network dimensioning.

1) WLAN

The WLAN system in QualNet is based on IEEE 802.11a standard. The PHY modes that define the communication with the appropriate rate and SNR given in Table III [15].

TABLE III. Parameters for PHY mode in WLAN

PHY	1	2	3	4	5	6
Rate(Mbps)	*6*	*12*	*24*	*36*	*48*	*54*
SNR(dB)	*0-10*	*10-14*	*14-21*	*21-31*	*31-32*	*32-38*

The effective throughput depends on the procedures on MAC layer. The adopted approach is to use only half of the physical bitrate as effective throughput due to the MAC procedures. This means that maximum available throughput (*Rmax*) for the application will be when the AP PHY mode is 6 and serves only one user. Minimal available throughput (*Rmin*) will depend on the predefined number of maximum

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possible users on WLAN who share the network capacity. This number can be predefined with admission control procedure (adopted value *Nmax*=10). Adopting this approach, the equations (3, 4) are used for calculating the minimal and maximal throughput in the WLAN network. The maximum and minimum throughputs are then used to create system of two logarithmic equations according to (2).

By setting maximum (=1) and minimum (=0.1) possible values of the utility function, system of logarithmic equations is formed.

$$R_{\max} = \frac{PHY_{\max}(54Mbps)}{2} \qquad (3)$$

$$R_{\min} = \frac{PHY_{\min}(6Mbps)}{2}\frac{1}{N_{\max}} \qquad (4)$$

The logarithmic equations for the system are given with (5) and (6), as follows:

$$u_{\max} = a\log_{10}(bR_{\max}(1-PER)) = 1 \qquad (5)$$

$$u_{\min} = a\log_{10}(bR_{\min}(1-PER)) = 0.1 \qquad (6)$$

These equations are used to define the utility values. The adopted approach for estimation of WLAN utility is done in simplistic manner by using only half of the physical throughput. Alternative approach for utility estimation of the WLAN can be with OFDM analysis. This type of estimation is done for the WiMAX system as elaborated in the following subsection.

2) WiMAX

The WiMAX system in QualNet is based on IEEE 802.16e standard. Estimation of the utility for WiMAX is performed by PHY and MAC analysis of the WiMAX technology. The received SNR in WiMAX defines the modulation and the coding used for sending appropriate number of bits/symbol. This mapping is given in Table IV [16]. The number of subcarriers in the system is *N*=2048 and the channel bandwidth is *B*=20MHz. The effective duration of the symbol is obtained in standard manner according to [17]:

$$T_N = NT_s \qquad (7)$$

where *Ts=1/fs*, and *fs=8/7B*. The guard interval between the uplink and downlink of the MAC frame is calculated with:

$$T_g = \{\frac{1}{4};\frac{1}{8};\frac{1}{16};\frac{1}{32}\}T_N \qquad (8)$$

Total symbol duration is given with the following equation:

$$T_{Ntotal} = T_g + T_N \qquad (9)$$

The total number of symbols (*Tot_Sym*) is obtained from the MAC frame duration which can be adaptive according to standard, but for the analysis duration of 5ms is used.

This total number of symbols (*Tot_Sym*) is obtained when the MAC frame duration is divided with the total symbol duration. From the total number of symbols only the symbols used for data transfer are labeled as effective and are used for defining the utility function. The effective number of symbols (*Eff_Sym*) is given with the following equation:

$$Eff\_Sym = Tot\_Sym - (\sum_{i=1}^{5} X_i) \qquad (10)$$

where

$$(X_1 + X_2 + X_3 + X_4 + X_5) = (3,1,7,1,1) \qquad (11)$$

are five groups (indexed with *i*) of symbols for broadcast, contentions slots and preambles in the MAC frame [18].

TABLE IV. Mapping SNR in bits/symbol in WiMAX

Modulation and Coding	SNR	Bits per symbol
BPSK: 1/2	*3*	*96*
BPSK: 1/4	*6*	*192*
QPSK: 1/2	*8,5*	*288*
QPSK: 1/4	*11,5*	*384*
16 QAM:3/4	*15*	*576*
16 QAM:2/3	*19*	*768*
64 QAM	*21*	*864*

The approach for estimation the utility of the WiMAX system is done according to the analysis elaborated in [18], where the total number of symbols for all active users (*Us_TotSym*) in WiMAX depends on the frame duration (*Fr_Dur*) and the SNR for every user:

$$Us\_TotSym = R * Fr\_Dur * (\sum_{i=1}^{7} \frac{Nss_i}{bits\_sym_i}) \qquad (12)$$

where *R* is the available throughput for the incoming user, Nss_i is the number of serving users with appropriate bits/symbol depending on their channel (SNR). The possible values for $bits\_sym_i$ in equation (12) correspond to the seven mappings (index *i* denotes particular row) in Table. IV. For example, if there are 3 users with SNR < 3, than for *i*=1 in (12), Nss_i =3 and $bits\_sym_i$ =96 for the three users. The throughput is used to model the utility for WiMAX with system of logarithmic equations (13, 14) :

$$u'_{\max} = a\log_{10}(bR'_{\max}(1-PER)) = 1 \qquad (13)$$

$$u'_{\min} = a\log_{10}(bR'_{\min}(1-PER)) = 0.1 \qquad (14)$$

where, due to predefined system dimensioning with admission control $M_{max}=20$ (similar to N_{max} value adopted for WLAN), the maximal ($Nss_i=1$, $bits\_sym_i=864$) and minimal throughput are given with the equations (15,16):

$$R'_{\max} = \frac{Eff\_Sym}{Fr\_Dur * (\sum_{i=1}^{7} \frac{N\_SS_i}{bits\_sym_i})} \qquad (15)$$

$$R_{\min}^{/} = \frac{Eff\_Sym}{Fr\_Dur * (\frac{M_{\max}}{bits\_sym})} \tag{16}$$

C. Performance evaluation

The simulations with the proposed simulation platform are performed with 8 users in a square simulation environment (1000x1000m) with 16 running applications. The simulation duration is 600s in order to provide sufficient statistical regularity of the results. This implies that further increase of the number of users (and thus the number of the applications) will not change the trend of the results. The user's follow random waypoint mobility model and communicate with the networks on two separate channels. The path loss model is two-ray and the shadowing factor is 4dB. The performance evaluation of the three RRM strategies based on Nash, QRE and SNR are presented with the following parameters of interest:

- Dynamic allocation of applications per networks
- Average application throughput on WiMAX
- Average usage of WLAN
- Application handovers

The results for the *dynamic allocation* of the applications with Nash/SNR/QRE decisions observed on WiMAX and WLAN networks are given on Figure 2. and Figure 3.

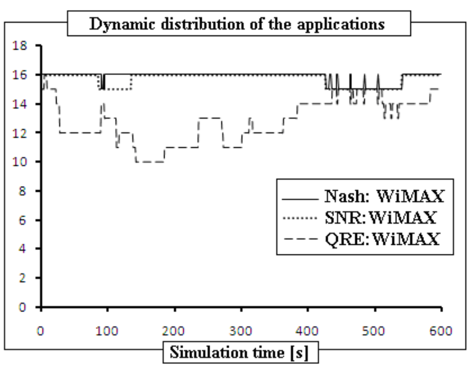

Figure 2. Dynamic distribution of the user's application on WiMAX network with Nash/SNR/QRE decisions

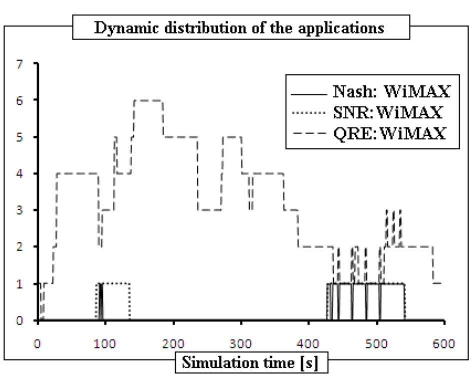

Figure 3. Dynamic distribution of the user's application on WLAN network with Nash/SNR/QRE decisions

The analysis of this parameter shows the load balancing feature of the distributed RRM in the reconfigurable system. Because the terminals do not have network related information (number of serving users, applications, etc.), they estimate their utilities dynamically for the game according to static network parameters and on their input in the network (two applications). The results show that using SNR and Nash strategies similar results are obtained for the load balancing, resulting in very rare usage of the WLAN. The QRE strategy, since it is tailored to do the opposite of Nash, results in frequent WLAN usage. In this sense, the QRE strategy provides better load balancing in the distributed decision making process.

The *average application throughput* per user on WiMAX is shown in Figure 4. This parameter is averaged during the simulation time because WiMAX is always available (full coverage) for the mobile users in the scenario. The average application throughput per user is a mean value of the throughput that both applications experience on the user terminal. The results show that QRE yields highest application throughput per user compared to SNR and Nash strategies which have similar performances.

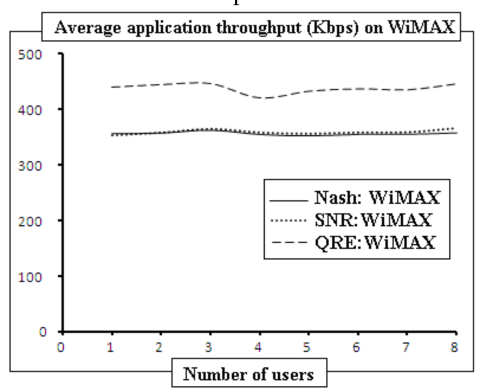

Figure 4. Average throughput per application for each user on WiMAX network with Nash/SNR/QRE decisions

The *average usage* of WLAN AP is shown on Figure 5, measured as throughput. It shows how much the AP was used during the simulation time on average by the users. The QRE strategy invokes highest usage of the WLAN AP due to the dynamic distribution of the applications on both networks. SNR and Nash have similar average AP usage. This parameter is also linked to the previous parameter that showed the average throughput per application for each user on WiMAX. When the deployed RRM yields more frequent AP usage in the scenario it produces lesser load on WiMAX and thus WiMAX throughput increase on average basis.

The application handovers are shown on Figure 6, in a normalized manner, where the strategy with the highest number of handovers (QRE) corresponds to 100%. This parameter shows how much handovers are occurred in the reconfigurable system for all of the user's applications with each RRM strategy. In addition, this parameter shows how the RRM strategy is prone to performing vertical handovers in the system. This parameter is highest with QRE

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technique, whereas Nash results in slightly higher handover initiation compared to SNR. There is an imminent degradation of quality when vertical handover occurs because the reconfiguration of the communication protocol stack on the link user-network disrupts the service quality. In this sense, the QRE results in highest performance degradation compared to SNR and Nash.

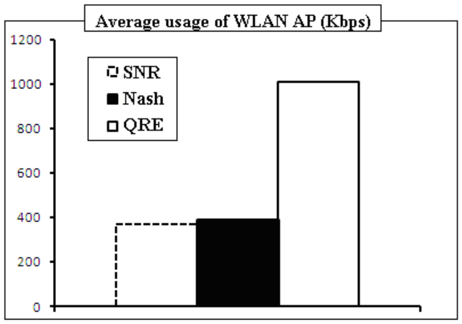

Figure 5.Average usage of WLAN AP: Nash/SNR/QRE

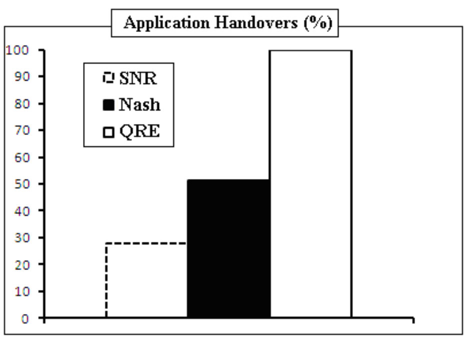

Figure 6.Handovers in (%) with Nash/SNR/QRE decisions

The performance results depend on the analytical modeling of the utility, the analysis of the networks and the scenario model. However, the presented framework approach is general and applicable in similar environments where terminals deploy distributed RRM to explore reconfigurability benefits and maximize their preferences. Furthermore, the results show the tradeoff between the throughput of the application and the handovers initiations as degradation factor. Such tradeoff should be considered when managing terminals in reconfigurable systems.

V. Conclusion

This paper proposes and evaluated novel user oriented RRM strategies for reconfigurable WiMAX/WLAN system. The strategies are distributed, based on game theory concepts (Nash and QRE), where the game is played by the applications on each terminal modeled as players. The RRM strategies result in appropriate network selection for each application on the user's terminals and are compared to SNR based strategy. The results show the tradeoff between the load balancing, user's throughput and handover initiation between the strategies. The provided framework can be used in distributed RRM strategies to tune user preferences by balancing application's throughput demands and handover initiation between the networks in the reconfigurable system.

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