

An Economic-Driven Joint Radio Resource Management with User Profile Differentiation in a Beyond 3G Cognitive Network

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ABSTRACT- This paper proposes a new Joint Radio Resource Management (JRRM) strategy which, as a difference from previous works in the literature, introduces economic and user differentiation concepts. This economic-driven algorithm is based on guaranteeing a certain user acceptance of a given service, combining both the economic and technical dimensions, while at the same time increasing the operator revenue. Two user profiles with different needs are considered, namely consumer and business users, and it is shown that the needs of both profiles can be met by means of the proposed framework. Three implementations of the proposed JRRM are compared. Two of them are based on a user-centric approach, whereas the third implementation falls into the joint user-centric and network-centric category aiming at maximizing the operator revenue while maintaining the user satisfaction at a target contracted value. In this case, particular attention is paid to business users and to strategies based on resource reservation to improve their utility as well as the operator revenue.

I. INTRODUCTION

In the forthcoming heterogeneous wireless scenarios, the multiple available access systems will be combined on a common platform in an optimum way according to the Always Best Connected (ABC) concept [1]: the perspective of Beyond 3G (B3G) networks is to allow users accessing any kind of wireless anywhere and anytime by making use of the multiplicity of access technologies together with terminals with reconfigurability capabilities [2]. In this framework, introducing cognition processes is of up most importance. The technologies should be able to operate in a complex environment, observe it, make behaviour choices and receive feedbacks from it, all while learning to determine future behaviour based on past and current feedbacks [3]. The internetworking among different Radio Access Technologies (RATs) proposed in the B3G networks introduces a new dimension in the Radio Resource Management (RRM). In particular, Joint Radio Resource Management (JRRM) is the identified process to manage dynamically and co-ordinately the allocation and de-allocation of radio resources (e.g. time slots, codes, frequency carriers, etc.) between different RATs for the spectrum bands allocated to each of these systems, so that a more efficient usage of radio resources will follow.

Most of RRM schemes can be classified as either user-centric or network-centric. User-centric RRM schemes attempt to maximize the interests of individual users, whereas network-centric ones optimize network interests. Distributed power control and minimization of outage probability can be thought of as examples of user-centric resource management. Maximization of objectives like the sum of network throughputs falls into the network-centric

category. User-centric and network-centric RRM schemes are motivated by different interests, and hence, ought to result in dissimilar resource allocations.

In [4] a user-centric fuzzy neural based strategy for JRRM operation was presented including a reinforcement learning mechanism to adapt the algorithm in order to achieve the desired QoS constraints. In that context, the user satisfaction concept was associated with the minimum bandwidth allocated to the users. However, the users' feelings also depend on the price paid for the service. This means that a very high bandwidth at a very high price may be undesirable for some users that prefer lower bandwidths at more reduced price. Even though technical issues related to the dynamic operation of the network have traditionally been targeted quite independently from economic aspects, the research community has already identified the need for a major interaction. Micro-economic concepts have already been applied to radio resource management related issues such as admission control [5], power control [6] and packet scheduling [7].

This paper represents a step towards a joint network-centric and user-centric economic-driven JRRM scheme by introducing revenue and pricing considerations into radio-interface management decisions considering as a basis for technical decisions the algorithm presented by the authors in [4].

To account for the different willingness of users to pay for the received service, two different user profiles are considered in this paper: consumer and business. Business users are more bandwidth and performance demanding and the prices they are willing to pay are higher. Consequently, from the operator point of view, they represent an important source of income. Therefore, some kind of priority should be given to the resource assignment of these users, in order to improve their performances and the operator revenue.

Intelligent Resource Reservation (RR) strategies have been widely invoked in the past, in case of horizontal handover, using predictive procedures [8][9], as an effective way to reduce handoff call dropping probability by assigning higher priority to handoff calls rather than to new calls, due to the fact that users are more sensitive to call dropping than new call blocking. This paper proposes to extend the handoff call resource reservation concept to a heterogeneous scenario by reserving resources for business users, in case of both horizontal and vertical handovers, which to the authors' knowledge, has not been so far considered in the open literature. Finally, taking into account that in micro-economics it is often advantageous to employ pricing discrimination according to the users' preferences, the option of charging business users in a different manner with respect to

consumer ones is also considered in this paper as a way to further improve the operator revenue, while maintaining the user satisfaction constraints.

The rest of the paper is organized as follows. Section II introduces some micro-economic concepts in the context of JRRM. Section III, presents the proposed economic-driven JRRM. In Section IV, the proposed RR scheme is introduced. Section V describes the multi-RAT scenario where the proposed strategy is evaluated as well as some representative results. Finally, Section VI summarizes the conclusions.

II. JOINT RADIO RESOURCE MANAGEMENT WITH UTILITY AND PRICING

In the context of an economic-driven JRRM, the concept of satisfaction is different if measured from a user-centric or from a network-centric perspective. However, it should be kept in mind that both user and network operator satisfaction strongly depend on the bandwidth allocation and pricing policies. As a result, in this paper, two metrics have been identified in order to quantify the user and the network operator satisfaction.

A. User-centric metric: user acceptance

From the user point of view, the notion of *user acceptance* of a given service is retained. The user acceptance is thought to be an appropriate indicator of the user satisfaction, since it includes the trade-off between the price paid and the perceived quality. Specifically, the user acceptance can be defined as the probability that the users are satisfied with the service obtained from the network in accordance to the price they are paying. Therefore, the acceptance should be an increasing function of the utility that the user perceives and a decreasing function of the price, given [10].

$$A(u, p) = 1 - \exp(-Cu^\mu p^{-\varepsilon}) \quad (1)$$

where C , μ and ε are constants representing the different user sensitivity to utility and price.

The utility is a function that depends on the specific service characteristics and the elasticity of the applications. Inelastic applications (e.g. real time voice) are characterized by a step utility function depending on e.g. whether the allocated bandwidth B is above or below a given threshold. On the other hand, elastic applications (e.g. data applications) exhibit a smoother function of the allocated bandwidth. Particularly, in this paper the utility is defined as [10]:

$$u(B) = \frac{(B/K)^\xi}{1 + (B/K)^\xi} \quad (2)$$

where $0.2 \leq K \leq 4.2$ and $2 \leq \xi \leq 20$ tune the utilities.

It is worth highlighting that the user acceptance concept measures the subjective perception of the service, mainly depending on the utility perceived versus the price paid for it. For example, a value of user acceptance A means that during the $A\%$ of the time, the user considers the QoS received as satisfying with respect to the price paid, so that there is no relationship between the user acceptance concept and performance figures such as blocking/dropping. Finally notice that a study of the user behaviour in the long term, evaluating whether or not it is going to switch to another operator, depending on the specific acceptance, is out of the scope of this paper.

In order to consider that different users may exhibit a different sensitivity to the specific service, two user profiles, have been defined in this paper, whose acceptance functions as a function of the allocated bandwidth are plot in Figure 1 (i.e. $\mu=2$ and $\varepsilon=1.5$ for consumer users and $\mu=40$ and $\varepsilon=2.5$ for business users). The consumer profile represents the population segment for which the price may be more relevant than the allocated bandwidth and therefore its acceptance is high even for relatively low bandwidths and decreases very fast for high bandwidths because they are not willing to pay for them. On the contrary, the business profile represents the population segment for which the most important thing is the allocated bandwidth rather than the price. Consequently their acceptance is low for low bandwidths and decreases slowly for high bandwidths.

B. Network-centric metric: network operator

From the network operator point of view, the revenue is considered as the network metric to define the operator satisfaction. The operator revenue can be formulated as a function of the price the users are paying and the user acceptance, in the sense that only users accepting the service will be in practice generating revenue. This leads to the following definition of revenue [10]:

$$R = \sum_{i=1}^N p_i A(u_i(B_i), p_i) \quad (3)$$

where N is the number of users, p_i is the price paid by the i -th user, B_i its bandwidth and $A(u,p)$ the user acceptance.

III. ECONOMIC-DRIVEN JRRM

The proposed economic-driven JRRM algorithm is based on fuzzy neural methodology and operates in a heterogeneous scenario with three available RATs, namely UMTS (Universal Mobile Telecommunications System), GERAN (GSM EDGE Radio Access Network) and WLAN (Wireless Local Area Network) and the objective is to provide, for each user, the most appropriate RAT and bit rate allocation, taking into account the following inputs:

- Technical inputs: They consist of measurements of the signal strength SS_k and resource availability RA_k for each RAT k . Mobile speed MS is included to take into consideration mobility constraints in the RAT allocation.
- Economic inputs: They consist of the price p_j to be paid for service j and the desired total user acceptance A^* .
- Operator policies: They consist of a set of high-level directives that specify the construction of the inference rules in the fuzzy neural block.

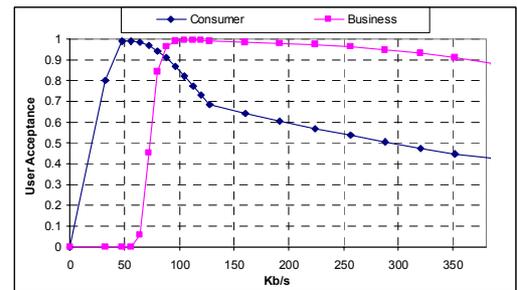


Figure 1 User acceptance for the two user profiles

The proposed JRRM scheme, shown in Figure 2, consists of two main blocks: A Fuzzy Neural Network (FNN) and a second block performing JRRM decision prediction and resource reservation. The FNN consists of a Fuzzy Logic Controller (FLC) based on three procedures denoted as fuzzification, inference engine, and defuzzification, which are detailed in [4], and a reinforcement learning algorithm. This procedure provides the system with adaptive capabilities embedding cognitive-based mechanisms which let the network be aware of its current status in terms of user traffic and position variations. More specifically, the reinforcement signal considered here is the overall user acceptance $A(u,p)$, and consequently, the error signal minimized by the reinforcement learning procedure is:

$$E(t) = \frac{1}{2} (A^* - A(t))^2 \quad (4)$$

where $A(t)$ is the current average user acceptance at time t and A^* is its target value. For details on the operation of the reinforcement learning algorithm, the reader is referred to [4], where a user centric approach without economic-driven considerations was considered (i.e. only bit rate considerations). Finally, the outputs of the algorithms are:

- The RAT selected by means of the so called FSD parameter (Fuzzy Selected Decision), which is an indicator of the appropriateness of selecting a RAT in front of another one.
- The most appropriate bandwidth B that should be allocated to the active users.

On the other hand, the RR block consists of a Recursive Least Square (RLS) predictor [11], which estimates the future FSD values defining the JRRM decisions and which is associated with a RR algorithm detailed in the following section.

IV. RESOURCE RESERVATION ALGORITHM

When dealing with JRRM a handoff failure might occur as a consequence of a lack of resources in the targeted cell/RAT. Such a failure will normally end up with a dropping of the considered call. Consequently, and in order to avoid that this occurs mainly for the business users, a RR procedure involving different RATs has been envisaged as a proper solution. A first step in developing a suitable RR mechanism calls for predicting what is likely to happen. Considering that the handoff process is a direct consequence of the FSD crisp values provided by the FNC, a RLS predictor [11] capable of estimating these FSD values has been identified, so as to properly reserve resources for business users' handoff calls. The block diagram of the RR mechanism, which is applied to business users is described in Figure 3, where BW_D is the amount of bandwidth reserved to business users in case of handover prediction (i.e. 64 Kb/ and 128 Kb/s in case of GERAN and UMTS target cell, respectively), N_c is the number of consumer users attached to the target cell and BW_{Dc} is the minimum bandwidth that can be allocated to a consumer user to guarantee its target acceptance (i.e. 32 Kb/s according to Figure 1 when the user acceptance is 0.8). In addition, notice that the old cell is the cell the mobile is currently attached to and the target cell is the cell the mobile is supposed to join after the handover, provided that enough resources are available. In case of business users, when the predicted FSD level corresponding to a new RAT is higher than the one of the current RAT, a handover is predicted and a sufficient amount of resources (i.e. BW_D) should be

reserved in the target cell, so as to avoid a dropping. If a sufficient amount of resources cannot be allocated in the target cell, the RR algorithm activates the so-called *Virtual Resource re-organization* in order to re-distribute the resources already assigned to the consumer users in the target wireless cell, so as to make room for the otherwise potentially dropped business mobile, as it is shown in Figure 3. In particular, the amount of bandwidth reserved for the consumer users attached to the target cell after re-organization, is the minimum bandwidth BW_{Dc} guaranteeing the target acceptance of consumer users. If during the Virtual Re-organization phase the amount of bandwidth equal to BW_D is not available to the business user, no reservation is made and the economic-driven JRRM acts as usual. In this case, a dropping is likely to occur if the handover prediction was correct. Finally, the economic-driven JRRM decides the final bit rates allocated to each user. Notice that the virtual resource re-organization phase only modifies the resource availability that is an input to the fuzzy neural scheme, but the final decided bit rate is given by the economic-driven fuzzy neural JRRM algorithm execution. This is the reason for calling *virtual* to the previous intermediate bit rate reservation only used for calculation purposes.

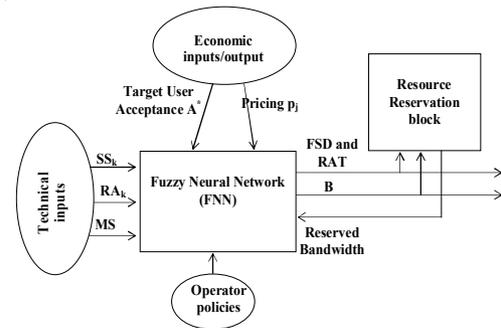


Figure 2 Economic-driven JRRM algorithm

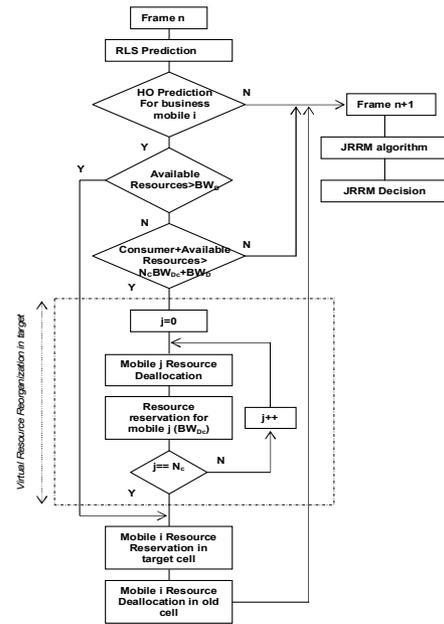


Figure 3 Block diagram of resource reservation

V. RESULTS

The proposed economic-driven JRRM is evaluated in a multicell scenario, with a seven cell deployment, including 4 UMTS base stations, 2 GERAN base stations and one WLAN access point, as it is shown in Figure 4. The considered scenario consists of circular cells, with radii 150m for WLAN, 650m for UMTS and 1km for GERAN.

A mobility model with users moving according to a random walk model inside the coverage area is adopted with a randomly assigned mobile speed in the interval [0,50] km/h and a randomly chosen direction.

The propagation model considered for UMTS and GERAN is given by $L=128,1+37,6 \log d$ (km), which assumes that the frequency band is similar for both systems [12]. For WLAN the propagation losses inside the hotspot are modeled by $L= 20 \log d(m)+40$ [13].

The beginning and the end of the user's activity periods are defined according to a Poisson scheme with an average of 6 calls per hour and user and average call duration of 180 seconds. The set of available bit rates in UMTS are {32 kb/s, 48 kb/s, 64 kb/s, 80 kb/s, 96 kb/s, 112 kb/s, 128 kb/s, 192 kb/s, 256 kb/s, 320 kb/s, 384 kb/s}, considering a single UTRAN FDD carrier with maximum allowed uplink load factor 0.75. For GERAN, the set of bit rates is {32 kb/s, 48 kb/s, 64 kb/s, 80 kb/s, 96 kb/s}, assuming a total of four carriers available and coding scheme CS-4. For WLAN it is considered that the total bandwidth available (11 Mb/s) is equally distributed among the WLAN users (i.e. the higher the number of users the lower the bandwidth per user will be). It is also assumed that no more WLAN users are accepted when the bandwidth per user is less or equal than 384 kb/s. A single access point is considered. A static pricing is considered. In particular, the price the user pays for the service provided is proportional to bandwidth allocated (i.e. $p=0.01 \cdot B$).

The retained performance metric is the *GoS (Grade of Service)*, which is here defined as $GoS=P_b(\%)+10 \cdot P_d(\%)$, where P_b stands for blocking probability and P_d for dropping probability. Simulation results have been obtained considering that the target acceptance probability A^* is retained to 0.8 for both business and consumer users. This choice is considered to be reasonable since it means that during the 80% of the time the user is satisfied with the service perception and the price paid for it.

The following JRRM implementations will be compared in terms of user and network satisfaction and bandwidth allocation:

- Technical-driven JRRM
- Economic-driven JRRM
- Economic-driven JRRM with RR

Implementations a) and b) fall into the user-centric category. In particular, the technical-driven JRRM, described with details in [4], just takes into account radio-interface issues in the RAT selection process and the user satisfaction concept just includes technical considerations such as the minimum bandwidth allocated to the users. Besides, the economic-driven JRRM incorporates micro-economic concepts in the RAT selection procedure and in the user satisfaction. On the other hand, implementation c) falls into the joint user-centric and network-centric category aiming at maximizing the operator revenue while maintaining the user acceptance $A(t)$ at the target value A^* . Notice that each implementation is motivated by different

interests and consequently each one results in different resource allocation, with respect to the others. In case of the technical-driven fuzzy neural JRRM, the satisfaction probability (i.e. the probability that the allocated bandwidth is above the satisfaction bandwidth) is set to 80%, for comparison purposes with the economic-driven implementation (i.e. $A^*=0.8$). Table 1 and Table 2 present some illustrative performance figures of the considered algorithm for implementations a) and b) when a total of 100 consumer and business users have been considered, respectively.

Similarly, and to allow a fair comparison, the satisfaction bandwidths in the technical-driven case are selected as the minimum bandwidths allocated in more than 80% of the cases by the economical-driven JRRM (i.e. the 20-th percentile of the allocated bandwidth distribution).

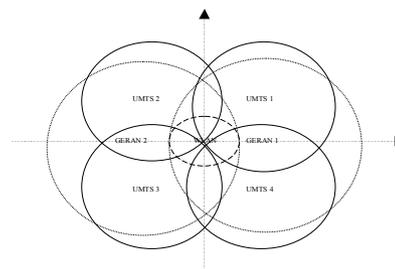


Figure 4 Simulation scenario

Focusing on the economic-driven JRRM, the higher willingness of business users to pay for high bandwidths turns into an overall increase in the allocated bandwidth with respect to consumer users. Similarly, and due to the higher bit rates available in UMTS, the allocation of business users in UMTS is higher than the allocation in GERAN, while the opposite occurs for consumer users. Notice that the economic driven JRRM provides higher revenues to the operator and higher bandwidth allocated for the users, than the traditional technical-driven JRRM approach.

Table 1 Consumer Performance figures

	Technical-driven JRRM	Economic-driven JRRM
% UMTS Selection	35	45
% GERAN Selection	63	54
%WLAN Selection	2	1
Revenue	1.17	1.66
Average assigned bandwidth	84.5 Kb/s	115.3 Kb/s

Table 2 Business Performance figures

	Technical-driven JRRM	Economic-driven JRRM
% UMTS Selection	50	54
% GERAN Selection	48	45
%WLAN Selection	2	1
Revenue	2.5	3.06
Average assigned bandwidth	157 Kb/s	171.8 Kb/s

For the results shown in the rest of the section, the users located in the scenario are 50% of the business class and 50% of the consumer class. The implementations considered for comparison purposes are b) and c).

Figure 5 and Figure 6 illustrate the GoS of consumer and business users in case the RR process is active (i.e. Economic-

driven JRRM+RR in the figures) or not (i.e. Economic-driven JRRM in the figures). First of all, it is worth noting that when the economic-driven JRRM is applied without giving higher priority to business users by the RR process, their GoS is higher than the one of consumer users. The reason is that business users are more bandwidth demanding, so that their droppings and blockings are more likely to happen than those of consumer users. In order to avoid this behaviour and to satisfy the most performance demanding user profile while consequently improving the operator revenue, prioritization must be given to business users by RR. This is shown in Figure 5 and Figure 6, revealing that when the RR mechanism is applied for business users, their performance results are improved with respect to consumer.

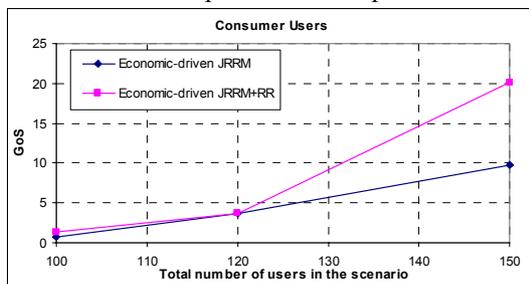


Figure 5 GoS of consumer users

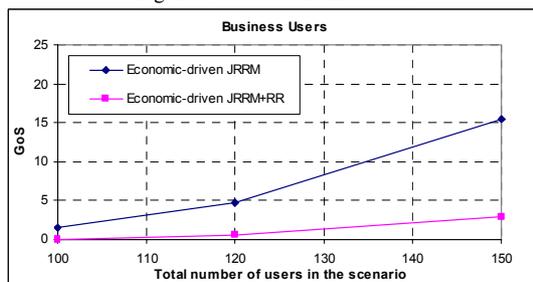


Figure 6 GoS of business users

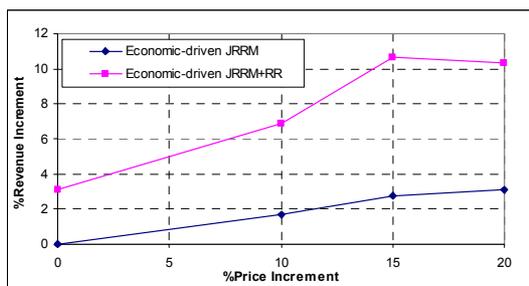


Figure 7 Revenue gain by price discrimination and RR

In addition to this, considering that it is a well known fact in micro-economics that pricing discrimination according to users' preferences can allow an increase in revenue, in this paper, in order to maximize the operator revenue, pricing strategies can be differentiated for consumer and business users, considering that business users are willing to pay higher prices as long as their QoS perception is good. Then, the pricing discrimination strategy in this paper considers that business users price per unit of bandwidth is increased in a certain percentage with respect to the price paid by consumer users (i.e. 0.01). Figure 7 shows the gain in terms of revenue as a function of the price increase of consumer users when there are 150 users in the scenario. The revenue gain is measured with respect to the case in which RR is

not applied and both consumer and business users pay the same. The revenue is increased by performing price discrimination both in the cases when RR is applied and when not. The application of RR leads to higher revenue gains, up to values of 11%. In any case, the price has to be increased taking also into consideration the business users' acceptance function. Otherwise, the price paid by business users may become excessive turning into user dissatisfaction and smaller revenue gains, as it is shown in Figure 7 when the price paid by business users is increased more than 15% with respect to the consumer users price.

VI. CONCLUSIONS

This paper has presented the inclusion of micro-economic concepts, in a JRRM framework. Two user profiles depending on their sensitivity to price and utility have been considered, namely consumer and business users. By means of the proposed economic-driven JRRM, significant revenue gains are obtained while keeping the user acceptance of the service at a desired rate. On the other hand, particular attention has been paid to define a strategy based on RR, according to JRRM decision reliable predictions, to improve the performances of the most bandwidth demanding profile, which is as well willing to pay higher prices. Finally, it has been shown that charging different prices to different user profiles, based on the user acceptance of the service, allows further increasing the operator revenue.

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