# Resource Auctioning Mechanisms in Heterogeneous Wireless Access Networks

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*Abstract* – The vision of the wireless communications beyond 3G is characterized by flexibility. Future communication networks should be able to flexibly allocate resources and radio access technologies (RATs) to maintain high quality of communication and efficient use of radio resources. This should be the task of the joint radio resource management (JRRM) algorithms. Furthermore, this flexibility should also cover the pricing mechanism which should be able to react to the instantaneous users' needs and resource availability. This will be tackled by a real time spectrum auction system. This paper draws an architecture which embodies the two mechanisms: JRRM and spectrum auction, in order to create highly efficient wireless systems.

## I. INTRODUCTION

Today's wireless communications comprise a broad variety of Radio Access Technology (RAT) standards. In Europe, the success of second-generation (2G) cellular system GSM (Global System for Mobile Communications) and the IP data connectivity support provided by GPRS (General Packet Radio System) paved the way towards evolved systems with higher data rate capabilities, such as the enhanced data rates for GSM evolution (EDGE) and finally the third-generation (3G) Universal Mobile Telecommunications System (UMTS). Moreover, in parallel with the evolution of cellular systems, several types of Wireless Local Area Networks (WLANs) like, e.g., the IEEE 802.11x standard emerged and became profusely used in home environments.

These new scenarios must indeed be regarded as a new challenge to offer services to the users over an efficient and ubiquitous radio access by means of coordinating the available Radio Access Technologies (RATs). In this way, not only the user can be served through the RAT that fits better to the terminal capabilities and service requirements, but also a more efficient use of the available radio resources can be achieved. This challenge calls for the introduction of new radio resource management (RRM) algorithms operating from a common perspective that takes into account the overall amount of resources offered by the available RATs, and therefore are referred to as JRRM (Joint Radio Resource Management) algorithms. Furthermore, for a proper support of such algorithms, suitable network architectures and procedures must ensure the desired interworking capabilities between the different technologies.

The User Terminals (UTs) will be able to use wireless services over more than one Radio Access Technology (RAT) simultaneously. This offers the opportunity to control and divide the data stream to the RATs which are most suitable for the service delivery. The control and traffic splitting mechanism are functionalities of the Joint Radio Resource Management (JRRM). This entity assigns locally and dynamically resources to the UT in order to maximize the overall QoS.

In this paper the resource allocation problem will be presented as a combination of economical and technical aspects. On the one hand, the technological resource allocation results in a higher overall QoS because of individual traffic splitting, whereas the decentralized economical resource allocation reacts instantaneously on the market situation change. Thus, the operator can adapt the RATs based on the demand according to the users' needs resulting in a higher monetary gain. Auction Sequences (ASs) taking place in each cell are necessary to get this economical properties. In turn, the user can express his urgency to get Radio Resource Goods (RRG) by his bid. Thus the auction sequence gives the users the possibility to actively influence the RRG in contrast to the Fixed Price Market, in which users can only passively get the spectrum according to the first-come-first-served principle [1].

The rest of the paper is structured as follows. In Section II, the auction mechanisms in the context of a single RAT are described in detail and accompanied by illustrative results on how the gains deriving from auctioning can be reflected. In turn, Section III develops the JRRM concepts from a purely technical perspective. This is supported by some reference solutions as well as illustrative performance metric. Then, Section IV is devoted to present the architecture that embodies the two mechanisms (JRRM and spectrum auction), so that technical and economical aspects are closely linked. Finally, Section V summarises the conclusions.

## II. AUCTION MECHANISM

Auctioning the Radio Resource Goods (RRG) of a cell changes the market philosophy in comparison to the Fixed Price Model (FPM). In the FPM, the users who order first will be served first. In an auction the users who bid the highest price get the RRGs. Thus, both the operator and the users gain from auction:

- The operator can approximate the users' willingness to pay with the auction resulting in a higher monetary gain. Secondly, because of the regulating effect of the

selling price according to the actual demand in the cell, the network's capacity will be distributed more equally in time leading to lower CAPEX and OPEX.

- The users can express their urgency to send, preference of the specific service and their utility of the specific data transmission with their bids. This individual differentiation is not possible in an FPM. Users can also exploit the lower spectrum price by avoiding the rush hour, thus optimizing his gain.

The auction will occur periodically in a very short duration [1]. Therefore agents in the proper MAC layers will execute the auction [2]. The Auction Sequence (AS) is assumed to be periodically because the controlling like in TDMA is periodically and the monetary gain of the operator is higher than in spontaneous auctions occurring if an RRG is available because of the higher demand.

In such an AS there are certain constraints of the RRG to be sold depending on whether the scenario considers the availability of a single or multiple RATs.:

### 1) Single RAT connection

The RRGs have to be independent of the users' behaviors and environments, because an operator can only sell RRG which he can definitely deliver within an auction period. For example, if an operator offers services or guaranteed link capacity as RRG in a very short term auction and a user comes into a radio shadow, the operator could not supply the user with the RRGs as promised. Thus only RRGs such as frequency-time bits in FDMA/TDMA, code-time bits in CDMA or time bits in TDMA (e.g.,WLAN IEEE 802.11) are allowed.

### 2) Multi RAT connection

The User Terminal (UT) can also be capable to transmit data over different RATs depending on the availability of the RATs and its multi-mode/reconfigurable capabilities. Assuming that not each user can transmit data over all RATs available and based on the service diversity of the different RATs, the RRGs of different RATs are differently valued, so both services and guaranteed link capacity from all available RATs cannot be auctioned using the same transaction in general.. Consequently, the RRG of each cell has to be separately auctioned. But if long term auctions are considered, that is a duration in call length, and all users are covered by all networks and capable to access all RATs, data and data rate can be auctioned.

In each auction multiple goods are offered. To choose the right auction type, the channel as the main bottleneck has to be taken into account. The multi-unit sealed-bid auction [3] possesses lower signaling effort than the open and the sequential auction. Moreover, its duration is determinable. Within the multi-unit sealed-bid auction class, the discriminatory auction provides the smallest possible signaling effort and leads the bidders to submit rational bids, because the price is equal to his bids won.

Considering an auction with the underlying mechanism of [1], constant data rate of the $3^{rd}$ layer traffic and a network capacity of 2 users, the QoS of the two service classes will decrease with a higher number of participants. The bidding strategy BIS1 in [1] is compared with the bidding strategy BISopt which is optimal in terms of allocation under the given budget constraint. The users can express his evaluation of the service classes by a preference vector. In this scenario the user values QoS 1 higher than QoS 2. Figure 1 shows the QoS which is defined as the quotient of the critical data successfully sent to the critical data needed, whereas the critical data are the amount of data which should be necessarily sent within this auction period to fulfill the QoS. In Figure 1 the QoS 1 is depicted over the number of users assuming the same traffic demanded from the $3^{rd}$ layer. The more users will attend the cell, the lower the probability to get RRGs, the lower the QoS will be. Additionally, the bidding strategy proposed in [1] is relatively close to the optimum in terms of allocation. The QoS 2 behavior possesses the same shape of the QoS 1, but it is lower based on the smaller preference the user has assigned.
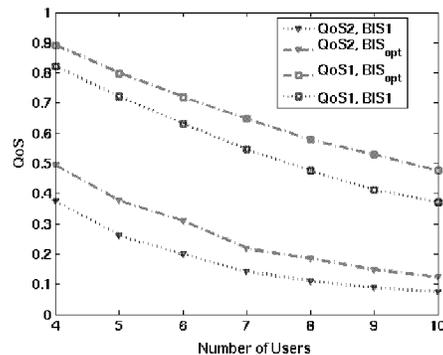


Figure 1 QoS comparison between two bidding strategies

## III. JOINT RADIO RESOURCE MANAGEMENT

JRRM refers to the set of functions that are devoted to ensure an efficient use of the available radio resources in heterogeneous networks scenarios by means of a proper coordination among the different radio access networks. The RRM functionalities that are not specific for the heterogeneous scenarios are the admission and congestion control, horizontal (intra-system) handover, packet scheduling and power control, etc. When these functionalities are coordinated among different RATs in a heterogeneous scenario, they can be denoted as "joint" (i.e. having the joint admission control, joint congestion control, etc.). In turn, when a heterogeneous scenario is considered, some additional functionalities arise, namely the Initial RAT selection (i.e. the functionality that decides the RAT a given service request should be allocated to at the set-up phase) and the Vertical (inter-system) handover (i.e. the functionality devoted to decide a seamless RAT switching for an on-going service) [4]. JRRM strategies may be useful to support a variety of objectives, such as avoiding disconnections due to lack of coverage in the current RAT, blocking due to overload in the current RAT, possible improvement of QoS by changing the RAT, support of user's preferences in terms of RATs, support of operator's preferences for RATs usage or load balancing

among RATs.

JRRM entity is responsible for the QoS guarantee and monitoring of the different radio interfaces. The QoS may be expressed in a variety of parameters, ranging from system-level performance indicators (e.g. blocking probability), to connection level figures (e.g. average bit error rate, average packet delay, etc.). Furthermore, smart JRRM algorithms may lead to capacity gains, thanks to the exploitation of the resource sharing leading to a potential trunking gain.

In case the offered traffic overcomes the maximum capacity manageable by JRRM mechanisms so that the QoS targets can not be met, Advanced Spectrum Management (ASM) strategies can be envisaged [1] to further extend the capacity available in the considered scenario. ASM concepts arises on the basis that the traditional concept of static allocation of licensed spectrum resources to networks operators in wireless communications seems to be not a suitable approach in a Beyond 3G scenario, characterised by changing traffic along time and space, changing availability of RATs, etc. ASM manages the allocation, de-allocation and the sharing of spectrum blocks dynamically within a single or among different radio access systems. Furthermore, the actual management must consider also the technical issues like interference avoidance between spectrums not spatially or temporally separated, management of intersystem interference, definition of guard bands, etc.

All the above considerations make clear that JRRM represents a key functionality in making feasible the famous concept of "connectivity anytime, anywhere and anyhow", especially with respect to the term "anyhow". Current operational scenarios (and, likely, even more in the future) are already multi RAT since the wide availability of multimode terminals allows users to access more than one network. Moreover, future terminals should be virtually able to access any kind of system through the exploitation of Software Defined Radio reconfiguration capability. This means that, in the future, the combination of CRRM+reconfigurable terminals will actually "completely hide" the technology to the user. Once known the service to be provided to the user, CRRM will allow the operator to establish and maintain the connection between the multimode/reconfigurable terminal and the "best" RAT (according to a given objective), chosen among those available within its multi-RAT coordinated network.

But, before coming to such scenario, an important aspect that should be taken into account in JRRM is the strict relationship not only with the technology evolution but also with the operator deployment strategy. This means that a JRRM algorithm optimum in a scenario with a given mix of RAT coverage and monomode and multimode terminals does not necessarily have good performance in a new scenario where the above mentioned mix is changed. The situation is then expected to be different with respect to current single system RRM. JRRM algorithms are likely to provide optimum performance only when designed taking into account some key aspects of the operational scenario.

Research community has already identified the importance of this topic, so that some contributions have been made in this field in recent years. In [6] the benefits of JRRM in terms of inter-system handover and inter-system network controlled cell reselection are analysed in a heterogeneous UTRAN/GERAN scenario. With respect to the combination of cellular and WLAN technologies, in [7] a methodology based on fuzzy logic and reinforcement learning mechanisms is presented that combines technical and economical issues to provide the specific RAT and bandwidth allocations. Similarly, in [8] a joint scheduling algorithm between UMTS and HIPERLAN is proposed. The access selection performance in heterogeneous networks has been also covered in the literature in a number of papers. To cite only a couple of them, please refer to [9] and [10] for details. In turn, in [11] and references therein, it is discussed that capacity in a cellular network can be expanded by rearranging traffic (both voice and data) between different RATs, where only multi-mode terminals are capable of doing so. By means of reallocating multi-mode terminals through vertical handover (connecting to another RAT) new incoming users with single-mode terminal capabilities may experience lower blocking probabilities. Reference [11] compares several substitution policies and evaluates them by means of simulations.

In order to give insight into the JRRM, several representative JRRM algorithms are compared in the following. The first reference algorithm does not take into account the JRRM concept, and it is denoted as Non-JRRM, (NJRRM). The users will be attached to a RAT which is randomly chosen among the ones in which the mobile measures the signal strength (SS) higher than its sensitivity. The second approach takes into consideration the JRRM concept in the following terms: among the cells to which the user could be attached to according to a Signal Strength criterion, the least loaded RAT will be chosen. Then, the criterion is denoted as Load-based JRRM (LJRRM). Finally, the third approach selects the RAT in which the mobile measures the lowest path loss, and it is denoted as Path-Loss-based JRRM algorithm (PLJRRM). In all the three cases, once the RAT has been selected, the bandwidth assigned to each user is the minimum bandwidth considered in the scenario in order to let the users being satisfied (i.e 192 kb/s in UMTS, and 48 kb/s for GERAN have been considered for the numerical results). Finally, the Fuzzy-neural JRRM approach is also considered [7].

In Figure 2 and Figure 3 the comparison of performances obtained through the execution of the algorithms is shown as a function of the number of users moving around the scenario. A target non-satisfaction probability of 1% (i.e. the probability that the allocated bandwidth is below the satisfaction level) is considered in order to compare the blocking and dropping performances. The results clearly show the benefits offered by the Fuzzy-Neural JRRM proposed in front of the other three alternatives. Even though in NJRRM, LJRRM and PLJRRM the admitted users are always satisfied, because the allocated bit rate is always the desired one, this is at the expense of a very high increase in both the dropping and blocking probability. On the other hand, the Fuzzy-Neural JRRM algorithm allows keeping the non- satisfaction probability to

the desired value (i.e. 1%) achieving at the same time much lower dropping and blocking probabilities.
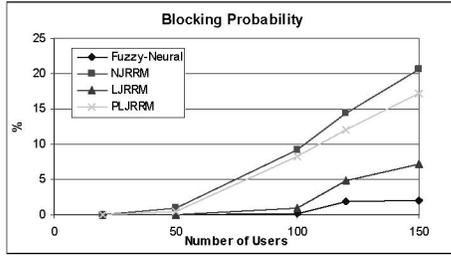


Figure 2 Comparison of the different implementations in terms of blocking
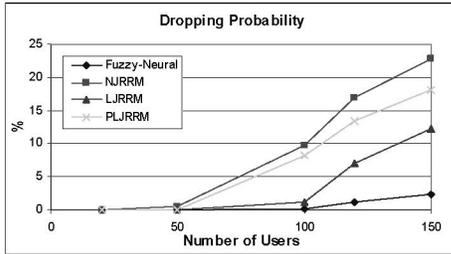


Figure 3 Comparison of the different implementations in terms of dropping

## IV. JRRM AND DISTRIBUTED AUCTIONING

In this section, the interactions between JRRM entity and the auctioning mechanisms are further elaborated. The basic starting principle is that the auctioning mechanism relies on JRRM (and also ASM if necessary) as the entities guaranteeing the QoS that will be offered in the auctions. Thus, the RRGs to be auctioned are physical resources with an associated QoS. There are a number of possible QoS levels, and user's bids are accompanied by a certain QoS request.

The JRRM module provides the EM (Economical Manager) with the required information about the occupancy of the different cells belonging to the different RATs as well as the QoS levels that the JRRM can support according to the current system conditions (see Figure 4). Clearly, these inputs to the EM may be valuable for determining a reserve price.

The EM will inform the JRRM of the result of the auction as well as the validity period. This information will be used for the different functionalities within the JRRM (e.g. packet scheduling) to provide radio resources as agreed in the auction. Here the scheduling algorithm is specifically different to the classical scheduling algorithms, since the economic aspect intervenes in the scheduling priority setting.

The functional element of the proposed resource auctioning mechanism in a B3G scenario with a variety of RATs is depicted in Figure 4. In general terms, the U-plane (user plane) contains the information to be transmitted, which will be buffered for a proper management (flow control and retransmission) over the segments of the radio link, both in the uplink (i.e. at the terminal side) and downlink (i.e. at the network side). The C-plane (control plane) will include the element corresponding to the economical aspects regarding the auctioning process, both at the terminal and network side, with the capability to interact through a suitable signaling protocol. In turn, the JRRM takes care of the allocation of the radio resources over heterogeneous RATs. Again, the JRRM at the network side can be assisted by the corresponding counter-part at the terminal side. Finally, the interaction between JRRM and EM as described in the previous section is clearly stressed in the figure.

In detail, the envisaged bidding procedure for the (t+1)th auctioning period is as follows (see Figure 5):

1) The controller at the network (termed as JRRM) informs EM about the total capacity to be offered and used for the (t+1)th auctioning period for both uplink and downlink. It is worth noting here that, for soft-capacity RATs (e.g. WCDMA), the total capacity to be offered will necessarily be an estimation rather than an absolute fixed value.



Figure 4 System model

2) EM informs the EM Agent (denoted as EM Terminal in Figure 5) about the total capacity to be offered for the (t+1)th auctioning period. Additionally, the capacity that has been allocated to each user in the t-th auction period and for both uplink and downlink is also forwarded to EM Agent. The reserve price for the (t+1)-th auction period is also communicated.

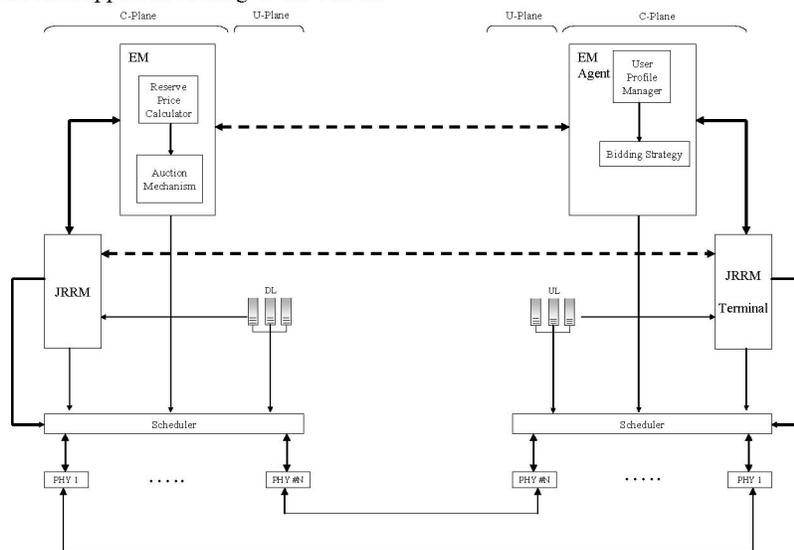3) Multi-mode Terminal (denoted as JRRM Terminal in Figure 5) informs to EM Agent about the buffer occupancy for critical and uncritical data as well as per service. This applies for the uplink bidding.

4) JRRM informs to JRRM Terminal, who in turns forward it to EM agent, about the buffer occupancy in the network side for critical and uncritical data as well as per service. This applies for the downlink bidding.

5) EM Agent forwards its bid to EM, stating for both uplink and downlink the requested number of bits (split per service and per critical/uncritical data) per validity period and the corresponding offered price. Each category has an associated QoS (e.g. a bit error rate lower than a given threshold).

6) The EM informs the EM Agent about the results of the auction in terms of the capacity allocated for the (t+1)th auction period, expressed in bits per user per service with certain QoS level and with an associated validity period.

7) Similarly, the results of the auction need to be transferred from the EM to the JRRM and to the JRRM Terminal.

After this process, JRRM and JRRM Terminal will manage radio resources according to suitable policies leading to guaranteeing the required QoS levels. During the validity period of the allocated resources, the actual achieved QoS will be tracked.

## V.    CONCLUSIONS

The introduction of JRRM increases the efficiency and the quality of wireless communications. The spectrum auction system enables the interaction of users and operators through the pricing mechanism in further increasing the efficient use of radio resources. An architecture containing both JRRM and spectrum auction mechanism is proposed in this paper. It promises higher gain in quality and efficiency for the future wireless communication systems.

### REFERENCES

[1]    C. Kloeck, Holger Jaekel, Friedrich K. Jondral: „Auction Sequence as a New Resource Allocation Mechansim"; VTC05 Fall, Dallas, 2005

[2]    C. Kloeck, Holger Jaekel, Friedrich K. Jondral: „Dynamic an Local Combination Pricing, Allocaiton and Billing System with Cognitive Radios, DySPAN 2005, Baltimore

[3]    V. Krishna: "Auction Theory"; Academic Press, ISBN 0-12-426297-X, 2000

[4]    J. Pérez-Romero, O. Sallent, R. Agustí, M.A. Díaz-Guerra, Radio Resource Management Strategies in UMTS, John Wiley&Sons, 2005

[5]    D. Grandblaise et al.:"Towards a Cognitive Radio based Distributed Spectrum Management"; IST05, Dresden, 2005

[6]    A. Tölli, P. Hakalin, H. Holma, "Performance Evaluation of Common Radio Resource Management (CRRM)", IEEE International Conference on Communications (ICC 2002), Vol. 5, April, 2002, pp. 3429-3433.

[7]    R. Agusti, O. Sallent, J. Pérez-Romero, L. Giupponi "A Fuzzy-Neural Based Approach for Joint Radio Resource Management in a Beyond 3G Framework", 1st International Conference on Quality of Service in Heterogeneous Wired/Wireless Networks, Qshine'04, Dallas, USA, October, 2004.

[8]    R.Mukerjee, J. Luo, M. Dillinger, E. Mohyeldin "Joint Scheduling Algorithms over Heterogeneous networks in a Reconfigurable Environment", 5th European Personal Mobile Communications Conference, April, 2003, pp. 591-596.

[9]    G. Fodor, A. Furuskar, and J. Lundsjo, "On access selection techniques in always best connected networks," in ITC Specialist Seminar on Performance Evaluation of Wireless and Mobile Systems, Aug. 2004.

[10]  J. Pérez-Romero, O. Sallent, R. Agustí, "Policy-based Initial RAT Selection algorithms in Heterogeneous Networks" , Mobile Wireless Communication Networks (MWCN '05). Marrakech-Morocco 19-21 Sept. 2005.

[11]  S. J. Lincke "Vertical handover policies for common radio resource management", International Journal of Communication Systems 2005; Published Online: 15 Mar 2005. DOI: 10.1002/dac.715.

Figure 5 Bidding procedure