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# Extending Auction Principles to Multi-RAT Scenarios

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**Abstract—** The introduction of new JRRM (Joint Radio Resource Management) algorithms operating from a common perspective that takes into account the overall amount of resources offered by the available RATs opens new potentials in system's flexibility and efficiency. On the other hand, auctioning radio resource goods of a cell changes the market philosophy in comparison to the fixed price model and both the operator and the users gain from the auction. The target of this paper is to focus on extending auctioning concepts into a heterogeneous RATs scenario. In particular, the interactions between JRRM entity and the auctioning mechanisms are further elaborated.

## INTRODUCTION

Today's wireless communications comprise a broad variety of Radio Access Technology (RAT) standards. 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.

On the other hand, a novel approach to manage radio resources aiming at achieving good revenues and user satisfaction is to make use of trading concepts, and particularly of auctioning mechanisms [1]. 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, the preference of the specific service and their utility of the specific data transmission with their bids. This individual differentiation is not possible in a FPM. Users can also exploit the lower spectrum price by avoiding the rush hour, thus optimizing his gain.

In this paper, JRRM concepts are accompanied with some reference solutions as well as some illustrative results. Similarly, auctioning mechanisms are initially developed in the context of a single-RAT, with some results revealing its potentials. Finally, the target of the paper is to focus on



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extending auctioning concepts into a heterogeneous RATs scenario. In particular, 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 Advanced Spectrum Management, ASM, if necessary) as the entity in charge of guaranteeing the QoS that will be offered in the auctions. Thus, the RRGs to be auctioned are physical resources with an associated QoS, then leading to a certain transmission rate capabilities. There are a number of possible QoS levels, and user's bids are accompanied by a certain QoS request.

### Joint Radio Resource Management

JRRM problem is complex and admits many possible solutions. Nevertheless, there is not an absolute optimal solution due to the multiplicity of possible criteria to consider, the constraints imposed by RATs characteristics, coupling architecture, implementation approach, user's and operator's preferences, etc. Consequently, a given JRRM strategy may result suitable in a specific framework and time-frame while not fitting another technology evolution stage and/or network constraints. For some functions, the boundary between JRRM and local RRM is becoming blurred. Even very low OSI layer

### A case study based on Fuzzy Neural approach

In order to envisage proper JRRM algorithm frameworks, it is important to consider that the variety of JRRM inputs belonging to different RATs will provide in general imprecise and very dissimilar information. As a result of that, since the fuzzy logic-based methodology has been proved to be good at explaining how to reach suitable decisions from such type of information [2][3], the framework for JRRM strategies development proposed here considers this approach. On the other side, the use of neural networks, which are good at recognizing patterns by means of learning procedures, can also be considered by tuning the fuzzy membership

functions properly, thus developing hybrid solutions incorporating both fuzzy and neural methodologies [4][5].

The proposed framework for JRRM algorithm implementation based on Fuzzy-Neural mechanisms consists of three main blocks: Fuzzy based Decision, Reinforcement Learning and Multiple Objective Decision Making [2]. The inputs to the algorithms are a set of linguistic variables  $LV_i$ , corresponding to different measurements. Also, techno-economical criteria in the form of user preferences (UP) and operator preferences (OP) are inputs of the algorithm.

The Fuzzy Based Decision, Reinforcement Learning and Multiple Objective Decision Making algorithms are executed every time a new user asks for admission in the system and during the user session. It assures the dynamical allocation and de-allocation of radio resources in the scenario and the selection of the most suitable RAT, while keeping the desired QoS requirements of all admitted users. Initial evaluations of the proposed JRRM approach were carried out in simplified scenarios [6][7].

### Reinforcement Learning in a multi-cell scenario

The reinforcement learning mechanism allows setting the average value of an objective and measurable performance indicator to a target value. In particular, the non-satisfaction probability  $P_i(t)$ , is retained here as target performance indicator. The target rate  $P^*$  can be set to any desired value (e.g.  $P^*=1, 3, 10\%$ ) and the system is able to keep this value during the whole simulation time, as it is shown in Fig. 1 for three different values of  $P^*$ .

Furthermore, during the simulation time in the example of Fig. 1, the Fuzzy-Neural system has to cope with two sharp traffic variations. At simulation start, the whole system switches from a situation in which no mobile is located in the scenario to another one, where 100 users are moving around the scenario and demanding service. In addition to this, at simulation frame 1000000, 50 more users join the scenario. Notice that, at the



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beginning of the simulation, a transient period after which the Fuzzy-Neural system converges to the desired QoS condition is necessary, whereas, in correspondence with the second artificial traffic change, the users are unaware of this sudden change and only concerned with the contracted QoS in terms of dissatisfaction.

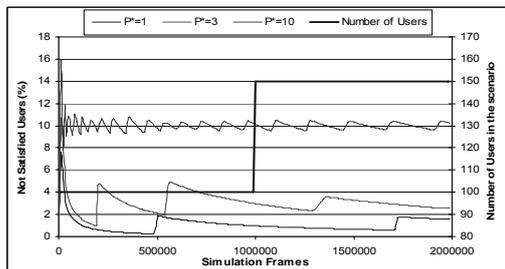


Fig. 1 Evolution of the non-satisfaction probability

## Comparison with other JRRM approaches

In order to compare the performances of the proposed Fuzzy Neural algorithm against other approaches, three alternative algorithms are considered.

The first alternative 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).

In Fig. 2 and Fig. 3 the comparison of performances obtained through the execution

of the three algorithms is shown as a function of the number of users moving around the scenario. A target non-satisfaction probability of 1% 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.

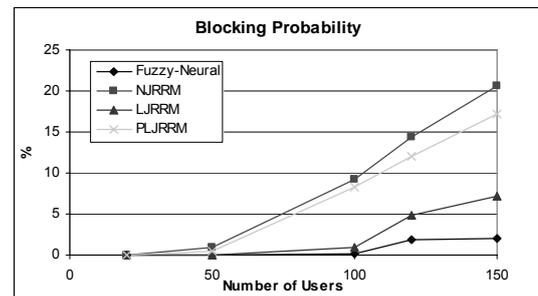


Fig. 2 Performance comparison of the different implementations in terms of blocking

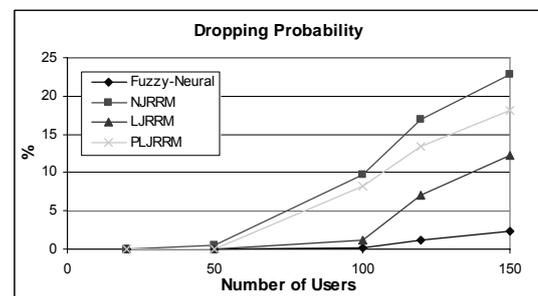


Fig. 3 Performance comparison of the different implementations in terms of dropping

## Practical Feasibility

With respect to the numerical complexity of the proposed algorithm, it should be mentioned that the number of operations in the procedure is low enough to ensure



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operation in real time by means of software approaches. In that sense, the required operations should be considered at the following two levels:

- In order to achieve the fuzzy-based decision with respect to the RAT and bandwidth allocation, the type of operations to be performed are essentially comparisons and sums. Also a small number of multiplications and divisions are required. As a result of that, the number of operations to achieve a decision per user is in the order of 5000, which turns into a requirement of about 100 $\mu$ s per user on a single state-of-the-art general-purpose processor (e.g. 2 GHz). Then, real time operation is feasible even with a high number of users, since the time constraints are typically fixed at the radio frame-time scale (e.g. in the order of several milliseconds).
- With respect to the reinforcement learning algorithm, the effect is the modification of the parameters of the membership functions at layer 2 and layer 5 used by the fuzzy-based decision procedure according to the system evolution. Since this modification occurs at the long-term, it does not pose constraints for real-time operation. In fact, the evolution of the parameter changes can be done offline with respect to the real time reconfiguration.

### **Auctions in a single RAT scenario**

In communication systems, the operator represents the auctioneer's side and the users are the bidders. The Economic Manager (EM) responsible for the auction is located in the Medium Access Control layer (MAC) inside the control plane of a Radio Access Technology (RAT). EM controls the spectrum allocation procedure cell by cell through auctions. Its counterpart is located in the MAC layer of the user terminal (see Fig. 4). The goods offered are RRGs which can be bandwidths  $b$  leased for a certain time duration  $T$ . During each duration  $T$ , an auction takes place in which the free RRGs are

offered. In this auction both the currently served users and the new yet unserved users participate.

In such a highly dynamical process the user cannot bid by himself. An EM Terminal located in the MAC layer should represent the bidder's behavior. This behavior has to be expressed in a form, which an algorithm can handle. Therefore, users' wishes, demands and behaviours should be represented by a set of parameters or functions [9]. Not only private information can influence the bidding strategy, but also the experience of the past auctions. Since a user participates on several auctions, the information of past allocation and price development may be the input to a prediction algorithm in order to improve the bidding strategy.

On the operator's side an auctioneer's agent located in the proper MAC-layer represents the operator's behavior. Its tasks include the announcement of an auction every  $T$  time units, calculating and predicting the reserved price based on fixed costs and executing the auction mechanism.

EM and EM Terminal act and react in a periodic auction sequence. In our previous investigations, the focus in auction theory was mainly on auctions which occur once. This spectrum allocation approach needs a more sophisticated consideration of auctions. The auction sequence has to be considered as a dynamic process. The intention of maximizing expectations can be directly applied in this process, because a user takes part as often as his gain and his good-allocation can be approximated by the expectations. Therefore, optimizing the bidding strategy with respect to the expectations makes sense. From the economical point of view, this auction process is more suitable than established billing strategies concerning the operator's revenue especially in a frequently visited cell [8].

### **System description**

A resource allocation method based on auctions is evaluated in a future mobile communication system. The auction is located in the EM and will be executed by the subentity Auction Mechanism (AM), see Fig.



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4 . The EM is logical located next to or inside the Base Station (BS) within the control plane and is responsible for the RRGs allocation under economical aspects. The RRGs will be auctioned and the user who wins RRGs will get General Resource Elementary Credits (GRECs). Besides the EM at the operator's side, the RAA (Resource Auction Agent) at the users' side comprises the three main entities DATA-GREC-Mapping (DGM), Bidding Strategy (BIS) and User Profile Manager (UPM) which handles the bidding process. Both in the UpLink (UL) and the DownLink (DL) the entity DGM maps the MAC data of the QoS-classes and their parameters into GREC categories. These categories can mainly be distinguished between critical data which should be urgently sent within this auction period in order to meet the QoS and uncritical data which could be transmitted. This information is an input to the entity BIS which is located in the User Terminal (UT). The BIS also needs user specific profile information such as his preferences and purchase power provided by the entity UPM. Furthermore, BIS gets additional information to be executed for the auction such as the reserve price  $r$  from the Reserve Price Calculator (RPC) and may predict the auction process like the behaviour of the other bidders. The last information will be provided by the allocation vector which is broadcasted to all participants. This allocation method has both an operator's and a user's leverage. The RPC aims at maximizing the operator's monetary gain, whereas the RAA wants to satisfy the user's utility by minimizing costs. The auction mechanism has to be common knowledge to calculate both the reserve price  $r$  and the bid vector  $bid$ . Information broadcasted and the granted resource to the end user may be flexibly configured by the network. The optimal value is resulted from the interworking with RRM modules, so that on the other hand the capacity does not degrade significantly due to badly connected UTs.

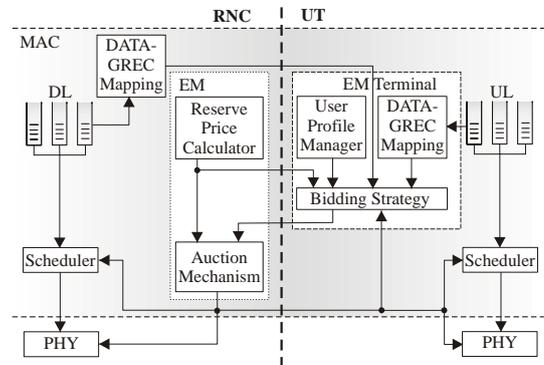


Fig. 4 : Auction system for a single RAT

## Auction Schedule

At first, the RPC calculates the reserve price  $r$ . The EM announces the auction at time  $nT$  by broadcasting the number of GREC  $N_{max}$  to be offered and the reserve price  $r$  each bid has to exceed (see Fig. 5). The EM Terminal receives this announcement and calculates the bid vector  $bid$  based on the aforementioned information. The EM collects all bid of the users who want to participate and allocates the GRECs according to the specific auction mechanism. The result will be transmitted by the allocation vector to each UT which can gain the information about the GRECs won and instructs the MAC scheduler and the PHY to send the data accordingly. Contemporarily, the information especially for the DL will be conveyed to the entities at the DL-side which are responsible for transmitting the data. After the data transmission, another auction starts at time  $(n+1)T$ .



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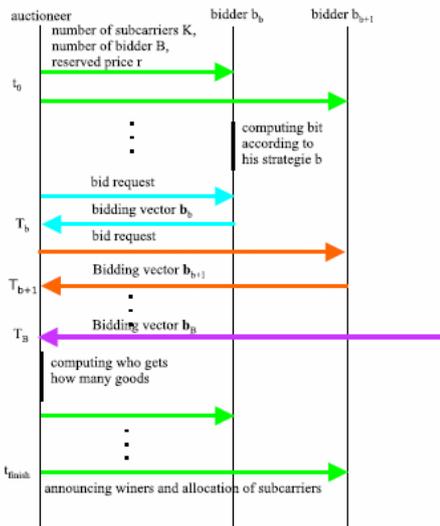


Fig. 5: Auction signalling

## Auctions in a multi-RAT scenario

The auction mechanism in a heterogeneous radio access network scenario is built under a number of premises:

- The network operator offers a network deployment with certain statistical quality parameters (e.g. 5% outage probability). Then, radio resource goods will be auctioned on the same terms (i.e. a radio resource good will be allocated to a user with the understanding that this radio resource will lead to a correct reception of the transmitted information with e.g. 95% probability). Clearly, the user should eventually pay only for the radio resources effectively got and not for the radio resources granted in the auction.
- The total amount of radio resources per cell to be auctioned depends on the operator's radio network deployment (e.g. number of carriers per cell) as well as on the JRRM performance. Thus, the amount of radio resource goods available will in general vary along time.
- Given that transmitted power level is an inherent function of the RRM

mechanisms and that the suitable power level will vary in the very short term (e.g. reacting to Rayleigh fading), it does not seem reasonable to include the power level in the auctioned good especially for circuit switched services.

- It is considered that the auction mechanism relies on operator's network deployment and JRRM performance, so that the auction can be placed in terms of amount of bits that can be transmitted with an associated QoS level.
- When multi-RATs are very tightly coupled through the common Radio Resource Controller (CRRC) controller [10], cell level EM can be reallocated in the CRRC. Interworking between EM and scheduling module can be realised by the lub interface.

The envisaged bidding procedure for the (t+1)th auctioning period is as follows (see Fig. 6 and Fig. 7):

- 1) The CRRC or 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.
- 2) EM informs EM Agent 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 (termed as JRRM Terminal in Fig. 7) 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,



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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.

### Conclusion

This paper has presented a framework for incorporating auctioning concepts in multi-RAT scenarios by combining the auctioning procedure with JRRM strategies. According to our recent investigations on fuzzy logic based JRRM, we see a significant performance gain compared to the non JRRM case. It also shows the sensitivities to the selecting parameters such as the signal strength and system load. An important conclusion is the essential impact of the network load information for JRRM performance. Excitingly, fuzzy logic implementation provides sufficient good performance without much demand of the calculation power. In combining with the auction based spectrum management, which aimed at a higher economical gain for the operators, an overall system management structure is proposed. Based on that, a

reconfigurable system being able to optimize multiple objects, e.g. the spectrum efficiency, high QoS for selected users and high revenue for operators is possible, provided that fuzzy logic based implementation owning the ability of self-learning.

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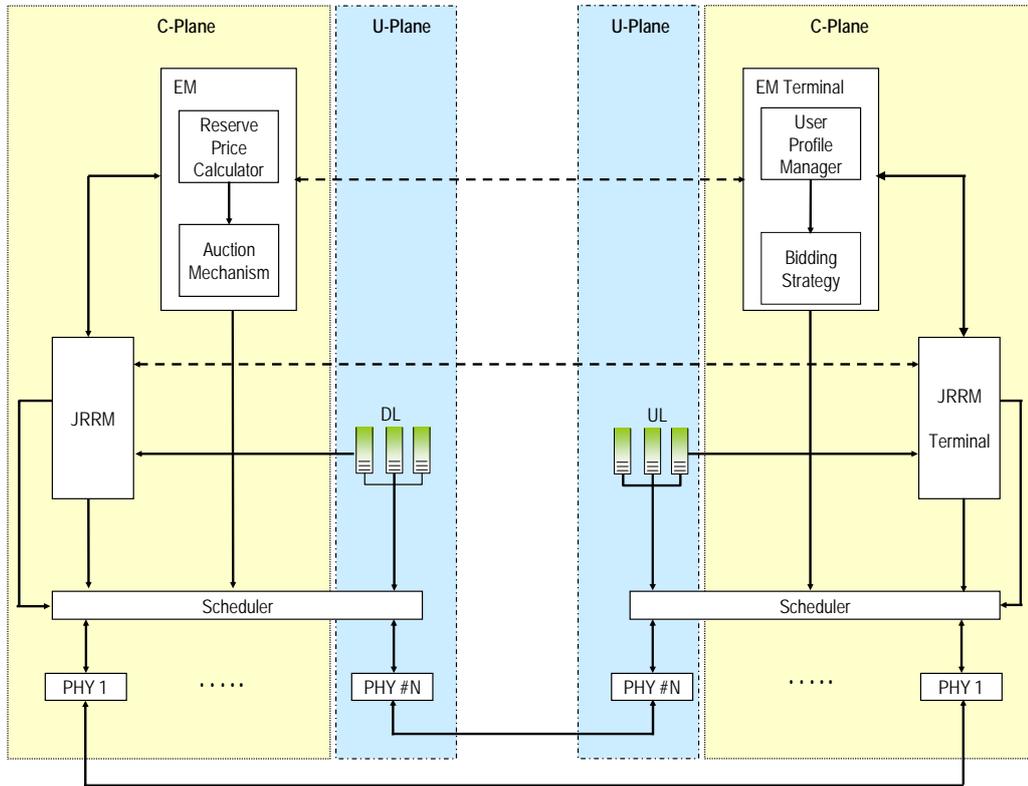


Fig. 6: EM interworking with User-Plane JRRM

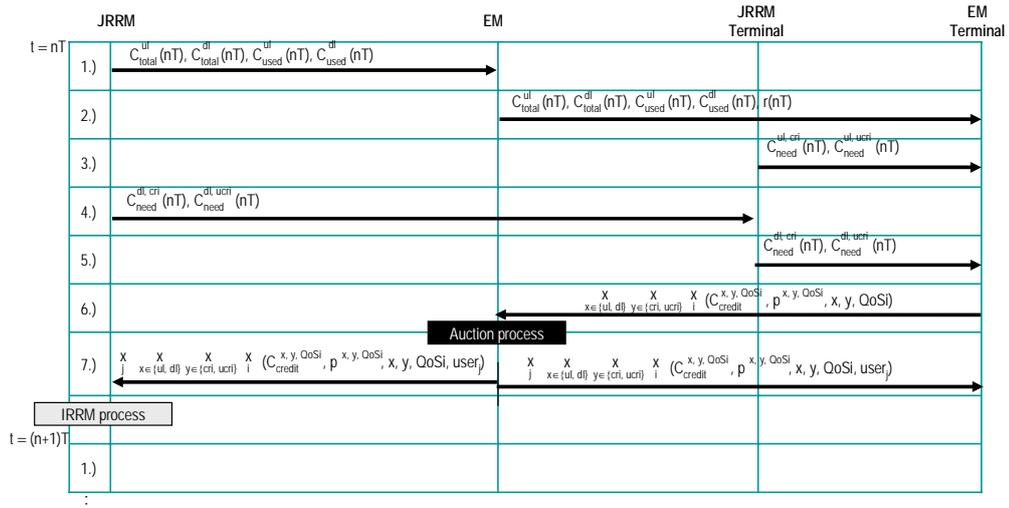


Fig. 7: MSC for Auctioning in Multi-RAT Environment