A New Pricing Model for Next Generation Spectrum Access

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***Abstract*— We briefly review several concepts that are central to the design of spectrum management algorithms emphasizing on pricing. These include: (1) FCC auctions, (2) single-unit auctions (3) peak-load pricing. Based on these concepts and models, we propose a new pricing spectrum's pricing model for the CAB operated by the spectrum broker for homogeneous CDMA networks.**

***Keywords*— Wireless Networks, Dynamic Spectrum Access, Coordinated DSA, Spectrum Pricing**

I. INTRODUCTION

Spectrum management, typically the responsibility of a government agency (e.g. the FCC in the United States), is the planning, allocation, coordination, and management of the joint use of the electromagnetic spectrum through operational, engineering, and administrative procedures. The objective of spectrum management is to enable electronic systems to perform their functions in the intended environment without causing or suffering unacceptable interference.

Some of the crucial factors that have an impact on spectrum management include:

- Spectrum regulation and licensing
- Spectrum pricing
- Spectrum sharing
- Spectrum allocation assignment
- System design for spectrum efficiency

Traditional spectrum allocation results in a slow process of assigning spectrum licenses. [1] Each license is for a fixed amount of spectrum in a given region and is intended for a specific purpose. (e.g. mobile wireless spectrum in cellular and PCS bands). The result has been inefficient and inflexible use of assigned spectrum, and the slow deployment of new wireless services. For example, large swaths of allocated spectrum are poorly utilized. Almost 90% of spectrum on average stays unused in the USA much of the time. Between 40-80% of unused broadcast spectrum is in rural areas. Additionally, measurements indicate that spectrum utilization varies dramatically in location and time. [2], [3]

These observations, along with the dramatic increase in demand for spectrum, have led to research into Dynamic Spectrum Allocation (DSA). DSA approaches, made possible in large part to frequency agile software defined radios and cognitive radios, may be broadly divided into coordinated and uncoordinated approaches. In coordinated DSA, a given amount of spectrum is reserved for dynamic assignment to network operators and users in a given region. Requests for spectrum are sent to a spectrum server and licenses are assigned for a given time period (e.g. thirty minutes) to operators and/or users. In uncoordinated DSA, network operators and/or users determine the location of unused spectrum through spectrum measurements and may begin operating in this used spectrum subject to interference constraints. Uncoordinated DSA raises interesting questions regarding spectrum property rights. Incumbent license holders view their spectrum license as exclusive in a given region while proponents of DSA state spectrum can be shared as long as interference to incumbent is "acceptable".

Table 1 summarizes the advantages and disadvantages of fixed and dynamic spectrum allocation.

Table 1: FSA vs DSA

Fixed Spectrum Allocation	Dynamic Spectrum Allocation
Advantages: • Ease of regulation &management • Control of interference **Disadvantages:** • Lacks flexibility • Priori assignment of spectrum to services before deployment • Cannot adapt the usage of spectrum and capacity demands throughout the day • High initial Capital Expenditures (CAPEX) • Can lead to poor utilization	**Advantages:** • Improves the overall spectrum efficiency • Ensures spectrum matches demands • Satisfy users (QoS) and increase operator's revenues • New business models and more rapid introduction of services • Response to emergencies and natural disasters **Disadvantages:** • More complex system implementation • Challenging regulatory & management environment – "Spectrum rights"

The focus of our research is in coordinated DSA with emphasis on system architecture, spectrum pricing and allocation. This paper, in particular, examines existing dynamic pricing models and proposes a new spectrum pricing model for coordinated DSA. The rest of the paper is organized as follows: Section II briefly presents our proposed architecture for coordinated DSA, Section III describes alternative dynamic spectrum pricing methods from both auction theory and peak-load pricing and Section IV presents our new proposal for dynamic spectrum pricing. Finally, Section V summarizes our conclusions and future work.

II. CANDIDATE ARCHITECTURE FOR COORDINATED DSA

We briefly outline a proposed architecture for coordinated DSA. In particular, we illustrate the concept of a Coordinated Access Band (CAB) and the system architecture. Additional details may be found in [4].

A. *Coordinated Access Band (CAB)*

Coordinated Access Band (CAB) is a contiguous block of spectrum reserved by regulating authorities, such as the FCC, for controlled dynamic access. Multiple parts of the radio spectrum can be allocated as CAB spectrum. The CAB spectrum can be assigned to individual network operators or users to support multiple different services. For example, it can support mobile CDMA and TDMA voice and data services and OFDM fixed wireless services. For a geographical region, allocation of various parts of CAB spectrum to individual networks or users is controlled by the Spectrum Broker (Figure 1). The spectrum broker grants a time bound lease to the requesters for a given amount of spectrum. Key to the operation of this spectrum broker is the pricing and allocation algorithms.

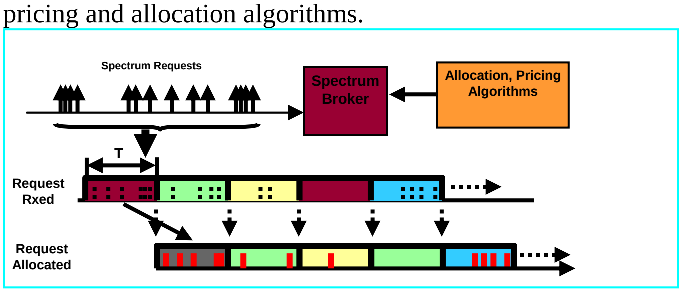

Figure 1: Spectrum Allocation Model

B. *System Architecture*

The main components of the proposed DIMSUMNet[1] cellular architecture (Figure 2) are: (1) a Spectrum Information and Management (SPIM) broker, (2) a radio access network (RAN) consisting of new type of base stations (3) A RAN manager (RANMAN), and (4) new intelligent end-user devices. DIMSUMNet employs two new control protocols: (1) SPEctrum Lease (SPEL) protocol and (2) a Spectrum Information Channel (SPIC) protocol between the BS and the end-user devices. The SPIC protocol is used to determine the amount of unused spectrum currently available while the SPEL protocol is used in the request and allocation of spectrum. The architecture is described in [4] with details.

The spectrum broker is responsible for the pricing and allocation of spectrum and perceives time only in batches or windows of T time units called allocation frames. In this paper we propose a novel pricing algorithm which is a combination of dynamic pricing models (e.g. auction and peak-load pricing). Requests received in a time window (n-1), if accepted, are allocated in window (n). The allocation algorithm will processes all of the requests in each frame. Spectrum may be allocated to one or more base station depending upon the original request and available spectrum. The allocation of the spectrum must be consistent with established RF engineering rules. For example, the allowable frequency reuse factors for the reuse of RF channels must be followed. The complexity of the allocation algorithm will increase when combinations of different technologies are allowed (e.g. CDMA, TDMA, and OFDM systems). We will focus on homogeneous system (i.e. all operators using the same technology).

The CAB band resembles a licensed band in that the spectrum lease is a short-duration license. Our system allows for either the network operator or the individual end-user to request spectrum. In this paper, we will only consider requests for spectrum from the network operators. The license could be allocated for a single time period (T) or for multiple periods (stickiness) according to the operators' preferences and the licenses' demand or availability. In our particular model the auctions may consist of a single round or multiple, allowing the users to bid for single homogeneous licenses or combinations. In this paper we will assume the simplest case, considering single round for single-unit auctions.

Consider the operation of our proposed system with cdma2000 mobile wireless network operators. The network operators will independently determine their need for spectrum in a given region for the next time period T. A request for spectrum, in increments of the RF channel bandwidth (1.25 MHz), is delivered to the spectrum broker during the auction period. These requests are region specific (i.e. for one or more base stations). A single bid is required for each 1.25 MHz RF channel in a single round. For example, if a service provider requires two 1.25 MHz channels, it would issue two bids; one for each RF channel. When all requests are received, the broker determines the "winners" (following a pricing and allocation algorithm) and spectrum is assigned for a period of T units.

A new protocol is introduced regarding the bids submission to the Spectrum Broker. An example of our bid vector would be:

{B1, B2, B3, B4, B5, B6}

- **B1**: Location of the Base Station
- **B2**: Amount of spectrum required
- **B3**: Duration
- **B4**: Provider ID
- **B5**: Bid or Max. Price
- **B6**: Duration ("stickiness")

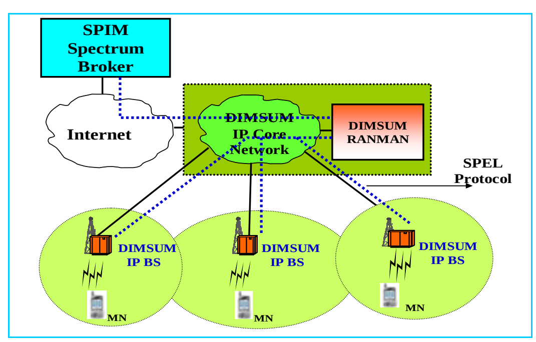

Figure 2: Cellular architecture with Coordinated DSA

[1] Dynamic Intelligent Management of Spectrum for Ubiquitous Mobile networks (DIMSUMNet).

III. DYNAMIC SPECTRUM PRICING

This section examines dynamic pricing techniques for spectrum pricing. We begin our discussion with an overview of the FCC spectrum auctions and examine the potential application of this type of auction to our coordinated DSA system. We then provide a description of various auction models and discuss the application and limitations of these models to our systems. We conclude this section with an overview of peak-load pricing. Our proposal for dynamic spectrum pricing, which is a combination of an auction-based approach and peak-load pricing, is presented in the following section.

A. FCC auctions

In 1994 the FCC organized the first spectrum auctions in the United States and it continues to run auctions to allocate spectrum based upon the increased demand for wireless networks. FCC spectrum auctions are open to any eligible company or individual that submits an application and initial ("upfront") payment, and is found to be a qualified bidder by the Commission. [5] They are conducted electronically and are accessible over the Internet via a web browser. Current spectrum allocations assign licenses for a long duration (i.e. 20years) and over a wide geographic area.

The licenses are auctioned region by region and multiple licenses are put in auction simultaneously in discrete bidding rounds. The bids are sealed, and are placed per individual license, exceeding the corresponding highest previous bid by a minimum increment ("activity rule"). A frequently used method of calculating a bid increment is a specific percentage amount (e.g., 10%) of the highest bid. The termination rule is described as one round that consists of no bids. The payment rule follows the "pay-your-bid" pricing.

There are two types of FCC auctions: Simultaneous Multiple-Round (SMR) auctions and package bidding (not yet implemented by the FCC). In each approach, the United States is segmented into regions and a spectrum license is simultaneously auctioned in each region. In SMR auctions, each regional auction is independent. If a wireless service provider requires a given license in multiple regions, it must participate in multiple auctions. In the second case of the package bidding, bidders may place bids on groups of licenses (i.e. licenses in multiple regions). This type of auction is a better expression of the value of any synergies (benefits from combining complementary items) between the same license spectrum in adjacent regions. Package bidding auctions encourage straightforward bidding and permits bidders to employ flexible backup strategies. Limitations in this type of auctions include a possible bias to bidders seeking large aggregations due to a variant of the free-rider problem, called the threshold problem, where a single license is part of an entire package that somebody else wants. Also, if all combinations are allowed, identifying the revenue maximizing assignment is an intractable integer programming problem when there are many bidders and licenses. Auction Nr. 31 refers to package bidding but is still on hold and the FCC is negotiating to finalize the auction rules with the operators.

Both auctions are planned to last several weeks starting with long bidding periods and ending with an increase in the number of rounds per day and a decrease of the duration per round. If a bidder is not able to maintain the activity in a given round, it may use an activity rule waiver (if available) or lose its eligibility. Usually each bidder is allowed three waivers. The bidders are able to review the results with a Web Browser and the Auction Tracking Tool. The auction ends when there is only one remaining bidder and all bidding activity stops. The winners are requested to complete the license down payments after 10 business days.

We identified the following similarities and differences between the FCC auction and our proposed pricing model as highlighted in the Table 2.

Table 2: Comparing our Pricing Model and the current FCC model

Similarities	**Differences**
Pre-auction process required	Faster pre-auction process
Bid increment rule	No waivers allowed
Combinations allowed	Feasible restricted list of combinations allowed due to interference at co-located regions
Winner determination algorithm	More advanced allocation and pricing algorithms increasing the fairness
Agent with algorithms required	Artificial intelligent agent running the process in each time window T
Web based	Efficient spectrum reuse

The FCC plans to auction AWS (Advanced Wireless Services) spectrum (the bands are around 1.7 GHz to 2.1 GHz) during the summer of 2006. In addition, it also aims to put rules to auction former TV frequencies around 700 MHz for mobile data. The U.S. mobile operators are eyeing with interest these upcoming radio spectrum auctions that will open up large amounts of frequencies to mobile data services. [6]

The 700-MHz spectrum is especially important because it can reach farther and penetrate walls better than higher frequencies. These frequencies have been used for UHF (ultrahigh frequency) TV stations but are being phased out of that use.

B. Auctions – Brief overview

The auction as discussed in the previous section is the current dynamic pricing model applied from FCC to assign the spectrum to the mobile wireless operators. In this section we will provide a brief description of the current auctions [7], [8],

[9], [10], [11] schemes and in the end of the section we decide upon appropriate metrics to evaluate them.

The auction is a method for allocating scarce resources based on competition. It consists of a bidding mechanism, where the seller (auctioneer) defines the auction rules according how the winner is determined and the value he must pay. Each buyer chooses a bidding strategy. Usually the auction rules and type define a game among the buyers. There are five different types of auctions we are going to discuss, focusing mainly on the single-unit auctions.

In the English auction, users bid the highest price they are willing to pay for an item and the bidding activity stops when the pre-determined auction duration is complete. The item is sold to the highest bidder at their bid price. It allows dynamic adjustment of bidders' valuations by giving information about other bidders[2]. English auctions also allow the seller to specify a reserve price below which the item will not be sold.

In the Dutch auction, the auctioneer starts at a very high price – starting bid. The standing price is gradually lowered, typically by means of an exogenous counting device (a clock, or a pointer). The process continues until a bidder indicates a buy signal, i.e. raising his hand, at which time that bidder wins the unit. It raises sellers' revenue if the bidder wants the item badly and it is considered to be fast. "Dutch auction" is also sometimes used to describe online auctions where several identical goods are sold simultaneously to an equal number of high bidders.[3]

In an Anglo-Dutch auction the auctioneer begins by running an ascending auction in which price is raised continuously until all but two bidders have dropped out. The two remaining bidders are then required to make a final sealed-bid offer that is not lower than the current asking price, and the winner pays his bid.

In the Sealed High-Bid Auction or First-Price Sealed-Bid Auction (FPSB)[4], all bidders simultaneously submit bids and they do not know the bid of the other participants. The highest bidder pays the price they submitted. The multi-object form of the first price auction is called discriminatory auction. The format is largely used for procurement, also used for refinancing credit and foreign exchange.

The Vickrey auction or the second price auction operates similarly with the English auction[5]. The highest bidder obtains the item at the price offered by the second highest bidder. The advantage is that the bidders bid what they think the item is worth and there is no influence on what the others will bid.

Comparing the different types of auctions we conclude as following [7], [10]:

- Bidders tend to underbid what they believe the item is truly worth in hopes of getting the item for less, or in order to avoid the winner's curse.[6]
- All auctions are theoretically equivalent, but in practice Dutch auctions will produce less revenue than sealed first-price auctions
- The English and Vickrey auctions are equivalent in the outcome, under private values, but not strategically; in an English auction bidders can respond to rivals' bids.
- Finally the English, Sealed Bid and Classic Dutch are all pay-your-bid auctions except of the Vickrey that follows the "second price" rule.

In the following Table 3 we summarize the operations of the most studied auctions as referred in the literature. Our description is mainly based on the type of the auction, whether it is open or sealed and on the price that the winner has to pay.

Table 3: Auction's operation

Type	Operation
English or ascending price Open	Seller announces reserve price or some low opening bid. Bidding increases progressively until demand falls. Winning bidder pays highest valuation. Bidder may re-assess evaluation during auction.
Dutch or descending price - Open	Seller announces very high opening bid. Bid is lowered progressively until demand rises to match supply
First-price, sealed bid	Bids submitted in written form with no knowledge of bids of others. Winner pays the exact amount he bid.
Vickrey auction or second-price sealed bid.	Bids submitted in written form with no knowledge of the bids of others. Winner pays the second-highest amount bid
Multi-unit auctions Combinatorial	Express their preferences for bundles of items rather than individual items

When choosing an auction design, a variety of assessment criteria and measures (Table 4) may be applied such as:

- Revenue (seller profit)[7]
- Winner's curse
- Competition [8]
- Complexity[9]

In the following table we evaluate four single-unit types of auctions according to the listed criteria.

Table 4: Auctions Performance measures

Type of auction	Revenues	Winner's curse	Competition	Complexity
English	**1**	High	Medium	High
Dutch	**4**	High	Medium	Low
First price sealed	**3**	High	Medium	Low
Vickrey	**2**	Low	High	High

[2] When the users habe information about each other bids this is called an open auction.

[3] Economists call the latter auction a multi-unit English ascending auction.

[4] This type of auctions is called also Yankee Auction from the British

[5] In theory, the Vickrey is mathematically equivalent to the English auction, because in both the first-place bidder receives the item at a price equal to the second-place bidder's willingness to pay, plus the bid increment.

[6] It is also called Bid Shading, a tendency for the winning bid in an auction to exceed the intrinsic value of the item purchased

[7] The revenues depend on the linkage between the winning bidder payment and the value estimates of other bidders

[8] The Competition depends on the willingness to pay for the item

[9] The Complexity depends on the rules, timing issues, regulations etc.

The most complicated auction is the Combinatorial where the winner is determined after evaluating all the different combinations of items with a use of an appropriate algorithm. It is the main representative of the multiunit auctions. Combinatorial Auctions (CAs) [12], [13] provide a mechanism for combinatorial bidding by participating agents enabling them to express their preferences for bundles of items rather than individual items. They are proving to be extremely useful in numerous e-business applications, especially, in e-procurement, e-logistics, and Business to Business (B2B) exchanges. In multi-unit combinatorial auctions, each item has multiple instances or units. In a forward multi-unit CA, the auctioneer wishes to sell a bundle that consists of multiple units of different types of items and the buying agents submit multi-unit combinatorial bids where they may specify bids for different subsets (which could be multi-sets). The winner determination problem is obviously more challenging than in the case of single unit CAs [14], [15], [16]

There are certain limitations when applying auctions to our problem. First of all when the available number of licenses is greater than the requested from the operators, then the auctions are not able to serve the system. There is no competition for scarce resource and the operators are not willing to pay more since they know that there is no demand.

The second issue is the current bidding language that is applied. The bid is expressed with "OR" and "XOR" combinations as the following example. Assume that we have 5 items, *a, b, c, d, e.* A potential bid could look like this:
{a, b}:$5 OR {c, d}:$6 XOR {e}:$5.
The bid is translated that the bidder asks for any or both of the {a, b} and {c, d} pairs, but does not allow both combinations: {a, b} and {e} or {c, d} and {e}. [17]
On the other hand an example of our bid vector would look like:
{B1, B2, B3, B4, B5, B6}, where

- **B1**: Location of the Base Station
- **B2**: Amount of spectrum required
- **B3**: Duration
- **B4**: Provider ID
- **B5**: Bid or Max. Price
- **B6**: Duration ("stickiness")[10]

The current bidding language as implemented or even proposed from the other researchers cannot satisfy the combinatorial nature of our problem. Additionally there is a computational problem, having as input, bids and as outputs, the allocation of items to bidders. This is a difficult computational problem considered as NP-complete. [12]

C. *Peak-load pricing*

Peak-load pricing (PLP) refers to the pricing of economically non-storable commodities whose demand varies periodically. PLP is often used by electricity [18], [19], [20], [21], [22], telephone and other public utilities and also the Internet [23] as a means of reflecting the investment they have made to meet peak demand for their services. This pricing scheme corresponds to high competition and price discrimination problems when efficiency is needed due to the increasing role for services in the economy. Therefore it is ideal for industry practice and real world applications. In the rest of this section we will describe the PLP model and how its constraints could be translated into the spectrum pricing problem.

PLP refers to the "on-peak" and the "off-peak" time period. On peak usually is described when the demand of the product exceeds the supply and additional units should be produced, when off peak is considered as the condition when supply satisfies the demand. According to the literature the market conditions determine which period is "high" and which season is "low." [24]. Usually the model is applied to monopolistic markets where the units' producer i.e. the regulated sector has full control of the management environment but today is spread over competitive industries i.e. airlines and hotels. The constraints of the PLP after deriving efficient prices are mainly to maximize the Welfare profit, called also the net social benefit and optimize the producer's profit in terms of revenues. [25]

As illustrated in Figure 4 the producer charges a higher price (PHi), PHi=b+β[11] during peak times (DHi) and a lower price (PLo), PLo=b, during off-peak times (DLo).

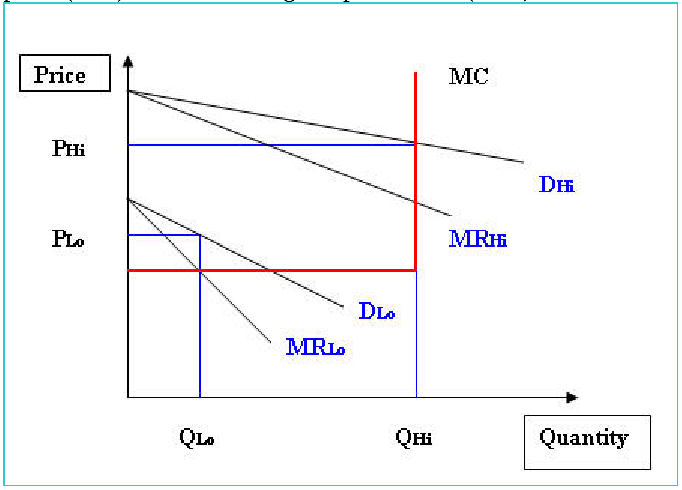

Figure 4: PLP Scheme

Building on Steiner's model [26] the following equations derive for the Welfare equation:

W=TR+S-TC (1), where

W=net social benefit
TR=total revenue
S=consumers' surplus
TC=total costs

$$W = \int_0^X P(x)dx - C(X), \quad (2)$$

P(X) = demand function

[10] It is defined as the number of time slots an accepted demand can continue to use its spectrum allocation. More details could be found in [4]

[11] The b equals the operational cost and the β is the cost of providing a unit of additional capacity.

C(X) = total cost function
X= $(x_1,x_2,\ldots x_n)$, is the total demand

After maximizing equation (2), the price equals the marginal cost.

In other cases during the peak hour diverse technology might be deployed to help fulfill the demand. For example during the peak-period it may be more economical to employ an additional technology type to meet the peak-period demand, anticipating lower construction costs and higher operating costs, thus offering cost advantages. The model in that case is extended studied in [27].

A very interesting case is the PLP with demand and supply uncertainty. "Efficient pricing rules require consideration of willingness to pay for services rendered, when supply is sufficient to meet demand, and for services not rendered plus any rationing costs incurred in excess demand states". [25] In this case the possibility of "outage" arises, which is the excess demand in certain states. The costs associated with outage are separated into three elements (1) rationing cost, which is the cost incurred by utility in allocated scarce supply (2) disruption cost and (3) surplus loss as defined in [28]. Assuming multiple time periods [25], the price in each time period should be set equal to the expected, deterministic short run marginal cost, including the expected marginal disruption and rationing costs. On the capacity side, per unit cost equals the expected marginal disruption and rationing costs. Summarizing the utility needs to use both price rationing as well as quantity rationing to efficiently allocate available capacity.

According to the PLP theory there are two models under uncertainty mode, the one refers to single technology and single pricing period and the second to multiple periods and multiple technologies. The latter case will be investigated.
We assume T periods, t=1,…,T of equal length in a typical day. Demand in period t is denoted as $X_t(P_t,\omega)$, $\omega \in \Omega$ and is assumed to be only a function of P_t.
P= $(P_1, P_2,\ldots P_t)$ the vector of T prices. Assuming also several technologies $h=1,\ldots.H$. The available capacity would be defined as:

$$Z_h\ (Y,\omega) = \sum_{j=1}^{h} Sj(Yj\omega)\ , (3)$$

Consequently the U_t, willingness to pay function at period t is:

$$U_t(Q,\omega) = \int_0^Q \underline{P}_t(x,\omega)dx \quad (4)$$

$\underline{P_t(x,}\ \omega)$ is the demand function.

Finally according to [25] there are certain conditions developed to characterize the optimal reliability and capacity, where the formulas are getting more complicated.

In a single pricing period with only one technology used the optimal price could be calculated as following. The optimal price will include also the willingness to pay (Λ). Assuming that our system is characterized with multiplicative uncertainty the optimal price will be the product of maximizing the Welfare function [25] for single technology and single pricing period:

$$P^{**} = b + \gamma(\frac{\beta}{\alpha}) - \Lambda\ , (5)$$

Where b usually is the operating cost at the agent's side to handle as many operators and bids he is configured i.e. Internet cost, software updates
β= usually is the cost of producing an additional unit, in our case would be the opportunity cost if the licenses were assigned to different operators in that particular time window T
α,γ = parameters defined in [25].

In our case and our system requirements, we stand between the one technology, the single pricing period and the multiple technologies, multiple periods. In our system there are several pricing periods during the day, but we assume the simple case with only one technology (CDMA) considering homogeneous networks and licenses. As a result we could formulate our problem with the equations (3) and (4) defining the optimal reliability, capacity and optimal price under the condition of $h=1$. In that case we should be able to calculate the optimal price in each pricing period, similarly with equation (5).

Also the PLP formulas as defined could manipulate a vector of time and price. But it is not certain if they could also work with a more complicated vector, as already defined, which contains various parameters including the price; a need might arise to modify these formulas when testing the system in a certain way that it would be possible to separate and evaluate the items in the vector applying certain criteria as required.

Finally, in telecommunications the PLP is gaining relevance, including our case, for two reasons. "First, with growing competitiveness of the market for interconnection services, the regulators tend to replace the regime of fixed prices with a price-cap regime. Second, since the Internet user is biased towards off-peak times, Internet service providers have an interest in more refined PLP of call-origination charges". [29]

IV. Proposed model

After describing the two most popular dynamic pricing models in the public utilities' sector, it is obvious that the "one size fits all" does not work in our spectrum pricing problem. There are certain pricing models on telecommunications proposed in [30], but they could serve more the bandwidth specifications and requirements rather than following the spectrum terminology, where the source is broken into channels and is not treated as an entity and also there is no congestion factor.

We propose a hybrid dynamic pricing approach using the advantages of auctions and PLP. We argue that during the off-peak time the PLP approach is used, when during the peak-period the auctions mode is more appropriate. In the off-peak time the price is decided from the peak load pricing as discussed later, when in the auction mode, the system is using as reserve price the price that was decided in the last off-peak period and was stored in the table of a database. The system is querying the database and is deciding about the auction's reserve price. Our general framework is illustrated in Figure 5. The system is managed from an agent described as information broker[12], is hosting an application that consists of an algorithm that handles the spectrum demand and according to the network load decides what pricing model to apply. Also the agent is aware of the spectrum utilization of each user that owns a chunk of the spectrum. The ultimate goal of the broker is to allocate the spectrum efficiently and assign the winners, determining about the price they have to pay. The capacity is measured as the number of available licenses or channels that could be assigned to the mobile wireless operators that request additional spectrum for each time period *T*.

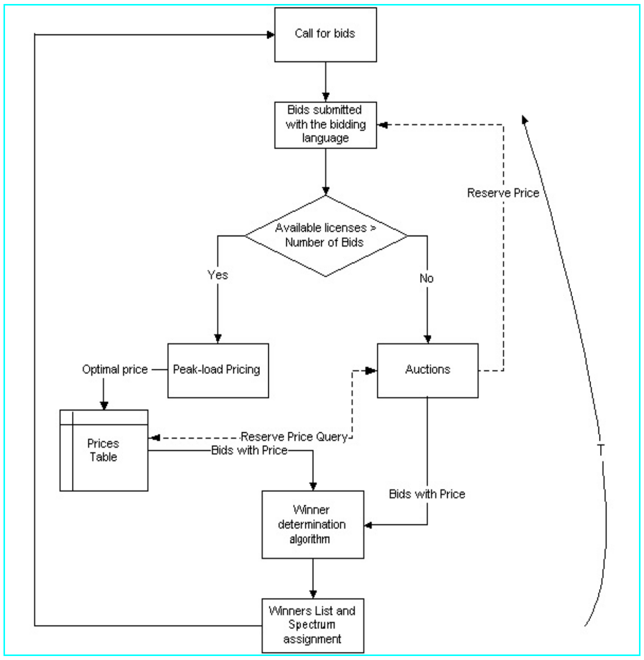

Figure 5: The new spectrum's pricing model

A more detailed approach of the proposed model is presented in Figure 6. The model consists of five phases. In the first phase, the preliminary phase, the bidders submit the spectrum requests in vectors that contain information about the bidders and their intentions, such as required spectrum and accepted channel interference. In the second phase the broker compares the requests with the available spectrum channels and determines about the pricing model of the next phase, whether auctions or PLP. After the broker is making the decision we enter the third phase. In case of auctions the broker is querying the database to determine about the Reserve Price as discussed. Then the bidders complete their vector submission adding the price. In case of PLP the broker computes the price. It is calculated by applying the single technology with multiple pricing periods as already described. The input would be the bid vector as described in phase 1 and for each time period *T* a different optimal price will be calculated and announced to the bidders as the price they have to pay per channel, in order to gain access to additional spectrum. The optimal price after calculated is stored in a simple database or a buffer; each entry into the database's table is related to a time stamp, in order to keep track of the historical data and the price. At time stamp T_3 the broker receives all the bids and is ready to manipulate them. In phase 4 the broker runs the auction, when for simplicity we assume only one round with a single-unit auction without any negotiation included between the broker and the bidders. In order to announce the winners, the broker runs a winner determination algorithm similar to [15], [16]. The applied winner determination algorithm 'weighs' also other parameters besides the bidders' price such as "stickiness", emergency or high priority issues and social welfare. The algorithm should be able to rank the winners according to the previous and announce the winners. Finally in phase 5 the spectrum winners reconfigure their equipment into the new frequency. The proposed model is considered real-time and the needed time window is T, which is the total time needed to complete its phase.

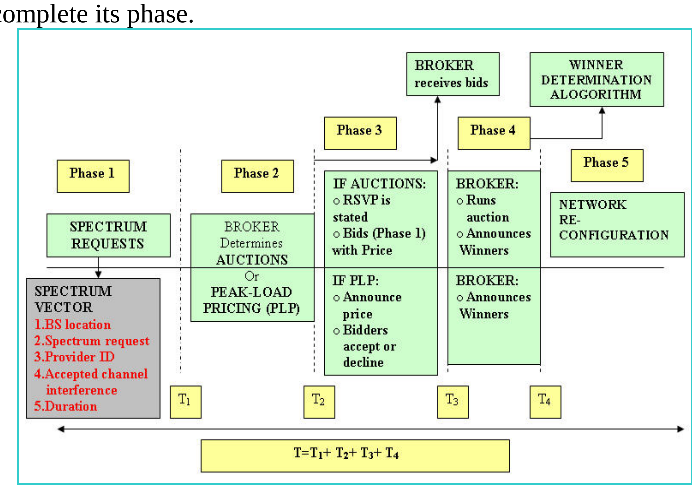

Figure 6: The proposed model's timeline

There are several advantages of this new pricing model. First it is not only based on price to determine about the winners but also in other critical parameters. This increases the system's fairness and efficiency aiming to grant access more often to the "small players" and reveal also the real demand and the bidders' preferences.

A second advantage is that the system is flexible to assign price anytime, computing the optimal price for each time period. The database as introduced in converting the whole application into an efficient system based on historical data enhancing the whole process.

Another advantage is that this system is unique and could be tested with different auctions models considering the same theory and evaluating the results. The proposed system is a comparison between a peak-load pricing model and any single-unit model deciding about the optimum solution according to the revenues and the spectrum's allocation efficiency.

Finally this system could have also a practical value, since the applied pricing models are used in real problems and applications. Its practical perspective is increasing the research value and is motivating the researchers for further studies.

[12] An infomediary that gathers and organizes large amounts of data and acts as an intermediary between those who want the information and those who supply the information

There are few limitations that could be identified in our system. First of all the formulas used should be carefully refined especially in the peak-load pricing case and addressed into the problem's constraints. The new introduced bidding vector might be too complicated, consisting of all these items increasing the system's complexity. However, in our future experiments we could customize the vector determining upon the most important items (i.e. price and duration), or compare vectors with different items allowing several combinations. Also this system needs time to be implemented; a number of simulations should emerge testing the system under different conditions and carefully defined metrics.

V. Ongoing research

In the future we aim to test the proposed system and report results of our simulation experiments under certain assumptions identifying restrictions and limitations. Specifically we intend to run experiments developing certain common metrics to compare the two pricing periods in terms of benefits for the regulator and the bidders. Some of the proposed metrics could measure the system's performance such as complexity defined as the time needed to complete all system's phases or the optimum revenues for the regulator and the optimum social welfare. Different cases or scenarios will be investigated, comparing single-unit auctions and PLP with homogeneous licenses and different loads of bidders, ending potentially with multiple-unit auctions and diverse licenses.

Additionally we plan to implement and test the system's Winner Determination Algorithm that will introduce the concept of the "adjusted price" in order to rank the bids and determine the winners. The adjusted price will be the total after adding the social welfare, the submitted price and the efficiency, each multiplied by an estimated coefficient, the higher value the higher the importance. The ultimate target is to compute a new value that will include all the system's important factors and increase the system's fairness in terms of decision and spectrum allocation.

VI. Conclusions

In this paper, we address spectrum management for coordinated spectrum access in cellular networks. We first presented background concepts of Coordinated Access Band (CAB) and a candidate architecture cellular architecture with broker based DSA. We then outlined key concepts of our new proposed spectrum pricing model, namely (1) auctions, and (2) peak-load pricing and also (3) we described the current FCC auctions. We outlined an integrated spectrum allocation and a new pricing framework aiming to solve our stated problem in a theoretical base and continue in the future with simulations.

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