

A Novel Idea of Dynamic Radio Spectrum Management

Using Peak Load Pricing Algorithm

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ABSTRACT

The concept of Dynamic Spectrum Access (DSA) will allow the radio spectrum to be traded in a market like scenario allowing Wireless Service Providers (WSPs) to lease chunks of spectrum on a short-term basis. Such market mechanisms will lead to competition among WSPs where they not only compete to acquire spectrum but also attract and retain users. Currently, there is little understanding on how such a dynamic trading system will operate so as to make the system feasible under economic terms. Synthetic monitoring is a good complement when used with passive monitoring that together will help provide visibility on application health during off peak hours when transaction volume is low. Several concepts are reviewed that are central to the design of spectrum management algorithms emphasizing on spectrum charging and allocation. In connection with these concepts and models, the authors suggested a Peak Load Spectrum Charging Algorithm for the Harmonized Usages Band (HUB) operated by the spectrum broker for homogeneous CDMA networks.

Keywords

CLC, Peak Load Charging, DSA, WSP, HUB

1. INTRODUCTION

A radio spectrum management agency of the government is accountable for the planning, allocation, harmonization and management of the joint access of the electromagnetic spectrum through operational, engineering, and administrative procedures [1]. Spectrum management of the agency has some objectives to facilitate electronic systems to carry out their function in the intended environment without causing or suffering unacceptable interference. There are some crucial factors that have an impact on spectrum management including spectrum regulation and licensing, spectrum pricing, spectrum sharing, spectrum allocation-assignment, and system design for spectrum competence. Each license is for a fixed amount of spectrum in a given region and is intended for a specific purpose (i.e. mobile wireless spectrum in cellular and PCS bands). The result has been inefficient and inflexible for the use of assigned spectrum, and the low deployment of new wireless services. Traditional spectrum allocation results in a slow process of assigning spectrum licences [4]. For example, large swaths of allocated spectrum are poorly utilized. Almost 90% of spectrum on average stays unused much of the time. Between 20-90% of unused broadcast spectrum is in rural area [5]. Additionally, measurements indicate that spectrum utilization varies dramatically in location and time. 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 harmonized DSA, a given amount of spectrum is reserved for dynamic assignment to network operators and users in a given region. There are some requests for spectrum which are sent to a spectrum server and licenses are assigned for a given time period (i.e. half an hour) to operators and/or users. Network operators and/or users, in uncoordinated DSA determine the location of unused spectrum through spectrum measurements and may begin operating in this used spectrum object to interference constraints. Regarding spectrum property rights, uncoordinated DSA of incumbent license holders raises interesting questions viewing 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*.

2. HARMONIZED USAGES BAND

A contiguous block of spectrum, Harmonized Usages Band (HUB) is reserved by regulating authorities for controlling dynamic access. The HUB spectrum can be allocated to use as multiple parts 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 HUB spectrum to individual networks or users is controlled by the spectrum Broker Figure 01 [2]. 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 charging and allocating paradigms.

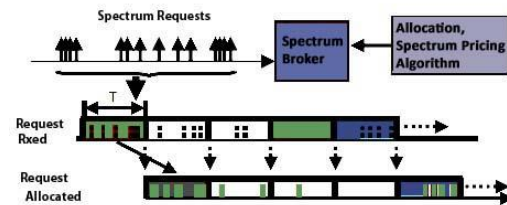


Figure 01: Spectrum Allocation Paradigm

3. CLIMAX LOAD CHARGING

Climax Load Charging (CLC) refers to Peak Load Pricing (PLP) of economically non-storable commodities whose demand varies periodically. The use of CLC is often utilized by electricity, telephone and other public utilities and also the Internet as a means of reflecting the investment have made to

meet climax demand for their services. This charging scheme corresponds to high competition and charge 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. The authors show the PLSP (?) algorithm and how its constraints could be translated into the spectrum pricing problem.

CLC refers to the 'on-peak' and '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'. 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 hostels? The constraints of the CLC 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.

As illustrated in Figure 02 [8] the producer charges a higher price (PH_i), $PH_i = b + \beta$, the b equals the operational cost and β is the cost of providing a unit of additional capacity, during peak times (DH_i) and a lower price (PL_0), $PL_0 = b$, during off-peak times (DL_0).

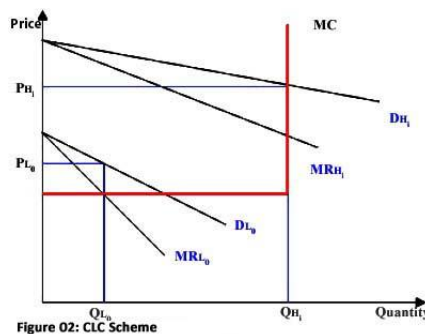


Figure 02: CLC Scheme

Building on Peter O. Steiner's model [7-8] the following equations derive for the welfare equation:

$$\omega = TR + S - TC \text{ -----(i)}$$

If the total revenue gathered is TR and S is consumers' surplus, and TC goes towards the total costs, then the difference, ω , is the net social benefit.

$$\omega = \int_0^X P(x) dx - C(x) \text{ -----(ii)}$$

$P(x)$ for demand function, $C(x)$ for total cost function, and X for $x_1, x_2 \dots \dots x_n$ is the total demand.

In other cases, during the peak hour diverse technology might be deployed to help fulfill the demand. For instance 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.

A very interesting case is the CLC 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 cost incurred in excess demand states". 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. Assuming multiple time periods, 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 Peak Load Pricing (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. Assume T periods, $t=1, \dots \dots T$ of equal length in a typical day. Demand in period t is denoted as $X_t (P_t, \omega_t)$, $\omega \in \Omega$ and is assumed to be only a function of P_t . P equals to $p_1, p_2, \dots \dots p_t$ the vector of T prices. Assuming also several technologies h equals to $1, \dots \dots H$. The available capacity would be defined as

$$Z_h(Y, \omega) = \sum_{j=1}^h S_j(Y_j, \omega) \text{ -----(iii)}$$

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

$$U_t(Q, \omega) = \int_0^Q P_t(X, \omega) dx \text{ -----(iv)}$$

$P_t(X, \omega)$ is the demand function. According to the theory of peak-load pricing [9] there are certain conditions developed to characterize the optimal reliability and capacity, where the formulas are getting more complicated.

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

$$P^{**} = b + \gamma \left(\frac{\beta}{\alpha} \right) - \Lambda \text{ -----(v)}$$

where b usually is the operating cost at the agent's side to handle as many operators and bids configured i.e. Internet cost, software updates. β usually is the cost of producing an additional unit, in this 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 the theory of peak load charging.

There are several pricing periods but the authors assume the simple case with only one technology CDMA, considering homogeneous networks and licenses. As a result, it will be easy to formulate problems with the equations (iii) and (iv) defining the optimal reliability, capacity and optimal price under the condition of h equals to 1. In that case it can be calculated that the optimal price in each pricing period, similarly with equation (v).

The CLC is gaining relevance, including the two reasons. "First, with growing competitiveness of the market for interconnection services, the regulator tends 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 CLC of call-origination charges".

4. PEAK LOAD SPECTRUM PRICING ALGORITHM

From the study of the most popular dynamic charging paradigms it is obvious that the *one size fits all* does not work in this spectrum problem. Some of the certain charging paradigms on telecommunications recommended in Pricing Communication Networks, but they could serve more the bandwidth specifications and requirements rather than following the spectrum terminology, where the source is broken into channels and it is not treated as an entity and also there is no congestion factor.

Dynamic charging approach of a hybrid system can be recommended using the advantages of auctions and CLC. During the off-peak period, the authors argue that the CLC approach is used, during the peak-period the auctions mode is more apt. In the off-peak time the charge is decided from the peak load charging, when in the auction mode, the system is using as reserve 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 in Figure 04. The system is managed from an agent described as information broker, is hosting an application that consists of an algorithm that handles the spectrum demand and according to the network load decides what charging algorithm 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 .

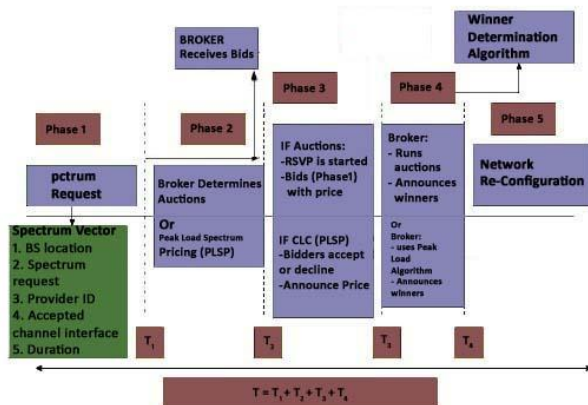


Figure 03: Peak Load Spectrum Pricing Algorithm's Timeline

There are five phases consisted in the PLSP algorithm's timeline Figure 03. 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 CLC.

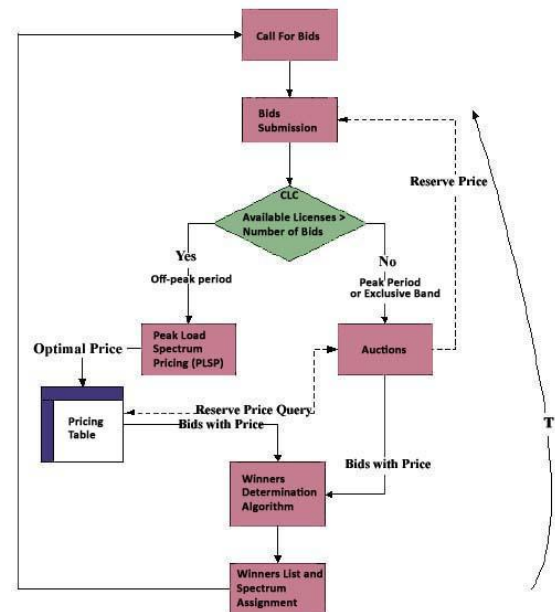


Figure 04: Peak Load Spectrum Pricing Algorithm

At the step T_2 the broker receives all the bids and is ready to manipulate them. After that making decision the broker enters the third phase. In case of auctions the broker is querying the database to determine about the reserve price. Then the bidders complete their vector submission adding the price. In case of PLSP the broker computes the charge. It is calculated by applying the single technology with multiple pricing periods. The input would be the bid vector as described in phase1 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 date and the price. In phase 4 the broker runs the auction, when for simplicity the author assumes 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 brokers run a winner determination algorithm similar to 'Integer programming for combinatorial auction winner determination and Algorithm for optimal winner determination in combinatorial auctions' [3,7]. 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.

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

A second advantage is that 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. The mentioned system is a comparison between a peak load pricing algorithm and any single-unit algorithm deciding about the optimum solution according to the revenues and the spectrum's allocation efficiency.

5. CONCLUSION AND FUTURE WORKS

The bidders, in different simultaneous auctions could bid that will include only one stage with a couple of rounds which will be investigated further in the future. A faster per-auction process is aimed to perform where the licenses' agenda will be according to the initial bidders' preferences. The announced license list should be interference free especially at co-located regions. A platform of web based will allow the bidders to participate in auction characterized from efficient spectrum reuse. The broker should be an artificial intelligent agent that will host advanced allocation and pricing algorithm. This system could have also a practical value, since the applied charging algorithms are used in real problems and applications. Its practical perspective is increasing the research value and is motivating the researches for further studies. Economic theories have been used to analyze networking [6] and communications problems where interacting decision-makers have conflicting objectives. In particular, auction and game theories are good tools to deal with distributed problems from an economic point of view. This is because the service quality that each user receives in a competitive environment is often affected by the action of other users who also try to contend for the same pool of resources. Dynamic Spectrum Allocation coupled with fine granularity switching of services by end-users will engender a flexible and competitive environment for trading wireless services. Regarding to this, auction and game theories that are captured the interaction among spectrum broker, service providers, and end-users in a multi-provider setting.

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