# Cloud-Assisted Spectrum Management System with Trading Engine

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***Abstract*—The radio spectrum scarcity represents a major challenge for wireless communication systems, this is a result of allocating radio spectrum statically with exclusive assignment policy. Many studies stated that most of the assigned radio spectrum is underutilized. This tight situation was a motive to turn into Dynamic Spectrum Allocation (DSA) and design systems that could handle DSA efficiently. We designed an integrated Cloud Spectrum Management System (CSMS). In this system we introduce a Cloud Spectrum Broker (CSB) that uses geo-location cloud-based database to monitor and share radio spectrum between Primary Users (PUs) and Secondary Users (SUs). The core of CSMS is the trading engine, which is designed to handle requests from competing SUs in an auction-based algorithm. The architecture and vital building blocks of the Cloud Spectrum Management System (CSMS) are discussed in details in this paper.**

***Keywords—component; Spectrum Management; Dynamic Spectrum Access DSA; Cloud Spectrum Services CSS; Cognitive Radio CR; Cloud Spectrum Broker CSB; Spectrum Trading; Licensed Shared Access.***

## I. Introduction

Undoubtedly, the radio spectrum is a vital resource for all wireless communication technologies that needs to be properly managed to expand the wireless communication industry and provide many services and applications with good Quality of Service (QoS). Currently, we live in an emerging wireless technologies era where everything is connected wirelessly with massive data traffic. Due to this rapid growth in wireless sector, the demand for extra spectrum is increasing constantly. Static Spectrum Allocation is currently used to assign fixed spectrum portion for each Mobile Network Operator (MNO) or spectrum holder. With this allocation mechanism, most of the assigned spectrum is underutilized. Thus the existing regulatory policies of spectrum assignment can't cope with the steadily increasing aforementioned requirements.

That shed the light on another flexible scheme named Dynamic Spectrum Access/Allocation (DSA). DSA enables SUs to opportunistically exploit the unused spectrum of PUs while protecting the rights of both parties [1]. This technology requires the SUs' devices to change their parameters and tune themselves to new frequencies many times. Cognitive Radio (CR) is a new paradigm for wireless communication. Based on observation and predefined objectives, CR can intelligently adapt its parameters leading to the selection of the best operating frequency band and transmission parameters [2].

In this paper we add a new entity called "Cloud Spectrum Broker (CSB)" entity that will exploit various CR techniques and algorithms to detect underutilized spectrum chunks then communicate with a cloud based spectrum database to store information about the underutilized spectrum. CSB will communicate with licensed spectrum owners "Incumbents" to get information about their underutilized spectrum and offer this spectrum to other customers like Mobile Operators. CSB will be a part of a cloud based spectrum management system that is proposed here:

**Cloud Spectrum Management System (CSMS),** it provides components and a set of Application Programming Interfaces APIs to manage the spectrum allocation and ease the communication between all the entities within the CSMS system. Our main contribution is to design a flexible system architecture that can fit into the context of dynamic spectrum management based on cloud computing infrastructure and services. This provides an easy way to utilise the existing unutilized spectrum based on location and other radio characteristics. Also we envision the requirements and develop the design principals and recommendations for implementing and adapting to the Cloud Spectrum Broker concept and its use cases.

The core component of the CSMS is the trading engine that is essentially required to handle requests from competing secondary holders at various geographic regions, handle auction bids, brokerage and various other transactions while ensuring profitability of the primary spectrum owner. A mechanism to ensure continuous maximum-effort resource deliverance and fulfillment is crucial to satisfy legal contract terms and high Quality of Service (QoS) within a highly dynamic trading environment.

At section II, we have a quick review on the important background and previous work related to our proposed system. We present our proposed CSMS architecture with all the vital building blocks and their detailed functionalities at section III. The trading engine is the core component of the CSMS, so in section IV we introduce the full functionalities of the trading engine with its followed algorithm as well. The challenges and future work are listed at section V.

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## II. PRELIMINARIES AND RELATED WORK

Many researches and projects were established in the context of spectrum management. Spectrum management aims to use the radio spectrum efficiently in addition to increasing the total social interest; this is achieved by a set of regulating rules and procedures [3]. Spectrum management comes in different fashions, such as "Command and Control" where the regulator takes a pivotal position in assigning or allotting blocks of spectrum to operators and protecting operators from interference. In so-called liberalized spectrum management, market measures are used in the assignment/allotment process whereby spectrum is traded or bought at auction. Generally speaking, spectrum management requires two sub-systems: the spectrum management database and the spectrum management decision system [4].

At [5], Alptekin and Bener studied architecture for a competitive spectrum exchange marketplace. It considers a short term sub-lease of the underutilized spectrum of spectrum holders. Game theory was used to choose the pricing model; a Nash equilibrium point was applied to tell the spectrum holders the ideal price for maximum revenue.

When there isn't a clear vision about the buyers' estimation of the wireless resources' value, spectrum auctions shown to be the most appealing trading mechanism. (Bridge 2010) is one of the related implemented business models where spectrum could be traded in real time within an online market [6]. Auction's main advantages are that it allocates the spectrum resources to the buyers who valuate it most in addition to increasing the total revenue [6, 7].

In [8], it considers the problem of spectrum management at secondary cognitive users where there is a leader node which should handle some operations like the detection of primary, scanning the channel and coordination of the nodes. Channels are sensed in the order of their detection probabilities. The leader node is changed per each scan based on a generated credit history by a fair mechanism. The functionalities of spectrum management consume much energy from the operating devices. It has been shown that the proposed scheme can achieve better energy efficiency in terms of overall low battery consumption.

In [9], the authors introduced the concept of spectrum broker for TV white spaces secondary spectrum markets. In this work, the broker trades the white spaces by matching bids and offers. The trading process should be multi-dimensional to define the secondary users' rights regarding the frequency band, bandwidth, maximum emission power, geographic region, availability period, resource price…etc. The main challenge was to choose multiple winners for the spectrum auctioning process to maximize the economic revenue.

## III. CSMS ARCHITECTURE

The Cloud Spectrum Management System (CSMS), which is considered the engine of the cloud broker, is composed of different layers and components as shown in Fig. 1. Following is a summary of those layers and components:

### A. *Core Services Layer:*

This layer is considered the key layer of the CSMS, as it contains the vital components to perform spectrum management processes and offer brokerage services. These components are listed below:

#### 1) *Spectrum Transaction Management System*

This component is mainly responsible for collecting, storing, modifying, and retrieving the spectrum transactions requested by any system entity (e.g. Mobile Devices, Primary Spectrum Holders, Secondary Spectrum Holders, Cloud Spectrum Broker and Cloud Spectrum Database). One major characteristic of this management system is: Spectrum Transactions should be consistent and atomic to prevent interference, and for the spectrum allocation to be in a consistent state (e.g. if Primary holder of the spectrum rented some frequency units, it should be decreased from its total spectrum and added to the secondary Spectrum Holder portfolio of spectrum). The partial Spectrum Transaction should be rolled back in case of failure or the Primary Spectrum Holder claimed the rented spectrum.

#### 2) *Real-time Trading Engine*

This is the main component responsible for the actual trading of the frequency units available for allocation; in which, the coordination and actual trading occur between primary and secondary holders of the spectrum and are mediated by the cloud broker. It performs the analysis of incoming market data so that the system can decide what should be traded. The incoming information includes the location, the price and the quantity of the available spectrum bands for trading. System's database captures the incoming information for further development of trading strategies. Finally, this received information is stored to be used by the analytical engine – will be mentioned later – as historical data so that the broker could have sufficient information to learn, suggest, and predict the spectrum usage and demand patterns.

#### 3) *Match Making*

This component is responsible for finding the best match of frequency units available for trading according to price and location criteria of the available spectrum. It utilizes an efficient algorithm that performs the matching process.

#### 4) *Rules-based Engine*

This engine is responsible for setting the rules of trading and brokerage criteria that helps in developing an efficient and customizable trading and brokerage service.

#### 5) *Analytics Engine*

This is the central component of the core services layer that uses multi-objective optimization algorithms and smart cognitive components to analyze and help in trading's decision-making process.

#### 6) *Negotiation broker*

This component is responsible of choosing a strategy from a list of strategies that exist in the system's strategy pool and historical information, in order to automatically handle most bargaining cases, costs, offers, and decide what offers to accept and what counteroffers to propose.

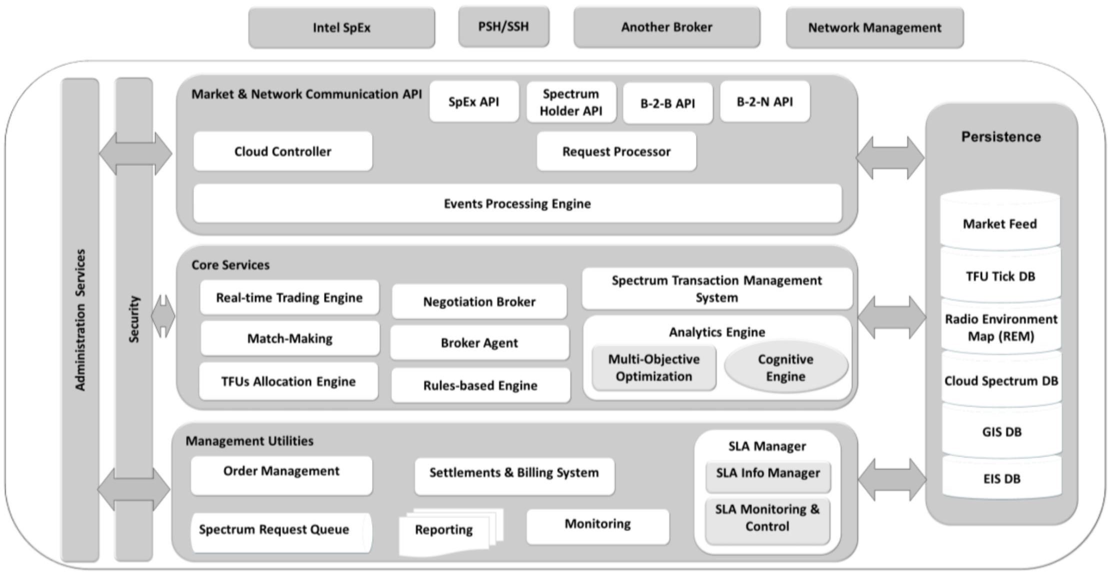


Fig. 1. Cloud Spectrum Management System Architecture (CSMS).

*B. Market and Network Communication API:*

In this section we discuss the market and network APIs that are offered within the cloud spectrum management system.

*1) Request Processor*

This component is responsible of processing the requests from other brokers, primary and secondary spectrum holders besides other network requests.

*2) Cloud Controller*

Cloud Controller is the main cloud component responsible of communicating between the core trading services layer and requests processor in order to complete spectrum transactions.

*3) Events Processing Engine*

This engine is responsible of processing event–based requests (e.g. spectrum orders, congestion triggers … etc.)

*4) Spectrum Holder API*

Spectrum holder API exposes the broker functionality to spectrum holder systems to make the communication process easier for renting and reclaiming frequency units.

*5) B-To-B (Broker-To-Broker) API*

It is the API that exposes the broker functionality and transactions with other brokers. For example, a broker could negotiate available spectrum to be leased and rented by another broker.

*6) B-To-N (Broker-To-Netwrok) API*

It is the API that exposes the broker functionality and interactions with the spectrum network components. This makes the communication process easier between the broker entity and other network components by regulating the transactions and tracking messages between them.

*C. Management Utilities:*

This part of the architecture contains the entities that are concerned with all the procedures related to secondary users' requests from receiving the orders till monitoring and billing of the rented spectrum units.

*1) Order Management*

Order Management is a system to manage the orders requested by secondary system to rent and acquire spectrum units for a period of time from the primary users who have the exclusive right to access that spectrum.

*2) Settlement and Billing System*

It is the billing system for the completed and settled spectrum transactions. It tracks the current secondary user of each spectrum unit and charges him according to the pre-agreed prices.

*3) Monitoring*

This module monitors the components to control transactions, orders and other aspects of the system to make sure that the system is working properly.

*4) Reporting*

This module is dedicated to provide the systems' owners with reports and statistics depicting the broker's overall operations status.

*5) Service Level Agreement (SLA) Manager*

The SLA module is the set of components that will be put in place to manage the quality of service and make sure that the agreed upon terms and conditions are met.

*D. Persistence Layer:*

This layer represent the data store and persistence of all –

spectrum – related information needed by the cloud spectrum management system and marketplace to indicate the availability of spectrum to be allocated, leased, rented, or reclaimed to spectrum owners. It also contains information about the transactions being executed between spectrum holders (Primary and Secondary). Furthermore, the persistence layer has a database layer that contains information about the market prices and a directory of all spectrum market brokers that exist and are ready to negotiate spectrum quotes.

### *E. Administration and Security Cross Layers:*

These cross layers are responsible of providing security and administration over the whole spectrum management process. This to make sure of the authenticity of spectrum holders who are eligible to rent or lease the spectrum and also to facilitate the creation of rules of the spectrum brokerage services by the broker administrators.

## IV. TRADING ENGINE FUNCTIONALITIES

The system under consideration is shown in Fig. 2. It is comprised of a primary spectrum owner, secondary spectrum owner within a single or multiple geographic locations, and the trading engine. The trading engine is essentially responsible for:

1. Handing bids and requests.
2. Continuously assigning and reclaiming resources to and from secondary holders.
3. Logging resource attributes and utilization periods into a resource utilization database.
4. Determining the minimum resource lease price P* for each frequency resource.
5. Conducting auctions.
6. Issuing transactions.
7. Adjusting resource lease prices based on statistical utilization history.

The primary spectrum owner feeds the trading engine with currently available and unavailable frequency resource units at various geographical regions. Such resources are available for lease to secondary spectrum owners who are willing to compete for temporal ownership. Each secondary owner will request a group of frequency resources for a desired period of time and at specific geographical regions. As a result of the highly dynamic nature of such requests and time-varying resource availability, the trading engine must continuously attempt to find a near optimal configuration to ensure efficient resource distribution and balanced profitability considering both the current and future request pools. Fig. 2 illustrates a top-level diagram of the trading engine, followed by a detailed description of the functionality of each block and process.

### *A. Core Algorithm*

The core algorithm functionalities are:

1. Processing received requests that include the desired bandwidth and duration of the lease.
2. Communicating with the auctioning algorithm.
3. Determining the minimal bid prices.
4. Radio resources assignment after auction settlement and reclamation after lease expiry.

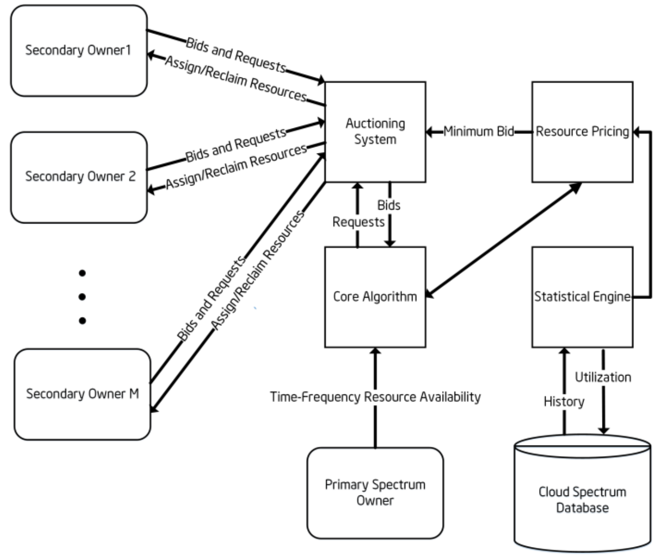


Fig. 2. Trading engine system design

If the amount of available resources exceeds the demand of the requesters, the core algorithm computes revenue for each secondary owner via the resource pricing block and sorts the secondary owners list, highest revenue first. The core algorithm will begin to assign and fulfill resources sequentially (highest to lowest revenue). If the amount of available resources does not meet demand, an auction is conducted.

### *B. Resource Pricing*

This block receives bandwidth and lease period request parameters from the core algorithm, and returns the computed revenue for each request. The revenue is calculated using the curve shown in Fig. 3.

In the curve, a minimum price P*is a function of a defined bandwidth (B*) and lease period (T*) expressed as P*(B*, T*) per unit resource. Penalty zones are enforced for requests demanding higher or lower bandwidth of lease periods. In the case of requests that are higher than either B* or T*, the price per resource unit per time unit is generally increased to hinder greedy requests which maximizes profit instantaneously but may decrease profitability over the long run. On the other hand, requests that are lower than B* or T* are most likely not to have high priority, and the price per resource may be increased to encourage higher resource requests.

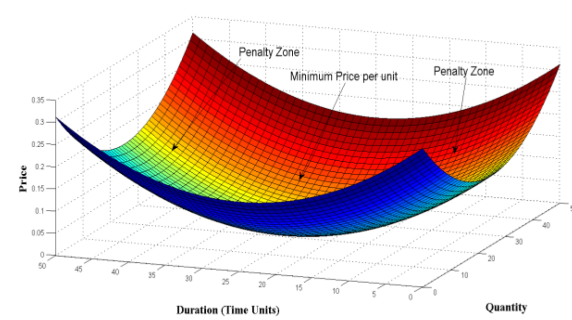


Fig. 3. Revenue curve

The curve shown above may be adjusted or `customized to suit different usage profiles at the initial deployment of the trading engine, where insufficient utilization statistics are available. When enough statistics can be extracted from the resource utilization database, the curve may be adjusted by a set of computed conditional occupancy probabilities.

### *C. Auction Algorithm*

The auction algorithm is operated when the supply resource pool is lower than demand. In this scenario, the core algorithm uses the minimum price from the resource pricing curve (P*) plus an empirical positive gap constant as a base auction bid. The base bid is communicated by the core algorithm to the requesting secondary owners. A timed auction is conducted where secondary owners will continue to increase bids during the auction time. The closing bids are sorted descendingly as shown in Fig. 4. The owner of the highest bid will receive the resources, followed by the second highest, etc., until resources in the pool are exhausted. The choice of auction duration should be proportional to the trading frequency. The chosen auctioning algorithm preserves the fairness among all the bidders by considering the lowest price associated with the last winning bidder. So, all the winning bidders can afford the final price per radio resource unit. Also this distributes the available radio resources between as many users as possible and not limiting it only to the one who submitted the highest bid price.

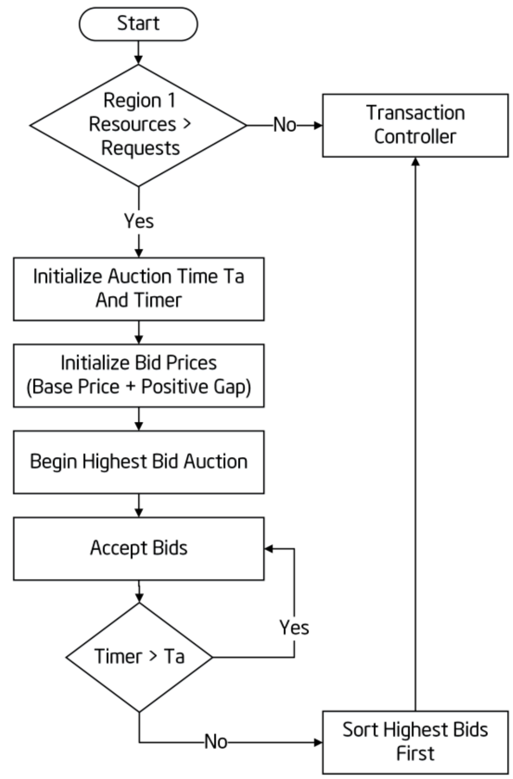


Fig. 4. Auction controller algorithm –repeated for all regions-

### *D. Statistical Engine*

The purpose of the statistical engine is to provide a learning mechanism to predict the occupancy and utilization states of all resources in the resource pool. The utilization statistics are used to calibrate the minimum prices and penalty zones of the resource pricing curve.

The minimum price is expected to be a function of demand. Higher demand resources should be priced higher than their lower occupancy counterparts. Similarly, penalty zones can be adjusted according to the probability of occupancy in the future. For example, if the probability of occupancy of a frequency resource is high in the near future, current requests with longer lease periods are penalized higher and vice versa. The probability of occupancy can be readily derived by obtaining sampled probability density functions for different observation timeframes, specific days of the week, geographical locations, recurring occasions, events, and many other factors. The entire trading system is summarized in Fig.5.

## V. CHALLENGES AND FUTURE WORK

When designing a complex and critical system as CSMS, we face many challenges. The major point is how to make an optimal design that contains all the needed blocks to achieve all the required objectives. Some of the important tradeoffs are the real-time requirements of this system, response time compared to the minimum waiting time for the interacting entities, the optimal resource price in case of wide different valuations from secondary users' perspective and defining the optimal resource block dimensions in frequency, time, and location. Also many considerations would be taken regarding the spectrum reclaiming process to preserve the primary users' rights and the secondary users' as well.

Our future work will concentrate on providing a complete spectrum reclaiming algorithm for the rented spectrum. This reclaiming algorithm should consider all the expected situations i.e. regular or urgent reclaiming and mitigate the harmful reclaiming impacts on both primary and secondary users. We need to develop a suitable learning mechanism to observe all the spectrum resources and speculate their characteristics to save time in future working cycles. A learning mechanism would help in taking spectrum assignment and reclamation decisions in real time with high precision based on the previous observed spectrum information.

## CONCLUSION

In this paper we designed a system that can help to provide new radio spectrum resources and overcome the problem of spectrum sacristy and unavailability. The proposed Cloud Spectrum Management System has many layers and components. CSMS coordinates between all the entities in the wireless network to perform spectrum trading process between primary and secondary users.

All the spectrum information and spectrum transactions requested from all entities are stored in the core layer of CSMS. CSMS performance tends to meet real-time requirements, regulatory rules and efficient matching between operators' requests and available resources. Most of spectrum management objectives are applied at this system. We also

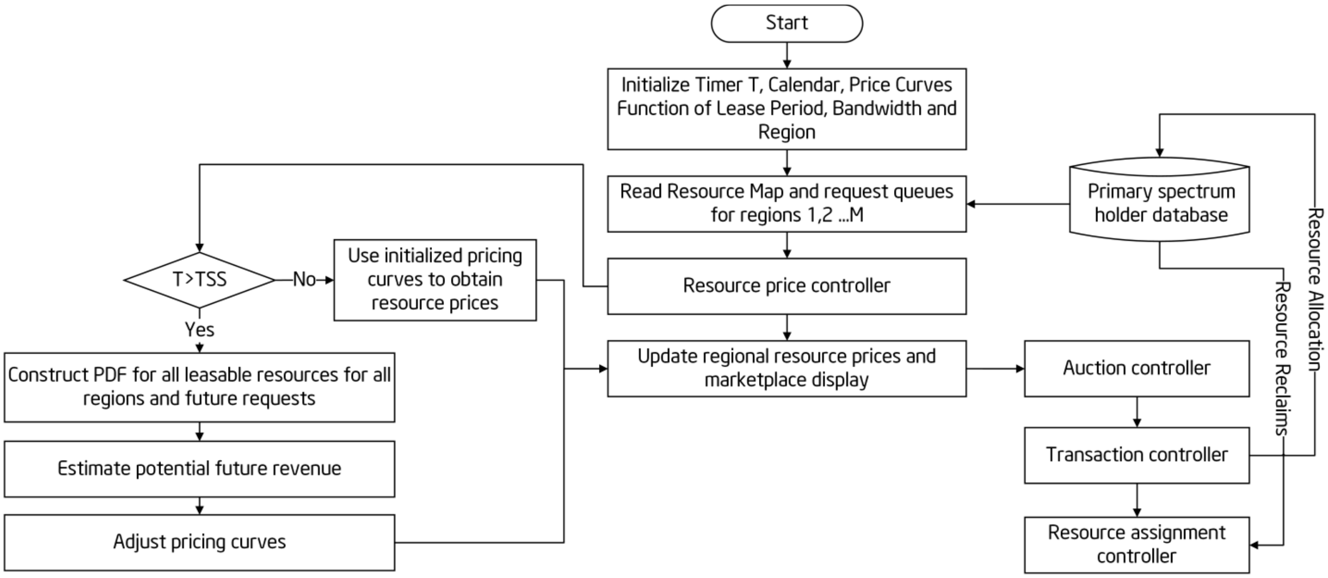


Fig. 5. Trading engine system chart

proposed a real-time trading engine that processes all the operators' spectrum requests and apply spectrum auctions if needed. We developed a proper auctioning algorithm that handles all the requests and calculates the optimal resource price. Finally, to improve spectrum utilization over time, we added a statistical engine to learn spectrum utilization from past observations to calibrate the minimum prices and penalty zones of the resource pricing curve.

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