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# A comprehensive spectrum trading scheme based on market competition, reputation and buyer specific requirements

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ABSTRACT

In the exclusive-use model of spectrum trading, cognitive radio devices or secondary users can buy spectrum resources from licensed users or primary users for a short or long period of time. Considering such spectrum access, a trading model is introduced where a buyer can select a set of candidate sellers based on their reputation and their offers in fulfilling its requirements, namely, offered signal quality, contract duration, coverage and bandwidth. Similarly, a seller can assess a buyer as a potential trading partner considering the buyer's reliability, which the seller can derive from the buyer's reputation and financial profile. In our scheme, seller reputation or buyer reliability can be either obtained from a reputation brokerage service, if one exists, or calculated using our model. Since in a competitive market, the price of a seller depends on that of other sellers, game theory is used to model the competition among multiple sellers. An optimization technique is used by a buyer to select the best seller(s) and optimize purchase to maximize its utility. This may result in buying from multiple sellers of certain amount of bandwidth from each, depending on price and meeting requirements and budget constraints. Stability of the model is analyzed and performance evaluation shows that it benefits sellers and buyers in terms of profit and throughput, respectively.



## 1. Introduction

Cognitive radio (CR) enabled devices termed as secondary users (SUs) can solve the problem of spectrum scarcity [1,2] in the unlicensed band by sharing the under-utilized licensed band with the licensed or primary users (PUs). This spectrum sharing has been categorized in three models: commons, shared-use and exclusive-use models [3]. Commons model is applied in unlicensed band (e.g., ISM band) where spectrum can be accessed by everyone and hence, is becoming congested due to the increased usage and number of wireless devices. In the shared-use model, SUs sense the licensed spectrum to exploit it opportunistically, i.e., they use the licensed spectrum when it is not used by PUs. Although in this model SUs can access the spectrum without any cost, it has several limitations [4,5]. These include: (i) requirement of continuous sensing and careful deployment of SUs, (ii) increment of communication overhead, and (iii) difficulty in finding and switching to a free channel because spectrum holes may not always be available.

On the other hand, the exclusive-use model has several advantages and does not suffer from the above mentioned limitations. In this model, SUs have exclusive rights to access the spectrum by buying channels from primary service providers, hereafter termed as primary services, for a short or long period of time without any need for spectrum sensing.

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Besides, SUs can buy the spectrum at a lower price and the primary services can make some profit by selling their unused resources to the SUs, benefitting both the primary and the secondary services. This type of spectrum access model between the primary and the secondary services has been adopted in different contexts by exploiting different solution techniques [6–14].

In [15], we introduced a spectrum trading model using the exclusive-use model where a buyer chooses a seller based on the seller's reputation, service contract duration, signal quality and bandwidth of the offered spectrum. However, in that paper we did not consider the reputation of buyers as seen from sellers' perspective for trading purpose. The consideration of a buyer's reputation is also of paramount importance for a successful leasing based trading. Therefore, in this paper, we have incorporated several practical aspects of spectrum trading to elevate it to a more realistic level. First, we introduce a buyer's reputation and credit score which can be used as criteria by a seller to assess the reliability of a buyer. This is essential in buyer selection when the payments of a contract are in installments or in postpaid basis. A buyer's reputation is calculated based on a seller's own experience and recommendations from other sources. Experience is calculated based on payment completion, timely payment and percentage of contract completion of a spectrum lease. Trustworthiness of recommenders is also considered important to reduce the impact of false recommendations.

In the traditional credit rating system, there exist many agencies (e.g., Standard & Poor's, Moody's and Fitch ratings) who assess the creditworthiness of a company or a government, while the others such as credit bureau and consumer reporting agency collect and evaluate the credit information of individual consumers for applications such as bank loan, leasing, employment, etc. [16]. Currently, there exists no reputation/reliability brokering service for spectrum trading. However, with increased business opportunities of spectrum trading, such brokering service is expected to become available in future. Therefore, in our model, we keep provision for a seller to obtain a buyer's reliability score from a broker or the seller can calculate it through own analysis.

Second, we consider competition among sellers and model this competition using non-cooperative game theory to determine the Nash equilibrium trading price. In [15], inherent competition among sellers was assumed, and therefore, market equilibrium was used to determine the supply and demand of the spectrum bandwidth. In the case of multiple sellers and buyers, market equilibrium calculates the combined supply of sellers as a single supply curve and that of the buyers as a single demand curve. This was sufficient in [15] because sellers were assumed to be unaware of the spectrum price of other sellers. However, if sellers are aware of the prices of other sellers and they compete with each other in maximizing their own profits, non-cooperative game theory is the best candidate to model the price competition. Therefore, in this paper, we use non-cooperative game theory to determine the pricing solution. Third, we consider two types of buyers in the market: (i) price sensitive and (ii) price insensitive. Price sensitive buyers are those who buy spectrum from sellers and maximize their utility or satisfaction within the budget constraint. In contrast, price insensitive buyers are focused on buying their required bandwidth rather than considering price as a constraint.

Thus, in the proposed model, a buyer and a seller will be aware of each other's reputation to ensure successful trades. Overall, the major contributions of this paper can be summarized as:

- The selection of buyers is based on their reliability, which can be either obtained from a broker or calculated by a seller considering the buyer's financial profile, seller's own past trading experience and recommendations from other sources about that buyer. Experience is quantified utilizing payment completion, timely payment and percentage of completion of contract duration, while the creditworthiness of a buyer is theoretically modeled using a generalized credit scoring model using logistic regression.
- Introduction of competition among sellers and its theoretical model with a non-cooperative game theory.
- Modeling of two types of buyers, namely, price sensitive and price insensitive buyers, and their analytical solutions for the required amount of bandwidth purchase maximizing utility functions.
- Analysis of the proposed model against the existing popular and recent models [15,17] in terms of throughput and economic benefits.

The rest of the paper is organized as follows: related works of spectrum trading using game theory are described in Section 2. Section 3 describes the system model with the assumptions considered in this paper. Buyer selection process is presented in Section 4. Section 5 models competition among sellers, while Section 6 describes the analytical solution used by a buyer in buying the spectrum. Performance evaluation is presented in Section 7, while Section 8 concludes the paper.

## 2. Related works

Spectrum trading has been applied to solve the pricing issue in network models in different ways to reach the optimal and stable solution. These are [17]: auction, classical optimization, game theory and microeconomic approach. In the auction approach, trading is time-dependent where the bidding decision is taken at a certain interval or at a fixed time. Optimization can be used in spectrum trading to maximize or minimize an objective function of a seller or a buyer under some constraints. This objective function can express a trading goal (e.g., maximum profit, minimum cost) in mathematical terms. Game theory is used when a system exists with multiple entities with different objectives and an equilibrium solution is desired rather than satisfying a single objective with a global optimum solution.

A spectrum market is considered in [7] where the same seller is evaluated differently for different buyers based on their usages and locations. Stochastic learning algorithm is used to find the optimal price in the presence of limited information (e.g., buyer's utility function, prices of other sellers) in order to maximize the profit of the sellers. But the seller's utility function for selecting buyers is ignored in this work. As a result, sellers are unaware of the nature of demand from the buyers.