Physical Communication 29 (2018) 203–216

Contents lists available at ScienceDirect

Physical Communication

journal homepage: www.elsevier.com/locate/phycom

Full length article

Carrot and stick model for dynamic secondary radio spectrum trade with QoS optimization

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ARTICLE INFO

Article history:
Received 5 January 2018
Received in revised form 24 April 2018
Accepted 9 June 2018
Available online 19 June 2018

Keywords:
Cognitive radio
Radio resource management
Resource allocation
Secondary radio spectrum
Software radio
Spectrum management leasing
Tax penalty

ABSTRACT

Cognitive Radios (CR) propose for an opportunistic access to new Secondary Users (SUs) in the white spaces existing in the already licensed radio spectrum on a non-interfering basis with the current Primary Users (PUs). The Secondary Spectrum Markets (SSMs) have lower operating costs as compared to those for the Primary Licensed Operators (PLOs) as they do not require to license dedicated spectrum bands for their operation. This naturally makes CR a disruptive technology and its emergence is inevitably subject to economic viability challenges and technological hijack threats by the PLOs. The existing literature does not address the possible use of economic malpractices by the PLOs to raise the spectrum reuse costs to be no longer affordable by their direct competitors.

This research proposes a secondary spectrum trade model based on a carrot and stick rule to keep the business in the SSMs competitive and fair using monetary incentives and penalties based on participation behaviors. A methodology for QoS optimization using Genetic Algorithms (GAs) with respect to those requested by the SUs is implemented. The simulation results indicate that the overall revenues of the participating PLOs with unfair bidding behaviors are lowered due to the incurrence of penalty costs.

1. Introduction

Cognitive Radio (CR) is considered as a promising technology to solve the current radio spectrum scarcity problem. The actual utilization of the licensed spectrum is not uniform throughout the allocated spectrum and there are parts that are being underutilized [1,2]. The CR proposes the improvement in the spectrum utilization efficiency by using Dynamic Spectrum Access (DSA) to accommodate new Secondary Users (SUs) [3] in the underutilized portions of the already licensed radio spectrum. This requires for an exclusive use of the radio spectrum resource under Spectrum Manager leasing [4]. The Spectrum Manager leasing requires the Primary Licensed Operators (PLOs) to act as the Spectrum Managers that decide about the rights they choose to lease without any requirement of a prior approval from the Federal Communications Commission (FCC). The PLOs must retain the de facto control, as newly defined [4], i.e., the PLOs are responsible to report back to the FCC and conform to the service and the interference rules.

The secondary radio spectrum pricing and the Quality of Service (QoS) are two important aspects of the current research on the CR technology. The radio spectrum reuse requires a coexistence of the current communication businesses and the future Secondary Spectrum Markets (SSMs). The introduction of new SSMs will result in an increased competition in the business as it will provide the users with alternative service providers. The future SSMs may pose a potential threat to the business of the current PLOs especially if the CR proves to be a disruptive technology [5]. The survival of the current PLOs will be even more difficult if the SSMs can offer a QoS that is competitive to that offered by the PLOs to the users. As direct competitors in the business, the current PLOs might indulge in some malicious activities to manipulate the economic parameters as attempts to run future SSMs out of business by establishing a monopoly over the enabled secondary spectrum resource. So, the PLOs may pose the technological hijack threats or the economic viability challenges to the future SSMs for their survival in the communication business. This situation becomes inevitable considering the communication infrastructure reuse need by the SSMs [6] that is owned by the PLOs. Also, the PLOs will be unable to compete in costs with the SSMs that unlike the PLOs, do not require to purchase the licensed radio spectrum for their operations. A manipulation of economic parameters might elevate secondary spectrum price to be too expensive for the SUs to afford it as an alternate technology [7,8].

This paper presents a dynamic non-cooperative auctioning game based on a carrot and stick rule for secondary radio spectrum trade for improvement in the spectrum utilization efficiency of

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https://doi.org/10.1016/j.phycom.2018.06.004
1874-4907/

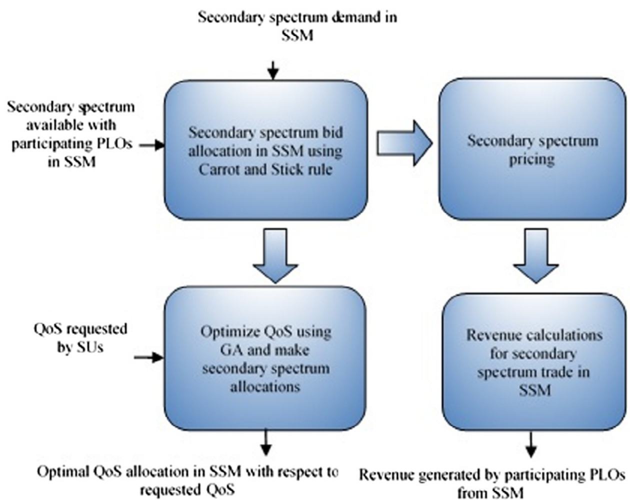

Fig. 1. The flow graph for the pricing and the QoS optimization for the secondary spectrum trade and profit calculation for the participating PLOs in the SSM.

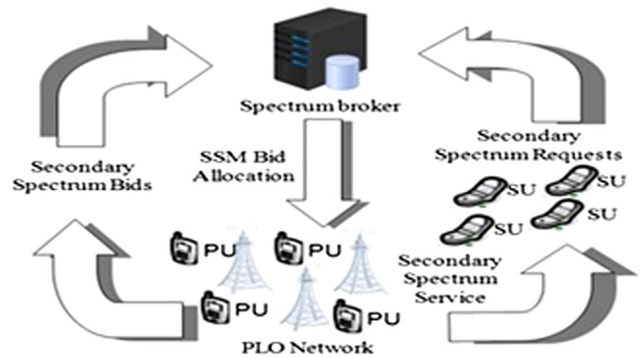

Fig. 2. The centralized architecture for secondary spectrum trade in the SSM.

the allocated spectrum. A centralized architecture [9–11] for the cognitive operation is assumed for the SSM that provides service to the users in the geographic area of its location. The SUs submit their requests to a centralized spectrum broker that accumulates all requests to create a secondary spectrum demand for a given bidding period. The SUs also specify the QoS values in their request in a predefined format. The PLOs submit their bids, specifying the quantity and rates for the given bidding period. The spectrum broker calculates the prices of secondary spectrum using a clearing price rule and makes purchases by qualifying the bids by the PLOs based on the value that each offers to the SSM [12,13]. The Spectrum broker also calculates the revenue generated by each qualifying PLO based on the secondary spectrum price and the purchases made from each participating PLO and creates a pool of spectrum spaces purchased from the qualifying PLOs. The spectrum broker then uses the evolutionary approach of the Genetic Algorithms (GAs) to allocate spectrum spaces that are optimal to those requested by individual SUs. Fig. 1. presents the flow graph for pricing, profit calculation and the QoS optimization for the secondary spectrum trade.

Pricing before allocation makes the allocation independent of channel arrival rates. The spectrum pricing is fair as probability of qualifying a bid depends on the amount of secondary spectrum made available for reuse with unique clearing price for all qualifiers and a compensation to the SUs for their bad experience with sellers in past in the SSM. The QoS optimization is based on the user/application level for their respective QoS requirements. The model acknowledges the tradeoff that exists among spectrum allocation and the related economic considerations. The model guarantees truthfulness, individual rationality and Ex-post budget balance as no seller qualifies before other offering lower unit price.

The communication by the PLOs and SUs with the centralized spectrum broker has been assumed to be over secure communication links that guarantee privacy. The bid allocation and the secondary spectrum allocation are performed centrally. No direct communication is required between the PLOs, between the SUs or between the PLOs and SUs. This minimizes the communication overhead in the proposed methodology for the secondary spectrum reuse. The radio environment is assumed to have been sensed already and the spectrum sensing has been left out of the scope of this paper. Spectrum sensing and its different techniques have been studied by a large body of research [14–17]. Fig. 2 presents the centralized trade scenario among the PLOs and SUs in the SSM.

2. Related work

The secondary spectrum auctioning [18–22,34] has been considered as a useful methodology to trade the Exclusive Use Rights (EUR) of the available spectrum for an agreed time. The conventional auctioning methodologies e.g. VERITAS consider truthful buyer-only auctions [23] but their extension for a dynamic allocation, fails to either maintain the truthfulness or to enable the spectrum reuse [24]. X. Zhou et al. in [25] implemented spectrum auctioning as an extension of the *McAfee* model to minimize the existing tradeoff among the spectrum efficiency and its economic robustness. Downsides of the model proposed in [25] are that different bid patterns exist that perform differently for the same interference avoidance algorithms even for the same topology. Also, the choice of the buyer groups causes degradation in spectrum utilization when considering economic robustness and the model might not remain truthful when dynamic supply is considered [24]. The carrot and stick rule-based model not only considers a dynamic supply but also requires no grouping of buyers for pricing that avoids a possible degradation in performance due to their grouping.

Q. Sun et al. in [24] proposed a double auctions model for dynamic spectrum supply. Downsides of this model are that in its proposed methodology, the buyers group together independent of the auctioning process to avoid the interference but grouping must be done after auctioning to avoid buyer manipulation. The bidders with the least per channel bid qualifies before the others with higher values, but introduction of randomization may change the winning bidders. Also, even the auction winners have no guarantee even of secondary spectrum access and the revenue shares. The carrot and stick rule-based model is independent of buyer grouping and hence their possible manipulation and guarantees the revenue share to the qualifying PLOs and a compensation to the SSM for their bad experience in the past with the sellers.

In the model presented by S. H. Chun et al. [26] the sellers are guaranteed the largest expected profit when they bid jointly. The downsides of this model [26] are that the sellers might want to collude to form a monopoly and maximize their revenues by forming a grand alliance. Also, the assumption that the profitability of an alliance might be lowered with inclusion of additional sellers contributing extra FBs, does not seem to be right. The buyers report their types that are used to determine the value of items that they win and also the profitability of the sellers may not necessarily be true. Hence there are clear chances of manipulation by the buyers. The buyers must choose amongst the sellers based on their experience but there is no compensation mechanism defined for this bad experience. The carrot and stick rule-based model considers independent bids rather than joint biding, and the profitability of the PLOs and spectrum allocation to the SUs is independent of any