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TWO STAGE QOS-AWARE COEXISTENCE FRAMEWORK FOR TVWS

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ABSTRACT

In this paper, we formulated a heterogeneous coexistence framework in TV White Space (TVWS) consisting of Primary Users (PUs), Secondary Users (SUs) and IEEE 802.19.1 standard using the Cournot economic game model. TVWS is associated with temporary buying and selling of spectrum and hence, the use of the economic model. The robustness of the proposed model stems from the unique SINR requirements of the PUs were considered. Secondly, IEEE 802.19.1 standard plays a double role of database provider and heterogeneous coexistence framework. QoS is an important performance indicator for wireless communication and hence, there is a need for a QoS coexistence model in TVWS. Our goal is to design a Cournot QoS-aware spectrum game model for the PUs. Thus, resulting in a QoS-aware coexistence framework for TVWS.

Keywords: *Cournot duopoly, economy model, Game theory, Heterogeneous co-existence, QoS, TVWS*

1. INTRODUCTION

The spectrum measurement campaign as conducted by the US Federal Communication Commission (FCC) re-affirm the notion that most of the allocated licensed spectrum are under-utilized [1]. Hence, there is a need for efficient spectrum usage models. Cognitive radio (CR) is set to revolutionize spectrum access schemes in wireless communication by initiating and executing Dynamic Spectrum Access (DSA) scheme [2]. To this end, communication regulations worldwide have keyed in to DSA by relaxing spectrum rules to enable Secondary Users (SUs) to gain temporary access to a licensed spectrum in the absence of Primary Users (PUs). Beginning with TV channels in the VHF-UHF bands (54-72 MHz, 76-88 MHz, 174-216 MHz, and 470-806 MHz). Hence TV White Space Band Devices (TVBD) connote White Space Devices (WSD) that operate in a primary user-free TV spectrum. TVWS consists PUs and SUs. However, priority is given to the PUs, with the SUs given access in the absence of the PUs.

As expected, many wireless standards are envisioned to be deployed in the TVWS. The standardization targeting of TVWS includes IEEE 802.22 for Wireless Regional Area Networks (WRANs) [3], the IEEE 802.11af, otherwise known as "Super Wi-Fi", or "White-Fi", "Super" because of its cognitive properties, and "White," which works in TVWS frequencies [4]. With the plethora of networks jostling for spectrum access in the TVWS, coexistence between different operators, standards and technologies are expected to mar the QoS of the end-users if the network is not well coordinated, thereby causing more problems to Radio Resource Management (RRM) module. In the presence of a well-defined coexistence mechanism, the graph in Figure 1 is obtained, which follows Shannon's capacity law. Contrarily, in the absence of a coexistence framework, the graph in Figure 2 is attained which negates the

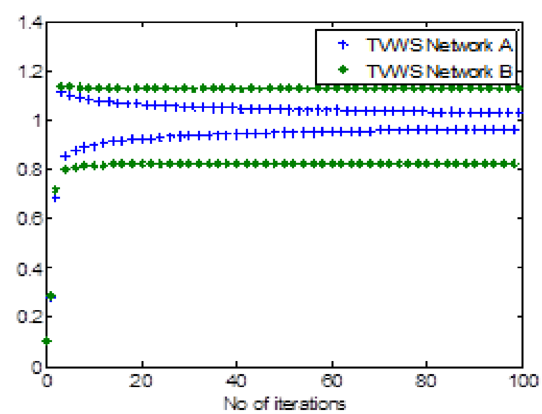

Figure 1. System Capacity Of Coordinated Networks

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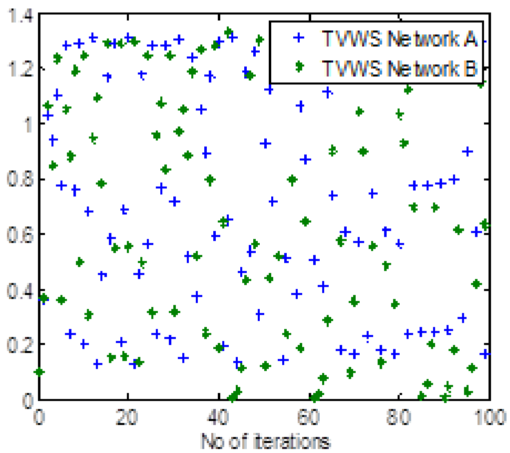

Figure 2.System Capacity Of Chaos Networks

Shannon system capacity theory by increasing noise in the network. Heterogeneity and coexistence are not novel to wireless standards as both have been successfully implemented in ISM bands. However, this is expected to be an important topic in TVWS because of the variability of TV channels, which is spatial-temporary in nature. In addition, the lower frequency bands are characterized as long waves. Hence travel farther than the ISM waves and are not easily attenuated. Thereby making interference control among the SUs an important research issue.

Different initiatives have also been proposed by IEEE 802.19 on how to improve coexistence in TVWS via centralized architecture [5]. Currently, TVWS technology is designed to be operated via database operator as spectrum sensing devices tested by FCC fail to provide adequate protection to PUs. TVWS database providers are categorized into non-profit seeking (e.g. Google) and profit seeking database operator (e.g. Spectrum bridge [6]).

TVWS relies on the temporary act of buying and selling of spectrum. Therefore, economic models find applicability. Economic models are associated with Quality of Service (QoS) and hence, has been received research attention [7]. In many research works, QoS are computed through a decision variable modelled as cost. Therefore, there is a need to incorporate price and some measure of (e.g., SINR, throughput, loss probability, jittery etc.) as a cost function for the PUs. This work considered SINR cost model. In TVWS, the minimum decodable SINR for digital TV is 15 dB. The motivation for PUs to engage in spectrum trading is make extra revenue. However, it comes with a cost in QoS drop for the PUs as spectrum sharing is noted for the introduction of noise into the wireless channels. Hence, there is a need to design spectrum sharing game considering the QoS of PU receivers.

We consider spectrum bandwidth game consisting of multiple PUs (players of the game), where each one seeks to maximize its own revenue, with no player having no incentive to deviate from the Nash Equilibrium (NE) point. In this study, we set to formulate A TVWS QoS-aware spectrum trading game with reduced TVWS management entities. Considering that many operational modules are involved in the operation of TVWS technology. It is natural to expect an increase in the TVWS latency in terms of synchronization and coordination. Hence, there is a need a streamline all the entities and if possible, merge some of them into a single unit. We tend to achieve this by delegating IEEE 802.19.1 to double their role as spectrum coexistence coordinator and database operator. Based on the set objectives, the main contributions of this paper is

- A novel QoS based model for TVWS based on signal degradation derived from signal to noise interference ratio.
- Two-stage model framework for coexistence in TVWS.

The rest of the paper as follows. The overview of related works are discussed in Section **2**, System model in Section **3**, model framework Section **4**. Simulation results are presented in Section **5**. Finally, conclusions are drawn in Section **6**.

2. RELATED WORKS

Several prior studies in TVWS has considered game theory as an attractive mathematical tool for resource allocation. In [8], game theory model was used in power control problem to decrease the interference experienced by PUs. The author only considered PU interference without considering the SINR requirements of the PUs. Recognizing the need to develop a TVWS spectrum pricing for rural broadband market under a delay cost function, a rural area secondary spectrum market was considered in [9]. The work only considered a delay cost function for PUs. Thus making their work suitable for only delay-sensitive networks. A dynamic spectrum allocation framework that exploits either fixed-price or combinatorial auctions has been studied in [10].

In [11], the design and implementation of a TVWS coexistence prototype system architecture, based on real-time secondary spectrum market policy using a centralized infrastructure, was studied. While in [12], the theoretical architecture of the Radio Resource Management (RRM)

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framework for opportunistic TVWS exploitation using an auction-based approach was presented. A novel spectrum sharing algorithm supporting secondary users with WiFi-like capability in TVWS has been investigated [13]. Price competition under slotted resource allocation and price war were focused in [14]. Spectrum pricing considering spatial and frequency reuse was studied in [15]. The author was able to show that by exploiting the theory of probability, spectrum owners can earn extra profit through frequency and spatial reuse. A game theoretical analysis of the price-QoS market in the presence of service providers was studied in [7]. The author was able to show that pricing and QoS can be jointly considered

Centralized pricing scheme in TVWS technology based on game theory have been studied. Study on competition in dynamic spectrum leasing under duopoly game theoretical framework was studied in [16]. The author focused on the derivation of intrinsic parameters of the economic game theory such as demand and cost. Exploiting the channel heterogeneity of TV channels, an economic game theory was formulated in which channels characterized by having same attributes are priced same using the mean field market model [17]. Other works that have considered pricing issues in TVWS markets are [6, 18].

In all the works considered, the QoS of PUs in terms of signal degradation were not considered. Secondly, there are separate coexistence and database entities for TVWS resulting in numerous modules. Based on the noticeable gap, this work tends to proffer solutions to the problems listed above via game theory.

3. SYSTEM MODEL

3.1 System Overview

Consider a TVWS networks consisting of multiple PUs and SUs as shown in Figure 3.0. The usage pattern of the PUs is assumed to be a random process with independent ON- and OFF-periods [1 0]. An ON-period represent that a channel is busy while an OFF-period regarded as a potential spectral opportunity for the SUs. The PUs channel, *X*, is a random variable (r.v) which follows a negative exponential distribution with Poisson process parameter λ. We first considered a time domain model, *T*, slots as units for secondary user channel. At each instance, *T,* the PU computes its traffic

$$p_{on} = \frac{\lambda^{N} e^{-\lambda t N}}{N!} \qquad (1)$$

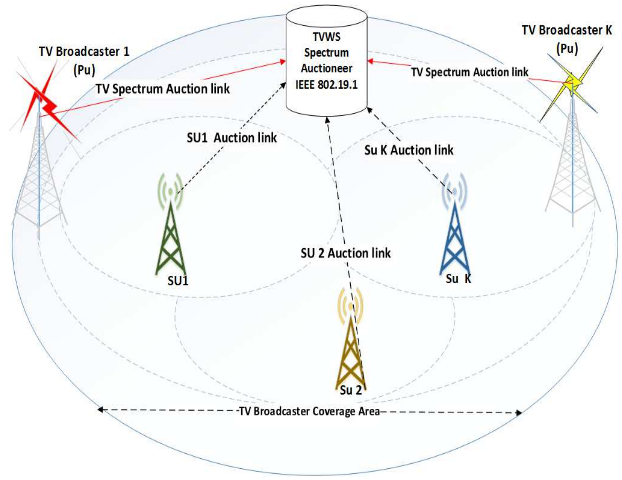

Figure 3. Deployment Scenario

where N is the PUs portfolio of channels. The PU traffic intensity can be easily be derived as

$$\lambda^{(t)} = \frac{T_{ON}}{T_{ON} + T_{OFF}} \qquad (2)$$

Then, the secondary user can use the channel is given as

$$p_{off} = 1 - p_{on} \qquad (3)$$

With the aid of primary user OFDM technology, spectrum trading can occur in the time domain (TDMA) and frequency domain (FDMA. Now, we derive the SUs spectral resources $B_{(s)}$ in frequency domain

$$B^{(S)} = \sum_{i=1}^{K} B_i - B^{(P)} \qquad (4)$$

where $\sum_{i=1}^{K} B_i$ is the bandwidth portfolio of the PUs which can be of any channelization such as 6 MHz for united states TV (FCC regulation) and 8 MHz for united kingdom (Ofcom regulation), $B^{(P)}$, is the primary user incumbent transmission frequency. Eq. (4) is the distinguishing factor that enables dynamic channel sharing in TVWS in the frequency domain.

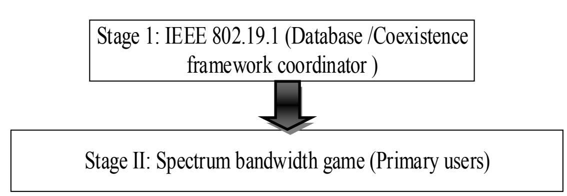

Figure 4. Two Stage Tvws Trading Module

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Based on the above system a two stage TVWS trading module is illustrated in Figure 4.

3.2 System Model

The OFDM technology is the physical layer modulation scheme adopted by TVWS networks based on OFDM technology provides excellent inter-carrier interference mitigation. Thus, enabling spectrum leasing in time and frequency domains and as such, many spectrum trading auction model has OFDM as the model of choice [6, 18]. The maximum achievable data rate *r* of user $k \in K$

$$r_k\left(B_k\right) = B_k \ln_2\left(1+\frac{P_k^{\max} h_k}{n_0+\sum_{i\in K} P_{(i)}^{\max} d_{ik}^{\;\theta}}\right) \quad (5)$$

where $P_k^{\max}$ is the user *K*'s maximum transmission power, $P_i^{\max}$, is user *i* maximum transmitting power which is considered as interference to user k, B, is the bandwidth, n_0 is the noise power density h_k is the channel gain which is independent of operator, θ is the pathloss component and d_k denotes the distance of a transmitter i and d_{ik} denotes the distance between base station *i* and *k*. In literature, Eq. (5) is known as a signal to noise interference ratio (SINR) and is denoted by γ. SINR and spectrum channel efficiency is linked in Eq. (6) stated as

$$k = \ln_2\left(1+K\gamma_i\right), Where\, K = \frac{1.5}{\ln\left(0.2/BER^{tar}\right)} \quad (6)$$

BER is the target bit-error-rate (BER). The primary user charges the secondary user a price *p* per unit bandwidth for using its resources. By using adaptive modulation, SUs maximize its throughput.

4. TWO STAGE COEXISTENCE MODEL

In this section, we focused on the development of our two-stage coexistence framework. The role of the each component unit in the framework is analyzed. We commence with Stage I involving the IEEE 802.19.1 by describing their expected role. Then, using Cournot non-cooperative spectrum game, spectrum price is derived in Stage II.

4.1. Stage I

In TVWS coexistence framework, the central duty of IEEE 802.19 is to serve as a resource allocator using a centralized architecture as distributed architecture will not yield an optimal solution. Consequently, many proposals have emerged on the deployment of a centralized regulatory framework for coexistence in TVWS. Based on the above, we are proposing the following;

- Coexistence Algorithms - The functionality of the algorithm is to analyze statistics collected from different TVBD and check if there is a need to for coexistence. In such a situation, the algorithm will be executed to help in decision making for all the TVBD to coexist. The standard supports three decision-making
- Coexistence Discovery Information Server (CDIS) - The functionality of this entity is to update/ refresh coexistence related information, such as location information of a TVBD and spectrum utilization by TVBD networks.
- Coexistence Enabler (CE) - Communication between coexistence manager and TVBD network or device is the responsibility of coexistence enabler. CE obtains coexistence information from coexistence manager and configures the received commands into the TVBD requirements under its control.

Based on our framework, the IEEE 802.19.1 will be designated as the central auctioneer. The central auctioneer serves a clearing house to broadcast the pricing variables. Prices are computed independently by the TVWS networks. Furthermore, we assume that conflict among PUs has resolved by FCC which ensures that there is no interference among the PUs. The secondary conflict which happens when two TVWSs are in the transmission range of each other is resolved by using protocol interference model.

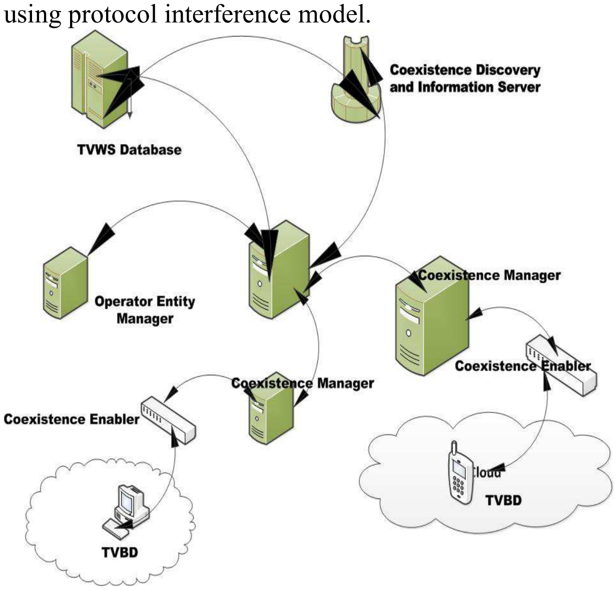

Figure 5. Deployment Scenario Of IEEE 802.19

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4.2. Stage II

We proceed to formulate the Cournot spectrum bandwidth sub-game for competitive primary users taking their QoS into consideration

Game (Cournot Spectrum Game): The primary user strategy is to determine the spectrum bandwidth to lease and the leasing price to the secondary users considering the competition from other potential competitors. However, the game becomes interesting because, the primary users have to strategically consider their QoS.

- Players : Primary users (M_i, M_{-i})
- Strategy space: Primary user, M_i, chooses a spectrum Bandwidth B from the feasible set $B_i = [1, \infty)$. Similar for operator M_{-i}.
- Payoff function: Primary user operator, M_i, wants to maximize the revenue $U^i_{(s)}(B_i, B_{-i})$ defined in Eq. (7). Similar for operator M_{-i}.

The primary user revenue is the price per unit spectrum bandwidth that the secondary users are willing to pay and given as:

$$U_i^{(P)}(B_i, B_{-i}) = \left[\begin{array}{c} (B_i \ln_2 \ )\times \\ \left(\begin{array}{c} 1 + \dfrac{P_i^{\max} h_i}{n_0 + \sum_{i\in K} P_{(s)}^{\max} d_{ik}^{\theta}} \\ + B_i \mathbf{p_i} \end{array}\right) \end{array}\right] \quad (7)$$

Furthermore, using the laws of logarithm, Eq. (7) can be simply transformed into

$$U_i^{(P)}(B_i, B_{-i}) = \left[\begin{array}{c} \left(B_i P_i^{\max} h_i d_i^{\ \theta} p_i\right) - \\ \left(B_i \left(n_0 + \sum_{i\in K} P_{(s)}^{\max} d_{ik}^{\ \theta}\right)\right) \end{array}\right] \quad (8)$$

where p_i the spectrum price, which can be decomposed into

$$p(M_i, M_{-i}) = \varpi(B_i + B_{-i}) \quad (9)$$

where ϖ is the *spectrum substitutability* factor given as $(\vartheta_i - \vartheta_{-i})$. Note that Eq. (9) demonstrates the strategic interdependence between users. By choosing this form, it is assumed that players receive a diminishing marginal price with increasing bandwidth (a standard assumption in network theory). The strategy space $\mathbf{B}_i$ of each *PUN* is a compact, convex set with a minimum and maximum spectrum quantity constraint denoted by $\underline{B}_i$ and $\bar{B}_i$ respectively.

4.2.1 PU revenue modelling

For the problem formulation, we derive the utility function as a quadratic function, which is the standard practice in utility maximization. The motivation for using the quadratic function is given as (i) the utility function is concave, and therefore, it is able to represent the saturation of user satisfaction as more spectra are offered for transmission. Concave utility functions are widely used to quantify the satisfaction. (ii) Differentiating the resultant quadratic utility function results in a linear bandwidth demand function, which makes the subsequent analysis tractable. The utility i obtained by selling M_i can be expressed formally as:

$$U_i^{(P)}(B_i, B_{-i}) = \sum_i^K pB_i - cB_i \quad (10)$$

where c is the signal degradation that primary user incurs by sharing its bandwidth with the secondary user stated as:

$$c = B_i\left(n_0 + \sum_{i\in K} P_{(s)}^{\max} d_{ik}^{\ \theta}\right) \quad (11)$$

4.2.2 Cournot QoS aware PU modelling

Signal degradation is an important performance indicator. The minimum decodable SINR for digital communication is 15 dB. This means that for the primary user to satisfy their end-users, there is a need to maintain this threshold. Therefore, the primary user needs to find optimal spectrum position between the QoS of its users and at the same time lease their currently unused spectrum for marginal profit. Primary user QoS-aware revenue formulation $U^i_{(p,QoS)}$ is stated as

$$U_i^{(P,QoS)}(B_i, B_{-i}) = \sum_i^K pB_i - cB_i \geq \gamma_{th}^i \quad (12)$$

Applying the K.K.T (Karush-Kuhn-Tucker) conditions to Eq. (12), we have

$$U^i_{(p,QoS)}(B_i, B_{-i}) = \sum_i^K pB_i - cB_i - B_i\gamma_{th}^i = 0 \quad (13)$$

By expanding Eqs (9-13), the primary user revenue is stated as

$$U_i^{(P,QoS)}(B_i, B_{-i}) = \left[\begin{array}{l} B_i^2 P_i^{\max} h_i d_i^{\ \theta} \vartheta_i - B_i^2 \vartheta_i - \\ B_i^2\left(n_0 + \sum_{i\in K} P_{(s)}^{\max} d_{ik}^{\theta}\right) \\ - B_i \gamma_{th}^i + (B_{-i} B_i \vartheta_{-i}) \end{array}\right] \quad (14)$$

The Nash equilibrium (NE) which is to identify the

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Best Response BR of each of the firm quantity as a function of the other firm and find where they intercept. We twice differentiate and set equal to zero. That is where each of the PU maximizes its utility with respect to (wrt) to another. Finding the first order condition (FOC) of Eq.(14) by taking the partial derivatives with respect to B_i yields

$$\frac{U_i^{(P,QoS)}(B_i,B_{-i})}{\partial B_i}=\begin{bmatrix}2B_iP_i^{\max}h_id_i^{\,\theta}\vartheta_i-2B_i\vartheta_i\\ -2B_i\\ \times\left(n_0+\sum_{i\in K}P_{(s)}^{\max}d_{ik}^{\theta}\right)\\ -\gamma_{th}^{i}+\left(B_{-i}\vartheta_{-i}\right)\end{bmatrix}\quad(15)$$

The second order condition (SOC) of Eq. (15)

$$\frac{U_i^{(P,QoS)}(B_i,B_{-i})}{\partial^2 B_i}=\begin{bmatrix}2P_i^{\max}h_id_i^{\,\theta}\vartheta_i-2\vartheta_i\\ -2\left(n_0+\sum_{i\in K}P_{(s)}^{\max}d_{ik}^{\theta}\right)\end{bmatrix}\quad(16)$$

5. PERFORMANCE EVALUATION

5.1 Parameter Setting

We consider a TVWS environment with two primary services (primary service one and two) and a secondary service The total frequency spectrum available to each primary service is 12 MHz denoted as B_i. Each of the primary user has two channels N_{tol} = 2 under its license. The target BER for the secondary service is BER^{tar} is 10^{-6}. $c1$,$c2$ =1dB. For the dynamic price adaptation algorithms, the initial prices are set as follows: υ1[0], υ2[0] = 1. Lambda = 0.4, 0.8. Some of the parameters will change in the course of the simulations.

5.2 Performance Evaluation

5.2.1 TVWS spectrum demand function

The demand function of TVWS networks is determined by inverse demand function. As can be seen from Figure 6, when the quality of the offered spectrum is high in-terms of γ_i as indicated in Eq.12, the demand for spectrum by the TVWS operators is high because the QoS offered to their clients will meet the high QoS demanded.

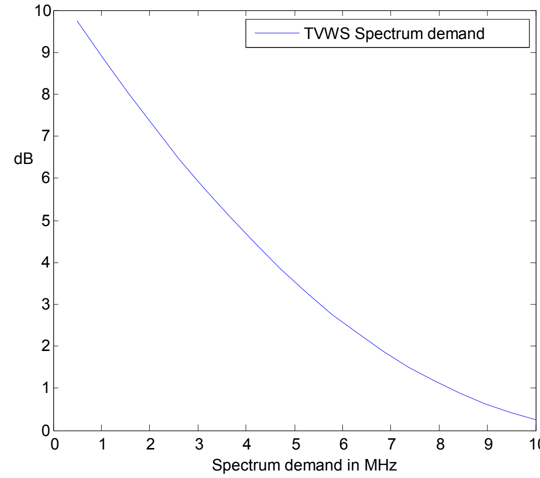

Figure 6. TVWS Demand Function

5.2.2 Effects of PU offered spectrum and price

Spectrum price will play a key role in determining the acceptability of TVWS in rural areas and other places where TVWS will find applicability. From Figure 7, when the price factor υ_1,υ_2 decreases from 10 to 2, the price of the offered spectrum increases. In this scenario, we are not computing the quality of offered spectrum as it will be discussed later. This tends to suggest that as PU try to maximize their payoff by increasing the quantity of spectrum shared, their marginal price keep depreciating. This is oblivious based from Eq.5.

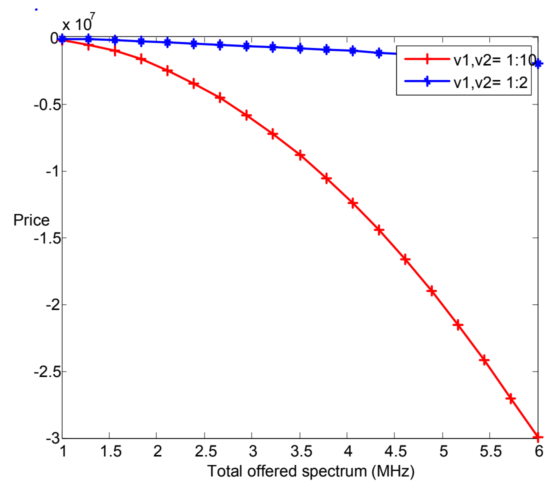

Figure 7. The Effects Spectrum Price.

5.2.3 PU price and profit function

Figure 8 shows the profit of primary service one as a function of offered spectrum. When the offered spectrum increases, the profit decreases. Contrary to general expectation as can be seen from the dotted lines, PU will expect that the more they offer

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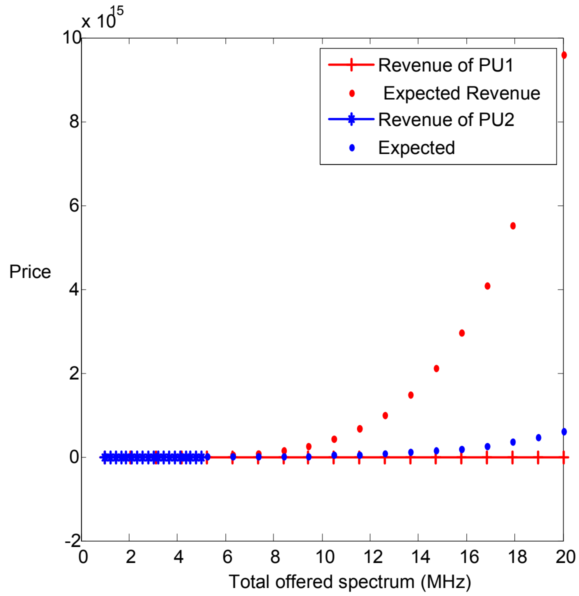

Figure 8. Profit Of PU

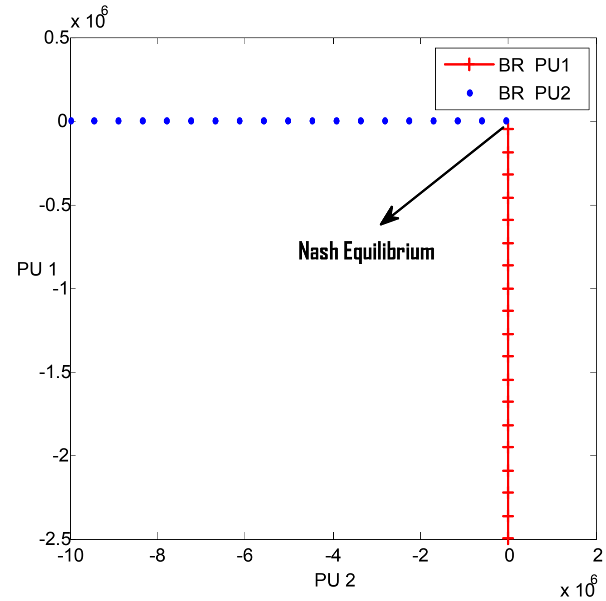

Figure 9. BR And NE

more spectrum, the more the revenue. From the simulated result and from Eq.5, the price is determined by the price factors as stipulated earlier. The graph can be adeptly defined as the more the offered spectrum, the less the real revenue. The price which results in the highest profit is the best response. That is, given the prices of other primary services, the best response for a particular primary service is the price for which the profit is maximized. Revenue of PU is determined by price factors as can be seen as when the price factors are small which can be translated as when offered spectrum quantity is small, price and revenue increases.

5.2.4 Best Response and Nash Equilibrium

The best response functions for both the primary users are shown in Figure 9 under different channel quantity PU1, PU2 for secondary users. As has been stated in Eq.(15). The Best Response (BR)for the primary users occurs at each of the primary users offering half of the available spectrum for heterogeneous coexistence. The Nash Equilibrium (NE) is located at the point where the best response functions of the primary user intersect. Above, the NE point, the PU will be making a loss. On the TVWS networks point of view, when the channel quality becomes better, since a secondary user can transmit at a higher rate due to adaptive modulation, the demand for spectrum opportunities increases. As a result, the primary service can offer a higher price. To evaluate the channel quality, we introduce a new model called duration model to calculate the stability of the primary user offered spectrum

6. CONCLUSION

In this paper, it has been shown that it is possible to reduce the number of operational modules needed for the implementation of TVWS technology. The 802.19.1 standard was delineated to function as database operator for the spectrum duopoly spectrum game. For the primary user, the cost of sharing spectrum is modeled as a function of the quality of service (QoS) degradation. We use Cournot game model to analyze this duopoly market situation and the Nash equilibrium is considered as the solution to this game.

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