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SPECTRUM AUCTION FOR DYNAMIC SPECTRUM ACCESS WITH ENERGY EFFICIENCY

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ABSTRACT

Scarcity of radio spectrum as a result of the increase in the use of the radio spectrum led to the concept of dynamic spectrum access. This work proposes a generic pricing algorithm for dynamic spectrum management in soft real time. A sealed bid auction with reserve price is proposed with the use of the concept of green payment to serve as an incentive to prioritise power efficient users. Dynamic spectrum access allows users of the radio spectrum to gain access on short term basis to the unused radio spectrum. The paper examines the need for a reserve price, its benefit to both the wireless service provider and the wireless users. Our results show how discriminatory pricing with the green payment would help energy efficient users to gain access to the spectrum at the expense of the non-efficient user. We concluded that the green payment could reduce the amount of energy saved in the system.

Keywords: Spectrum Auction, Reserve Price, Green Payment, Energy Efficiency.

1. INTRODUCTION

The huge shift towards wireless communications brought about by the advent of smartphones and related devices. Smart phones provide us access to different services such as wide verity of applications, social media networks among others. This has fundamentally increased the number of devices seeking access to the wireless networks. More importantly, as mobile technology advances, a large and growing part of the applications and functions offered by devices like smartphones are relying more on the use of a radio spectrum. This is leading to congestion of the radio spectrum. The cause of the congestion is associated with the traditional fixed spectrum allocation schemes put in place by the different regulatory authorities. Fixed allocation guards against interference from anyone apart from the person the band was allocated to. This allocation mechanism worked perfectly in the past, but because of the rapid increase in the demand for the radio spectrum, the scheme is leading to “artificial spectrum scarcity”(Chuan & Anqing, 2011). Research also shows that primary licence holders are not making use of their allocated frequencies in space and time (Force, 2002). Dynamic spectrum access (DSA) has been proposed as a remedy to the inefficiencies of static spectrum allocation (Xin & Song, 2012). The excess spectrum can be used to improve energy efficiency of wireless systems by allowing more flexible use of power.

This work proposes a DSA mechanism that would allow trading of the radio spectrum in use by wireless networks for a short duration using spectrum auction. A special green payment mechanism is used to serve as an incentive for power efficient users. The green payment can be described as a form of tax and subsidy. This is such that the bid of the power efficient users are subsidised, while users transmitting above the power threshold would pay a form of tax, allowing efficient users to have priority access to the spectrum. Reserve price is introduced because it allows the service to be long term profitable when the spectrum is sold, especially in low demand geographical locations. Our work envisions an autonomous auction process to allow users participation without necessarily having a professional expertise in an auction process. The broker, also referred to as the wireless service provider (WSP), would auction out the spectrum among competing users in soft real-time. For soft real-time applications, a sealed bid auction performs better since all bidders submit bids simultaneously, thereby reducing the amount of processing time(Xin & Song, 2012).

The scheme here adopts a concept of coordinated access band (CAB) as proposed in (Kamakaris, Buddhikot, & Iyer, 2005). An example of CAB can be the spectrum which was used for broadcasting on analogue TV until recently and the proposed system can also be coordinated with the band of the current cellular network (Kamakaris et al., 2005).The auction process in this work is repeated for each assignment round, after which the channel is allocated depending on the number of available channels

K (availability of spectrum) and number of bidders at a particular time *(t)*. The transmit power of each bidder plays a role in determining the reserve price and the Signal to Noise Ratio (SNR) of each user. The price acceptance and subsequent allocation of channels is envisioned to be carried out by an automated proxy server similar to what is suggested by CAB-M2 in (Kamakaris et al., 2005) or the eBay's proxy server (Kamakaris et al., 2005).

The notion of users, spectrum lease and allocation process used in this research is quite similar to (Buddhikot, Kolodzy, Miller, Ryan, & Evans, 2005; Gandhi, Buragohain, Cao, Zheng, & Suri, 2008; Kamakaris et al., 2005; Siong, Cheng, & Shean, 2008). Our approach has a further advantage, as it is envisioned for a wider geographical area and less information exchange is carried out between users and WSP. A user (U_i) can be deemed to have access to the spectrum provided his bid $(b_i)$is above the reserve price $(b_i > r_i)$, where the reserve price (r_i) is calculated by the WSP. The successful bidders are allocated the spectrum provided the signal to interference plus noise ratio (SNIR) is above the minimum threshold and all the rights associated with its usage cease after the allocated period. The scheme also tackles the problem of energy consumption by using the green payment to encourage power efficient users to transmit at the expense of non-energy efficient users.

The rest of the paper is organised as follows. Section 2 describes the system architecture and some basic definition of the terms used. Section 3 describes the auction model. Results and discussion are analysed in section 4 and section 5 provides the conclusions.

2. SYSTEM ARCHITECTURE

The important features of the system are the database, the spectrum broker, the users and the green payment. The relationship between them is illustrated in Fig.1.

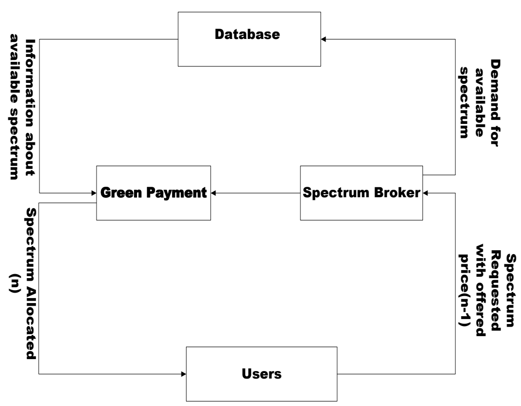

Figure 1: Spectrum allocation process

The green payment is a form of subsidy or tax. This can initially be a fund set aside by the regulatory authority as an incentive for DSA. This could be done to help overcome resistance to change, which is natural with humans. This fund would be toped up by the tax generated from users who are not power efficient while power efficient users would benefit in form of a bid subsidy. In this work the bidding price of each user is generated from a uniform distribution as explained in section 3. The adopted strategy aims to punish selfish users who transmit at high power making the channel not reusable. A user u_i) transmitting at high power would be charged even when the transmission fails and a user transmitting at low power but fails to win the bid would not get the subsidy from the green fund.

The spectrum broker is a central entity which is responsible for coordinating the CAB and issuing time bound spectrum access to all users. Different spectrum brokers can be located in a geographical location. The spectrum broker can only assign spectrum which is not in use by the primary users after probing the database.

The users can be mobile phones, computers or other devices that have potentially equal access to the spectrum. We assume that the spectrum broker knows the user locations and all users within the same cell or close to each other cannot be assigned the same channel at the same time. The users are divided into three groups, each with different SNR targets as shown in table 1. All users are assumed to have same budget and cannot spend more than their budgets under any circumstance.

Two different pricing scheme have been examined in this work, first is discriminatory pricing which is also known as "*pay your bid",* where users pay a different amount to use the spectrum depending on the bid submitted and the second method is the uniform pricing, where all users pay the same amount for the spectrum regardless of the bids submitted.

We further look at a situation with price feedback, a situation where users are given information about the reserve price. This is examined because in everyday bargaining where people are told to bid true values the heuristic approach is to bid low.

3. THE SYSTEM MODEL

In this paper an uplink transmission with fixed cell structure and fixed number of channel per cell is modeled. Each channel is allocated in a manner that prevents assigning the same channel to adjacent cells in order to prevent interference. Borrowing of unused channel from a cell is allowed in our modeling but the maximum number of channel that can be used in a cell is fixed (F_{max}). It is worth pointing out that the system should work in a similar manner regardless of the number of cells. We consider a spectrum market with a centralized broker using a single WSP. We model an uplink transmission using the WINNER II B1 propagation model as detailed in (Gandhi, Buragohain, Cao, Zheng, & Suri, 2007). The traffic model used has an arrival rate described by a Poisson distribution with a mean value of λ and an inter-arrival rate which is described as an exponential distribution with a mean value of μ. Transmissions are generated randomly and independently of each other. We assume a batched spectrum demand received in a time window as suggested in (Subramanian & Gupta, 2007). The auction process is assumed not to affect the arrival rate of the system and users are assumed to be active for fixed transmission length. A generic repeated game is modeled, where bidders follow a pedestrian bidding strategy suggested in (Subramanian & Gupta, 2007) with a large number of potential bidders N).The users are constrained by their budget. The users are divided into 3 groups depending on their transmit power (Low, Medium and high) which enable them to have a target SNR. The SNR level of each user determines the level of tax or subsidy paid by each user.

The CAB C is divided into non-overlapping bands (J). Where Bw is the required bandwidth

$$J=\frac{C}{B} \qquad (1)$$

The rules of the auction require users to submit bids in form of discrete positive increment such as$b_i, b_i \pm \Delta_1, b_i + \Delta_2 \dots b_i \pm \Delta_k$ for user i. Where $b_i$is the initial drawn from $F(v) = [0,1]$ and Δ_k represent a positive or negative increment. It is positive if the value of b_i is below the reserve price and negative if the user has won successive bids as shown in the flow chart in Fig. 3. The bids for all user is received by the WSP as shown in the matrices in equation 2.

$$B = \begin{bmatrix} b_1 & b_2 & \cdots & b_i \\ b_1 \pm \Delta_1 & b_2 \pm \Delta_1 & & b_i \pm \Delta_1 \\ \vdots & \vdots & \ddots & \vdots \\ b_1 \pm \Delta_k & b_2 \pm \Delta_k & \cdots & b_i \pm \Delta_k \end{bmatrix} \qquad (2)$$

Where the users are represented from $(1,2 \dots. i)$ and $(\Delta_1, \Delta_2, \dots \Delta_k)$ represent the bid increase from initial bid in a multiple of Δ_1. The bid of each is the either taxed or supplemented by the green payment which is at the WSP as shown below for user i.

$$ƀ_i = b_i \pm \beta \qquad (3)$$

Where $ƀ_i$is the final value of the bid which would be considered by the WSP as the bid submitted by user i. The value is positive β if the user i is to be supplement and negative β if the user is to pay the tax. The value of β is calculated as shown below based on the SNR of the user. A dynamic reserve price $r_i(1 \dots..n)$ which is dependent on the number of users requesting the use of the spectrum at time t, the transmit power and number of available channel is calculated by the WSP for each user. The number of users requesting the use of the spectrum is referred to as the congestion factor C_f. The higher the numbers of users intending to transmit at time t the higher the value of C_f.which is same for all the users who want to transmit within the same period$t$ and the values are as shown in table 1 and it is used in calculating the reserve price. User i reserve price can be calculated as shown in equation 4.

$$r_i = \frac{G_i C_f C_r}{K} \qquad (4)$$

Where G_i is a measure of the received power for user i, determined by the amount of power received by the WSP. $C_f$is the congestion factor that measures the congestion level of the system. K is the number of channels available, the higher the number of channels the lower the reserve price and vice versa and C_r is the central frequency used.

The method in calculating the reserve price in this paper helps to tie the value of the spectrum to the market value and allows for user specific reserve price. For example, 2 users transmitting at different power level at the same time t would have different reserve price.

The reserve price is calculated by the broker who receives demand S at different time instant t. The broker would process the same using the first price sealed bid auction and access is granted to highest K bidders for duration d) after which the lease expires. The spectrum broker transmits a periodic broadcast containing idle channels and the SNIR for the system in the period $t-1$. The SNIR is calculated as shown in equation 5

$$SINR_i = \frac{G_{ii} T_i}{\sum_{j \neq i} G_{ij} T_j} \qquad (5)$$

Where: G_{ii}, T_i are the gain and transmitted power of user i respectively. G_{ij},T_j are the gain and transmitted power of the noise.

If SNIR is below the threshold the transmission is assumed to have failed and if otherwise it is assumed that transmission is successful. The bit rate of each user is associated with the received SNIR using the Shannon truncated bound as explained in (Krishna, 2002).

Each user in the same group is assumed to be transmitting the same amount of energy and each user is assumed to either be in transmitting or in sleep mode. The energy consumed by the users in sleep mode is assumed to the negligible therefore, it is not considered in this work. While the total energy consumed by each user group is as shown in equation 6

$$E = \sum_{1}^{N_g} TP \qquad (6)$$

Where N_g is the number of users in the group, T us the transmission time and P is the power of transmission. The transmission time depends on the bit rate of each of user groups.

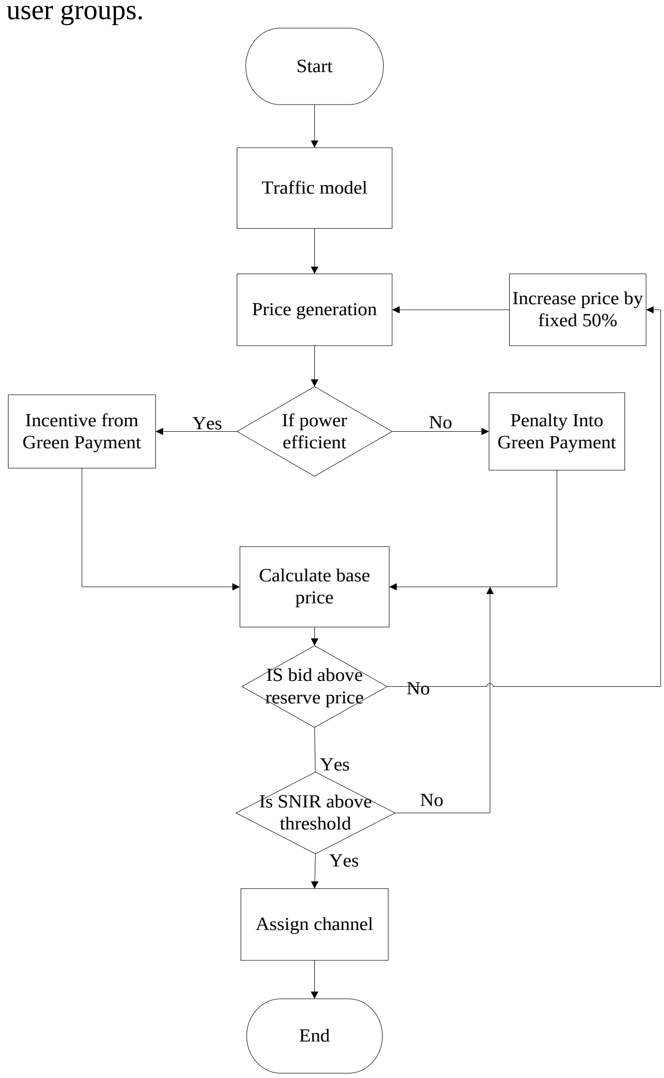

Figure 2: System flow chart

Multiple winners emerge in an auction period depending on the number of channels available and the winning bidders constitutes a winner set S

$$S \in L(1 \dots \dots . K) \qquad (7)$$

The users in the winner set can either bid a value $b_i = r_i$ to give them value of maximum utility or bid $b_i > r_i$ to give a utility $W_i - b_i$. Let B represents the summation of the winning bid at r and Mrepresents the winner set above $r$with cardinality P, expected revenue is the sum of all winning bid in the auction period

$$R = SB + MP \quad (8)$$

Rcan be realized in different ways and with different equilibrium depending on S and the reserve price. The auction is carried out again after a period t) which has to be large enough to allow for reasonable amount of bid to be received and small enough to avoid much delay

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4. RESULT AND DISCUSSIONS

The problem formulation for the seller was derived from the fact that the WSP does not know how much each of the bidders are ready to pay. We assume that the users derived the initial value from a uniform distribution between a value [0 1]. Other parameters used are as shown in the table below.

Table 1: Parameters Used

Parameters	Value
Cell radius	2 km
Interference threshold	-40 dBm
SNIR threshold	10 dB
Users in a cell	100
Number of cell	19
Target SNR	4 dB for User Group 1 8 dB for User Group 2 15 dB for User Group 3
Congestion factor	0.5 If $N \geq \frac{U}{8} < \frac{U}{4}$ 0.6 If $N \geq \frac{U}{3} \leq \frac{U}{3}$ 0.75 If N is $\frac{U}{3} \leq \frac{U}{4}$ 0.85 If N is $\geq \frac{U}{2}$ Where U=100
Packet length	128 $bits$
Height of Base station	15 m

Fig. 3(a) shows the total revenue derived by the WSP using discriminatory pricing with and without reserve price, uniform pricing with reserve price and with the reserve price. The result shows that discriminatory pricing with reserve price would generate a little more revenue to the WSP than the uniform pricing scheme with the reserve price. Discriminatory pricing scheme without reserve price performs worse compared to the schemes with reserve price. This shows that reserve price would help generate more fund if the spectrum is sold. The inefficiency of uniform pricing scheme is due to the fact that the winning K bid pays an average of the K bids.

Three price discovery methods are examined in this work. The first method allow the users with the losing bid to increase their bids randomly, the second method is 50% bid increase after losing previous round and the third is uniform random increase with price feedback. The result is as shown in Fig. 3(b).

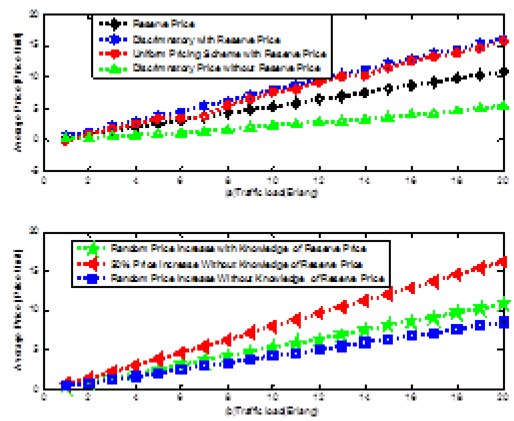

Figure 3: Graph of sellers revenue

As seen from Fig. 3(b), at low traffic load (below 4 Erlang) the 3 methods of price increase mechanism performs in a similar manner in terms of revenue generated rising as traffic load increases. As the traffic load increases the random price increase mechanism with the knowledge of reserve price performs better because the users would only place a bid above the reserve price. It is worth pointing out that pedestrian bidding strategy is used in this work. The strategy allow bidders to reduce

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their bids after winning successive rounds of bidding allowing maximization of the utility of the user and prevents price from increasing excessively.

Fig. 4 shows the delay against throughput for the 3 groups. It can be seen that the high powered users experience the most delay, followed by the medium powered users and then the low powered users. The high powered users experience the most delay because they are always paying the tax and not receiving any subsidy for their bids therefore their bids are mostly rejected except when the lower powered users are not transmitting. It can also be seen that the delay for all the 3 users groups increases significantly at 8 Erlang, which is the maximum throughput the system can support.

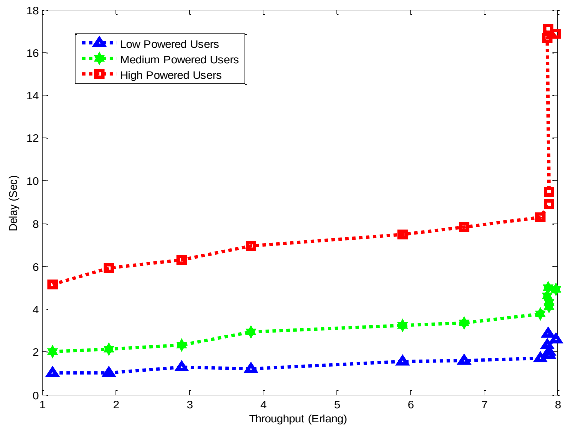

Figure 4: Users Delay against Throughput

The green payment has an impact on the auction process as seen from Fig. 5 based on the bid to cover ratio (BCR). The bid to cover ratio is defined the ratio of accepted bid to rejected bids.

$$(BCR) = \frac{Number\ of\ Bids\ recived}{Number\ of\ bids\ accepted}$$

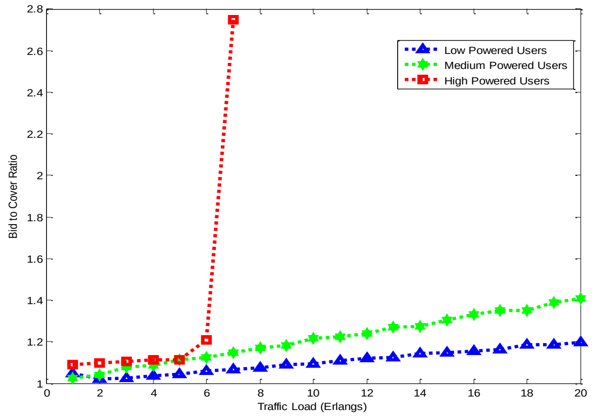

Figure 5: Bid to cover ratio against traffic load

To an economist the higher the BCR the better in terms of the success of the auction as this indicates higher demand. However, in this work it can be seen that the lower the BCR the better. This is because high BCR indicates that the user group attempts many times and only get access to the spectrum on few occasions. This is as a results of rejection of the bid. A user is assumed to be in transmitting mode to be able to attempt to transmit and the rejection of the bid amounts to energy wasted. Therefore, in terms of energy consumption of the system, the lower the BCR the better because it also means that less amount of energy is wasted.

Figure 6(a) presents the energy consumption per file. The energy consumed per file for the high powered users reduces as the traffic load increases because the high powered users are more likely to be in the sleep mode most of the time as they are only able to transmit only when others are not transmitting and also because they transmit at higher bit rate compared to the other user group. This trend continues until when the system reaches maximum capacity where the low powered users are transmitting all the time leaving the high powered users no choice than to be in the sleep mode. The Energy consumption level for the low and medium powered users are almost same at low traffic loads but increasing slightly between 2 and 8 Erlang. This reduces significantly after 10 Erlang because the low powered users are dominating the system.

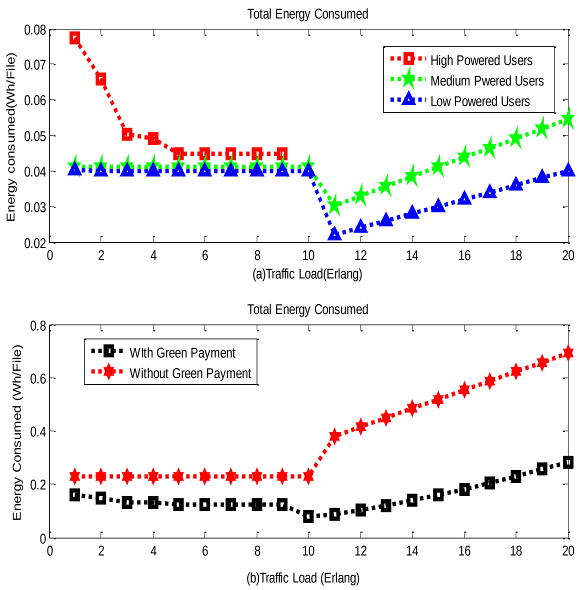

Figure 6: Energy Consumption of the System

Figure 6(b) shows the overall energy consumption with and without the green payment. It can be seen that there is a significant difference between the two scenarios especially at high traffic load.

Figure7 shows energy saving gain at different level of green payment for 3 different traffic loads. The graph shows the difference between the green payment scenario and the non-green payment scenario. It showed when the green payment is increased from 1 to 8, with 1 indicating that the users is either given a subsidy or tax worth 90% of initial bid of the user and 2 indicating 80% of the initial bid going down to 8 which indicates 20% of the initial bid of the user. This shows that the level of the green payment can actually determine the amount of energy saving achieved by the WSP.

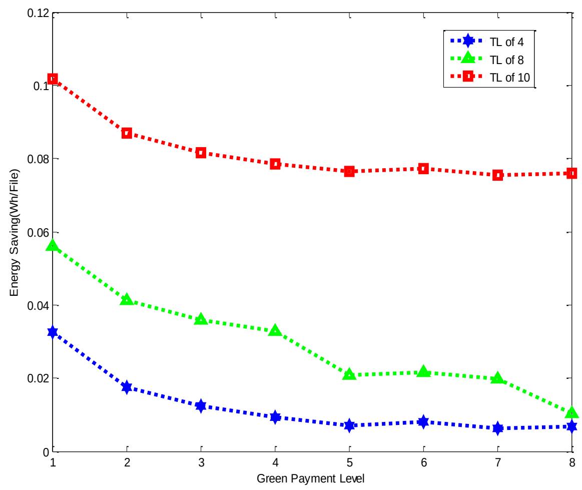

Figure 7: Energy consumed by the Users

5. CONCLUSIONS

An energy efficient dynamic pricing mechanism in a multi-winner scenario using seal bid auction process with reserve price was proposed with a special green payment to help energy efficient users. It is shown that discriminatory pricing would generate more revenue compared to uniform pricing with the green payment and the introduction of reserve price would help generate more revenue to the WSP if the spectrum is sold. We also showed that the green payment would help in energy conservation and would prevent high powered users from transmitting especially during the period that the system is fully loaded. Finally we showed that the level of the green payment can be used to determine the amount of energy saving level in the system.

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