# Economic Modeling With Green Resource Management for Future Wireless Broadband Networks

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***Abstract*—A framework is proposed for future energy aware dynamic spectrum access broadband networks where the demand for the radio spectrum is time varying. The network comprises of several Wireless Service Providers (WSPs) whose aim is to maximize profit by providing broadband services to users in a specific location, a central regional entity named Transmission Central Authority (TCA) and the end users seeking access to the broadband network. The paper proposes a model that is energy efficient and maximizes the profit of the WSP when the WSP cooperates and allows the TCA to serve as a form of a regulator. It is shown how the proposed model allows for better utilization of the network resources, saves energy, and maximizes the profit of the WSP without compromising the QoS of the users.**

***Index Terms*—Green Radio Resource Management, Mobile Broadband, Economic Modelling**

## I. Introduction

The demand for mobile broadband services has grown significantly in the last decade as a result of the increase in the popularity of mobile and portable devices which allow users to access various services anywhere and anytime [1]. Significant demand is also being seen from new services, such as TV, video streaming, and other multimedia services which require bandwidths that cannot be supported by some of the cellular service providers [1]. The early success of mobile broadband can be attributed to the fact that users were provided with speeds that are usually reserved for fixed broadband networks.

Presently users take up contracts with Wireless Service Providers (WSPs) over a period ranging for 1 to 24 months however, with the concept of Dynamic Spectrum Access (DSA), as proposed in [2], it is envisioned that in the near future users may be allowed more freedom to switch from one provider to another depending of their requirements. Furthermore, with the emergence of IEEE 802.22 based regional wireless area networks exploiting the TV white spaces, based on the concept of DSA and cognitive radio, this should give rise to multiple WSPs participating in an hierarchical spectrum trading such as the one proposed in [3]. This should allow WSPs to provide broadband services during temporary events such as the Olympics, festivals, or carnivals. Having multiple service providers in the same geographical region providing similar services allows for competition among the WSPs. This also allows the users to seek the best or most price efficient services [2]. The concept of Mobile Virtual Network Operators (MVNO) was formulated in [4] which offers some level of freedom to users by allowing the switching from one provider to the other with the help of the spectrum broker. However, this can lead to an increase in the amount of energy consumed by the wireless network as a result of having each provider providing their infrastructure. This might be counterproductive because of the urgent need to reduce the amount of energy consumed by the telecommunication networks as a result of the climate change. This led to the concept of a *green cellular network* [5-7]. Hence, this paper proposes an energy efficient model for such networks. Furthermore, a reduction of energy can also be beneficial to the WSP and users by helping to reduce the economic cost of electrical energy consumed. Hence, modern wireless networks need to put in place energy reduction techniques to meet the future need. However, such techniques must be applied with caution to maintain the QoS of the system.

On the part of the users, there are two major factors that can influence which WSP to associate with: These are the price (in terms of price of the energy consumed and the price for the radio spectrum) and the QoS provided. Price indicates the value of the service to both the users and the WSP. The QoS determines the satisfaction of the users which can be referred to as the value for money. [2] proposed a framework based on an auction and game model for DSA capturing the interaction that exist between multiple WSPs and end users by proposing a sealed bid knapsack auction that maximizes revenue generated and prevents collusion. The paper showed that Nash equilibrium can be achieved under some certain conditions. However, the paper did not examine the QoS of the users or the energy consumption by the system. [8] implemented a multiple service provider network. The paper showed the possibilities of multiple WSPs providing a convergence network. [9] examined how users can pick a service provider based on multi-dimension service quality perception using Fuzzy multiple criteria decision making process. [10] analyzed a system which is QoS driving with multiple WSPs. The paper examined a scenario when users turn selfish as a result of having the choice of switching from one WSP to the other, and the QoS offered to the users depends on the overall network load. The paper showed that equilibrium can only be achieved when most of the users do not switch between QoS functions.

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This paper proposes an economic framework for multiple WSPs who provide broadband services to users within the same geographical location. The proposed model is necessary because it is becoming increasingly difficult for a single WSP to provide for all users especially during major events such as a football match or the Olympic Games. This paper also examines how the WSPs can cooperate with each other to maximize profit and reduce the amount of energy consumed.

This paper is organised as follows: Section II describes the proposed system architecture. Section III explains the system model. The results and discussions of the results are provided in section IV. Section V provides the conclusions.

## II. System Architecture

The system architecture considered in this paper comprises the following elements:

### A. Transmission Central Authority (TCA)

This paper assumes that the TCA is formed by the WSPs coming together to form an association to use the radio spectrum efficiently and provide the best available services to the users. The role of the TCA is to receive the requests from the users and based on the information received, the TCA allocates the users to the WSP that can provide the required QoS without compromising the Signal to Noise plus Interference Ratio (SNIR) of the other users in sharing the same channel using the Shannon's channel capacity equation. The TCA also computes and sends the appropriate transmit power to the users to maximise the user's SNIR level. Furthermore, the TCA is also energy aware with the aim of saving energy. This is achieved by checking the status of each of the WSPs and the traffic load in the system and then it either turns the WSP ON or OFF depending on the traffic demand. The turning ON and OFF is based on the identified demand by the TCA and is similar to the model considered in [11]. However in this paper, the price and QoS game are the major determining factor rather than coverage. We assume that it is possible for a WSP from a few of the WSPs to provide full coverage at low traffic loads hence the switching OFF and ON is necessary because traffic load fluctuates.

### B. Wireless Service Providers (WSPs)

These are the service providers whose aim is to provide broadband services to users with the aim of maximising profit. This paper assumes that the carrying capacity of each WSP is different, along with the number of users that can be supported. At full load, it is assumed that no single WSP can support all the users in the system at the same time, hence the need for multiple WSPs. The WSPs provide information regarding their current traffic load level and the available channels to the TCA. Each of the WSPs determines the amount to charge the users based on their internal policies. However, there is a minimum amount of channels that must be in use for each of the WSP to break even or to be profitable. If this minimum required load level cannot be satisfied the WSP agrees to transfer their present load level to another WSP who can provide the same level of QoS, and such WSP would be shut down by the TCA until the minimum guarantee level of demand can be met. Hence, we model the interactions that exist between the WSPs in the form of a price competition between the WSPs. The switching ON and OFF is done for two main reasons: one is to make sure that the WSPs remain in operation only when it is profitable and the other reason is to minimise the level of energy wasted by powering up a WSP who is not profitable, especially when another WSP can provide the same level of service. Furthermore, as shown later, any WSP that does not provide the guaranteed QoS to the users is penalised by the TCA. A WSP only operates below the profit level only when the QoS required by a user cannot be supplied by another WSP.

### C. The Users

The users are mobile broadband users who wish to access to the radio spectrum but require different levels of QoS. The user sends a request with the maximum amount they can afford to pay to the TCA. The TCA then finds the appropriate WSPs that can provide the service to the user. The user is allocated a WSP that can provide the required QoS at the cheapest rate. We assume that the users are price sensitive. If no WSP can provide the QoS cheaper than the maximum amount specified by the user, then the user has to increase the maximum amount, or no service is provided to the user. The number of users seeking to access the spectrum varies with time. The achievable transmission data rate ($T_r$) of each user also varies. This is based on the achievable SNIR which is provided for by the Truncated Shannon Bound (TSB) as proposed in [12]. TSB is a model that captures the behavior of adaptive modulation techniques. It is as described below

$$T_r = \begin{cases} 0 & SNIR < SNIR_{threshold} \\ \alpha . S(SNIR) & SNIR_{threshold} < SNIR < SNIR_{max} \\ Thr_{max} & SNIR > SNIR_{max} \end{cases}$$

$$S(SNIR) = log_2(1 + SNIR) \quad (1)$$

Where $S(SNIR)$ is the Shannon bound and $\alpha$ is the rate reduction factor, $Thr_{max}$ is the maximum throughput for the codeset and $Thr$ is the throughput of the system. $Thr_{max}$ and $SNIR_{threshold}$ are specified in the parameter table. The $SNIR_{threshold}$ is the minimum threshold that allows the detection of the information at the receiver and $SNIR_{max}$ is the maximum SNIR beyond which there is no change in throughput.

## III. System Model

We model the uplink of a broadband network with multiple WSPs $S = (1,2 \dots \dots . S)$ serving $N = (1,2 \dots , \mathrm{N})$ users within a geographical location. This is based on the principle that a channel can be divided into multiple sub-channels for multiple users known as the Orthogonal Frequency Division Multiple Access (OFDMA). Each WSP has its own infrastructure covering this area and the channel conditions are time varying. We also consider the presence of a TCA as explained in the previous section. The users request the use of the spectrum at time $t + 1$ sends their required quality of service and their offered price to the TCA at time $t$. The WSP sends their current load, information regarding the free channels and the price to be charged to the TCA. The number of users in the system and the number of users connecting to a WSP varies over time. However the total number of users $(N)$ connected to WSP $j$ cannot exceed the capacity of that WSP $(C_j)$.

$$\sum_{i=1}^{N} N_{i.j} \leq C_j \qquad (2)$$

The price charged by the WSP is dependent on the traffic load $(L)$ at time $t$, the network size of the WSP $(S)$ (this is considered because it is assumed that the larger networks provide better QoS hence they charge more), the QoS required by the user $(Q)$ and the internal policy of the WSP $(V_j)$ as shown below:

$$R_P = kQ + V_jS + L(t) \qquad (3)$$

In this paper $V_j$ is represented using a random variable with the range specified in the parameter table and $k$ is a constant. Based on the information received by the TCA, the TCA then calculates the appropriate transmit power of the user. TCA allocates the users requesting the use of the spectrum to the WSP based on the WSP that can provide the required QoS at the cheapest rate. If two or more WSPs can provide the same service at the same rate then the WSP who has more load is picked in order to explore the possibility of turning OFF the other WSPs. If more than one of the WSPs are having same load and are ready to provide the same QoS at the same rate then the TCA picks one of the WSPs at random. The carrying and data rate capacity of each of the WSP varies. Each WSP is allocated a fixed capacity within a given range, as specified in the parameter table at the beginning of the modeling process, and this is maintained throughout the modeling process.

The power consumption of each WSP is divided into two parts as shown in equation (4) below:

$$W_j(b) = \alpha_j + \beta_j N_j \qquad (4)$$

Where $W_j$ is the power consumed by WSP $j$ in Watts which is a factor of the number of resources/channels $(b)$ in use, $\alpha_j$ is the power used to power the equipment of the WSP in the OFF and wakeup states and the last part of the equation $(\beta_j N_j)$. It is dependent on the number of users that the WSP $j$ is serving per channel in the ON state[11].

$$\alpha_j = t_{off.j}P_{off} + \rho E_{wakeup})(\frac{1}{1-\mu_{sl}}) \qquad (5)$$

$$\beta_j = (t_{RX.j}\frac{P_{RX}}{\mu_{RF}} + t_{TX.j}\frac{P_{TX}}{\mu_{RF}})(\frac{1}{1-\mu_{sl}}) \qquad (6)$$

$t$ is time, $P_{off}$ is the power consumed in the off state, $E_{wakeup}$ is the energy consumed in the wake up state $\rho$ is the number of times that the WSP is switched off $\mu_{sl}$ is the battery back-up and power supply loss. $P_{RX}t_{RX.j}$ is the energy consumed when transmitting $P_{TX}t_{TX.j}$ is the energy consumed in the receiving state and $\mu_{RF}$ is the efficiency of the antenna amplifier. It is assumed that each user in the system can connect to any WSP in the system.

Each of the WSPs competes for the users whose utility is as shown below:

$$U_i = a_iQ(b_i, T_i) - R_Pb_i - R_wT_i \qquad (7)$$

$$Q = e^{\frac{QoS_{Supplied}}{QoS_{Required}}},\ 0 < Q \leq 2.71 \qquad (8)$$

Where $e^1 = 2.71$, $a_i$ is a positive parameter that serves as a weighting factor to indicate the relative importance of the service to the user, $R_P$ is the price per unit of resources $b_i$ consumed and $R_w$ is the unit price for each watt of $T_i$ transmit energy consumed by user $i$ in watts. The aim of each user is to maximize their utility $(Max(U_i))$. The maximization problem facing the user is to choose the right amount of transmit power $(T_i)$ and resources $(b_i)$ that maximizes the utility. This can be done by finding the maximum point in the equation as shown below:

$$\frac{dU_i}{db_i} = a_iQ'(b_i) - R_P = 0 \qquad (9)$$

$$\frac{dU_i}{dT_i} = a_iQ'(T_i) - R_w = 0 \qquad (10)$$

The profit function of the WSP is as shown below

$$\pi_j(b_{i,}Z, W_j) = \sum_{i=1}^{N} R_Pb_i - \left[C_b\sum_{i=1}^{N} b_i + C_wW_j(b_i) + \sum_{i=1}^{N} C_q(Z-Y)\right] \qquad (11)$$

where $\frac{1}{Q} = Z$

Where $C_b$ is the cost of providing the total $b_T$ resources available to WSP $j$, $C_w$ is the energy cost for consuming $W_j$ watts of energy and $C_q$ is the cost of the WSP not meeting the QoS of the user as a result of inference from other users sharing the same channel. If the QoS of the user is satisfied then $C_q(\frac{1}{Q} - Y)$ is zero hence $Y$ is 0.367 for $\sum_{i=1}^{N} C_q(Z - Y) = 0$. This paper assumes that before a WSP would break even

$$\pi_j \geq 0 \qquad (12)$$

The profit function of the WSP can be maximized by acting on each of that terms that make up equation (11) and finding the optimal point as shown below:

$$\pi_j^*(b_{i,}Z, W_j) = \frac{d\pi_j(b_{i,}Z,W_j)}{db_{i,}} + \frac{d\pi_j(b_{i,}Z,W_j)}{dZ} + \frac{d\pi_j(b_{i,}Z,W_j)}{dW_j} \qquad (13)$$

## IV. Results and Discussions

An event driven simulation with a varying level of traffic load and budget constrained users has been used to study the performance of the proposed wireless network. The Winner II B1 propagation model as proposed in [13] is used and the other parameters used are specified in Table 1 below.

To determine the effectiveness of the proposed scheme, we examine the performance of the system with and without the TCA (without the TCA means the WSPs are not cooperating in any way). We also consider scenarios with fixed numbers of WSPs in the system (3 and 10 WSP) in order to understand the performance of the system.

TABLE I. PARAMETERS USED

| **Parameter** | **Values** |
|---|---|
| Cell radius | 4 $km$ |
| $SNIR_{Treshold}$ | 1.8 $dB$ |
| Efficiency of RF | 20% |
| Efficiency of power Supply | 10% |
| Number of Users | 5000 |
| Noise Floor | -114dBm/MHz |
| Average transmit power | 5 Mbps |
| Average File Size | 2 $Gbits$ |
| Number of Channels | 4 |
| Maximum Number of WSP | 15 |
| Range of Available channels per WSP | [50 400] |
| Range of offered price | [5 10] |
| $Thr_{max}$ | 4.5$bps/Hz$ |
| $Y$ | 0.367 |
| $K$ | 2 |
| Capacity of each WSP | Rand(10,20) |
| $V_j$ | Rand(1, 5) |
| Height Of Base Station | 15$m$ |
| $SNIR_{max}$ | 21 $dB$ |

Figure 1 shows the average energy consumed with TCA, without the TCA with 3 WSPs and 10 WSPs. The average energy consumed by the system without the TCA is significantly more than when the users are cooperating using the TCA, especially at low and medium traffic loads.

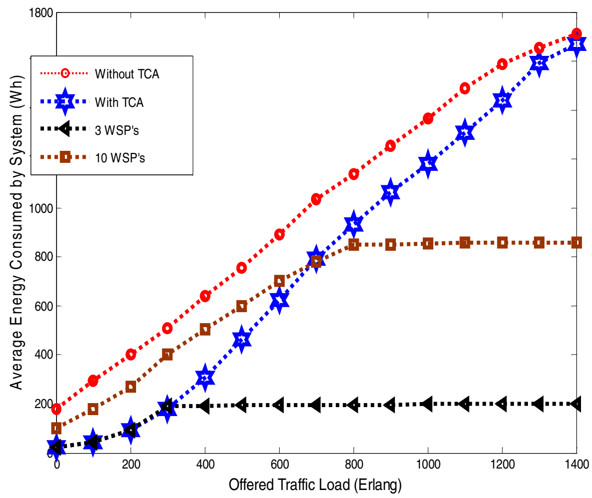


*Fig. 1. Average Energy Consumed Against Traffic Load*

However, as the traffic load increases the gap between the consumed energy reduces gradually. This is because, at a high traffic load, the TCA has no option but to keep most or all of the WSPs in the ON state to satisfy the requirements of the users. However at low and medium traffic loads the TCA can afford to shut down some of the WSPs. It can also be seen that with 2 WSPs the average energy is almost same as that of the model with the TCA at lower traffic load. However after about 300 Erlang traffic loads the average energy per file is relatively constant and lower. This is because the system has reached a saturation point where it can no longer support an increased traffic load.

Another important parameter is the average profit. This is because the aim of the WSP is to maximize profit. We examine the average profit against the traffic. The result shows that the model with the TCA performs best. This is because the TCA shuts down WSPs that are not required. It can also be seen that with 3 and 10 WSPs the profit of the system is higher than without the TCA at lower traffic load but after the system reaches a saturation point the average profit declines. This is because the system can no longer support the traffic and hence the WSPs would be incurring charges for not providing the required QoS.

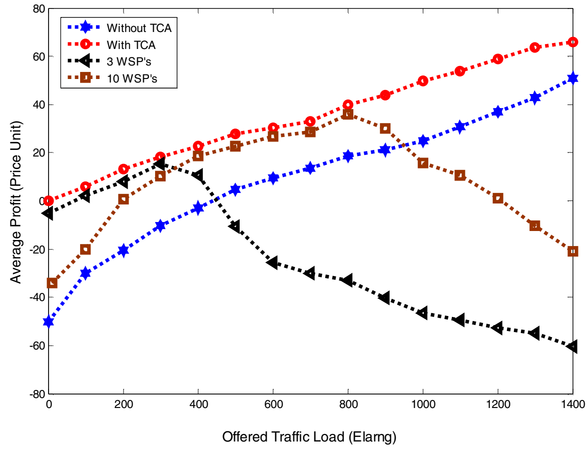


*Fig. 2. Average Profit of System Against Traffic load*

To examine if the proposed model affects the system performance characteristics of the users, we also examine the blocking characteristics of the system with TCA without the TCA with 3 and 10 WSPs. Figure 3 shows the blocking probability against traffic load. It can be seen that the blocking probability performance with and without the TCA is almost the same throughout the range of offered traffic load.

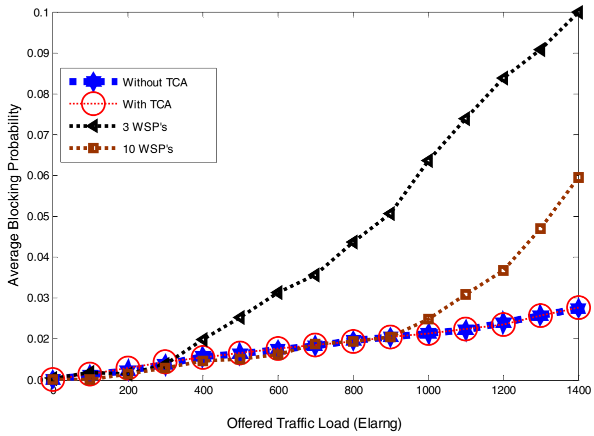


*Fig. 3. Blocking Probability Against Traffic Load*

This shows that the proposed model does not lead to more blocking in the system. However, it can be seen that with 3 and 10 WSPs the blocking characteristics are significantly higher after 300 and 900 Erlang of traffic respectively. This is because there is more collusion in the system and the system is unable to support any more users. This shows the reduction in energy seen in figure 1 from the scenarios with 3 and 10 WSPs is a result of the systems becoming saturated, rather than a result of the system performing better.

Another performance metric that is examined is the delay against traffic load in the system as shown in Figure 4. The delay against traffic load increases, because as the traffic load increases more users are served, and more collusion occurs in the system leading to an increase in delay. This also shows that the proposed scheme with the TCA performs as good as the scheme without the TCA in terms of the delay. Our result also shows that with Fixed WSPs (3 and 10) the system can cope at lower traffic loads but at higher traffic loads more delay is experienced.

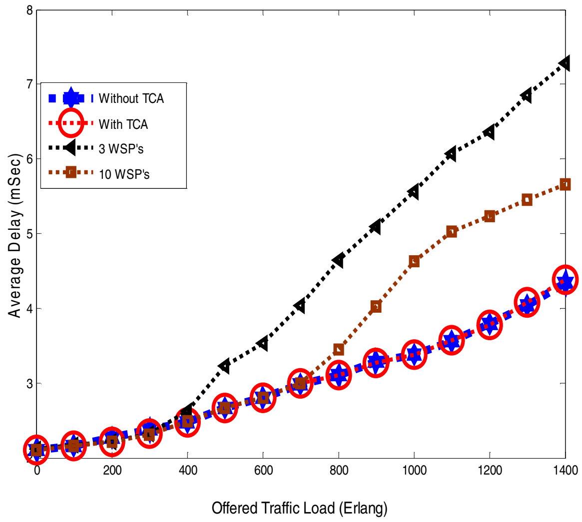


*Fig. 4. Average System Delay Against Traffic Load*

To examine the satisfaction of the users in the system with and without the TCA, we examined the utility of the users in the system against the traffic load as shown in figure 5. This shows that the utility of the users decreases with increase in traffic load as expected. This is because with the increase in traffic load in the system the interference increases and the WSP is not able to sustain the required QoS of the users 100% of the time. However, it can be seen that the scheme with TCA performs better because the TCA helps in regulating the transmit power of the users hence the users are not wasting energy unnecessarily, which leads to better satisfaction. It can also be seen that with 3 and 10 WSPs the satisfaction of the users is significantly worse at higher traffic loads. Hence, the reduction in energy seen in figure 1 does not translate into a better system.

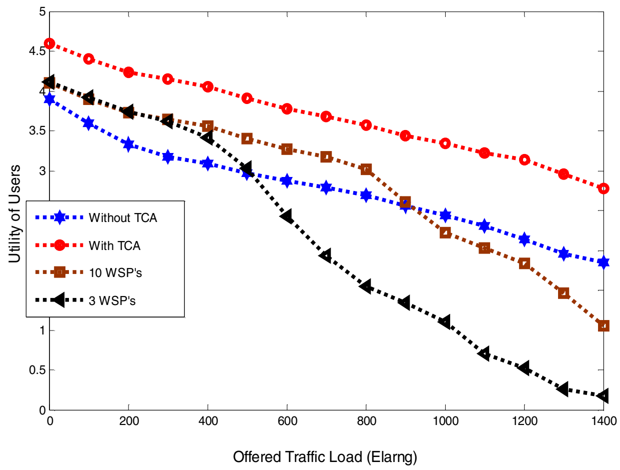


*Fig. 5. Utility of Users against Traffic load*

## V. Conclusions

This paper proposed a wireless broadband network with multiple Wireless Service Providers who aim to provide broadband services to users within a geographical location. The aim of the service providers is the maximize profit and reduce the amount of energy consumed by the system. We proposed a model with the Transmission Central Authority (TCA) who serves as the middle man and can shut down WSPs that are not needed depending on the traffic load in the system. The results showed that the proposed scheme helps in reducing the average amount of energy consumed by the system when compared to the scheme without the TCA by an average of about 20%. Our results also showed that both the average profit and the user satisfaction are also better with the TCA by about 90% and 15% respectively. It is also shown that the scheme does not affect the performance characteristic of the users in terms of delay and the blocking probability when compared to a scheme without the TCA.

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