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Energy Efficiency in Cognitive Radio Network: Green Technology Towards Next Generation Networks

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ABSTRACT

Energy efficiency of mobile network is always a challenging task. From the past decade, it is observable that the users who are using multimedia services are increasing in rapid way. These multimedia applications require higher data rates. High data rates will consume more energy of mobile network, which results poor energy efficiency. To meet higher data rates and to achieve energy efficiency, Cognitive Mobile Network with small cell model was explained in this paper. Dynamics of the power grid also have significant impact on mobile networks, hence smart grid implementation was proposed instead of traditional power grid. Most of the existed studies on cognitive mobile network focussed on spectrum sensing only. This paper focussed on cognitive radio network implementation by considering spectrum sensing and smart grid environment. An iterative algorithm was proposed to attain equillibrium condition to the problem. Interference management and energy efficient power allocation were achieved with the introduction of smart grid. Simulation results proved that optimum power allocation and energy efficiency are possible with the introduction of smart grid in cognitive network

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1. INTRODUCTION

Invention of digital gadgets like feature mobiles and tablets are motivating engineering to go for higher dat rates. The issue of higher data rate is directly related with higher power consumption. If the device is providing high data rates will use more power when compared to traditional device. From the network provider point of view, they are spending almost half of their total amount only on power expenses. High data rates are demanding high energy which leads to high power consumption. The power consumption has a considerable impact on environment due to CO_2 emission. All these issues led to think about the energy efficiency of mobile networks.

Conversion of homogenious networks into HETerogenious NETwork (HETNET) [3] is one of the techniques which can increase the energy efficiency. Macrocell can provide the large coverage area, but they are not providing high data rates for multimedia applications (particularly at cell edges). To meet these constraints, micro cells were introduced in macro cell region to increase data rates for multimedia applications [3]. Micro cell covers small coverage region, hence they require less power [7]. They can provide higher data rates in the vicinity of microcell. Microcell base stations are energy efficient, as they are using the small power level. If we increase number of microcells, then addressing the handoff problem is always a problamatic task [6]. Improper handoff rates will degrade the performance of the network. Hence, there should be a joint deployment of macrocell with different micro cell will solve energy efficiency problem with proper handoff rates [10].

The concept of Cognitive Radio Network (CRN) is introduced to address the problems of Spectral Efficiency (SE). With CRN, it is possible to improve SE. CRN will collect information about current spectrum usage and find the unused frequencies [1]. After getting the list of all unused frequencies, it will use them in proper way. There is huge data rate requirement for mobile networks to handle multi media communications [3,10]. Scarcity of the spectrum is one of the reason for this problem [9], hence we should use spectrum in an efficient way.

There are many studies which can address energy efficiency in CRN and HETNET. Hasan *et al.* [15] presented solution to maximise CRN effifiency. Lasaulce *et al.* proposed power control mechanism in wireless networks. Zhang *et al.* [14] studied cooperative sensing schedule algorithm with the aid of partially observable Markov decision provess. Treust *et al.* proposed distributed power control mechanism in CRN [9]. All these studies cannot consider the power grid, which can provide power to all communication networks. Power blackout is burning issue in all traditional power grids [11,12]. Otimization electricty transmission and distribution will convert conventional grid to smart grid. With the help of intelligence control algorithms and network technologies, it is possible to reduce the power usage. In this paper, I explained the green cognitive mobile networks with small cells.

2. DESIGN STRATEGIES

Figure 1 shows the cognitive radio environment with different micro cells which are power by a smart grid.

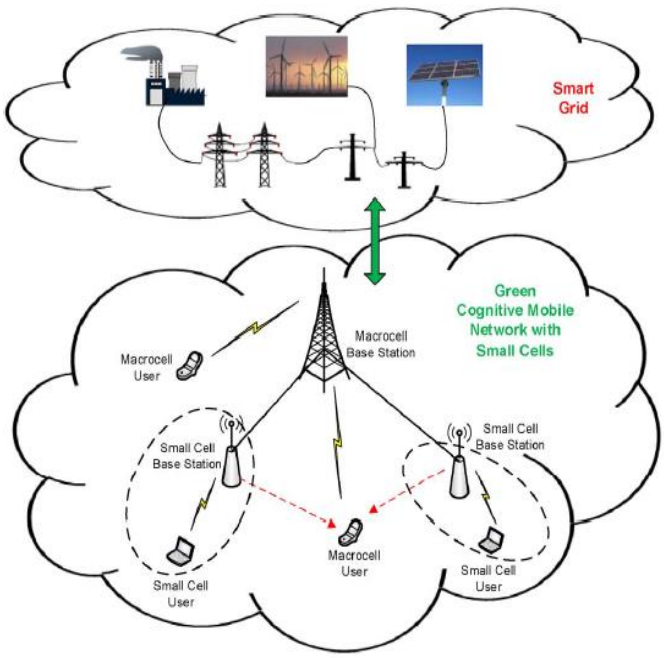

Figure 1. CRN with smart grid

2.1. CRN with Microcells

Let us assume that the entire region covered by Macrocell Base station and several number of small cells. This set up will convert homogenious structure into heterogenious network [3]. These microcells connected to macrocell via broadband connection. Each microcell has defined capacity and serves for limited number of users. Macrocell should aware the spectrum usage of microcell [2,5,7]. This can be done by cognitive radio technology. With this technology, micro cell also monitor sorrounding radio spectrum and access the channels in intelligent way. The cellular system under this condition will operate on time slotted principle. In every time slot, the spectrum resource liscenced to macro base station is divided into number of subchannels. The communication between macrocell and its users can be done through OFDMA [5,11].

Macrocell and microcell are sharing the same spectrum to increase the spectral efficiency, but cross tier interference will exist between these two cells. To avoid this interference, interference price mechanism was proposed. The microcells can change their transmitted power based on interference price and channel condition. Assuming that, all microcells are deployed with a considerable distance, there is no interference mitigation effect.

2.2. Electricity Consumption Design

The number of information bits that are transmitted per unit transmit energy cycle is normally taken as a measurement for energy efficiency. For a proper trade off between energy efficiency and data rate, we should not only consider the transmitted energy but also other ways of energy consumption [10,11]. Broadly, we can divide the total power consumption at base station into 3 types.

1) Static power (independent of bandwidth of the base station and also active antennas. It will take the power consumption of cooling system etc...)
2) Dynamic power (it depends on active antennas and bandwidth)
3) Power conversition power (which defines the total power over a defined or desired amplifier efficiency)

2.3. Smart Grid Implemenation with Real Time Pricing (RTP) and Demand Side Management (DSM)

Dynamic electic consumption is possible by DSM. It was designed by utility companies to saticify the needs of defined customers. With this mechanism, we can decrease emission of danerous gases and also to reduce electricity bills [7,12]. RTP is one of the efficient dynamic pricing protocols. In this protocol, pricing mechanism depends on cost of energy supply. When including a sub-subsection you must use, for its heading, small letters, 11pt, left justified, bold, Times New Roman as here.

3. PROBLEM FORMULATION

By considering the macrocell, microcell and available retailers, we can divide the smart grid process into 3 stages as shown in figure 2.

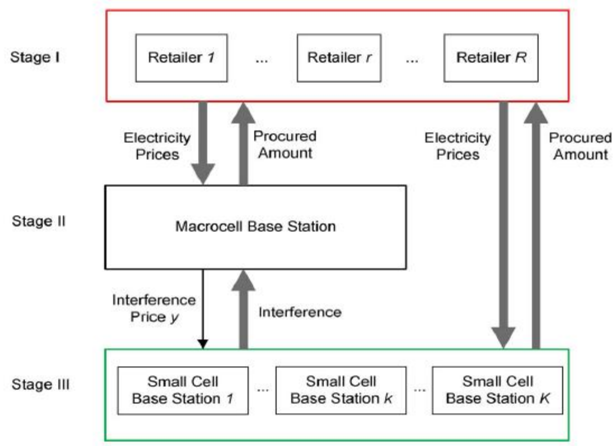

Figure 2. Three stage process

From fugure 2, it is clear that stage I has retailers and offer services to both micro and macro cell with real time electricity price x_r. Now in stage II, Macro cell decides to choose the particular retailer which depends on amount of electricity consumed i.e. q_m. Based on q_m, energy efficient power allocation p_m was calculated. In stage II, macrocell is leader and it will offer interference price to microcell i.e y. in stage III, based on the inputs of retailer's electricity price and interferenc price y, microcell will select the best retailer.

In this process, each stage strategy is affecting next strategy. The following analysis will explain the optimization of defined stages in such a way that the one stage decision should not affect other stages in huge manner. We can't reduce this effect completely, but we can reduce it in considerable way.

4. PROBLEM SOLUTION

Equillibrium between three stages is one of the finest solutions to reduce the effect. Hence we can discuss the power allocation strategy at every stage.

4.1. Power Allocation for Microcell

Microcell should choose possible retailer from the information of retailer price and also on the interference price from macrocell [3, 4, 9]. Let us assume that a microcell k with its net utility function μ_k. Let p_k is the transmitted power of microcell. From [5], we can define net utility function as

$$\frac{\partial^2 \mu_k}{\partial p_k^2} = -\frac{W h_k^4}{(\sigma_k^2 + p_k h_k^2) ln2} < 0$$

Where W is the transmission bandwidth, h_k is channel gain and σ_k is gaussian noise.
From the above equation we can derive optimum power allocation of microcell and can be obtained as

$$p_k = \frac{W}{\mu_k(\sum_{r=1}^{R} x_r B_{kv} s_{rk}) + \lambda_k g_{km}^2) ln2} - \frac{\sigma_k^2}{h_k^2}$$

Where x_r is the real time electricity price offered by a retailer, B_{kv} is the power allocation efficiency of micro cell and s_{rk} is the parameter which denotes procurement of electricity from r or not, if this value is 1, it is taking from retailer r and if it zero it is not taking from r. λk is weight factor of micro cell and g_{km}^2 is the gain between macrocell user and microcell.

4.2. Power Allocation for Macrocell

Macro cell can procure electricity from one of the retailer and adjust its power strategy according to individual micro cell requirements and offer interference price to micro cells [5,6]. Hence, the net utility factor in the case of macro cell completely depends on μ_m and p_m. From the decomposition theory, we can divide this power allocation problem into two divisons. They are

1) To maximise μ_m, first we should fix the interference price and then calculate p_m.
2) Find the final interference price in optimal configuration.

$$I_m = \sigma_m^2 + \sum_{k=1}^{K} g_{km}^2 \left[\frac{W}{\mu_k(B_{kv} x_{rk}) + \lambda_k y g_{km}^2) ln2} - \frac{\sigma_k^2}{h_k^2}\right]$$

From the above equation, optimum power allocation of Macro cell can be obtained as

$$\frac{\partial \mu_m}{\partial p_m} = \frac{W h_m^2}{(I_m + p_m h_m^2) ln2} - \alpha(\sum_{r=1}^{R} x_r B_{mv} s_{rm}) = 0$$

Where, B_{mv} is the power allocation efficiency of macrocell and s_{rm} is the parameter which denotes procurement of electricity from r or not, if this value is 1, it is taking from retailer r and if it zero it is not taking from r with respect to macrocell. If macro cell selects the lowest retailer price value, and then s_{rm} should equal to 1. Hence p_m can be written as

$$p_k = \left[\frac{W}{(B_{mv} x_{rm}) \propto ln2} - \frac{I_m}{h_k^2}\right]$$

4.3. Equillibrium Algorithm

To get equillibrium condition between retailer, macrocell and microcell, simple iterative algorithm was proposed.
Step1: Assign electricity price value x_r foe all retailers
Step 2: Macrocell should decide the interference price y
Step 3: Macrocell should select the particular retailer and also about how much to procure
Step 4: Microcell has to perform power allocation with respect to energy efficiency.
Step 5: All retailers has to update their prices by following the condition

$$x_r(t) = \beta_r(x_{-r}[t-1])$$

Where, β_r is the best response function of retailer r, x_{-r} is the offered price of other retailers and t-1 represents the iteration level.
Step 6: Repeat the steps 1-5 until to get the following condition

$$\frac{\|x(t) - x(t-1)\|}{\|x(t-1)\|} \leq \varepsilon$$

Here, ε should be very small value, considerably 1-2%.
Step 7: Stop the process of iteration.

5. SIMULATION SETUP & RESULTS

Let us assume the defined conditions such as
Radius of Macrocell = 1000m
Radius of Microcell = 20m
Penetration loss = 20dB for exterior and 10dB for interior
Pathloss between microcell user and its macrocell basestation =
15.3+37.6 log (distance between macrocell basestation and microcell user + penetration loss of exterior wall)
Pathloss between microcell basestation and its user = 46.86+20log (distance between microcell and its user + penetration loss of interior wall)
W=5
Static power = 88 W
Dynamic power = 75W
Power allocation efficiency = 0.34
$\mu_k = \lambda_k = 1$
$\alpha = 0.5$ and $\beta = 10$
Each base station has 50 channels.
The following figure 3 shows the effect of α on energy efficiency metric.

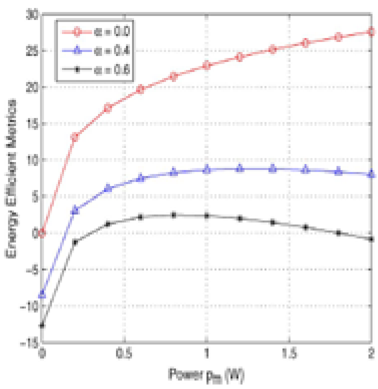

Figure 3. effect of α on energy efficiency

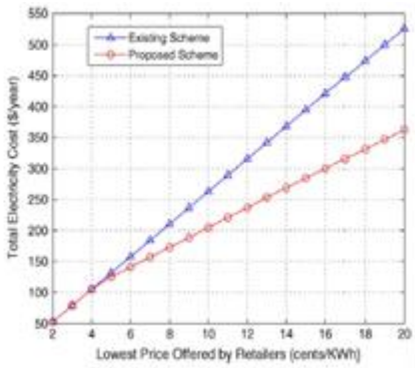

Figure 4. Total electricity cost with retailer for existed and proposed scheme.

As the α increases, the energy efficiency will decrease. The following figure 4 shows the trade off between total electricity cost and prices offered by retailers for existed and proposed schemes.

6. CONCLUSION

In this paper, cognitive radio network implementation with deployment of microcell was discussed. Energy efficient power allocation possibilities were discussed by adjusting the amount of electricity of macro and micro cells. It was also shown that, interference price problem and optimum power allocation was possible with the introduction of smart grid. To achieve equillibrium condition to the problem, an iterative algorithm was proposed. Finally, it was shown that the proposed method was much efficient with respect to energy efficiency and total electrical cost.

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Seetaiah Kilaru finished his Doctor of Philosophy in Communication Engineering. He worked for CISCO network as a sponsored project fellow. His research interest includes Cognitive Radio Networks, Massive MIMO, Femtocells and Cellular & Mobile Communications. Currently, he is working as Professor (Department of Electronics & Communication Engineering) in Sri Venkateswara Engineering College, Telangana, INDIA.

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