Increasing Energy Efficiency with Channel Condition Based Activation for a Cognitive Radio Mobile Network

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***Abstract*—Cognitive radio is an uprising technique designed to solve the problem of spectrum utilization effectively. In a cooperative cognitive radio mobile network (CRMN), battery-powered cognitive mobile node (CMN) frequently sense and report primary user's (PU's) existence to exploit a spectrum hole. The energy consumption increases when all CMN sense and report to centralized controller (CC) in order to make a final global decision. An appropriate strategy is needed to be developed in order to decrease the overall energy consumption, improving energy efficiency (EE). This paper proposes communication channel based activation (CCBA) for CMN in a CRMN. Numerical results shows that even with CCBA limiting some CMN to be activated, helps in increasing EE and global probability of false alarm (FA/W) for the CRMN.**

Index terms– Cognitive Radios, Channel Condition, Energy Efficiency.

1. Introduction

4G wireless communication system are deployed in many countries however the ever increasing demand of wireless mobile devices and services gives rise to many upfront issues e.g, spectrum usage crisis and energy consumption either due to usage or protecting the licensed spectrum [1]. Such challenges gives a drawback for future mobile communication networks, though still it is far better in term of data rate and mobility. But considering the boom in wireless services the spectrum scarcity problem seems to be on the rise when the 5G systems are deployed by the 2020. Traditional spectrum allocation strategies cause temporary and geographical holes in the licensed band [2].

Cognitive radio is a promising technique which dynamically exploits the under used spectrum among the operators in order to overcome the spectrum scarcity problem [3]. Cognitive radio which is capable of sensing and adapting to the environment accordingly [10]. This technique is promising and has a greater chance to be used as future mobile communication systems. In cognitive radio mobile network (CRMN), the frequency allocated to primary user (PU) when vacant is used by cognitive mobile node (CMN). This scenario is only applicable in a case where the CMN while using the primary user radio spectrum must vacate it if the PU becomes active during this time period, and the

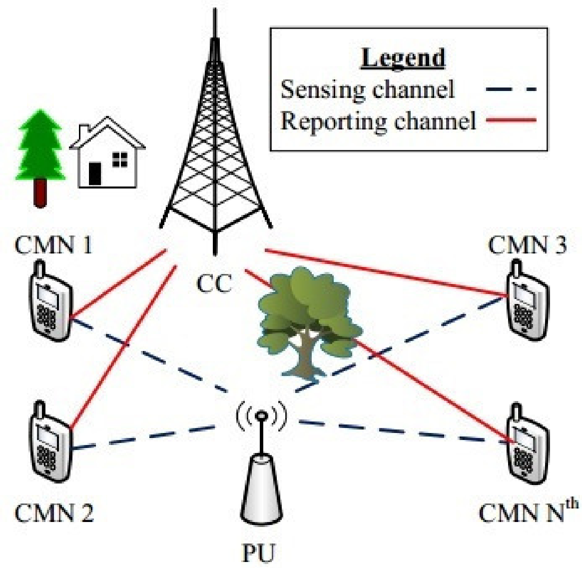

Figure 1. CRMN System Model

cognitive user must find the unused frequency spectrum of the PU (i.e. mobile network) [4].

Spectrum scarcity problem needs to be addressed as under usage of spectrum leads to waste of resources. Spectrum sensing (SS) [5], [6] is a crucial element in CRMN, to effectively and accurately detect PU's activity for limiting the interference to primary network. Various methodologies have been introduced e.g. using sensing devices [7] and optimizing location based on distance of sensing devices used [9].One of the most propitious advancement in the recent times is spectrum sensing dealing with the problem of underused spectrum [8].In order to overcome this problem there must be little interference in the primary spectrum and base station. A successful sensing stage can overcome this primary interference [10].

In order to prevent the primary user interference the SS process must be accurate and the process is of utmost importance. CRMN usually use one of the mentioned techniques; distributed or cooperative. The major difference between the said techniques is of the number of CMN reporting (one and

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more than one respectively). Cooperative sensing is largely employed to improve the sensing accuracy and sensing efficiency [4] upto a greater extent but it also increases the chance of interference to the primary network, as the number of reporting CMN increases. The reporting and decision making is controlled by a centralized node, also known as fusion center, the decision based on a specific fusion rule i.e OR rule, AND rule, K-out-of-N rule [11]. Time frame for a CRMN can be categorized into two specific time slots; sensing time slot t_s, when all CMN sense the specified spectrum and the reporting time slot t_r when all the CMN report their individual decision to the centralized controller (fusion center) [6].

When the number of cooperating CMN increases it also increases the system energy consumption [14], [15], which results in decreasing the energy efficiency (EE) of the network. Due to the rapid rise in energy costs and uprising carbon footprints of existing systems, energy efficiency measured in bits per joule, is gradually accepted as an important design criteria for future mobile communication systems [16], [17]. This proposes channel condition based activation (CCBA) for CMN in CRMN when reporting loss is considered. CCBA proposes limiting the number of cooperating CMN by screening those which have bad communication channel in between CMN and the centralized controller (CC). Numerical investigation shows great amount of improvement in two energy analysis metrics: energy efficiency and global probability false alarm per watt (FA/W) as compared to all CMN sensing and reporting.

2. System Model

We consider a CRMN consisting of n number of CMNs controlled by a fusion center known as centralized controller (CC) as shown in Fig. 1. The CC coordinates with all CMN in its domain to make a final decision regarding the presence of primary user and if the final decision finds the PU spectrum vacant, it allocates the spectrum to a CMN. Fig. 2 shows a time frame structure for a CRMN. Initially all CMN senses the spectrum of PU in time t_s and report back to the CC in time t_r. The global decision at the CC is done with the help of all CMNs cooperation. In order to evade intervention or concussion with the signal of primary user, CMN needs to check the latency of cognitive user. The energy detector provides a feasible, easy and low cost hardware solution [1]. An individual CMN senses the PU spectrum, collects samples and make its own individual decision. Let $y_i(t)$ be the sensed signal and is given as

$$y_i(t) = \begin{cases} x_i(t) + n_i(t), & \textit{if channel is busy} \\ n_i(t), & \textit{if channel is free} \end{cases} \tag{1}$$

where $x_i(t)$ and $n_i(t)$ denotes the PU signal and the noise signal at the specified sensed spectrum, respectively. Each CMN reports its individual decision in the form of bit '1' if channel is busy and '0' if channel is sensed free.

The local performance of each CMN is measured by probability of detection (p_d) and probability of false alarm (p_f). The detection probability is the probability of identifying a busy channel as used, whereas the false alarm probability is the probability of identifying a vacant channel as used. For simplicity, we used identical local performance among CMN i.e. Neyman-Peasrson detectors [11].

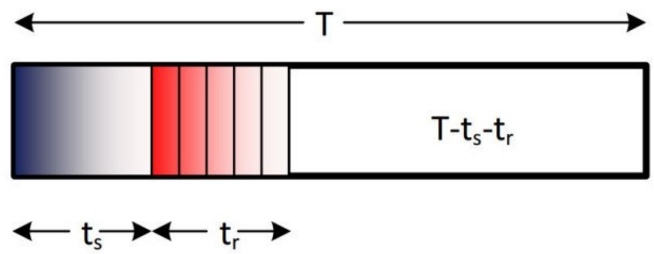

Figure 2. Time frame structure of CRMN

Every local decision by individual CMN needs to be reported to CC. At CC a specific fusion rule is applied in order to make a final decision. $K-out-of-N$ rule is a general fusion rule for a CC, where K is predefined threshold for the number of CMN having local decision '1'. Hence the global probability of detection and global probability of false alarm calculated at CC for $K-out-of-N$ rule [11] is given as

$$\mathcal{Q}^d(n) = \sum_{v=K}^{n} \binom{n}{v} p_d^v (1-p_d)^{n-v} \tag{2}$$

$$\mathcal{Q}^f(n) = \sum_{v=K}^{n} \binom{n}{v} p_f^v (1-p_f)^{n-v} \tag{3}$$

where p_d and p_f denotes the identical probability of detection and probability of false alarm for all CMN and K is a predefined threshold depending on the fusion rule being used e.g. OR-rule $K = 1$, AND-rule $K = N$, majority (MAJ) rule $K = \frac{N}{2}$. As all the CMN cooperates to determine whether the PU is present or absent. The primary user activity is modeled by a two-state ON-OFF [3] process

$$\begin{cases} Pr\{\text{Primary user is ON }\} = \phi_1 \\ Pr\{\text{Primary user is OFF }\} = 1-\phi_1 (= \phi_0) \end{cases} \tag{4}$$

where ϕ_1 is the PU transmission probability. The probability of selecting a CMN for transmission is $\phi_1(1-\mathcal{Q}^d(n))$ plus $\phi_0(1-\mathcal{Q}^f(n))$. Assuming perfect detection $\mathcal{Q}^d(n) \approx 1$, for a given data rate D and available transmission time $T-t_s-t_r$, the CRMN throughput Γ is given as

$$\Gamma(\mathcal{Q}^f(n)) = \phi_0(1-\mathcal{Q}^f(n))D\bar{T} \tag{5}$$

where $\bar{T}$ is the effective transmission given as

$$\bar{T} = \frac{T-t_s-t_r}{T} \tag{6}$$

2.1. Energy Efficiency

Let P^s and P^r be the power consumed by individual CMN during sending and reporting time t_s and t_r, respectively. Hence the total energy consumed E_T by the CRMN when n number of CMN are cooperating with CC is given as

$$E_T = n(P^s t_s + P^r t_r) \tag{7}$$

Energy efficiency η of a system is defined as [15], [17] the total number of bits transmitted successfully to the total energy consumed is given as

$$\eta = \frac{\Gamma(\mathcal{Q}^f(n))}{E_T} \tag{8}$$

Although energy efficiency and throughput are said to be important network metrics and widely used, they are not comprehensive enough for a cooperative environment. Hence an energy efficiency metric related to probability of false alarm known as " the global probability of false alarm per Watt (PFA/W) [15]" denoted by Ψ is given as

$$\Psi = \frac{1 - Q_f}{E_T} \tag{9}$$

2.2. Communication Channel

The communication channel (CH) between the CC and CMN is a random access channel [12] and is modeled as a direct-sequence/spread-spectrum multiple access (DS/SSMA) channel with coherent binary phase shift keying (BPSK) modulation in the simulation. The loss probability of reports to CC, is practically greater than zero and may depend on both the number of CMN reporting to CC and the up link traffic load. Let n be the number of CMN cooperating, we denote ρ_n as the loss rate of the CMN reporting packet. Assume the loss occurs independently in between the CMNs. Let b, be the number of bits of the reporting packet from CMN to CC, the loss probability is given as

$$\rho_n = 1 - (1 - P_e(n))^b \tag{10}$$

$P_e(k)$ is the probability of error of a bit and can be computed when the spreading gain is low and power control is used perfectly for the enhancements of Gaussian approximation [13], given as

$$P_e(k) \approx \frac{2}{3} Q\left[\sqrt{\frac{3G}{k-1}}\right] - \frac{1}{6} Q\left[\frac{G}{\sqrt{\frac{(k-1)G}{3} + \sqrt{3}\sigma}}\right] + \frac{1}{6} Q\left[\frac{G}{\sqrt{\frac{(k-1)G}{3} - \sqrt{3}\sigma}}\right] \tag{11}$$

with

$$\sigma^2 = (k-1)\left[G^2 \frac{23}{360} + (G-1)\left(\frac{1}{20} + \frac{k-2}{36}\right)\right] \tag{12}$$

Hence the global probability of false alarm $\overline{\mathcal{Q}^f}(n)$ considering the loss probability is given as

$$\overline{\mathcal{Q}^f}_{(}n) = \sum_{k=1}^{n} \binom{n}{k} \rho_k^{(n-k)} (1 - \rho_k)^k \mathcal{Q}^f(k) \tag{13}$$

Therefore, corresponding EE, $\overline{\eta}$ and probability of FA/W, $\overline{\Psi}$ considering the reporting loss are given as

$$\overline{\eta} = \frac{\Gamma(\overline{\mathcal{Q}^f}_{(}n))}{E_T} \tag{14}$$

$$\overline{\Psi} = \frac{(1 - \overline{\mathcal{Q}^f}(n))}{E_T} \tag{15}$$

3. Channel Condition Based Activation

Loss probability increases as a result of having too many CMN reporting to CC.If we can limit these CMN reports by the proposed scheme CCBA, it results in improving the energy efficiency. CCBA narrates that the i^{th} CMN can report only if its channel condition β_i is good i.e. only when (with CCBA)

$$\beta_i \geq \kappa \tag{16}$$

where β_i is the communication channel condition in between i^{th} CMN and the CC while κ is the predefined channel condition comparing threshold. The probability under CCBA strategy where each CMN can report to CC is given as

$$P_\kappa = \int_{\kappa}^{\infty} f(\beta) d\kappa \tag{17}$$

where $f(\beta)$ is Rayleigh fading probability density function for CMN's channel condition. Sometimes CCBA scheme can reduce the number of co-operating CMN which may effect the probability of detection $\mathcal{Q}^d$ and probability of false alarm $\mathcal{Q}^f$ [10]. Hence the global probability of false alarm $\mathcal{Q}^f_{CCBA}(n)$ considering the proposed CCBA approach and the loss probability is given as

$$\mathcal{Q}^f_{CCBA}(n) = \sum_{s=1}^{n} \binom{n}{s} P_\kappa^s (1 - P_\kappa)^{(n-s)} \overline{\mathcal{Q}^f}_{(}s) \tag{18}$$

Hence total energy consumed E_{CCBA} with respect to CCBA approach is given as

$$E_{CCBA} = \sum_{s=1}^{n} \binom{n}{s} P_\kappa^s (1 - P_\kappa)^{(n-s)} s(P^s t_s + P^r t_r) \tag{19}$$

Hence corresponding EE η_{CCBA} and probability of FA/W Ψ_{CCBA} under CCBA approach is given

$$\eta_{CCBA} = \frac{\Gamma(\mathcal{Q}^f_{CCBA}(n))}{E_{CCBA}} \tag{20}$$

$$\Psi_{CCBA} = \frac{1 - \mathcal{Q}^f_{CCBA}(n)}{E_{CCBA}} \tag{21}$$

The main focus lies in comparing energy efficiency; η_{CCBA} and $\overline{\eta}$ along-with, probability of false alarm per watt; Ψ_{CCBA} and $\overline{\Psi}$. The following section simulates the comparison between the above mentioned approaches.

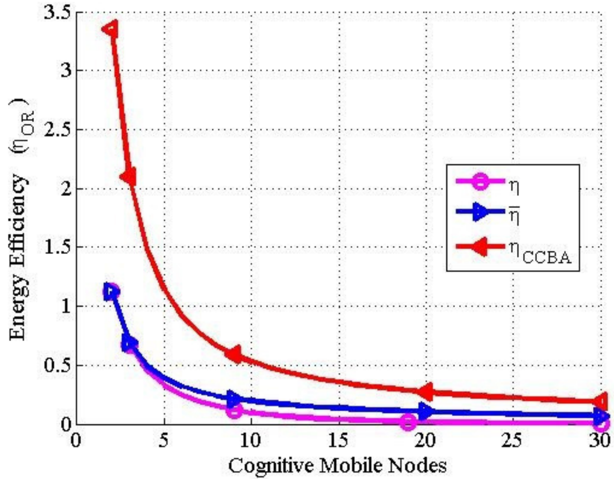

Figure 3. Plot energy efficiency to the number of CMN cooperating for OR fusion rule at CC.

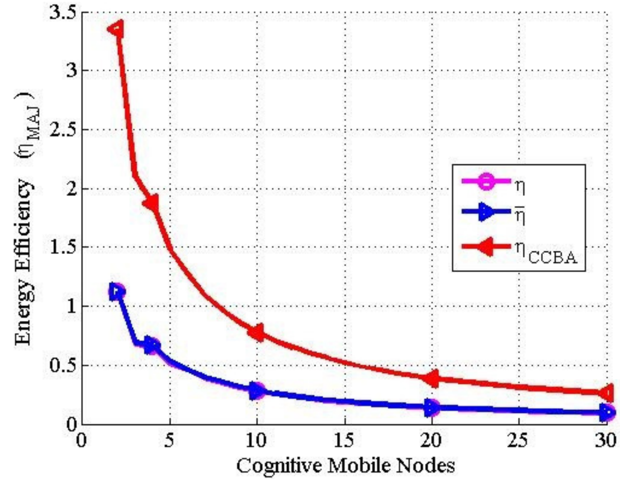

Figure 5. Plot energy efficiency to the number of CMN cooperating for MAJ fusion rule at CC.

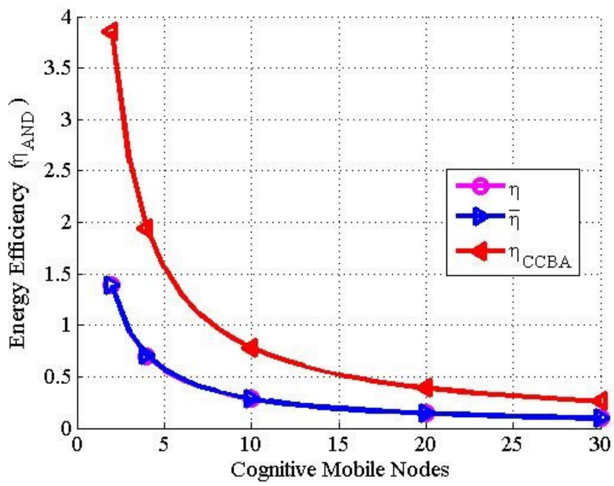

Figure 4. Plot energy efficiency to the number of CMN cooperating for AND fusion rule at CC.

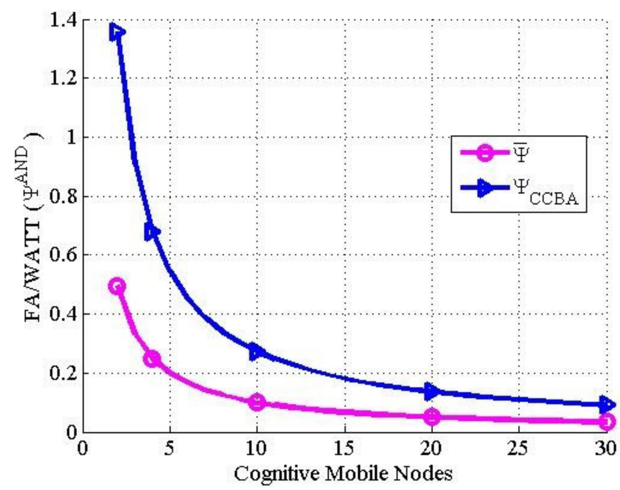

Figure 6. Plot FA/W to the number of CMN cooperating for AND fusion rule at CC.

4. Simulation Results

For our simulation result setup,we used MATLAB tool and assumed a centralized controller CC coordinating with $N = 30$ CMNs and assumed that a single PU exists with transmission probability $\phi_1 = 0.3$. The communication channel is modeled as a direct-sequence/spread-spectrum multiple access (DS/SSMA) channel with coherent binary phase shift keying (BPSK) modulation with $G = 4$ and $D = 2$. Fading coefficient were modeled by Rayleigh

Fig. 3, Fig. 4 and Fig. 5 are plotted for energy efficiency comparison to the number of CMS cooperating. Figures are plotted for different fusion rules applied for the global decision at the CC i.e. OR-rule, AND Rule and Majority rule, respectively. Each figure is plotted for η, $\overline{\eta}$ and η_{CCBA} for the increasing number of CMN cooperating. Irrespective of the trend used, there is a decaying trend for all schemes as the number of CMN increases. This is due to the fact that increasing the number of cooperating CMN, results in rising the total power and decreasing EE. As $N \geq 20$, the proposed CCBA schemes outperforms the conventional scheme by more than 40% irrespective of the fusion rule used. Fig. 3, Fig. 4 and Fig. 5 shows the effectiveness of the proposed CCBA approach.

Fig. 6 and Fig. 7 are plotted for global false alarm probability per watt comparison to the number of CMS cooperating. Figures are plotted for AND and MAJ fusion rules, respectively. Each figure is plotted for $\overline{\Psi}$ and Ψ_{CCBA} for increasing number of CMN cooperating. As $N \geq 20$, the proposed CCBA schemes outperforms the conventional scheme by more than 40%. This is due to the fact that CCBA limits the number of cooperating CMN to CC without

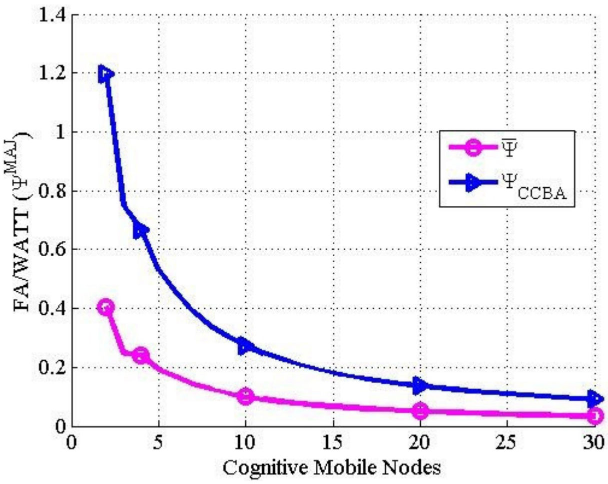

Figure 7. Plot FA/W to the number of CMN cooperating for MAJ fusion rule at CC.

effecting the system performance in terms of global false alarm probability per watt.

5. Conclusion

The proposed CCBA limits the number of activated CMN by measuring the communication channel quality, in order to preserve the multi-user diversity and hence increasing EE and PFA/W. Numerical investigation shows that CCBA, even by limiting the number of cooperating CMN provides significant improvement in EE as well as PFA/W compared to all CMN cooperating with the CC in CRMN. Hence proposed approach can help in decreasing the energy consumed for communication networks to be installed in future.

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