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Spectrum Sensing-Energy Tradeoff in Multi-hop Cluster Based Cooperative Cognitive Radio Networks

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***Abstract*—Cooperative spectrum sensing is an efficient solution to mitigate the primary hidden terminal problem through the involvement of the sensing result for cooperative users. Clustering is introduced to tackle the degradation in the performance of cooperative spectrum sensing caused by fading and shadowing of reporting channel, and also to reduce the control channel overhead when the number of cooperative users becomes very large. In practice, some cluster heads might be far away from the fusion centre, which leads to more energy consumption for reporting their results to the fusion centre, especially in large-scale cognitive radio networks. Furthermore, this case also may leads to a degradation of sensing performance. However, existing studies have not focused on these problems. In this paper, we propose a multi-hop cluster-based cooperative spectrum sensing scheme to reduce the power consumption, which also improves the sensing performance. The simulation results show that our algorithm can achieve better energy gains than conventional cooperative spectrum sensing algorithms.**

***Keywords*—cognitive radio; cooperative spectrum sensing; clustering technique; multi-hop cognitive radio.**

I. INTRODUCTION

The rapid deployment of new wireless devices and services has led to increasing demand for spectrum resources. However, recent radio spectrum measurements undertaken by the Office of Communications (OFCOM) in the UK have shown that most of the licensed spectrum bands are largely underutilized for significant periods of time in various geographical areas in the UK and the USA respectively [1].

Telecommunication regulators around the world put forward the idea of exploiting unused spectrum to improve the flexibility and efficiency of spectrum access based on dynamic spectrum access (DSA). By enabling the secondary use of spectrum on an opportunistic basis, a powerful and flexible wireless systems can be achieved everywhere. These systems will be able to provide further support for the traffic growth and changing demands in traffic. Cognitive Radio (CR) is a key enabling technology of DSA that allows sharing the licensed bands in an opportunistic manner. The cognitive terminals sense continuously the spectrum availability and serve its users without causing harmful interference to the primary users. Spectrum sensing is, therefore, a key component of cognitive radio networks.

The available spectrum bands can be determined by detecting the weak signal from a primary transmitter through the local sensing algorithm such as energy detection [2]. In practical applications, the received signal at each cognitive user may suffer from the hidden primary terminal problem and uncertainty due to fading and shadowing. In order to address the above issue, several research groups investigated in the last few years the possibility of introducing cooperation technique in sensing function [3].

Basically, the cooperation process between CR users in cooperative spectrum sensing (CSS) consists of three main phases: local sensing, reporting, and data fusion. The performance of centralised CSS depends largely on the performances offered in each phase. These performances are affected by many factors such as the accuracy of the local sensing, reliability of the reporting channel, data fusion techniques, network overhead, etc. It is well known that the benefits of cooperative spectrum sensing comes at the cost of control channel overhead and more transmission data, requiring more power consumption and introducing additional transmission delay. There are a number of contributions that have been proposed recently to address the problem of power consumption in CSS. For instance, in [4], the authors proposes to reduce the communication overhead by replacing observation reports by hard decision reports. In [5-6], the authors proposed a censorship strategy where only a user that has reliable information could report the sensing result to fusion centre (FC).

Clustering technique has been recently adopted in cooperative spectrum sensing for cognitive radio networks in order to overcome the problems exhibited by CSS [7]. In this method, the cognitive users are grouped into clusters and the user with highest SNR of reporting channel is chosen a cluster head (CH), which in turn sends the cluster decision to FC. However, existing cluster-based spectrum sensing approaches focus mainly on the classical clustering methods, which are not energy-efficient. Furthermore, although clusters that are far from the FC provide reliable local sensing decisions, but their low SNR reporting channel may lead to further deterioration in overall sensing performance due to the error reporting channel.

In this paper, we present a multi-hop cluster based cooperative spectrum sensing algorithm. By dividing the total clusters into multi-levels based on the distance between the cluster heads (CH) and the FC, the above issues can be solved, allowing to save more energy, and improving the spectrum sensing performance. This strategy will be more effective in the case of large-scale cognitive radio networks, where the number of CRs is large and the distances between the cooperative CRs and the FC are long. More specifically, in multi-hop algorithm, the CHs will not send their cluster sensing results directly to the FC as it is in traditional clustering approaches, which only reduces the reporting overhead, but they will send them to the nearest next level CHs towards the FC, thus less power consumption for decision reporting with reliable transmission channel, which leads to accurate spectrum sensing.

The rest of this paper is organized as follows. In section II, the system model is presented. The energy model of our algorithm is described in section III. In section IV, the mathematical analyses of the sensing performance for multi-hop clustering approach are provided. The evaluation analyses and the simulation results are given in section V. Finally, the conclusion is presented in section VI.

II. SYSTEM MODEL

We consider a wireless cognitive radio network with M cognitive radio users (CRs) that act as local sensing devices and that are organised into clusters. Each cluster has a cluster head that makes a cluster decision based on the local decisions received from its cluster members and reports the result to the cognitive base station that acts as a fusion centre FC. We also assume that the primary user signal at CRs is not initially known, therefore, we adopt an energy detector to conduct the local sensing, which is suitable for any signal type. In this detection algorithm, only the transmitted power of the primary system is known. So, this power will be detected firstly, and then compared with a predefined threshold to determine whether the spectrum band is available or not [2]. When the energy of the received signal is greater than the detection threshold λ, the detector will indicate that the primary user is present, which will depicted by exist hypothesis H_1, otherwise, the primary user is absent, which will be represented by null hypothesis H_0.

Fig.1 illustrates the structure of the cognitive radio network considered in our clustering approach. First, all CRs are grouped into clusters using LEACH-C protocol [8]. In This protocol, the optimal number of cluster heads CHs is determined by the FC in centralised way, according to the best reporting channel gain, distance from the FC, and the energy level of the CRs. Based on multi-hop routing mechanism, the fusion centre will determine multi-level cluster heads according to their distances from the FC. For instance, the FC will determine a set of level 1 CHs whenever the distance of CRs is less than a certain distance level predefined by the FC.

As shown in Fig.1, we considered a three-hop clustering CSS scenario for cognitive radio network with three level of cluster heads CH_{Li}, where i=1,2,3. Here, there are two types of communication: intra-cluster communication, and inter-communication. During the intra-cluster communication, each cluster member sends its sensing results to related CH directly, assuming that a free error communication between them because they are close each to other. In inter-cluster communication, each higher level cluster head CH_{Li+1} sends its decision to the nearest next lower cluster head CH_{Li}, and this process will be repeated until reaching the FC. The number of clusters in each level may be varying, while the number of cluster members will be fixed. Therefore, in some cases, some of lower-level cluster heads will relay a signal for more than one higher-level cluster head.

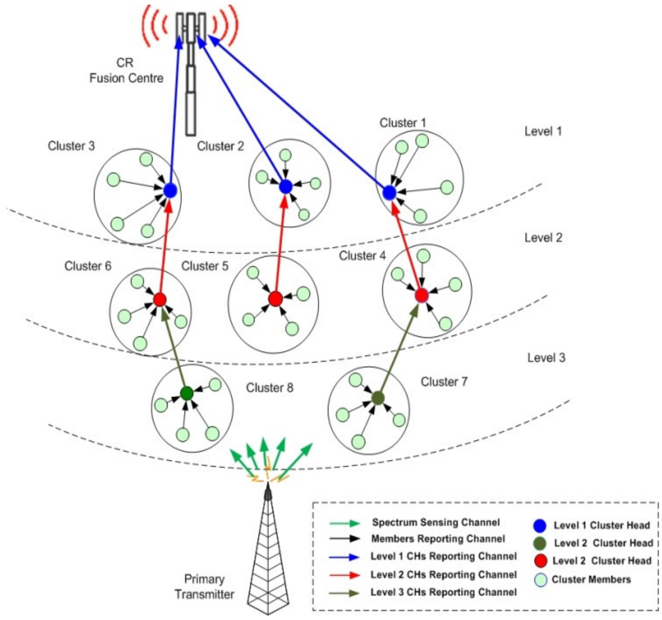

Fig.1. Multi-hop cluster-based cooperative spectrum sensing.

Here, we make the following assumptions:

a. We assume that the CRN topology is stable and consists of one fusion centre FC, one primary transmitter, and M of cognitive radio users CRs.

b. The cognitive users are either location aware, i.e., equipped with Global Positioning System (GPS), or location unaware, in which case, the FC broadcasts an advertisement signal to all CRs at a certain power level, where each CR user computes its approximate distance to the FC according to the received signal strength.

c. CRs can use power control to tune the amount of transmission power according to the transmission distance.

d. The instantaneous channel state information of the reporting channel is available to the CRs.

e. The channel between any two CRs in the same cluster is perfect since they are close to each other.

III. ENERGY MODEL OF MULTI-HOP CLUSTER BASED CSS

Typically, most of energy dissipation in a single wireless device is the result of transmitting energy dissipation to run the radio electronics, the power amplifier, and receiving energy dissipation to run the radio electronics. The energy required to transmit or receive one message of size B bits over a transmission distance R, is given by:

$$E_{TX} = \begin{cases} B\,E_{elec} + B\,\epsilon_{fs}\,R^2 & if\ R \leq R_O \\ B\,E_{elec} + B\,\epsilon_{mp}\,R^4 & if\ R > R_O \end{cases} \quad (1)$$

$$E_{RX} = B\,E_{elec} \quad (2)$$

Where E_{elec} denotes the electronic energy consumed to send or receive a message; E_{TX} represents the total energy consumed by the transmitter, while E_{RX} is energy consumed by the receiver. ϵ_{fs} and ϵ_{mp} denote the energy dissipated by the transmit power amplifier to maintain an acceptable SNR in order to transfer data reliably, and depend on the channel model, where R^2 is the free space path loss, while R^4 is the multipath fading loss, and $R_O = \sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}}$ is the breakpoint or threshold distance [9]. Power control can be used to invert this loss by appropriately setting the power amplifier; if the distance R is less than a threshold R_O, the free space model ϵ_{fs} is used; otherwise the multipath model ϵ_{mp} is used.

In general, the energy consumption of a conventional CSS during the sensing period may include the energy consumed in sensing the channel occupancy (E_s); the energy consumed in the sleeping mode (E_p); the energy consumed in computing the observations and making a local decision (E_c); and the energy consumed in transmitting the local decision to the fusion centre (E_R). In practice, E_p<E_c<<E_R, then we can ignore E_p and E_c. Under these considerations, the energy consumption of M CRs can be calculated as follows:

$$E_{local} = E_s + E_R \quad (3)$$

$$E_{total} = M E_{local} \quad (4)$$

We can see from (1-4) that the power consumption is mainly depending on the number of CRs and the distance between the CR user and the FC.

A. *Power Model of One-hop Cluster Based CSS*

In one hop clustering approaches, the data transmission begins when each cluster member sends its local sensing decision to the selected CH during each frame as shown in Fig.2.

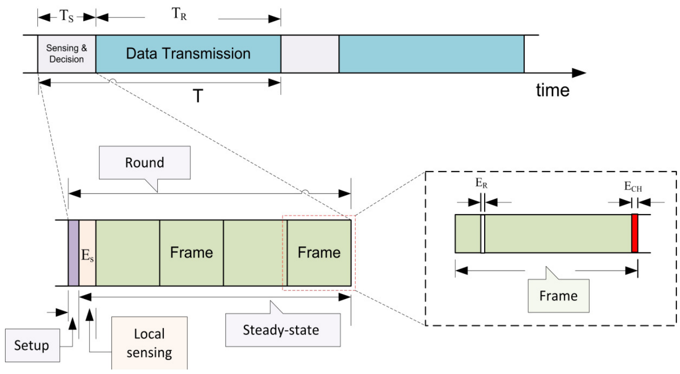

Fig.2. Frame structure of cluster based CSS.

Presumably, the distance between each cluster member (non-CH) and the closest CH is small, so the free space model (R^2) is adopted in energy dissipation. Thus, the energy consumed by each cluster member is expressed by:

$$E_{non-CH} = E_S + B\,E_{elec} + B\,\epsilon_{fs} R^2 \quad (5)$$

Furthermore, we assume that the FC is far from the CRs, thus the energy dissipation in each CH during a single frame follows the multipath model (R^4 power loss) and can be given as:

$$E_{CH} = E_{sensing} + E_{data\ receiving} + E_{data\ collect.} + E_{data\ tran.}$$

$$E_{CH} = E_S + BE_{elec}\left(\frac{M}{K} - 1\right) + BE_{DC}\frac{M}{K} + BE_{elec} + B\epsilon_{mp}R^4 \quad (6)$$

$$E_{Cluster} = E_{CH} + \left(\frac{M}{K} - 1\right)E_{non-CH} \approx E_{CH} + \left(\frac{M}{K}\right)E_{non-CH} \quad (7)$$

and the total energy consumed by the network is

$$E_{total} = E_{setup} + KE_{Cluster} \quad (8)$$

$$E_{total} = E_{setup} + (K+M)E_S + 2MB\,E_{elec} + MB\,E_{DC} +$$

$$E_{total} = E_{setup} + KE_{Cluster} \quad (9)$$

B. *Multi-hop Clustering Power Model*

In multi-hop cluster based CSS algorithm, the FC sets the cluster heads, and issues a TDMA schedule for each level of cluster heads. Then, each cluster head will issue its own TDMA schedule for cluster members. Based on this schedule, cluster heads not only collect the local sensing results from their cluster members, but also act as relaying users for lower level cluster heads. Thus, the cluster heads that are far away from FC will send their sensing results to the FC through intermediate cluster heads, which lead to consume less energy compared to direct reporting.

Here, the power consumption of each non-cluster head is the same as in one-hop clustering algorithm. The power consumption of cluster heads will be different, because the cluster heads are divided into multi-level depending on their distance from the FC, and only the level one cluster heads will send their results directly to the FC, while other level cluster heads will send their results through next level cluster heads until reaching the FC. As a result, the power consumption in each cluster head will be depending on the distance from other upper level cluster heads, as well as on the number of time that be receiving and relaying the results of lower level cluster heads.

The calculation of our multi-hop clustering algorithm is as follows. The non-cluster head users only need to perform the local sensing and send their sensing results to their CH, and because they are close each to other, thus, the energy consumed by each cluster member can be expressed by:

$$E_{non-CH} = E_S + B\,E_{elec} + B\,\epsilon_{fs} R^2 \quad (10)$$

The cluster head needs to fuse all local sensing results related cluster members and relay the results of other level cluster heads, so its energy consumption will be as

$$E_{CH}(i) = E_{sen.} + E_{data\,rec.}(i) + E_{data\,collection} + E_T(i) \quad (11)$$

$$E_{sen.} = Es \quad (12)$$

$$E_{data\,rec.}(i) = B\,E_{elec}[\left(\frac{M}{K} - 1\right) + Relays(i)] \quad (13)$$

$$E_{data\,collection} = B\,E_{DC}\frac{M}{K} \quad (14)$$

$$E_T(i) = \begin{cases} BE_{elec} + B\epsilon_{fs}d^2_{Relays(i)} * (\mathrm{Relays(i)} + 1) \\ \quad \mathrm{d_{Relays(i)}} < \mathrm{d_O} \\ BE_{elec} + B\epsilon_{mp}d^4_{Relays(i)} * (\mathrm{Relays(i)} + 1) \\ \quad \mathrm{d_{Relays(i)}} > \mathrm{d_O} \end{cases} \quad (15)$$

Where Relays(i) is the number of data relay, i represents the cluster head, and $\mathrm{d}_{Relays(i)}$ is the distance to its next hop CH. Finally, the total energy consumption can be written as:

$$\mathrm{E_{total}} = \mathrm{E_{setup}} + \mathrm{E_{non-CH}} + \mathrm{K} * \mathrm{E_{CH}(i)} \quad (16)$$

IV. Sensing Model of Multi-hop Cluster Based CSS

Cooperative spectrum sensing schemes are developed to improve the detection performance and shorten the sensing time. The performance of these approaches is measured mainly by two parameters: detection probability *Pd***,** which indicates that the primary user exists, and false alarm probability *Pf*, which indicates that the primary user is present while in reality it is not. Another important parameter is misdetection probability *Pm***,** which indicates that the primary user is absent while actually it is existing [2].

In our algorithm, each cluster member makes its own one hard decision: '0' or '1' mean absence or presence of primary activities, respectively. This one bit decision is reported independently to the FC via multiple intermediate CHs, which makes the final decision on the primary activity.

A. *Local Sensing*

Spectrum sensing is essentially a binary hypothesis testing problem, assuming that cognitive users are independent of each other, each implementing local detection and decision which are usually conducted using a simple energy detection algorithm (ED) [2], so the model can be described as follows

$$x_i(t) = \begin{cases} n_i(t) & , \; H_0 \\ h_i s(t) + n_i(t) & , \; H_1 \end{cases} \quad (17)$$

$x_i(t)$ is received signal of the ith cognitive user; $s(t)$ is transmitted signal of primary transmitter; $n_i(t)$ is zero mean additive white Gaussian noise; h_i is the channel gain; H_0 and H_1 represent that primary signal is absent and present, respectively. The main function of energy detection is to make a decision between the two hypotheses. During local sensing process, each CR makes local sensing using energy detection algorithm and reports its local observation to the fusion centre FC individually. The false alarm probability *Pf* and the detection probability *Pd* at each CR can be calculated as [2]

$$Pf = Q\left[\frac{\lambda - \mu_0}{\sigma_0}\right] \quad (18)$$

$$Pd = Q\left[\frac{\lambda - \mu_1}{\sigma_1}\right] \quad (19)$$

where, Q represents cumulative distribution function and can be expressed as: $Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^{\infty} \exp\left(-\frac{u^2}{2}\right)du$, $\mu_0 = N\sigma_n^2$, $\mu_1 = N\sigma_n^2(\gamma + 1)$, $\sigma_0^2 = 2N\sigma_n^4$, $\sigma_1^2 = 2N\sigma_n^4(\gamma + 1)^2$, N is the number of samples, σ_n^2 denotes noise power, and γ denotes to SNR, $where$ $\mathrm{SNR} = |h_i(t)|^2\frac{Es}{\sigma_n^2}$, and $\mathrm{E_S} = \sum_{\mathrm{K}=1}^{\mathrm{N}}|\mathrm{X(K)}|^2$.

Using a constant false alarm rate (CFAR) strategy and for $P_f \leq 0.1$, we can determine the predefined threshold λ as:$\lambda = N\sigma_n^2 + \sqrt{2N}\sigma_n^2 Q^{-1}(Pf)$, then this value will be used to determine the value of detection probability *Pd.* In non-fading environments, where $h_i(t) = h$ is deterministic, the probability of false alarm and detection of each CR user are the same as expressed in (18) and (19) above. On the other hand, when each CR user receives the primary signal through the Rayleigh fading channel, the received signal energy and SNR of each user are location dependent. In such a case, the average probability of detection $\overline{Pd}$ may be derived by averaging (19) over the fading statistics as follows [9]:

$$\overline{Pd} = \int_x P_d f_\gamma(x)dx \quad (20)$$

where $f_\gamma(x)$ is the probability density function of the received SNR at each CR user under the Rayleigh fading channel.

B. *Cooperative Sensing with Decision Fusion*

In practice, because of the imperfect reporting channel, errors can be occurring on the decision bits, which are transmitted by CR users. Thus, each reporting channel can be modelled as a binary symmetric channel with cross-over probability $\mathrm{P_e}$ which is equal to the bit error rate (BER) of the channel. Consider the i^{th} CR user. In our system model, we consider a binary phase shift keying modulation (BPSK) with AWGN channels, $\mathrm{P_e}$ can be given as [9]

$$P_e = \frac{1}{2}\left(1 - \sqrt{\frac{\acute{\gamma}}{(\acute{\gamma} + 1)}}\right) \quad (21)$$

where $\acute{\gamma}$ is the average SNR of the received signal at the FC.

The detection and false alarm probability with error probability *Pe* can be written, respectively, as

$$PD = Pd(1 - Pe) + (1 - Pd)Pe \quad (22)$$

$$PF = Pf(1 - Pe) + (1 - Pf)Pe \quad (23)$$

In order to get the final decision at FC, we need to use a suitable decision fusion method;therefore, we adopted the majority rule in our system model, which provides a trade-off between the spectrum utilization and the interference protection.

If the reporting channels between CHs and the FC are free errors, then the detection and false alarm probabilities at the FCcan be written as

$$Qd = \sum_{j=k}^{M}\binom{M}{j}(Pd_j)^j(1 - Pd_j)^{M-j} \quad (24)$$

$$Qf = \sum_{j=k}^{M} \binom{M}{j} (Pf_j)^j (1 - Pf_j)^{M-j} \qquad (25)$$

where M is the total number of cooperative users, and k =M/2.

In our clustering approach, we assume that the cluster members are close each to other, therefore, the intra-cluster communication channels (channels between cluster member and the related cluster head) are perfect (free error), while the inter-cluster communication channels (channels between CHs and the FC) are imperfect. Thus, the total detection and false alarm probabilities at the FC are given as follows

$$Qd = \sum_{j=k}^{M} \binom{M}{j} (PD_j)^j (1 - PD_j)^{M-j} \qquad (26)$$

$$Qf = \sum_{j=k}^{M} \binom{M}{j} (PF_j)^j (1 - PF_j)^{M-j} \qquad (27)$$

where PD_j and PF_j represent the detection and the false alarm probabilities of the j^{th} cluster head with reporting error probability $P_{e,j}$, respectively.

C. *Multi-hop Clustering CSS*

Consider a multi-hop clustering cognitive radio network with both identical and non-identical channels. We assume that there are L hops between primary user and the FC. Each non identical cluster head CH_L forwards the cluster results to the next hop cluster head CH_{L-1} with probability error P_E given as

$$P_E = \frac{1}{2}\left(1 - \prod_{i=1}^{L-1}(1 - 2P_{e,i})\right) \qquad (28)$$

Where $P_{e,i}$ is the probability error of one hop cluster. If the reporting channel is identical, (the SNR is the same for all cluster heads), i.e., $P_{e,1}= P_{e,2}=\ldots\ldots=P_{e,L-1}=P_e$, the equivalent probability error will be given as:

$$P_E = \frac{1}{2}(1 - (1 - 2 * P_e)^{L-1}) \qquad (29)$$

then, the total QD&QF probabilities of Multi-hop CHs routes will be expressed as

$$QD = Pd(1 - P_E) + (1 - Pd)P_E \qquad (30)$$

$$QF = Pf(1 - P_E) + (1 - Pf)P_E \qquad (31)$$

V. Simulation Results

In this section, we evaluate our algorithm using MatlabR2010b simulator [10] and compare it to existing approaches. The evaluation focuses on several metrics includingspectrum sensing performance, and energy consumption. The measurement of the energy gain metric of our algorithm will be achieved by finding the total energy consumed and comparing it to conventional clustering approaches.

A. *Power Mode Simulation*

For our experiments, we consider a cognitive radio network with100 nodes which are randomly generated and uniformly distributed between (x=0, y=0) and (x=200, y=200) with the BS at location (x=100, y=275), and the reporting message is 1 bit long. The communication energy parameters are given as [8]: E_{elec}= 50 nJ/ bit; E_{fs}=10 pJ/ bit/ m^2; E_{mp}=*0.0013* pJ /bit/ m^4; E_{DC}=5 nJ /bit.

Fig.3 illustrates the total energy dissipation in the network with different modes. We can show that the energy performance of the cluster based CSS scheme is better than the conventional mode. Furthermore, more energy reduction can be achieved when multi-hop clustering approach is used. It can also be shown that the energy consumption of conventional mode increases greatly with the increase of the number of CRs, while in other modes it increases slightly with the number of CRs, particularly in multi-hop clustering mode. The results also show that there is a slight saving in energy performance of 4-hop clustering mode compared with 2-hop mode.

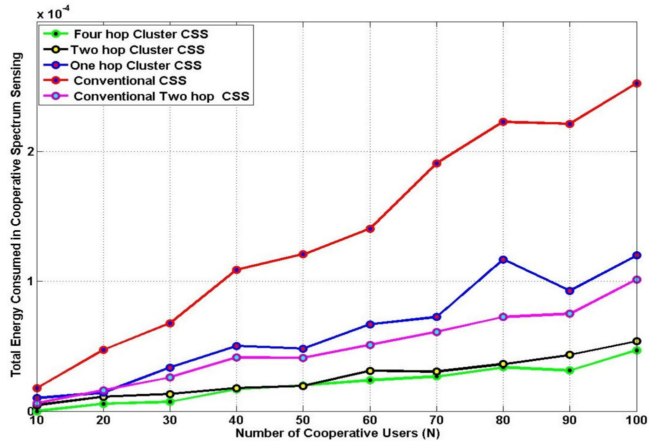

Fig.3. Average Energy Dissipation vs number of users with different CSS modes.

As shown in Fig.3, there is a great reduction in energy dissipation that can reach 52% in one-hop clustering mode compared to the conventional cooperative mode, whereas the two-hop clustering could achieve up to 55% more energy saving than one hopcommunication.Furthermore, a slight reduction in the energy consumed could be obtained when the number of hops is increased. The results in Fig.3 also indicates that energy saving in 4-hop is 12.6% more than 2-hop mode. In other words, multi-hop clustering CSS algorithm can provide a great energy efficient transmission, which is particularly true for a wide cognitive radio networks.

The sensing performance of multi-hop cluster-based CSS scheme is investigated under the perfect and imperfect reporting channels. The numerical results of our proposed algorithm are given to verify the analytical framework that is presented in the previous section. Fig.4 shows the ROC performance of multi-hop clustering CSS scheme over Rayleigh fading. In this simulation, we consider a 100 CRs are deployed randomly with different average SNR of sensing and reporting channels within the ranges of (-10, -5) dB and (-25, 25) dB, respectively. For simplicity, we assume that the noise power at each CR user is equal to 1, and that the majority fusion rule at both the cluster heads and the FC is used. The results of conventional mode are also provided for a comparison. As can be seen in Fig.4, the detection accuracy deteriorates as the number of error reports increases due to low

SNR. However, the sensing performance can be enhanced using clustering approach. By using the clustering mechanism, the local sensing will be sent to the FC via intermediate CR user (CH) that has the largest SNR of reporting channel. In this simulation, we set the number of clusters K = 5, and the reporting SNR of CHs are (25, 8, 3, 0, -1) dB.Simulation results indicate a clear improvement in sensing performance compared to traditional detection mode even with some CHs that suffer from poor SNR, especially the far CHs.

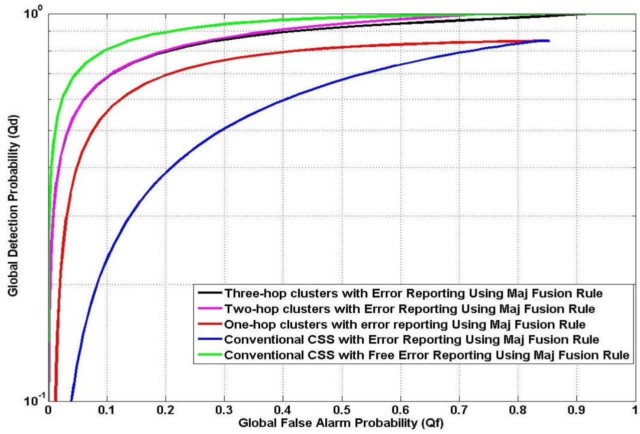

Fig.4. ROC curves for multi-hop Clustering CSS using Majority fusion rule.

Fig.4 also illustrates the advantage of detection capability of multi-hop clustering algorithm when the SNR of multi-hop is better than one-hop. Here, we assume that the clusters (k = 5) are formed at the FC based on the CR users' distances to the FC and divided into multi-hop levels. For instance, for two levels hop scenario, 2 in level-1 and 3 in level-2. In three levels hop scenario, 2 clusters in hop level-1, 2 in hop level-2, and 1 in hop level-3. Therefore, we can exploit the channel conditions between successive hops, which are much better than between far clusters and the FC. In our simulation, the SNR of the successive three levels hop communication are chosen randomly as (25, 8, 12, 14, 15) dB, respectively. In other words, 25 dB represents the SNR of reporting channel between the first CH_{L1} and the FC, 8 dB denotes to the SNR of reporting channel between the second CH_{L1} and the FC, and so on, while 15 dB is the SNR of reporting channel between the CH_{L3} and the first or second CH_{L2}. As shown in Fig.4, the sensing performance of multi-hop clustering scheme outperforms the one-hop mode,which basically depends on the channel conditions of the successive multi-hop.Although the sensing performance of multi-hop algorithm has not reached to the ideal case (Free error case), It canbe seen that there is an improvement in the sensing performance for 3-hop approach compared to 2-hop, resulting from good reporting channels and the short distances between CHs.

VI. CONCLUSION

In this paper, we have proposed a new multi-hop clustering approach for cooperative spectrum sensing. Based on our simulation results, the performance of the proposed algorithm has been evaluated through twoassessment points, including sensing performanceand the energy consumption.The transmission energy consumption of our proposed scheme has been derived and compared with that of the conventional one including direct reporting and 2-hop reporting schemes. Our simulation results have shown significant decrease in transmission energy consumption. The sensing parameters have also been derived and analyzed, and the obtained results have shown that the sensing performance of the multi-hop CSS is more accurate than one hop approach but incurs a slight increase in the sensing time due to successive data reporting.From these results, we can conclude that byincreasing the number of hopswe can improve the performance and efficiency of spectrum sensing. However, this improvement will be on the expenseof the power consumption needed to report the decision results. Therefore, tradeoffs between sensing accuracy and energy consumption need to be considered while designing spectrum sensing algorithms using CSS, in order to satisfy the requirement of the application. The future work will be focused on how manyhops should be selected for more effective performance.Depending on the number of CRs and the size of the cognitivenetwork, the optimizing value is expected to be varying.

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