Energy-efficient reporting scheme for cognitive radio networks

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Abstract
Cooperative spectrum sensing in cognitive radio network consumes a large amount of energy during spectrum sensing and reporting. An energy-efficient reporting scheme called the reduced energy consumption scheme for reporting has been proposed to reduce energy consumption. In this scheme, all secondary users will sense the channel and make a local decision about the spectrum. All these local decisions are forwarded to a common node known as the fusion centre. This counts the presence or absence of the primary user based on the secondary user’s local decisions. Whenever the counters count is greater than or equal to the threshold then the fusion centre sends a stop reporting feedback signal to the secondary users. In this way the energy consumption is reduced by diminishing the reporting secondary users and the energy efficiency is improved. The simulation and numerical results show a notable improvement in the energy efficiency of a reduced spectrum sensing scheme compared to the conventional spectrum sensing method.

\section{INTRODUCTION}

The demand for spectrum resources increases with an increase in wireless technologies. One way of providing a spectrum for all wireless users is by identifying the spectrum holes which are not utilised by the primary users. Therefore cognitive radio (CR) has been proposed to identify the non-utilised spectrum or white spaces \cite{1}. The basic aim of CR is to access the non-utilised spectrum of licensed users by the secondary users (SUs) without causing any interference to the primary users (PUs). The primary task of SU is spectrum sensing and this has to be done perfectly in order to avoid collisions with primary users \cite{2–4}. Therefore, to get accurate spectrum sensing results, cooperation between SUs is needed and is generally called cooperative spectrum sensing (CSS) \cite{5–8}.

In CSS, the primary users’ frequency spectrum is sensed by all the SUs and a local decision about the presence or absence of the primary user is taken individually at their level. These individual decisions are forwarded to a common receiver to make a final decision regarding white spaces \cite{9–11}. In \cite{9}, conventional hard fusion rules are used to combine the 1-bit local decisions. This reduces the overhead, but performance has to improve. In \cite{10}, soft CSS has been considered for making a global decision. In this all SUs will send their sensing report to the FC, this increases the overhead. In \cite{11} a 2-bit CSS scheme has been proposed and is the trade-off between hard and soft CSS. Meanwhile CSS reduces the shadowing and multipath fading problems accomplished by the individual SUs. However, it creates other problems like energy consumption, transmission delay and security issues \cite{12–15}. One of the major drawbacks in CSS is energy consumption. The energy consumption is expanded with the SUs and the system performance is diminished. System performance is measured in terms of efficiency and is defined as the ratio of average achievable throughput to the average energy consumption \cite{16}. By increasing the throughput or by decreasing the energy consumption one can improve the energy efficiency \cite{17, 18}.

To reduce the required energy, the authors in \cite{19} proposed two algorithms, namely reduced sensing and reporting schemes. In RES, the busy channels are not going to sense for the next sensing rounds. This method reduces the consumption of energy for sensing, but it also reduces the throughput. In RERS, the SU should select the list of channels to be reported. This has to be done carefully in order to improve the detection accuracy. In \cite{20}, the authors proposed an objection-based CSS. In this method only one SU will report its sensing result to the FC and broadcast the same to the remaining SUs. This reduces the energy consumption but the selection of broadcasting SU is a difficult task. A censoring algorithm have been proposed in \cite{21} in order to decrease the consumed...
energy in CSS. In this approach each SU will send its results to the FC only when the sensing results exceed a predefined range. A multi-objective optimisation technique was proposed in [22–24], to lower the consumption and to enhance the efficiency. The authors in [25–27] presented an energy-efficient scheme for wireless networks to reduce the power consumption. In [28, 29], an energy detection method is used for spectrum sensing, but it cannot avoid the uncertainty problem.

A new CSS scheme for reporting sensing results called reduced energy consumption scheme for reporting (RECSR) is proposed herein. This proposed method will reduce the reporting SUs to the FC. In this scheme, first SUs will sense the channel and make a local decision at their level. These decisions are sent to the FC in the allotted time slot using a TDMA scheme. The fusion centre will use two counters, namely the H0 counter and H1 counter, for counting local decisions. Whenever any one counter’s count is greater than or equal to 0, N/4, N/2, 3N/4 and N − 1, then the FC will send a stop reporting feedback signal to the SUs. After receiving a feedback signal from the FC, the SUs that are not reported will stop sending their sensing results to the fusion centre. Therefore the reporting SUs will be reduced in this scheme and the energy efficiency is improved by a notable amount.

The system model is introduced in Section 2 and the proposed CSS scheme is discussed in Section 3. Section 4 presents the numerical and simulation results of the RECSR scheme compared to a conventional scheme and the conclusions are drawn in Section 5.

2 | SYSTEM MODEL

Consider a cognitive radio network with N SUs, one PU and one FC, as shown in Figure 1. In CSS, the primary user’s channel is sensed by the SUs and makes its own decisions about the spectrum based on hypothesis testing as:

\[ Y(n) = W(n) : H_0 \]  
\[ Y(n) = S(n) + W(n) : H_1 \]

Figure 1 System model of cooperative spectrum sensing

where \( S(n) \) is the primary user transmitted signal, \( W(n) \) is the additive white Gaussian noise, \( Y(n) \) is the SU received signal, hypothesis \( H_0 \) represents the absence of the PU and \( H_1 \) represents the presence of the PU. The local decisions of each SU are calculated by two probabilities. These are probability of detection \( (P_d) \) and probability of false alarm \( (P_f) \). Probability of detection is defined as identifying the presence of the PU when it is actually present and the probability of false alarm is defined as identifying the absence of the PU when actually it is present, which are given as [12]:

\[ P_d = \Pr \{ E(n) > \lambda | H_1 \} \]  
\[ P_f = \Pr \{ E(n) > \lambda | H_0 \} \]  
\[ P_m = 1 - P_d \]  

where \( \lambda \) is the predefined threshold and \( E(n) \) is the received signal strength of the SU over \( K \) number of samples using an energy detection method, which is given as [12]:

\[ E(n) = \frac{1}{K} \sum_{n=1}^{K} |Y(n)|^2 \]  

In CSS, secondary users send their own decisions to the FC, then the FC makes a global decision based on the fusion rules. The global probability of false alarm and probability of detection using hard fusion is given as [12]:

\[ Q_f = \sum_{l=b}^{N} \binom{N}{l} P_f^l (1 - P_f)^{N-l} \]  
\[ Q_d = \sum_{l=b}^{N} \binom{N}{l} P_d^l (1 - P_d)^{N-l} \]

where \( b \) represents the decision statistics, and based on the \( b \) value the fusion rules are divided into three categories. These are (1) OR rule if \( b = 1 \); (2) AND rule if \( b = N \); and (3) MAJORITY rule if \( b = N/2 \).

In these fusion rules, to make a final decision all SUs have to send their local decisions to the FC. This increases the reporting energy consumption and also reduces the energy efficiency. Therefore, to lower the energy consumption and to improve the efficiency in CSS, a novel method for reporting results to the FC has been proposed that is known as the reduced energy consumption scheme for reporting.

3 | PROPOSED METHOD

In the conventional CSS method, SUs will sense the channel and report their sensing results to the FC in their time slot. The total consumed energy for sensing and reporting their results to the FC by all SUs is given as follows [16]:

\[ E_{\text{total}} = E_{\text{sensing}} + E_{\text{reporting}} \]
\[
E_{\text{conv}} = N * E_s + N * E_r + (P_1(1 - P_d) + P_0(1 - P_f)) E_t
\]

(9)

where \(E_s\) represents the energy consumed for spectrum sensing, \(E_r\) represents the energy consumed for reporting sensing results to the fusion centre and \(E_t\) is the consumed energy for data transmission by one SU. \(P_0\) represents the probability of the licensed spectrum free that is not utilised by the primary user and \(P_1\) represents the probability of the licensed spectrum occupied by the primary user. Whenever the spectrum is not utilised by the primary user then it can be used to transmit the secondary users’ data and the non-utilised spectrum is given by the mathematical equations as \((P_1(1 - P_d) + P_0(1 - P_f))\).

\[
E_s \propto \text{Number of samples} \ (K)
\]

(10)

\[
E_r \propto \text{Distance between SU and FC}
\]

(11)

\[
E_t \propto \text{Number of bits transmitted per sec}
\]

(12)

The energy required for data transmission exists only when the global decision by the FC is \(H_0\), that is the primary user is absent. When the primary user is absent, that is, the channel is free, then the secondary user can start sharing their data using the same primary users channel. But \(E_s\) and \(E_r\) always exist because all the secondary users should sense the spectrum and report their sensing results to the FC.

In the conventional CSS, the energy consumption required for spectrum sensing and reporting sensing results to the FC increases with the increased SUs. Therefore energy-efficient schemes are needed in order to reduce the energy consumption for spectrum sensing and reporting. The authors have proposed a new scheme for reducing the reporting SUs, that in turn reduces the total energy consumption.

The performance of the proposed RECSR scheme is given as follows:

- Initially all SUs will sense the channel after receiving instructions from the FC;
- Each SU will make a local decision at their level after completion of their sensing and send that local decision to the FC in their time slot;
- The FC will make a global decision based on the two counters, namely \(H_0\) counter and \(H_1\) counter;
- Whenever \(H_0\) counter’s or \(H_1\) counter’s count is greater than or equal to 0, \((N/4, N/2, 3N/4)\) and \(N - 1\) then the FC will send a stop reporting feedback signal to the SUs;
- After receiving a feedback signal from the FC, not reported SUs will remain silent;
- In this way the reporting of SUs to the FC can be reduced.

This method reduces the energy consumption required for reporting sensing results to the FC. A flowchart of the RECSR scheme is shown in the Figure 2.

![Flowchart of the proposed RECSR scheme](image)

**FIGURE 2** Flowchart of the proposed RECSR scheme

\[
E_{\text{prop}} = N * E_s + N_1 * E_r + E_f + (P_1(1 - P_d) + P_0(1 - P_f)) E_t
\]

(13)

where \(N_1 = N - K\), \(E_f\) is the consumed energy for sending a feedback signal and \(K\) represents the reduce number of SUs and is given as

\[
K = 1, 2, 3, \ldots, (N/2); N = \text{even}
\]

\[
K = 1, 2, 3, \ldots, (N + 1/2); N = \text{odd}
\]

The energy efficiency of the CR network is defined as the ratio of average achievable throughput to the average energy consumption and is given as

\[
\eta = \frac{\text{Average achievable throughput}}{\text{Average energy consumption}}
\]

(14)

where the average achievable throughput is defined as successfully delivered data in the CR network and is given as
\[ Tb = P_0 (1 - P_f) RT \] (15)

where \( R \) is the average data rate, \( T \) is the data transmission time and the term \( P_0 (1 - P_f) \) represents the probability of identifying free spectrum.

4 | RESULTS

In this section, the performance of the proposed RECSR scheme is shown by the numerical and simulation results. In this regard a CR network with 10, 25, 50, 75 and 100 cooperative SUs is considered. The authors assumed the consumed energies for spectrum sensing, reporting, data transmission and for sending feedback signal as 0.1, 1, 6 and 1.8 mJ, respectively. The total frame length and data rate are assumed to be 0.5 s and 1000 bps. Energy consumption for the conventional method and proposed scheme are calculated using Equations (3) and (4).

The main objective of the proposed scheme is to reduce the energy consumption for reporting sensing results to the FC. The authors calculated the energy consumption for a conventional method and the proposed scheme with a reduced number of SUs in the order of \( K \). In the conventional scheme, all SUs send their local decisions to the FC to make a global decision. However, in the proposed scheme the number of SUs going to report their local decisions to the FC depends on the counters count. The effects of reduced SUs on energy consumption, throughput and energy efficiency are shown in Figures 3–13. The variation in energy consumption with reduced SUs for \( N = 10 \) is shown in Figure 3. From this, one can observe that the energy consumption reduces with the increased number of reduced SUs. The energy consumption in the proposed scheme is equal to the conventional scheme for the number of reduced SUs being equal to zero. The maximum number of SUs reduced is \( N/2 \). In this case the energy consumed by the proposed scheme is less than the conventional scheme by 42 mJ. Hence 0–29% of energy consumption is reduced using the proposed scheme as compared to the conventional scheme.

The numerical and simulation results of energy efficiency in the conventional and proposed scheme are shown in Figure 4. From this, one can observe that the energy efficiency increases with the increase in the reduced number of reporting SUs. For \( K = 0 \), the energy efficiency in both the proposed and conventional schemes are the same. For \( K = N/2 \), the energy efficiency in the proposed RESCR scheme is 32% greater than the energy efficiency in the conventional scheme. Hence, the energy efficiency increases with the number of reduced SUs.

For \( N = 25 \), the variations in energy consumption, throughput and energy efficiency with reduced SUs are shown in Figures 5 and 6, respectively. The energy consumption

**FIGURE 3** Energy consumption versus reduced secondary users for \( N = 10 \)

**FIGURE 4** Energy efficiency versus reduced secondary users for \( N = 10 \)

**FIGURE 5** Energy consumption versus reduced secondary users for \( N = 25 \)
increases with the increased number of SUs in the conventional scheme but in the proposed scheme the energy consumption is improved. For $N = 10$, the energy consumption is reduced to 36%, but for $N = 25$, the energy consumption is reduced to 45%. The energy efficiency increases with increasing SUs. For $N = 10$, the energy efficiency increased to 32%, but for $N = 25$, the energy efficiency is increased to 40%.

For $N = 50$, the variations in energy consumption, throughput and energy efficiency with reduced SUs are shown in Figures 7 and 8, respectively. From Figure 8, one can observe that the energy consumption reduces with the increased number of reduced SUs. The energy consumption in the proposed scheme is equal to the conventional scheme for the number of reduced SUs. The maximum number of SUs reduced is $N/2$. In this case the energy consumed by the proposed scheme is less than the conventional scheme by 23 mJ. Hence 0–32% of energy consumption is reduced using the proposed scheme.

For $N = 50$, the energy efficiency in the proposed scheme is increased by 42% compared to the conventional scheme, which is shown in Figure 8. With an increase in SUs energy efficiency is also increased, which is shown in Table 1.

For $N = 75$, the energy consumption is reduced more than the energy consumption for $N = 50$. From Figure 9, one can observe that the maximum energy consumption reduced is 43% in the proposed scheme compared with the conventional scheme, which is shown in Figure 10.

Similarly for $N = 100$, the energy consumption and energy efficiency are improved in the proposed scheme compared to the conventional scheme but throughput is reduced, as can be observed from Figures 11 and 12, respectively. Table 2 shows the improved energy consumption and energy efficiency in terms of percentages compared to the conventional scheme.

For $N = 10, 25, 50, 75$ and $100$, the energy consumed for the proposed scheme saved different amounts compared to the conventional scheme, as shown in Figure 13. In the conventional

![Figure 6](image1.png) Energy efficiency versus reduced secondary users for $N = 25$

![Figure 7](image2.png) Energy consumption versus reduced secondary users for $N = 50$

![Figure 8](image3.png) Energy efficiency versus reduced secondary users for $N = 50$

**TABLE 1** Numerical results: energy consumption and energy efficiency for the conventional and proposed schemes with SUs

| SUs (N) | Energy consumption (mJ) | Energy efficiency (bits/J) |
|--------|-------------------------|---------------------------|
|        | Conventional | Proposed | Conventional | Proposed |
| 10     | 14.8         | 10.6     | 164,700      | 243,000   |
| 25     | 31.3         | 20.1     | 77,450       | 131,000   |
| 50     | 58.8         | 35.6     | 41,230       | 71,300    |
| 75     | 86.3         | 50.1     | 28,100       | 50,000    |
| 100    | 113.8        | 65.6     | 21,310       | 37,900    |

Abbreviation: SUs, secondary users.
scheme all SUs report their sensing results to the FC, whereas in the proposed scheme, reporting SUs depend on the decision logic count. Consequently, the energy efficiency in the proposed scheme has been improved compared to the conventional CSS scheme.

Generally, in the hard and soft fusion schemes, all SUs report their sensing results to the FC. This increases the energy consumption and reduces the energy efficiency. Therefore, to increase the energy efficiency and to reduce the energy consumption, the RECSR scheme has been proposed. This method reduces the reporting SUs to the FC to a maximum of \( N/2 \) and a minimum of 0.

\[ \text{FIGURE 9} \quad \text{Energy consumption versus reduced secondary users for} \quad N = 75 \]

\[ \text{FIGURE 10} \quad \text{Energy efficiency versus reduced secondary users for} \quad N = 75 \]

\[ \text{FIGURE 11} \quad \text{Energy consumption versus reduced secondary users for} \quad N = 100 \]

\[ \text{FIGURE 12} \quad \text{Energy efficiency versus reduced secondary users for} \quad N = 100 \]

\[ \text{TABLE 2} \quad \text{Numerical results: percentage of reduced energy consumption and improved energy efficiency with variable number of secondary users} \]

| Secondary users (N) | Improved Energy consumption (%) | Improved energy efficiency (%) |
|---------------------|---------------------------------|-------------------------------|
| 10                  | 29                              | 32                            |
| 25                  | 36                              | 40                            |
| 50                  | 40                              | 42                            |
| 75                  | 42                              | 43                            |
| 100                 | 43                              | 44                            |
5 Conclusion

A high energy consumption problem in CSS is identified and an energy-efficient RECSR scheme has been proposed herein. The proposed RECSR scheme reduces the energy consumption required for reporting sensing results to the FC by reducing the number of reporting SUs. A practical algorithm of the proposed scheme is presented to reduce the reporting SUs. By using counters at the FC, the reporting secondary users are reduced to a maximum of N/2. Simulation and numerical results show a significant improvement in the energy consumption and energy efficiency compared to the conventional scheme. The energy efficiency is increased by 30% and energy consumption is reduced by 40% in the RECSR scheme compared to the conventional scheme. The optimal number of secondary users is 50, at which energy consumption is reduced by 40% and energy efficiency is increased by 42% compared to the conventional scheme.

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