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Efficient Error Detection in Soft Data Fusion for Cooperative Spectrum Sensing

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Abstract

The primary objective of cooperative spectrum sensing (CSS) is to determine whether a particular spectrum is occupied by a licensed user or not, so that unlicensed users called secondary users (SUs) can utilize that spectrum, if it is not occupied. For CSS, all SUs report their sensing information through reporting channel to the central base station called fusion center (FC). During transmission, some of the SUs are subjected to fading and shadowing, due to which the overall performance of CSS is degraded. We have proposed an algorithm which uses error detection technique on sensing measurement of all SUs. Each SU is required to re-transmit the sensing data to the FC, if error is detected on it. Our proposed algorithm combines the sensing measurement of limited number of SUs. Using Proposed algorithm, we have achieved the improved probability of detection (PD) and throughput. The simulation results compare the proposed algorithm with conventional scheme.

Keywords: Cognitive radio, Spectrum Sensing, Soft Combining

1. Introduction

The demand for wireless system has been increased during the last few years and wider spectrum resources are needed. However the spectrum resources are

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limited and allocated according to a fixed spectrum assignment policy. The target of spectrum sensing (SS) is to sense the frequency hole and utilize that hole, if the licensed user called primary user (PU) is not using it. Thus, the detection of primary user is crucial to the performance of both primary network and secondary network. The detection performance can be primarily evaluated on the basis of two metrics, probability of false alarm (PF) and probability of detection (PD). The PD avoids the interference with the PU and PF reduces the spectral efficiency. The sensing decision of the local secondary user (SU) alone may not be reliable enough due to shadowing, multipath fading and time varying nature of wireless channels between SU and PU. To combat these issues, cooperative spectrum sensing (CSS) schemes have been proposed to take advantage of spatial diversity [1, 2, 3, 4]. It can greatly increase the PD in shadowing channels. CSS is classified into three categories based on how SUs share their sensing data in network [5]: centralized [1, 6], distributed [7] and relay assisted [3, 8]. In centralized category information from different SUs is combined in central base station to make a final decision, which is used here. The SS is done using five methods, which are matched filter detection [9], energy detection [10, 11], cyclostationary detection [12, 13, 14, 15] and wavelet detection [16]. The energy detection does not require any priori knowledge of primary signals and most importantly it has much lower complexity than the others. Therefore, it is widely applied in cognitive radio networks [17].

Each SU performs the SS via sensing channel and forwards the sensing information via reporting channel to the fusion center (FC), which eventually combines the sensing measurement of all SUs for the final decision. The CSS schemes using imperfect reporting channel are not proposed widely in the literature. Indeed increasing the cooperative SUs can improve the performance of network in terms of the PD while maintaining the PF at a desired level if perfect reporting channel is considered [18]. However, it is difficult to achieve desired sensing performance although many SUs are involved in the CSS due to imperfect reporting channel. The sensing data with error effects the performance of CSS. Moreover the large number of SUs involved in the CSS can decrease the energy efficiency of the network. Hence selecting the limited number of sensing measurements can increase the energy efficiency.

In [19], the authors have considered error effect on performance of SS and have proposed amplify and forward relying mechanism to reduce performance loss. In [20], rayleigh fading has been considered using several fusion rules such as OR logic and majority logic. Many of the SUs are dropped by FC due to imperfectness in their sensing results. In [21], K out of N SUs are chosen based on condition of channel. In literature, hard decision is used mostly when imperfect reporting channel is considered

We have proposed a novel scheme using soft data fusion in which SUs are required to forward sensing measurement along with CRC code. If FC detects error greater than threshold on the sensing measurement of SU, then that SU is required to re-transmit its sensing data using stop and wait automatic repeat request (ARQ). There are many ways of error detection in reporting channel, but cyclic redundancy check (CRC) is one of the best techniques for the detection of error [22]. In CRC method, certain number of check bits, often called checksum is appended to the sensing information of SU [22]. The FC determines whether or not the check bits agree with sensing information to make sure that an error is occurred in transmission or not. The main goal of this paper is to enhance the sensing performance by combining the sensing data of SUs with accurate sensing information using CRC and ARQ. A CRC-32 generator is used, which detects the error in sensing information of SUs. Specifically the contribution made to this paper is, to design the scheme which is able to combine error free SUs through CRC and stop and wait ARQ methods. The main contributions of proposed algorithm are: 1) detection of error through CRC, 2) to improve the PD with imperfect reporting channel while guaranteeing that the desired PF is maintained, 3) to improve the throughput of network.

The rest of this paper is organized as follows, section II describes the problem statement. Section III describes the system model. Proposed scheme is shown in section IV. Performance evaluation of proposed scheme is shown in section V. Finally conclusions are summarized in section VI.

2. Problem statement

The PD avoids the interference with the PU and a false alarm reduces the spectral efficiency. It is usually required for optimal detection performance to maximize the PD subject to the constraint of the PF. To improve the PD, cooperative SUs need to be increased. However, if the reporting channel has error, the performance of the detection is degraded. Fig. 1 shows a frame structure of the network. Each frame has two major phases, spectrum sensing phase and data transmission phase. The spectrum sensing phase is divided into five small

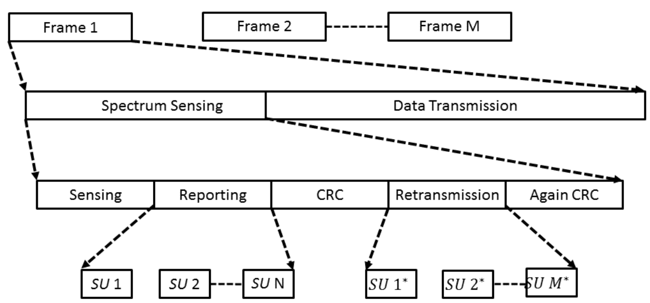

Figure 1: Frame structure for cooperative spectrum sensing

phases, sensing phase, reporting phase, CRC phase, re-transmission phase and again CRC for the re-transmitted sensing measurement. In the sensing phase, all cooperative SUs perform local SS simultaneously, while in reporting phase, local sensing data is reported to the FC. In CRC phase, CRC of each SU is conducted to detect the error. In re-transmission phase , sensing measurements of all SUs, on which error greater than threshold is detected are re-transmitted. In data transmission phase, data of SUs is transmitted.

The idea is to combine the sensing data of SUs for the CSS, whose error is less than threshold in the sensing measurement. The procedure of combination depends upon CRC, if the CRC detects error in the sensing information of any SU, then FC requests that SU to re-transmit its measurement. The re-transmitted data is again goes through CRC detection. If again error greater than threshold is detected then that SU is dropped out for CSS.

3. System model

Consider a secondary network of N cooperative SUs with one FC, which is overlapped with the primary network consisting of some PUs with their Primary base station. The objective of the SU is to sense the spectrum and utilize that spectrum, if it is not used by PU. The overlapped SU's networks is small, on which the SUs are randomly distributed. Let us denote $y_i(t)$ the energy of primary signal received at the ith SU at time instant t as shown in Fig. 2. The process of sensing starts with local sensing performed individually at each SU called local spectrum sensing (SS). It can be formulated as binary hypothesis problem with H_0 (absence of PU) and H_1 (presence of PU) as follows [23]

$$y_i(t) = \begin{cases} n_i(t) & H_0, \\ s(t)h_i + n_i(t) & H_1, \end{cases} \tag{1}$$

where $y_i(t)$ is received signal at ith SU, h_i is the channel gain between PU and ith SU, which is circularly symmetric complex Gaussian random variable and is called rayleigh fading model, s(t) is the transmitted signal by PU and $n_i(t)$ is the zero means additive white Gaussian noise at time instant t, i.e. $n_i(t) \sim N(0, \sigma_i^2)$. The CRC of the ith SU is measured by FC, if the error found is greater than threshold, i.e., $\xi_i > \xi$, the sensing measurement of ith SU is not combined for that particular sensing.

The CRC is a technique which is believed to be quite good in terms of error detection and easy to implement in hardware[24, 25]. It is based on polynomial arithmetic on computing the remainder of dividing one polynomial in GF(2) (Galois filed with two elements) by another [26]. A polynomial GF(2) is a polynomial in a single variable whose coefficient are 0 and 1 [22]. To compute

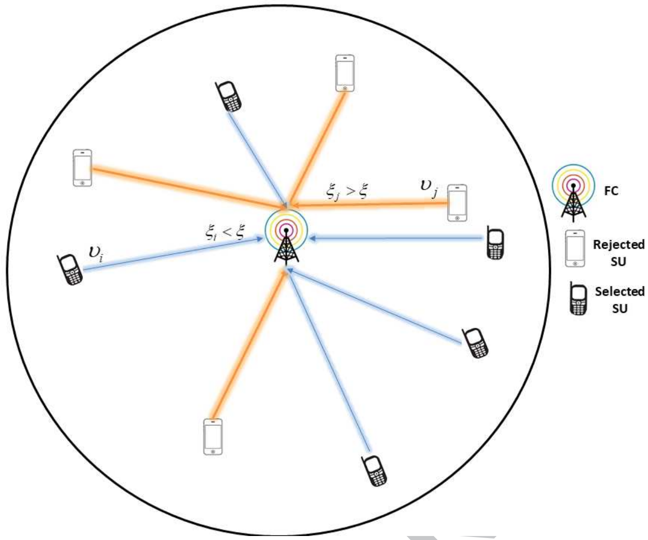

Figure 2: System Model

an R-bit CRC checksum, the generator polynomial must be of R degree [27, 28]. The sender appends R number of 0 bits to the B bits message and divides the resulting polynomial degree $B + R - 1$ by the generator polynomial [29, 28]. This produces remainder polynomial of degree $R - 1$ (or less). The remainder polynomial has R coefficients, which is the checksum. The quotient polynomial is discarded. The data transmitted is the original B bit message followed by the R bit checksum [28].

4. Proposed Algorithm

The eventual goal of this scheme is to improve the PD and throughput by combining the sensing measurement of best SUs. The FC is able to combine the sensing data of SUs for cooperation based on CRC of each SU. Using CRC, if the FC detects error greater than threshold on sensing data of ith SU, i.e., $\xi_i > \xi$, then that SU is required to re-transmit its sensing measurement. The ith SU appends R 0-bits to the B-bit sensing data transmitted by PU and divides the resulting polynomial of degree $B+R-1$ by the generator polynomial. Choosing a good generator polynomial is something of an art. The basic idea is to combine the sensing data of maximum error free SUs for cooperative sensing . All the users of a network in a particular cell is referred to as the total set. The FC divides the total set into three sets: selected set, ARQ set and rejected set. The SUs of selected set are allowed for the cooperation while SUs of rejected set are not allowed for the cooperation. The SUs of ARQ set again transmit their sensing measurement and their CRC is conducted by FC again. In other words, based on CRC, the SUs for which FC detects any error less than threshold in sensing data are inserted to selected set and remaining users of total set are moved to ARQ set. After CRC, FC broadcasts the IDs of SUs of ARQ set for the re-transmission of sensing measurement. When FC again gets the sensing measurement of SUs of ARQ set, they are being checked again through CRC, if FC again detects error on those SUs, then they will be dropped to rejected set. Even though the proposed algorithm request for re-transmission of sensing measurement if error occurs, but it still achieves better throughput as compare to conventional scheme due to sensing measurement of only selected SUs. The time for the re-transmission is fixed and short, if the re-transmitted sensing measurement of rejected SU is not received within that time, it will not be combined for final decision.

4.1. Local Sensing

To calculate the energy of signal from (1), we need to square each sample to get positive test statistics and add them up. Hence the test statistics of the ith SU is given by

$$\upsilon_i = \sum_{t=0}^{T-1} |y_i(t)|^2, \qquad i = 1, 2, ...T \tag{2}$$

where T is the total number of samples and y_i is the sum of the squares of T Gaussian independent random variables. It is shown that υ_i follows a central Chi square χ_c^2 distribution with T degrees of freedom if H_0 is true, otherwise it follows non-central χ_{nc}^2 distribution with T degrees of freedom and non-centrality parameter λ_i. The power received by ith SU is λ_i, which is defined as $\lambda_i = s^2(t)|h_i|^2$, where $s(t)$ is the PU signal energy transmitted during the sensing interval t. Hence we can write it as [30],

$$\upsilon_i \sim \begin{cases} \chi_c^2 & H_0, \\ \chi_{nc}^2(\lambda_i) & H_1, \end{cases} \tag{3}$$

The PDF of υ_i can be written as [31]

$$f(\upsilon_i) = \begin{cases} \frac{\upsilon_i^{\left(\frac{T}{2}-1\right)} e^{-\frac{\upsilon_i}{2\sigma_i}}}{2^{T/2}\Gamma(T/2)\sigma_i^T} & H_0, \\ \frac{1}{2\sigma_i^2}\left(\frac{\upsilon_i}{\lambda_i}\right)^{\frac{T}{4}-\frac{1}{2}} e^{-\frac{(\upsilon_i+\lambda_i)}{2\sigma_i^2}} I_{T/2-1}(\sqrt{\upsilon_i\lambda_i}/\sigma_i^2) & H_1, \end{cases} \tag{4}$$

where $\Gamma(.)$ is the gamma function and $I_v(.)$ is the vth order modified Bessel function. According to central limit theorem, if the number of samples is large, the test statistics υ_i is asymptotically normally distributed. The mean of the υ_i, when its H_0 is calculated as

$$E_c[\upsilon_i] = \int_0^\infty \upsilon_i \times \frac{\upsilon_i^{\left(\frac{T}{2}-1\right)} e^{-\frac{\upsilon_i}{2\sigma_i^2}}}{2^{T/2}\Gamma(T/2)\sigma_i^T} d_{\upsilon_i} = T\sigma_i^2, \tag{5}$$

and the variance is calculated as $E_c[\upsilon_i^2] - E_c[\upsilon_i]^2$. Hence we can write it as

$$Var_c[\upsilon_i] = \left(\int_0^\infty \upsilon_i^2 \frac{\upsilon_i^{\left(\frac{T}{2}-1\right)} e^{-\frac{\upsilon_i}{2\sigma_i^2}}}{2^{T/2}\Gamma(T/2)\sigma_i^T} d_{\upsilon_i}\right) - \left(\int_0^\infty \upsilon_i \frac{\upsilon_i^{\left(\frac{T}{2}-1\right)} e^{-\frac{\upsilon_i}{2\sigma_i^2}}}{2^{T/2}\Gamma(T/2)\sigma_i^T} d_{\upsilon_i}\right)^2, \tag{6}$$

which becomes,

$$Var_c[\upsilon_i] = 2T\sigma_i^4. \tag{7}$$

The mean of the υ_i, when its H_1 is calculated as

$$E_{nc}[\upsilon_i] = \int_0^\infty \upsilon_i \times \frac{1}{2\sigma_i^2}\left(\frac{\upsilon_i}{\lambda_i}\right)^{\frac{T}{4}-\frac{1}{2}} e^{-\frac{(\upsilon_i+\lambda_i)}{2\sigma_i^2}} I_{T/2-1}(\sqrt{\upsilon_i\lambda_i}/\sigma_i^2) d_{\upsilon_i} = (T+\lambda_i)\sigma_i^2. \tag{8}$$

and the variance is written as

$$Var_{nc}[\upsilon_i] = \left(\int_0^\infty \upsilon_i^2 \frac{1}{2\sigma_i^2} \left(\frac{\upsilon_i}{\lambda_i} \right)^{\frac{T}{4}-\frac{1}{2}} e^{-\frac{(\upsilon_i+\lambda_i)}{2\sigma_i^2}} I_{T/2-1}(\sqrt{\upsilon_i \lambda_i}/\sigma_i^2) \right) - \tag{9}$$

$$\left(\int_0^\infty \upsilon_i^2 \frac{1}{2\sigma_i^2} \left(\frac{\upsilon_i}{\lambda_i} \right)^{\frac{T}{4}-\frac{1}{2}} e^{-\frac{(\upsilon_i+\lambda_i)}{2\sigma_i^2}} I_{T/2-1}(\sqrt{\upsilon_i \lambda_i}/\sigma_i^2) \right)^2, \tag{10}$$

which becomes,

$$Var_c[\upsilon_i] = 2(T + 2\lambda_i)\sigma_i^4. \tag{11}$$

Both hypothesis can be written as [17],

$$\upsilon_i \sim \begin{cases} \mathcal{N}(T\sigma_i^2, 2T\sigma_i^4) & H_0, \\ \mathcal{N}((T+\lambda_i)\sigma_i^2, 2(T+2\lambda_i)\sigma_i^4) & H_1, \end{cases} \tag{12}$$

A CRC-32 polynomial generator [28]

$$G = x^{32}+x^{26}+x^{23}+x^{22}+x^{16}+x^{12}+x^{11}+x^{10}+x^{8}+x^{7}+x^{5}+x^{4}+x^{2}+x+1. \tag{13}$$

is used. When ith SU receives the signal from PU given as $\upsilon_i(t)$, it first appends the 32-0 bits with sensed data, which is divided by polynomial generator, which becomes [28]

$$R(i) = \frac{s_i(t)}{G}. \tag{14}$$

A checksum of 32-bits is achieved, which includes original sensed data given by $\upsilon_i(t)$. When FC receives the sensing data υ_i, it checks the CRC by dividing the data by G. If the error greater than threshold is detected on the sensing data of ith SU, it is requested to re-transmit the data given by υ_i^* otherwise ith SU is selected for the cooperation. Furthermore the proposed algorithm is shown in Algorithm. 1. The whole network is divided into three sets, selected set ($\hat{\mathbf{S}}$), ARQ ($\hat{\mathbf{A}}$) set and rejected set ($\hat{\mathbf{R}}$). Eventually all SUs will be either in the selected set or rejected set. The selected set performs CSS, the ARQ set has chance of transmitting the sensing data again and rejected set is not allowed to participate in CSS for that particular time period. Let's assume that SUs are

Algorithm 1 CRC Check

$Initialization\ Algorithm : CRC\ appending\ 32 - bit$

while $i = 1, 2, .., M$ **do**

  $AppendCRC32 - bit$

  for $i = 1, 2, ...M$ **do**

    $s_i(t) => s_i(t + 32) = \upsilon_i(t)$

    if $CRC_i(t) = \frac{\upsilon_i(t)}{G} = 0$ **then**

      $\hat{\mathbf{S}} \leftarrow ith\ SU$

    else

      $\hat{\mathbf{A}} \leftarrow ith\ SU$

    end if

  end for

  for $j = 1, 2, ...M^*$ **do**

    $s_j^*(t) => s_j^*(t + 32) = \upsilon_j^*(t)$

    if $CRC_j^*(t) = \frac{\upsilon_j^*(t)}{G} = 0$ **then**

      $\hat{\mathbf{S}} \leftarrow jth\ SU$

    else

      $\hat{\mathbf{R}} \leftarrow jth\ SU$

    end if

  end for

end while

randomly distributed, the ith SU first appends the 32-zero bits with the original sensing data, gets the checksum by dividing it by the generator polynomial and appends the checksum with original sensing data. When FC gets the original sensing data with appended checksum, it divides that bit stream by generator polynomial. If FC gets the remainder zero, then it combines the sensing data of ith SU for cooperation otherwise it is requested for the re-transmission of sensing data. If again error is detected in the re-transmitted data then that SU is inserted to rejected set as shown in Fig. 3.

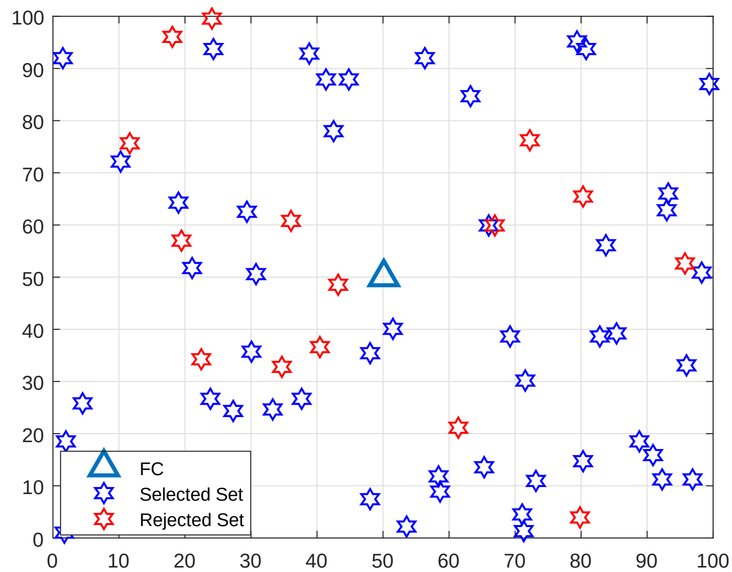

Figure 3: Selection of SUs for CSS

4.2. Performance Efficient Analysis of Cooperation

The SUs of combined set only decides the PD. When the sensing measurement of each selected SU is combined at the FC as

$$\upsilon = \sum_{i=1}^{M} \upsilon_i, \tag{15}$$

where M is the total number of SUs, on which no error is detected. The mean of all SUs is summed up and so is the variance. If the number of samples for each SU is same, then the mean for hypothesis H_0 and H_1 is $T\mho_\mu$ and $T\mho_\mu+\mho_\lambda$, where $\mho_\mu = \sum_i^M \sigma_i^2$ and $\mho_\lambda = \sum_i^M \sigma_i^2\lambda_i$. The summation of variance of all SUs for H_0 and H_1 is written as $2T\delta_\sigma$ and $2T\delta_\sigma + 4\delta_\lambda$, where $\delta_\sigma = \sum_i^M \sigma_i^4$ and $\delta_\lambda = \sum_i^M \sigma_i^4\lambda_i$. FC asks SUs to re-transmit the sensing data, whose sensing measurement has error. When the re-transmitted sensing measurement is received at FC, it again goes though CRC and combines with the already received sensing data of SUs, if no error is detected in it. In other words, only error free sensing measurement is combined at FC. The combined sensing measurement at FC is given as

$$\upsilon = \sum_{j^*=1}^{M^*} \upsilon_j^*, \tag{16}$$

where M^* is the total number of SUs, whose sensing measurement is combined at the FC including the re-transmitted data by SUs. The mean for hypothesis H_0 and H_1 after combining the sensing measurement of all selected SUs including re-transmitted sensing data is $T\bar{\mho}_\mu$ and $T\bar{\mho}_\mu + \bar{\mho}_\lambda$, where $\bar{\mho}_\mu = \mho_\mu + \mho_\mu^*$ with $\mho_\mu^* = \sum_{i^*}^{M^*} {\sigma_i^*}^2$ and $\bar{\mho}_\lambda = \mho_\lambda + \mho_\lambda^*$ with $\mho_\lambda = \sum_i^M {\sigma_i^*}^2 \lambda_i^*$. The summation of variance of all SUs for H_0 and H_1 after combining the re-transmitted sensing measurement of SUs with the SUs, which were selected in first CRC check is written as $2T\bar{\delta}_\sigma$ and $2T\bar{\delta}_\sigma + 4\bar{\delta}_\lambda$, where $\bar{\delta}_\sigma = \delta_\sigma + \delta_\sigma^*$ with $\delta_\sigma^* = \sum_{i^*}^{M^*} {\sigma_i^*}^4$ and $\bar{\delta}_\lambda = \delta_\lambda + \delta_\lambda^*$ with $\delta_\lambda^* = \sum_{i^*}^{M^*} {\sigma_i^*}^4 \lambda_i^*$. Hence hypothesis for selected set is written as

$$\upsilon \sim \begin{cases} \mathcal{N}(T\bar{\mho}_\mu, 2T\bar{\delta}_\sigma) & H_0, \\ \mathcal{N}(T\bar{\mho}_\mu + \bar{\mho}_\lambda, 2T\bar{\delta}_\sigma + 4\bar{\delta}_\lambda) & H_1. \end{cases} \tag{17}$$

The probabilities of both hypothesis for selected set is given as

$$P(H_0) = \frac{1}{\sqrt{8\pi T\bar{\delta}_\sigma}} e^{\frac{-1}{2T\bar{\delta}_\sigma}(\upsilon - T\bar{\mho}_\mu)^2} \tag{18}$$

and

$$P(H_1) = \frac{1}{\sqrt{4\pi T\bar{\bar{\delta}}_\sigma + 8\bar{\bar{\delta}}_\lambda}} e^{\frac{-1}{2T\bar{\bar{\delta}}_\sigma + 4\bar{\bar{\delta}}_\lambda}(\upsilon - (T\bar{\mho}_\mu + \bar{\mho}_\lambda))^2}. \tag{19}$$

The soft information-combining strategy is given by

$$\frac{P[\upsilon|H_1]}{P[\upsilon|H_0]} \underset{H_0}{\overset{H_1}{\gtrless}} \varphi, \tag{20}$$

where φ is the decision threshold for likelihood ratio test. The maximum tolerable PF (ς_p) is described as

$$\varsigma_p = \int_\varphi^\infty P(H_0) = \int_\varphi^\infty \frac{1}{\sqrt{8\pi T\bar{\bar{\delta}}_\sigma}} e^{\frac{-1}{2T\bar{\bar{\delta}}_\sigma}(\upsilon - T\bar{\mho}_\mu)^2} d\upsilon. \tag{21}$$

As we know that $Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty e^{(\frac{-\upsilon^2}{2})} d_\upsilon$, therefore (21) can be written as

$$\varsigma_p = Q\left(\frac{\varphi - T\bar{\mho}_\mu}{\sqrt{2T\bar{\bar{\delta}}_\sigma}}\right). \tag{22}$$

Meanwhile, the PD is computed as

$$P_{det} = \int_\varphi^\infty P(H_1) = \int_\varphi^\infty \frac{1}{\sqrt{4\pi T\bar{\bar{\delta}}_\sigma + 8\bar{\bar{\delta}}_\lambda}} e^{\frac{-1}{2T\bar{\bar{\delta}}_\sigma + 4\bar{\bar{\delta}}_\lambda}(\upsilon - (T\bar{\mho}_\mu + \bar{\mho}_\lambda))^2} d\upsilon, \tag{23}$$

which can be written as

$$P_{det} = Q\left(\frac{\varphi - (T\bar{\mho}_\mu + \bar{\mho}_\lambda)}{\sqrt{2T\bar{\bar{\delta}}_\sigma + 4\bar{\bar{\delta}}_\lambda}}\right). \tag{24}$$

We denote C as a channel capacity of CSS which is equal to $log_2(1+\gamma)$ [32], where γ is the average signal-to-noise ratio (SNR) of the SUs. Then the average throughput of proposed scheme is given by,

$$R_{th} = Q\left(\frac{Q^{-1}(\varsigma_p)\sqrt{2T\bar{\bar{\delta}}_\sigma} + \bar{\mho}_\lambda)}{\sqrt{2T\bar{\bar{\delta}}_\sigma + 4\bar{\bar{\delta}}_\lambda}}\right)\left(\frac{T - t_s - M(t_r + t_{CRC}) - t_c}{T}\right) C, \tag{25}$$

where T is total sensing time, t_s is sensing time, t_r is reporting time, t_{CRC} is the time given for CRC, and t_c is the re-transmission time. From equation (25), we can achieve the overall throughput of the network.

4.3. Energy Efficiency Analysis

The aim of the this subsection is to show the performance of the network with respect to energy consumption. The energy efficiency metric is defined as the ratio of average throughput of the network and energy consumed by the network. Typically the energy spend by each SU is due to sensing power and transmission power for reporting the sensed data. The amount of energy required to sense and transmit the sensed data of ith SU to FC over a transmission distance of R_i is given by [33, 34]

$$E_i = T_s P_s + R_i P_{t,i}, \tag{26}$$

where, T_s, P_s and $P_{t,i}$ denote sensing time, power consumption due to sensing and power consumption of ith SU due to transmission. Each SU forwards it's sensing measurement to FC. Hence the total energy consumed by a network is given by

$$E = NT_s P_s + \sum_{i=1}^{N} R_i P_{t,i} + (1 - P_0 P_f - P_1 P_d) P_{t,i} T_t, \tag{27}$$

where, $T_t = (T - T_s - (N)T_r)$ with N is the total number of SUs in the network, P_0 is the probability that the spectrum is unused and P_1 is the probability that the spectrum is used. The energy efficiency is defined as the average throughput of the network over energy consumed by the network, which is given by [33]

$$\varepsilon = \frac{R_{th}}{E} \tag{28}$$

The above equation is used to find the efficiency of proposed scheme.

5. Performance evaluation

The goal of the proposed scheme is to improve the PD and achieve the highest throughput with small time duration while guaranteeing that PF will not exceed maximum tolerable PF, which is considered 10^{-3} here. By using proposed scheme , we can achieve the improved PD with less time consumption. To verify the validation of the proposed scheme, the performance of proposed algorithm has been compared with conventional scheme using simulation in Matlab. The total sensing interval of $20ms$ is considered for both schemes with 32 number of information bits. The proposed scheme uses CRC-32, in which 32 number of CRC bits are appended with 32 information bits. The rayleigh fading model is considered, which is used for frequency selective fading. The simulation has been done using Monte Carlo simulation with 1000 number of iterations.

In conventional scheme, all SUs sense the spectrum and share their sensing measurement with the FC. In other words, the sensing data of all SUs is combined at the FC. The problem with conventional scheme is, performance of CSS is degraded due to the SUs whose sensing data is subjected to error. In proposed scheme, only SUs whose sensing measurement is error free are involved in CSS. All simulations are done according to the urban environment. Let us assume that SUs are randomly distributed in cell of radius 1km and PUs network is 1.5km in radius. Fig. 4 shows the performance of proposed scheme and conventional scheme in terms of PD. It is shown that using proposed algorithm, we can get the 10^{-8} probability of missed detection with the sensing data of 50 SUs only, while for conventional scheme, we need more than 100 SUs to achieve the same probability of missed detection. The ROC response of both schemes is shown in 5. It clearly indicates that the response of proposed algorithm is much better than that of conventional scheme. The energy consumption of the proposed algorithm is compared with conventional scheme in Fig. 7. It depicts that conventional scheme consumes more energy as compare to proposed algorithm and gives lowest throughput. In other words, we can say that the

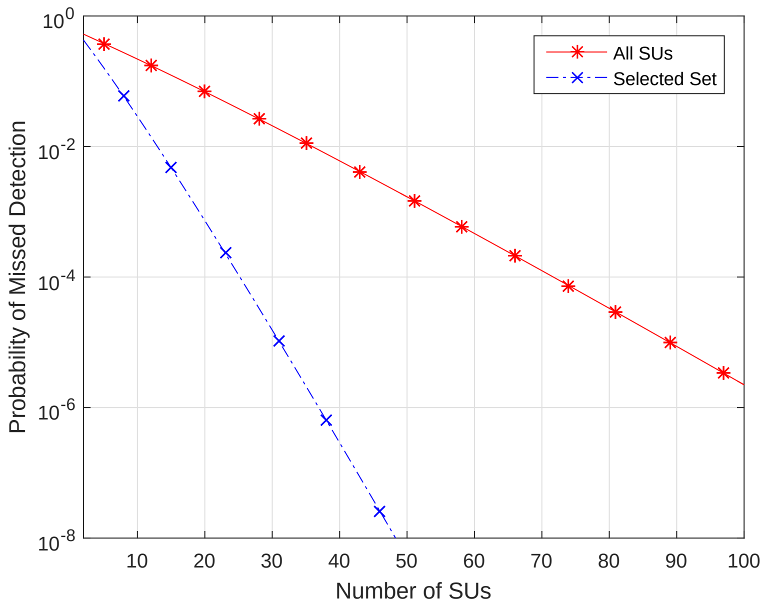

Figure 4: PD of proposed algorithm and conventional scheme

acceptable energy consumption is around $8000nJ$ for both schemes, after that the throughput gradually decreases. The proposed scheme achieves improved throughput as compare to conventional scheme. The throughput of proposed algorithm and conventional scheme is shown in Fig. 6 with different values of γ, which is average SNR of SUs. The simulation has been shown with higher SNR value of 20dB and lower SNR value of 0dB. We can see, if 20 SUs are involved in CSS using conventional scheme, we achieve the throughput of 1.42 bits/sec/Hz, when the SNR of channel is 20dB, while using the proposed scheme, with same SNR of the channel and same number of SUs, we get the throughput of 2.6 bits/sec/Hz. Moreover the figure also indicates that using proposed scheme , the throughput we achieve is 3.6 bits/sec/Hz, but using conventional scheme , we can not get that much throughput.

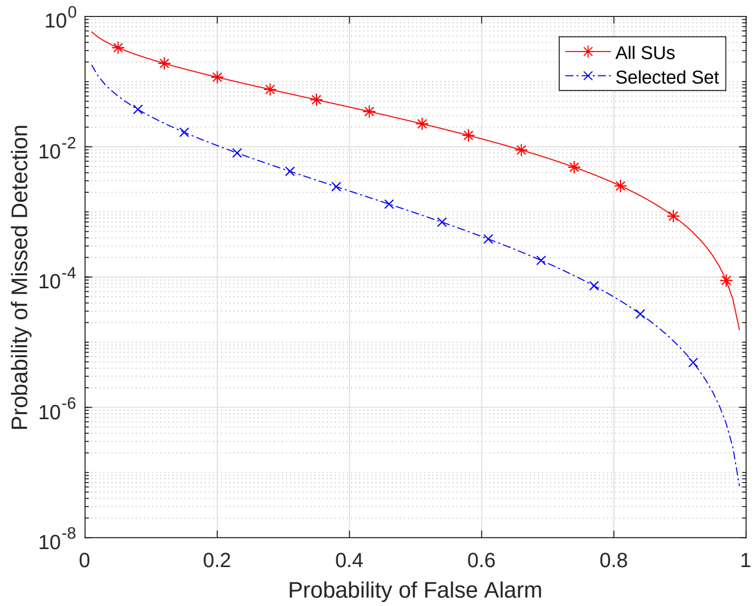

Figure 5: ROC of proposed algorithm and conventional scheme

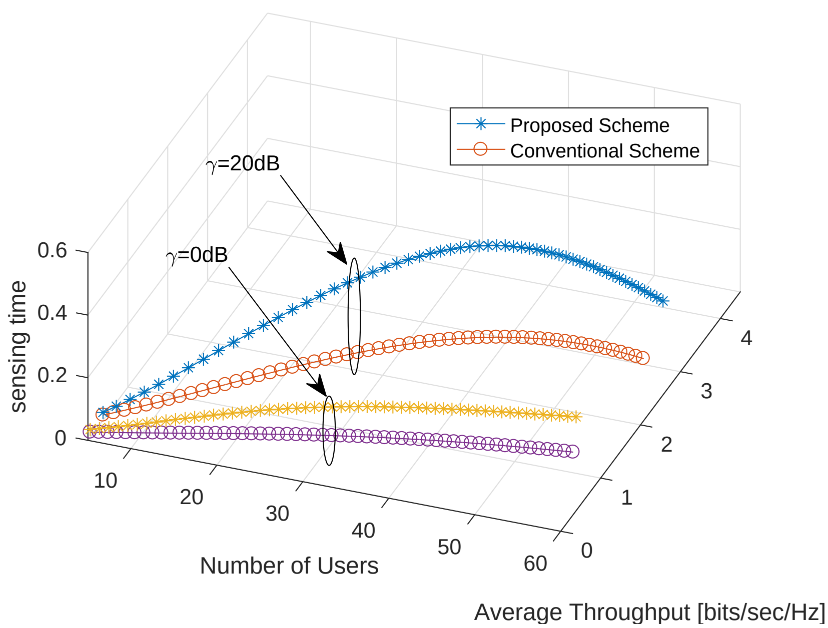

Figure 8: Throughput of proposed algorithm and conventional scheme with Total Sensing time and number of SUs involved in cooperation

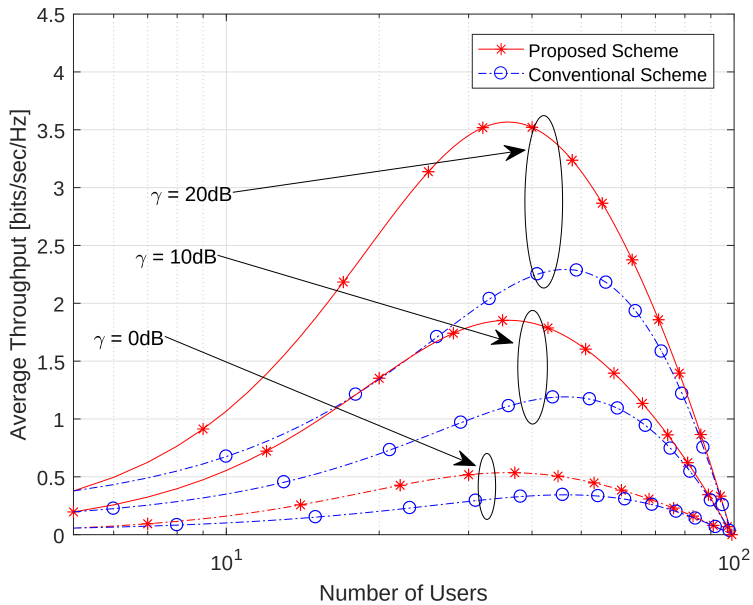

Figure 6: Throughput of proposed algorithm and conventional scheme

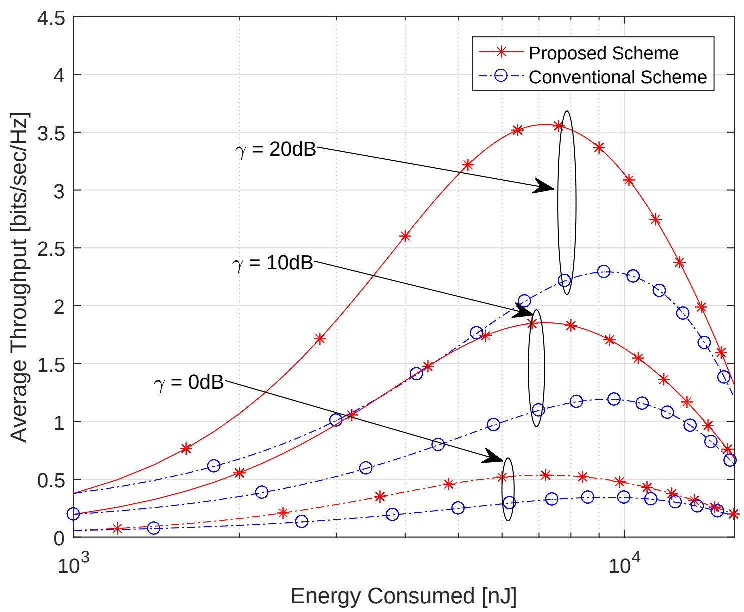

Figure 7: Throughput of proposed algorithm and conventional scheme with energy consumption

Moreover the performance of proposed algorithm is shown 3-dimensional in Fig. 8. It is clear that improved throughput is achieved using proposed algorithm even though it consume more sensing time as compare to conventional scheme. It can be seen that with 20dB of SNR, proposed algorithm consumes sensing time of 0.1sec but achieves throughput of 2.5 with 20 number of SUs, while conventional scheme consumes sensing time of 0.06sec with same number of SUs but it has lower throughput. In conventional scheme, sensing measurement of all SUs is involved including the sensing data with error. For this reason, the conventional scheme has lower throughput as compare to proposed scheme.

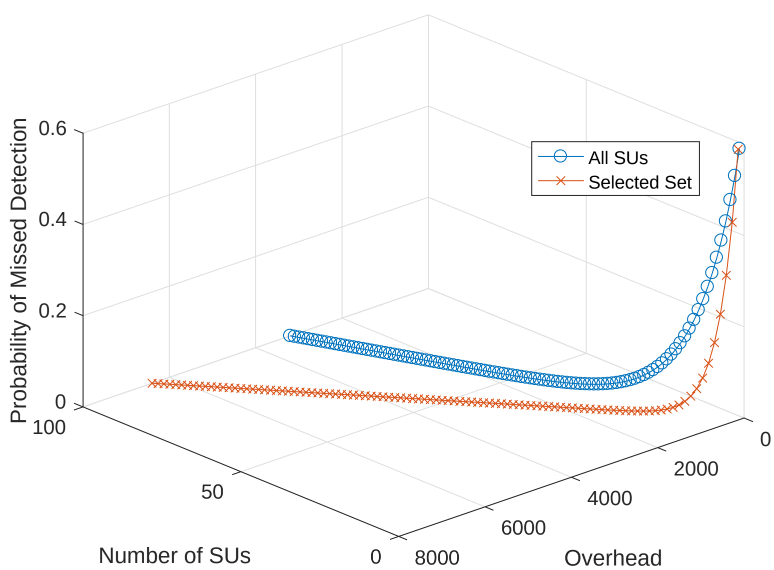

Figure 9: Overhead caused by proposed algorithm and conventional scheme in terms of bits

The overhead caused by the both schemes in terms of bits is shown in Fig. 9. It indicates that proposed algorithm causes large overhead, but it also achieves the highest performance as compare to conventional scheme. We can see from Fig. 9 that, if we have 15 number of SUs, the proposed algorithm has overhead of 960, but it achieves the probability of missed detection of 0.0047. With same number of SU, the conventional scheme has lower overhead, but it achieves the probability of missed detection of only 0.12, which shows that the performance of proposed scheme is better than that of conventional scheme.

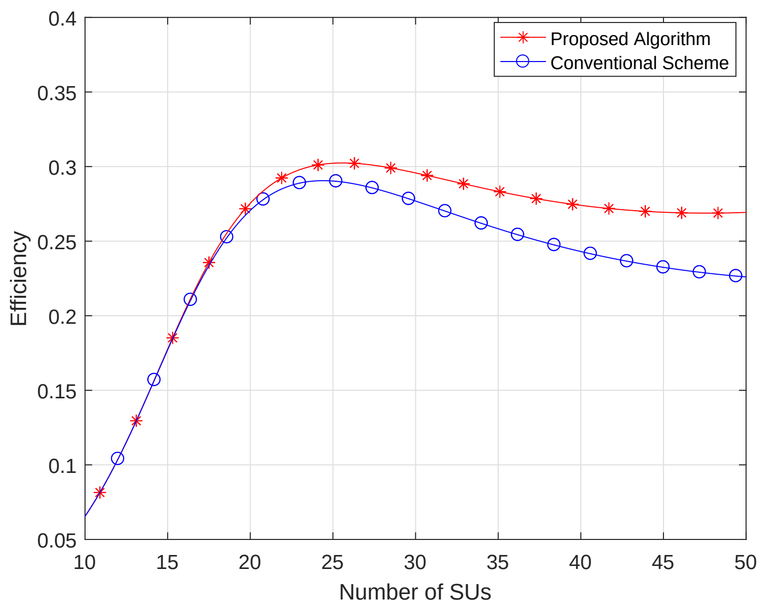

Figure 10: Efficiency of proposed algorithm and conventional scheme

The efficiency of proposed algorithm is compared with conventional scheme in Fig. 10 with increasing number of SUs. It clearly shows that efficiency of proposed algorithm is higher than that of conventional scheme. Due to increasing number of SUs, large amount of energy is consumed and throughput is decreased. The proposed algorithm only chooses limited number of SUs,

6. Conclusion

This paper proposes an algorithm which combines the sensing data of limited number of SUs for cooperative spectrum sensing. Each SU implements error detection method before reporting its sensing data to FC. The SUs are asked to re-transmit their sensing measurement if the error is found in the received sensing data at FC. In other words, only error free SUs are involved in CSS, due to which highest performance of the network is achieved as compared to the conventional scheme. Using proposed algorithm, the highest efficiency of the network is achieved as compare to conventional scheme.

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