Censoring for Improved Sensing Performance in Infrastructure-less Cognitive Radio Networks

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March 19, 2015
Related Work

- Sensor has limited power source
- Censoring as a means to save energy - increase lifetime
In [1], censoring was considered in a hard decision framework, where sensors apply one-bit quantization to their local measurements before transmission. It was proven that censoring enhances the performance in terms of error probability of the global decision besides the energy savings.

In [2]-[3], Censoring was applied to different topologies like TDMA, TBMA (Type Based Multiple Access), and sequential


Related Work

- These related works have a common assumption that a fusion center is present for coordination among the transmitting SUs

**Contribution:**

- We propose a censoring based hard-decision without a fusion center
- We characterize the proposed system in terms of average error probability, energy expenditure and network overhead
Network Model

- **M** SUs are opportunistically transmitting in the presence of a PU.
- A node *i* is connected to node *j* at time *k* if \( \bar{\bar{\tau}}_{ij} \geq \tau \) which is channel to noise ratio of link \( \epsilon_{ij} \).
- CSMA/CA protocol is assumed between SU nodes.

**Figure:** CRN model
Spectrum Sensing

- Each SU is equipped with energy detector as shown in the figure.
- The received signal at SU $i$ can be expressed as:

$$r_i(t) = \begin{cases} n_i(t) & \text{Given } H_0 \\ h_i(t)s(t) + n_i(t) & \text{Given } H_1 \end{cases}$$

Where,

- $h_i(t)$: complex-Gaussian channel gain between PU and the $i$th SU
- $s(t)$: signal transmitted by the PU
- $n_i(t)$: AWGN at the $i$th SU
Local Decisions

- We allow nodes to censor transmission.
- A node employs a two-threshold decision making process as shown in the figure.
- The detection process can be expressed as:

$$b_i(0) = \begin{cases} 
1, & x_i(0) \geq \eta_1 \\
0, & \eta_0 \leq x_i(0) < \eta_1 \\
-1, & x_i(0) < \eta_0 
\end{cases}$$

Where,

- $x_i(0)$: output of the energy detector.

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After the local decision phase:

- Each SU transmits its local decision to the available neighbor for $K$ times.
- Upon the terminations of the algorithm (i.e. at $k = K$), each SU makes a final decision based on the obtained decisions.

Figure: CRN cluster
To model the connectivity between SUs among the network, the *adjacency matrix* $A(k)$ is defined as:

$$a_{ij}(k) = \begin{cases} 1 & \text{if } \bar{\tau}_{ij}(k) \geq \tau, \ i \neq j \\ 0 & \text{otherwise} \end{cases}$$
The combining function of obtained decisions, and the decision function can be mathematically expressed as:

\[
F(b(n), n = 0, \ldots, k - 1) = b(k - 1), \quad 1 < k < K, \\
D(b(n), n = 0, \ldots, K - 1) = \\
\text{Dec}\left(\frac{1}{M}(b(0) + \frac{1}{Kp} \sum_{t=0}^{K-1} A(t)b(t))\right)
\]

where, \(b(k) = [b_1(k), \ldots, b_M(k)]^T\) be the vector of local decisions at time step \(k\) at \(M\) SUs

and, 

\[
\text{Dec}(x) = \begin{cases} 
1, & \text{if } x \geq 0 \\
0, & \text{if } x < 0
\end{cases}
\]
For a one threshold system, the local decision probabilities of the $i$th node under hypothesis $H_1$ and $H_0$:

$$\pi_{11} = \Pr(b_i(0) = 1|H_1) = e^{-\frac{\eta}{2}} \sum_{n=0}^{TB-2} \frac{1}{n!} + \left(\frac{\bar{\gamma} + 1}{\bar{\gamma}}\right)^{TB-1}$$

$$\times \left(e^{-\frac{\eta}{2(\bar{\gamma}+1)}} - e^{-\frac{\eta}{2}} \sum_{n=0}^{TB-2} \frac{1}{n!}\left(\frac{\eta\bar{\gamma}}{2(\bar{\gamma} + 1)}\right)^n\right)$$

$$\pi_{10} = \Pr(b_i(0) = 1|H_0) = 1 - \frac{\Gamma_l(TB, \frac{\eta}{2})}{\Gamma(TB)}$$

where,

- $\eta$: the local threshold at each SU
- $TB$: time bandwidth product
- $\bar{\gamma}$: average SNR
- $\Gamma(x)$ and $\Gamma_l(x, y)$ are the Gamma and lower incomplete Gamma functions, respectively.
For the censoring (i.e. two-threshold) system, we define the local decision probabilities of the $i$th node under hypothesis $H_j$, $j = 0, 1$ as:

\[
\begin{align*}
\pi_{1j} &= \Pr(b_i(0) = 1|H_j) = \Pr(x_i(0) > \eta_1|H_j) \\
\pi_{-1j} &= \Pr(b_i(0) = -1|H_j) = \Pr(x_i(0) \leq \eta_0|H_j) \\
\pi_{0j} &= \Pr(b_i(0) = 0|H_j) = 1 - (\pi_{1j}^c + \pi_{-1j}^c).
\end{align*}
\]
Average Error Probability

Censoring System

Global detection and false probabilities expressions are:

\[
P_d(K) \approx \sum_{c=0}^{M} \sum_{n} \frac{M!}{n!(M-n-c)!} n^c \pi_{11}^n \pi_{01}^{M-n-c} \left[ \frac{n}{\sqrt{(1-p)(M-c)}} \right]^c \left[ 1 - Q\left( \frac{n}{\sqrt{(1-p)(M-c)}} \right) \right]^{M-c}
\]

\[
P_{fa}(K) \approx \sum_{c=0}^{M} \sum_{n} \frac{M!}{n!(M-n-c)!} n^c \pi_{10}^n \pi_{00}^{M-n-c} \left[ \frac{n}{\sqrt{(1-p)(M-c)}} \right]^c \left[ 1 - Q\left( \frac{n}{\sqrt{(1-p)(M-c)}} \right) \right]^{M-c}
\]

Where,

- \( n \): number of ones in vector at time \( k \)
- \( c \): number of censored node at time \( k \)
- \( M \): number of SU nodes
- \( p \): probability of link connectivity

Then,

\[
P_e(K) = \pi_{H0} P_{fa}(K) + \pi_{H1} (1 - P_d(K))
\]
Let $E$ be the energy consumed by a node to transmit a decision (either 1 or –1) to neighboring nodes. Then, the average consumed a node in our proposed scheme is

$$E_{av} = \left( p_{H_0} (1 - \pi_{00}) + p_{H_1} (1 - \pi_{01}) \right) E \leq E,$$

which is less than the average energy consumed in conventional scheme $E$. 

Given that $C$ is the number of nodes which made a decision to censor transmission in a network, the average number of censoring nodes at any time can be expressed as:

$$
\mathcal{E}(C) = p_{H_0} \cdot \mathcal{E}_0(C) + p_{H_1} \cdot \mathcal{E}_1(C)
$$

where, $\mathcal{E}(X)$ is the expectation of $X$ and $\mathcal{E}_j(X)$ is the conditional expectation of $X$ given $H_j$. 

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Network Overhead

- The average number of censoring nodes is equal to
  \[ \mathcal{E}(C) = (p_{H_0} \pi_{00} + p_{H_1} \pi_{01}) M \]

- The average number of transmitted message per node in this case is
  \[
  \frac{(1 - (p_{H_0} \pi_{00} + p_{H_1} \pi_{01})) M \times K}{M} = (1 - (p_{H_0} \pi_{00} + p_{H_1} \pi_{01})) K \leq K
  \]
  which is less than the average transmitted messages in conventional scheme \( K \).
Figure: Average probability of error - $M = 51$, $TB = 5$ and $K = 10$. 
Energy Expenditure

Figure: Energy Expenditure - $M = 51$, $TB = 5$ and $K = 10$. 
Motivation and related work  
System Model  
System Analysis  
Numerical Evaluation  
Summary

Network Overhead

Figure: Network overhead - $M = 51$, $TB = 5$ and $K = 10$. 

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Censoring for Improved Sensing Performance in Infrastructure-less Cognitive Radio Networks
We proposed a distributed detection framework for infrastructure-less CRNs which allows SUs nodes to censor transmissions.

We characterize the proposed system in terms of average error probability, energy expenditure and network overhead.

Showed the attained gains in these terms when applying the proposed scheme.
Thank You!