A Comprehensive Merging Scheme in Collaborative Spectrum Detection

Wei Qiu^{1, a}, Changhua Yao^{2, b}

¹Chinese Satellite Maritime Tracking and Controlling Department, Jiangyin, China

²Institute of Communications Engineering, PLA University of Science and Technology, Nanjing 210007, China

^ammnown003@163.com, ^bmmnown004@163.com

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Abstract. In this paper, we propose a novel comprehensive merging scheme in collaborative spectrum detection (CSD) to achieve better throughput performance, considering the diversity of the reporting channels. Unlicensed users (UUs) with good reporting channel quality transmit quantized self observation statistics to detection center (DC), and others report their self judgements. DC makes the final judgement by carrying out comprehensive merging. The closed-form expressions of throughput and detection performance is obtained in the proposed comprehensive merging scheme. The simulation shows that the comprehensive merging scheme can achieve better throughput performance than hard merging scheme or soft merging scheme.

1. Introduction

In the centralized collaborative energy sensing, the hard merging scheme collects 1-bit self judgement, i.e., presence or absence of PU, while the soft merging scheme collects multibit information of the detected energy, which provides a better performance than the hard merging scheme at the cost of increased reporting cost. The reporting cost can not be ignored when the self sensing data is reported to the DC through a common control channel, which is stringent bandwidth-limited for the efficient usage of limited spectrum resource[1],[2],[3].

There are some researches which study cost-throughput tradeoff in a CRN that consists of a number of the UUs employing energy detectors and a single judgement DC. Many methods have been proposed to reduce the reporting cost. Some introduce multibit quantization combining scheme[4],[5], to reduce the amount of data transmitted, some focus on the selection of the collaborative users[6], and [7] proposes a reporting order control scheme to reduce the reporting time. To our best knowledge, related researches all adopt either hard merging scheme or soft merging scheme. In fact, the attenuations of reporting channels are hardly same [1], to meet the bit error rate (BER) required by the reliable communication, the data rates would be different. In hard merging, UUs with high reporting data rate waste their reporting capability, and in soft merging scheme, UUs with low reporting data rate introduce large cost.

We propose a novel comprehensive merging scheme to achieve better throughput performance, considering the effect of different data rates of reporting channels between each UU and DC. UU with good reporting channel quality would transmit multibit quantized self observation statistics to DC (just like soft merging), and UU with bad reporting channel quality would transmit self judgement (1 bit information) to DC (just like hard merging). DC makes the final judgement by carrying out Comprehensive merging. In the proposed scheme, UU can balance the cost and its contribution to detection by choosing the better reporting method, according to its reporting channel quality. The simulation shows that the comprehensive merging scheme can outperform hard merging or soft merging scheme.

2. SYSTEM MODEL

We consider the scenario of Fig.1. UU_i ($i = 1, \dots, M$, where M denotes the number of UUs) is the independent energy detector, and reports its self judgement or its quantized self observation statistics to DC via common control channel sequentially [1],[2]. Denote vector $R = [R_1, R_2, \dots, R_M]$ as a high to low arrangement of reporting data rates. In the Comprehensive merging scenario proposed, UU_i ($i=K+1, K+2, \dots, M$) with bad reporting channel reports self judgement to DC, UU_i ($i= 1, 2, \dots, K$) with good reporting channel reports self observation statistics to DC. DC makes the final judgement by carrying out comprehensive merging.

All the UUs perform self Spectrum detection simultaneously in the sensing phase, and report self data to the DC sequentially in the reporting phase. Data of UUs are transmitted in the data transmission phase if the DC declares that the PU is inactive. The durations of the sensing phase is τ_s , the durations of the reporting phase is τ_r , and the reporting delay of each UU_i is τ_{ri} . τ_{ri-s} is the reporting delay of UU_i if UU_i reports self observation statistics, and τ_{ri-h} is the reporting delay of UU_i if SU_i reports self judgement.

3. PERFORMANCE ANALYSIS

The DC receives two kinds of data reported by UUs according to system model proposed in section II, UU_i ($i=1,2,\dots,K$) reports its self observation statistics to DC, and UU_i ($i=K+1,K+2,\dots,M$) reports its self judgement to DC. We define $\bar{P}_d$ as the target probability of system detection with which the PUs are regarded as being sufficiently protected.

In the comprehensive merging scheme, for UU_i ($i=1,2,\dots,K$), following the analysis of soft collaborative energy detection in [8], we use the test statistic given by

$$T_{S-K} = \frac{1}{KN} \sum_{i=1}^K \sum_{n=1}^N |y_i(n)|^2, \quad (1)$$

According to central limit theorem, T_{S-K} can be approximated as:

$$H_0 : T_{S-K} \sim N(\sigma_u^2, \frac{1}{KN} \sigma_u^4), \quad (2)$$

$$H_1 : T_{S-K} \sim N((\gamma+1)\sigma_u^2, \frac{1}{KN} (\gamma+1)^2 \sigma_u^4), \quad (3)$$

The probability of detection with K nodes soft merging P_{d-K} is given by

$$P_{d-K} = \Pr[Y(i) > \lambda_K | H_1] = Q\left(\frac{\lambda_K - (\gamma+1)\sigma_u^2}{(\gamma+1)\sigma_u^2} \sqrt{KN}\right), \quad (4)$$

where λ_K is the soft merging detection threshold.

To achieve the given target probability of system detection $\bar{P}_d$, according to the OR-rule, the relationship between $\bar{P}_d$ and P_{d-K} is

$$\bar{P}_d = 1 - (1 - P_{d-l})^{M-K} (1 - P_{d-K}), \quad (5)$$

$$P_{d-K} = 1 - \frac{(1 - \bar{P}_d)}{(1 - P_{d-l})^{M-K}}, \quad (6)$$

The K nodes soft merging detection threshold λ_K is given by

$$\lambda_K = (\gamma+1)\sigma_u^2 (Q^{-1}(P_{d-K}) / \sqrt{KN} + 1), \quad (7)$$

The probability of false warning of K soft merging is given by

$$P_{f_K} = \Pr[Y(i) > \lambda_K | H_0] = Q\left(\frac{\lambda_K - \sigma_u^2}{\sigma_u^2} \sqrt{KN}\right), \quad (8)$$

The probability of system false warning P_f^{K-M} when K UUs report self observation statistics is given by

$$\begin{aligned} P_f^{K-M} &= 1 - (1 - P_{f_l})^{M-K} (1 - P_{f_K}) \\ &= 1 - (1 - P_{f_l})^{M-K} \left(1 - Q\left(\frac{\lambda_K - \sigma_u^2}{\sigma_u^2} \sqrt{KN}\right)\right) \\ &= 1 - (1 - P_{f_l})^{M-K} \left(1 - Q\left(\frac{(\gamma + 1)\sigma_u^2(Q^{-1}(1 - \frac{(1 - \bar{P}_d)}{(1 - P_{d_l})^{M-K}}) / \sqrt{KN} + 1) - \sigma_u^2}{\sigma_u^2} \sqrt{KN}\right)\right) \end{aligned} \quad (9)$$

where P_{f_l} and P_{d_l} are related to $\bar{P}_d$. Fig.3 shows that P_f^{K-M} decreases when K increases. In other words, in the comprehensive merging scheme, when the number of the UUs reporting their self observation statistics to DC increases, the accuracy of sensing result will be enhanced. When UU_i ($i=1,2,\dots,K$) reports its self observation statistics to DC, and SU_i ($i=K+1,K+2,\dots,M$) reports its self judgement to DC, the total reporting delay is

$$\tau_r = \sum_{i=1}^K \tau_{ri-s} + \sum_{i=K+1}^M \tau_{ri-h} = \sum_{i=1}^K \frac{D}{R_i} + \sum_{i=K+1}^M \frac{1}{R_i}, \quad (10)$$

The throughput is given by

$$C(M, K) = \frac{T - \tau_s - \sum_{i=1}^K \frac{D}{R_i} + \sum_{i=K+1}^M \frac{1}{R_i}}{T} (1 - P_f^{K-M}) C_0 \Pr(H_0), \quad (11)$$

The relationship between the throughput C and K is obtained:

$$\begin{aligned} C(M, K) &= \frac{T - \tau_s - \sum_{i=1}^K \frac{D}{R_i} + \sum_{i=K+1}^M \frac{1}{R_i}}{T} (1 - P_{f_l})^{M-K} \times \\ &\quad \left(1 - Q\left(\frac{(\gamma + 1)\sigma_u^2(Q^{-1}(1 - \frac{(1 - \bar{P}_d)}{(1 - P_{d_l})^{M-K}}) / \sqrt{KN} + 1) - \sigma_u^2}{\sigma_u^2} \sqrt{KN}\right) \right) C_0 \Pr(H_0) \end{aligned}, \quad (12)$$

4. Numerical Results and Discussions

The system is set up as follows: The number of UUs is set to be $M=18$, and the fixed frame duration $T=20$ ms. The sampling frequency is 6 MHz and the τ_s is 1ms. The given target probability of system detection $\bar{P}_d$ is 0.99. The SNR is -18dB. We set quantization bits of observation statistics $D=8$.

Fig.2 The simulation result.

Fig.2 shows that the proposed Comprehensive mergingscheme outperforms the hard mergingscheme or the soft mergingscheme, especially when the diversity of channel quality is obvious. The throughput first increases because the probability of system false warning decreases as K grows, and then the throughput decreases as K grows, because the cost increases fast when the UUs with bad reporting channel report their observation statistics rather than self judgements to DC. There is also throughput improvement when the data rates are the same.

5. Summary

We study cost-throughput tradeoff over different reporting channel quality in a collaborative network that consists of a number of the UUs employing energy detectors and a single judgement fusion center. We propose a novel comprehensive merging scheme which outperforms both hard mergingand soft merging scheme, especially when the diversity of the reporting channel is obvious. Moreover, even in the situation of same reporting channel quality, the throughput performance can benefit from the proposed scheme.

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