Adaptive Weighting in Cooperative Sequential Energy Detection considering Instantaneously Non-Identically Distributed Samples: Review

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***Abstract*: In Cognitive Radio (CR), spectrum sensing is a process of sensing the spectrum for the primary user activity though which CR takes decision for transmission. Cooperative detection is a scheme of spectrum sensing in which various CR cooperate with each other and takes their decision collectively. Sequential Detection in which past observations are also used for taking detection decision also used to improve the performance and to further enhance the performance adaptive weighting scheme is also employed. This paper is an effort to provide an overview on sequential cooperative spectrum sensing with adaptive weighting for the case of independent and identically distributed samples, which we would like to further extend to instantaneously independent non identically distributed samples case.**

***Keywords*: CR (Cognitive Radio), i.i.d. (independent and identically distributed), i.i.n.i.d. (instantaneously independent non identically distributed), LRT (Likelihood Ratio Test), ROC (Receiver Operating Characteristics), SPRT (Sequential Probability Ratio Test)**

I. INTRODUCTION

With the increasing demand for spectrum for various high speed and advanced applications, spectrum scarcity emerged as a problem. Cognitive radio networks, is a technology which is being developed to counter the problem of spectrum scarcity based on the concept of Dynamic Spectrum Access and Software defined radios. Spectrum Sensing is a technique used by the CR to detect the empty spectrums bands(white spaces/spectrum holes), which are currently not being used by the Primary user, the user to which that band is being allotted, and allow the CR to transmit in that band. Among the various methods for spectrum sensing Energy Detection is the simplest of the method, with an advantage of not requiring the information of characteristics of channels beforehand. [1]

Cooperative Detection is introduced as a method to further enhance the detection results. In this method various CR users spatial distributed from each other share their detection information with each other, so that a better detection decision can be made. Decision can be taken in two ways either centralized, where a central entity(Fusion Centre) take the decision and convey it to all the participating CR users, or decentralized way where each CR user determine its detection and share it with all other CR users.

The performance of signal detection is evaluated by two core factors: its robustness and detection time. For robust detection, the probabilities of missed detection and false alarm should be sufficiently small such that the error probabilities are less than predefined false alarm and missed detection constraints. The detection time is directly dependent on the number of samples required to reach a decision and there is a trade-off between the robustness of a detector and the detection time.

The conventional way of designing a signal detector using a single threshold is based on the likelihood ratio test (LRT), which achieves the optimal receive operating characteristic (ROC) for a fixed sample size. The detection threshold and minimum sample size needed for robust detection are jointly determined according to the predefined false alarm and missed detection constraints.

Sequential detection minimizes the average number of samples for the same false alarm and missed detection constraints by using past observations. The sequential detector uses two thresholds and compute LLR for each sample. If, the LLR crosses one of the threshold it stops sampling and takes a decision accordingly. If, the LLR doesn't crosses any threshold it takes on sampling next observation. Two thresholds ensure finite stopping time. If the LLR value exceeds the upper threshold, a decision is made in favor of H1. If the LLR value is lesser than the lower threshold, a decision is made in favor of H0. The sequential test was introduced by Wald, also called as the sequential probability ratio test (SPRT).

Most studies design the SPRT by assuming the case of independent and identically distributed (i.i.d.) samples. But this assumption, simplifies the underlying mathematics of many statistical methods. Also, a wireless mobile channel is modeled as a time-varying communication path between two stations. The first terminal can be the stationary base station (BS), while a moving mobile station (MS) represents the second terminal. In this scenario channels becomes a multipath propagation channel with fast fading.

High velocity of the mobile CR and primary user's (PU's) high carrier frequencies give rise to a short channel coherence time, which implies that the CR systems experience fast fading; samples acquired by a detector can be approximately independent but instantaneously non-identically distributed (i.i.n.i.d.), with long sensing time in low signal-to-noise ratio (SNR) environments.

Also, practically there is a factor of transition involved with the PU, i.e., the PU can become active or idle at any time. This implies that there can be correlation between the current and previous received samples, which can be utilized for improving detection performance. This correlation is dependent on the Doppler frequency. To take into account this PU transitions, the concept of adaptive weighting is being introduced where we a lot different weights to observations collected for performing sequential detection, which in turn are dependent on how often the PU do transitions, to perform SPRT, and then take the decision. In Exponential weighting higher weighting is given to the current observation and weighting decreases for the previous observations. But considering the fixed number of past observations degrades the efficiency when the CR user is sure about its current observation. But, the detection performance gain is limited for simple exponential weighted sum of the past observations.
Instead, if the q-weighted log likelihood ratio (LLR) of the past observations is added to the current LLR sequentially, the sequential sensing performance will improve.

II. Literature Review

Yeon-Jea Cho et al. [2], presented, LRT and SPRT considering i.i.n.i.d. samples for signal detection problems that are modeled by the primary user detection scenario in CR networks. Signals that were received through wireless channels, signal and noise samples were assumed to have a zero-mean complex-Gaussian distribution. They provided the design parameters for the ideal and practical LRTs considering i.i.n.i.d. samples and concluded that there exists performance gap between the ideal and practical LRTs which is a non-negligible Relative Performance Gap, between the ideal and practical tests, which asymptotically increases to one for a large number of cognitive nodes or samples. Furthermore, they provided a more generalized design of the SPRT based on the martingale analysis with known local PDFs and also proposed a practical version of the SPRT for unknown local PDFs which optimally approximate the ideal LLR with respect to its statistical mean. Their simulation results coincide with the theoretical results.

Table 1. Literature Review

Author	Journal	Work	Outcome
Yeon-Jea Cho et al. [2]	IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY	Signal detection methods in cognitive radios considering instantaneously non-identically distributed samples	Design parameters for LRT and SPRT for the i.i.n.i.d samples
Shaojie Liu et al. [3]	IEEE, 2016	q-weighed sequential (WSED) spectrum sensing scheme based energy detection in time varying channels	q-weighting provides better results than exponential weighting
Amit Baghel et al. [4]	IEEE, 2015	sequential spectrum sensing technique considering time varying channel moving-normal method applying adaptive weighting	Adaptive weighting provides better spectrum utilization and throughput
Pinyi Ren et al. [5]	IEEE, 2015	Cyclic-shifting based sequential CSS strategy for multi-channel cognitive networks (CN)	Efficiently reduce the energy consumption as well as achieve the same sensing accuracy as compared to the traditional CSS scheme.

Shaojie Liu et al. [3], gives a q-weighed sequential cooperative spectrum sensing technique. By utilizing past local observations with the current observation in calculating the current LLR, they have shown that their method has been able to deliver substantial detection performance improvement with less complexity. Their simulation results show that the detection performance is being affected by the probability of PU for turning its state from $H0$ to $H1$ and vice versa.

Amit Baghel et al. [4] investigated the adaptive weighting strategy using sequential spectrum sensing. When licensed user is changes its state, to improve the detection performance, dynamic weighting is being introduced which maximizes the spectrum utilization. Dynamic weight adjusts itself using linear relationship according to the primary user transition activity to utilize the spectrum effectively. They have shown that, the worst case (i.e. $\alpha = \beta = 0.1$) in adaptive weighting scheme is better than the conventional weighting for higher values of Pf.

Pinyi Ren et al. [5], proposed a cyclic-shifting based sequential cooperative spectrum sensing (CSS) strategy for multi-channel cognitive networks. This scheme assigns a unique sensing sequence for each cognitive user (CU). In traditional CSS scheme a common sensing sequence pattern is being shared by all the CUs. They have shown that their proposed strategy can efficiently reduce the energy consumption along with improving the network energy efficiency. Also they were able to achieve the same sensing accuracy as in the traditional CSS scheme.

III. Conclusion

Cognitive radios has a become a technology with a promising future, which could be seen as a part of upcoming future technologies, and hence there have been a constant efforts to make the technology better and better, with the similar approach implementing Cooperative Detection can provide us with even better results. Sequential Detection also improves the sensing capabilities by considering past observations to give better detection results. Due to primary user's transitional nature, to adaptive weighting is being employed in sequential detection to further improve the detection performance. All these concepts have already been implemented for the case when the received samples are i.i.d., we would like to extend these concepts further for the case of instantaneously independent non identically distributed samples (i.i.n.i.d.), which is a more practical and general case.

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