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Contribution to Working Group 1: Definition of cognitive algorithms for adaptation and configuration of a single link according to the status of external environment

Title: *Recent advances in multiantenna spectrum sensing: complexity, noise uncertainty, and signal rank issues*

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The wireless community is showing considerable interest in the development of Dynamic Spectrum Access (DSA) techniques as a means to alleviate the apparent scarcity of spectral resources as perceived nowadays. DSA adoption will require powerful spectrum sensing schemes in order to allow the usage of spectral holes while maintaining the interference produced to licensed (primary) users at sufficiently low levels. Wireless propagation phenomena such as shadowing and fading pose significant challenges to the reliable detection of primary users. The received primary signal may be very weak, resulting in very low Signal-to-Noise Ratio (SNR) operation conditions and "hidden node" situations. Cooperative sensing has the potential to overcome the effects of shadowing, though it still relies on standalone detectors whose performance should be optimized.

Depending on the amount of information available about the structure of the primary signal, different detectors may be designed. Exploiting specific signal features (e.g. training sequences, cyclostationarity, presence of a cyclic prefix, constant envelope, or spectrum shape), it is possible to improve detection performance with respect to simpler approaches which do not attempt to model the primary signal, such as energy detection. Although energy detection is a popular sensing technique due to its low complexity, it suffers from a serious drawback: setting the detection threshold for a given performance target (in terms of probabilities of detection and false alarm) requires precise knowledge of the background noise variance. Any uncertainty regarding this parameter translates in severe performance degradation, so that the detection / false alarm requirements may not be satisfied. On the other hand, exploiting the presence of pilots and/or cyclostationary features requires some level of synchronization with the primary signal, and in very low SNRs, the synchronization loops of the monitoring system cannot be expected to provide the required accuracy for the carrier frequency and/or clock rate estimates. Given the fact that spectral holes will have to be searched within very wide frequency swaths, computational complexity of the spectrum sensing mechanisms becomes another important issue.

These considerations motivate the search for spectrum sensing schemes which (i) operate asynchronously with respect to the transmitted primary signal, (ii) are robust to deviations from the underlying signal model, and (iii) are flexible enough to allow a tradeoff between performance and complexity. Sensing schemes based on the use of multiple antennas fit this profile. These schemes hinge on the fact that the noise should be independent from antenna to antenna, whereas in the presence of a received signal, spatial correlation will be present and amenable to detection. In this work we review and summarize some recent work on multiantenna spectrum sensing developed within the Spanish project COMONSENS (www.comonsens.org).

The problem is cast as the detection of a vector-valued signal term in noise. A Gaussian model for the signal term yields schemes based on second-order statistics which allow operation in low-SNR, asynchronous settings. The channel gains from the primary transmitter to the different sensor antennas are modeled as deterministic but unknown, as dictated by practical considerations. Since optimal (in the Neyman-Pearson sense) detectors require knowledge of these channel gains, alternative approaches must be sought. In this regard, we choose to adopt a Generalized Likelihood Ratio (GLR) approach based on a low-SNR approximation of the probability density function. Different scenarios are considered, depending on the assumptions adopted on the primary signals and on the noise process (which in turn are related to the calibration accuracy at the receiver):

- As a first step, the noise processes are assumed spatially and temporally white, and with known variances. This amounts to assume perfect calibration of the analog frontends in the receiver. The resulting detectors can be thought of as multichannel generalizations of the standard energy detector, and will serve as benchmarks for the performance of other approaches more robust to noise uncertainties. These detectors bear close relationship with several well-known diversity combining techniques from the communications field, such as Maximal Ratio Combining, Selection Combining and Equal Gain Combining, and are able to exploit knowledge of the temporal correlation (spectral shape) of the primary signal, if available.
- Secondly, the case in which the noise variances are not known is considered. Initially, all antennas are assumed to have the same (unknown) noise variance. Then, this assumption is relaxed in order to allow for noise processes of different powers at each antenna, as it is likely to happen in practice.
- The model is then generalized in order to allow for primary signals with spatial rank larger than one, as would happen for example if the primary transmitter employs some sort of space-time coding (Alamouti, etc.) so that the spatial rank is given by the number of independent transmitted streams. It is shown how to improve detection performance by exploiting knowledge of primary spatial rank.
- In some scenarios under strong co-channel interference (e.g. from other secondary systems) the actual background noise will present an unknown spatial correlation. In that case, any detector must exploit the temporal correlation of the signal, as opposed to that of the noise, which is temporally white. We present a low-SNR approximation of the GLR test for this case, assuming signals with spatial rank one.
- In other situations, such as severe multipath environments, the power spectra of both signal and noise may be unknown. It is nevertheless possible to generalize several of the previous detection schemes above to address this scenario, by reformulating the GLR tests in the frequency domain.