Cyclostationary Channel Power Measurements for CBRS Coexistence Assessment

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***Abstract*—We present a compressive approach for channel power measurements in coexistence scenarios involving heterogeneous cyclostationary channel usage and an example application in the Citizens Broadband Radio Service (CBRS) band. The method leverages known cycle periods of anticipated spectrum users, including wireless data networks with time-division duplexing and pulsed radar, to analyze channel power within a cyclic analysis period. The high degree of data reduction and low degree of computational complexity makes this method suitable for edge computing and long-term spectrum monitoring applications. The results of applying this technique to data recorded in the CBRS band demonstrate its effectiveness in distinguishing signal types, enabling coexistence assessment and supporting data-driven management of spectrum sharing frameworks.**

I. INTRODUCTION

Spectrum sharing and data-driven spectrum management have emerged as parts of a multi-faceted approach to improve the efficiency of radio spectrum usage [1]. In the United States, the Citizens Broadband Radio Service (CBRS) band serves as one example in which federal incumbents and commercial entrants share the same frequency allocation. In this framework, commercial users must avoid interfering with incumbent users. A private network of sensors, called environmental sensing capabilities (ESCs), must detect incumbent users and flag a cloud-based spectrum access system when protection is required. This then temporarily disables commercial access to the spectrum in order to meet prescribed protection criteria for the incumbents. Assessing this sharing ecosystem requires measurements that can help distinguish between different spectrum users. Toward this end, we developed a data analysis approach to leverage *a priori* knowledge of CBRS occupant systems.

Coexisting signals in the CBRS band are taken to be second-order cyclostationary processes, with power varying according to known cycle periods. These periods are standardized and documented at different time scales for both federal incumbents and commercial entrants. A plurality of commercial users operate standardized time-division duplex (TDD) air interfaces, including 4G long-term evolution (LTE), 5G new radio, and WiMAX [2, Fig. 7]. For these, industry standards set a limited number of uplink/downlink switch point patterns and fixed frame durations. Interference protection for incumbents is anchored by ESC certification testing [3, Table 1], which is defined across a narrow range of pulse repetition intervals.

In this paper, we apply cyclostationary statistics to leverage these known cycle periods. This helps assess the presence of different types of users with a high degree of data reduction and fine time resolution. This work exploits the well-known signal selectivity property of cyclostationary feature detection [4, Ch. 9.2]. However, our approach contrasts prior applications of cyclostationary signal processing in spectrum sensing. First, estimates of cyclic statistics have often been exploited to estimate unknown signal parameters [4, Ch. 9.6]. Further, prior work focused on complex baseband waveform processing across a small number of modulation symbols (order of tens of microseconds) to classify air interfaces based on cyclic prefix characteristics. In contrast, here, we assess occupancy rather than modulation parameters by analyzing channel power time series across known cycle periods on the order of 10 ms.

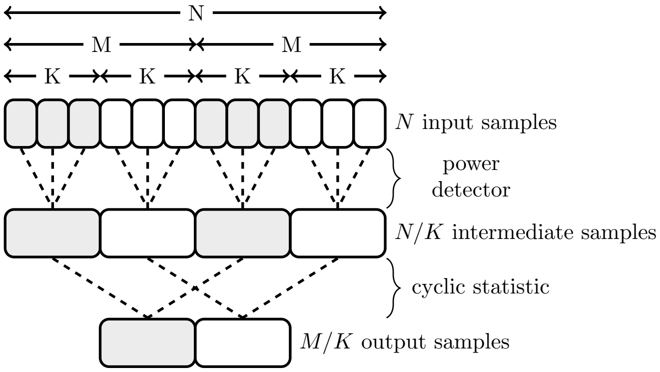

Fig. 1. Diagram illustrating the reduction of a channel power time series of length $N = 12$ samples into a single cyclostationary channel power trace. In this example, the detector period is $K = 3$ samples and the cyclic statistic period is $M = 6$ samples.

II. DEFINITION AND CALCULATION

Here we describe the calculation of *cyclostationary channel power* from a time series of contiguous samples of channel power measurements, with length N and sampling rate F_s. We apply a two-staged detection approach, shown graphically in Fig. 1. The first stage is a power detector (e.g., peak or average) with a *detector period* T_d comprising $K = T_d F_s$ samples. The second stage is a *cyclic statistic* (mean, maximum, minimum, etc.) applied across the intermediate samples sharing an index within a defined *cyclic analysis period* T_c, or $M = T_c F_s$ samples. The cyclic statistic is then computed across all N/M analysis periods. As an illustrative example, consider the intermediate result of a mean power detector. In this case, applying a mean cyclic statistic produces a result in which the n^{th} sample represents the mean power across the n^{th} sample of all N/M cyclic analysis periods. Similarly,

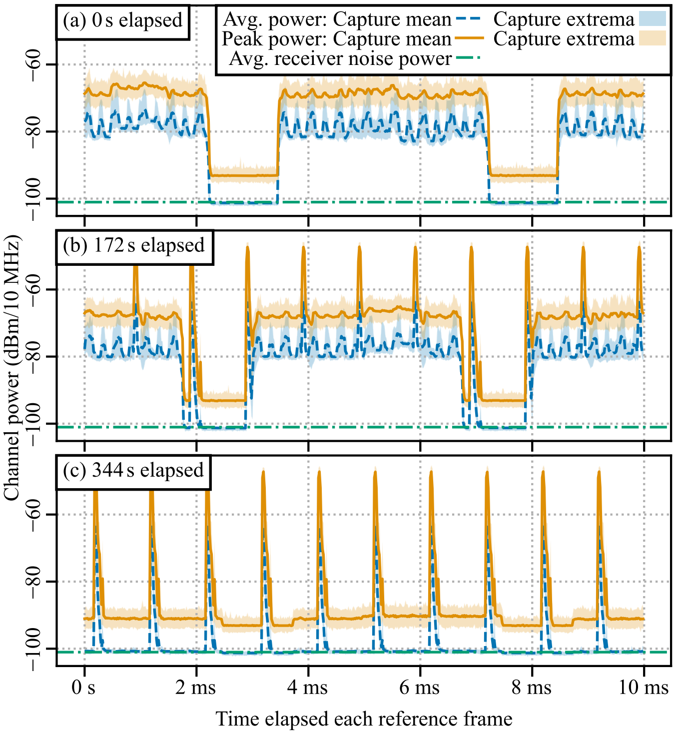

Fig. 2. Cyclostationary persistence plots of peak and average channel power measured by a CBRS spectrum sensor. These illustrate coexistence behavior as incumbents enter the channel: first (a) ongoing TDD cellular downlink transmissions by a secondary user, then (b) coexisting pulsed radar transmissions enter the channel, and (c) secondary user transmissions stop.

applying minimum and maximum statistics would yield the extrema observed in each n^{th} sample of the 400 periods. The result is compressive: each combination of detector and cyclic statistic produces M/K output samples, independent of N.

We choose values for T_d and T_c based on the time structures of expected signals in the coexistence environment. The detector period should be smaller than the duration of the shortest occupancy event of interest. The cyclic analysis period is the least common multiple of the commensurate cycle periods of anticipated signals, and M must be integer-divisible by K.

III. Results and Discussion

We applied this technique to measurements in the CBRS band. Our choices of power detectors and cyclic statistics yielded cyclostationary persistence plots. The spectrum monitoring sensor that captured the data was located near a sea port in coastal Virginia [5].

The sensor repeated frequency sweeps across 3550–3700 MHz in 10 MHz steps, matching the channelization of the CBRS band. Each step produced a time series of channel power samples with $N = 56$ megasamples at $F_s = 14$ MS/s. Peak and average power detectors were applied, both with $T_d = {}^1\!/_{56}$ ms ($K = 250$), the shortest transmission duration permitted in 5G cellular standards [6]. Each power detector produced $N/K = 224{,}000$ intermediate samples. We computed mean, minimum, and maximum cyclic statistics on each intermediate result, each configured with $T_c = 10\,\text{ms}$ ($M = 140{,}000$), the least common multiple of the cycle periods $\{1\,\text{ms}, 5\,\text{ms}, 10\,\text{ms}\}$ from pulsed radar, WiMAX, and TDD cellular, respectively. This time structure divided the total capture into $N/M = 400$ cyclic analysis periods, each of size $M/K = 560$ samples. Each cyclic statistic therefore produced a single series of 560 samples spanning the 10 ms cyclic analysis period with sample spacing $T_d = {}^1\!/_{56}$ ms.

To illustrate this application of the technique, a sequence of consecutive field measurements collected by the same sensor is shown in Fig. 2. The time elapsed since the measurement shown in (a) is shown for each plot in its upper left corner. In (a) and (b), the cyclic mean statistic for both the peak and average power detectors show clear TDD characteristics. The "on" period represents base station (downlink) transmissions aligned with the "configuration 2" from the coexistence specification [7], while "off" is dedicated mostly to uplink activity that is too weak to detect in this trace. In (b), pulsed activity with the same pulse rate as an incumbent radar enters the channel, before the cellular users vacate the channel in (c). Notably, the range of extrema are narrow here relative to the wide amplitude swing observed in each channel. Further, while the channel activity is apparent with time resolution below 20 µs, the full 4 s recording with 10 MHz instantaneous bandwidth was characterized with only six series of 560 samples.

IV. Conclusion

We developed a cyclostationary signal processing technique in a novel application to measurements of channel power in the time domain. Further, application to field data succeeded in identifying canonical coexistence behavior in the CBRS band. Such information may be useful in assessing and eventually optimizing spectrum sharing frameworks.

Acknowledgment

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References

[1] Federal Communications Commission, "Advancing Understanding of Non-Federal Spectrum Usage," Notice of Inquiry FCC 23-63, August 2023. [Online]. Available: https://docs.fcc.gov/public/attachments/FCC-23-63A1.pdf

[2] D. Boulware *et al.*, "An Analysis of Aggregate CBRS SAS Data from April 2021 to January 2023," U.S. Dept. of Commerce, Nat. Telecom. and Inf. Admin., Technical Report TR-23-567, May 2023. [Online]. Available: https://its.ntia.gov/publications/3311.aspx

[3] F. H. Sanders *et al.*, "Procedures for Laboratory Testing of Environmental Sensing Capability Sensor Devices," U.S. Dept. of Commerce, Nat. Telecom. and Inf. Admin., Technical Report NTIA TR-18-527, November 2017. [Online]. Available: https://its.ntia.gov/publications/3184.aspx

[4] A. Napolitano, *Cyclostationary Processes and Time Series*. Elsevier, 2020.

[5] D. A. McGillivray *et al.*, "Draft CBRS Ecosystem Sharing Assessment (SEA) Test and Metrology Test Plan," February 2023, draft. [Online]. Available: https://www.nist.gov/programs-projects/cbrs-sharing-ecosystem-assessment

[6] 3GPP TS 38.211, "New Radio (NR); Physical channels and modulation," 3rd Generation Partnership Project, Rev. 15.2.0, June 2018.

[7] ONGO-TS-2001, "OnGo Coexistence Technical Specifications," OnGo Alliance, Rev. 3.2.0, May 2022.