An Analysis of Low-Cost SDRs to Meet City-Wide Spectrum Utilization Measurement Requirements

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***Abstract*—This paper surveys the current marketplace offerings for low-cost software-defined radio (SDR) technology and proposes a framework for cost-optimizing distributed sensing networks using a scenario in the Citizens Broadband Radio Service band. To determine which SDR to select, it is necessary to model sensor performance within its operating context. We identify detection radius as a metric of primary concern in cost-optimizing a sensor network, and determine that further work is required to evaluate the sensitivity of low-cost SDRs.**

I. Introduction

Spectrum sensing can provide data to inform more effective resource sharing through improvement of radio propagation and transmission density models. Wide-area spectrum sensing networks can be expensive due to the number of sensors required to cover a large geographical area. If we are to measure spectrum utilization to quantify ever-increasing demand, it is critical to examine how to reduce the cost of distributed sensing networks. This paper introduces a dataset of low-cost software-defined radio (SDR) characteristics, and provides a framework for selecting SDRs for a distributed sensing network where deployment cost is a principal constraint.

Because sensor performance is defined in the context of its application, it is necessary to define a use case to have a productive discussion about sensor merits and drawbacks. Such a use case would constrain the problem space and provide a basis for reasonable assumptions, when required. To illustrate how the data presented in this paper can be used, we consider the case of a distributed sensor network designed to detect Citizens Broadband Radio Service (CBRS) Device (CBSD) use in Boulder, Colorado, with the ultimate goal of augmenting utilization data such as that described in [1].

The CBRS band of 3.55-3.7 GHz operates on a tiered authorization framework in which lower priority users are not permitted to interfere with higher priority users [2]. CBSDs exist in two classes. Category A CBSDs transmit a maximum EIRP of 1 W and can be indoors or outdoors with antenna heights less than 6 m; Category B CBSDs transmit up to 50 W EIRP and are located outdoors with antenna heights greater than 6 m. In this paper we explore detecting CBRS priority access or general authorized access use with the requirement of detecting Category A CBSDs.

II. Survey of Available Low-Cost SDRs

Beginning in early 2022, we started collecting information about SDRs costing $5000 or less. The resulting dataset contains 45 SDRs with specifications including maximum instantaneous bandwidth (IBW), maximum sample rate (SR), and operational frequency range [3]. We define "low-cost" as $700 or less, noting a gap in pricing between $700 and $1000. Due to the rapidly evolving nature of the market, we can only certify that the data were accurate at the time of the original survey. Still, the data provide insight into the landscape of the SDR market in 2022.

As illustrated in Fig. 1, only eight of the SDRs surveyed[1] cost less than $700 and are capable of measurement within the CBRS band. Of these eight sensors, summarized in Fig. 2, three lack a capability to export low level I/Q data [4], limiting flexibility in processing measurements. The remaining five are the RadioHound [5], HackRF One [6], bladeRF [7], bladeRF 2.0 micro xA4 [8] and ADALM-PLUTO [9].

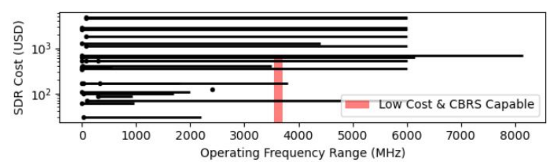

Fig. 1: Operating frequency range for low-cost SDRs.

Selecting SDRs for a distributed sensing network is more challenging than simply comparing data sheets. Data sheets can inform an appropriate operating range for each sensor, but they generally lack information on receiver noise figure, a critical characteristic for determining network configuration.

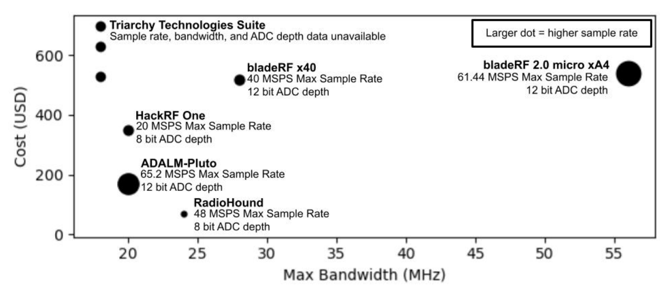

Fig. 2: Cost, maximum instantaneous bandwidth, and maximum sample rate of selected low-cost SDRs.

[1]Certain commercial equipment and materials are identified in this report to specify adequately the technical aspects of the reported results. In no case does such identification imply recommendation or endorsement by the National Telecommunications and Information Administration, nor does it imply that the material or equipment identified is the best available for this purpose.

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III. Framework for Sensor Network Optimization

The overhead cost of a sensing network is defined by two key factors: cost per sensing node and number of sensing nodes. The cost per sensing node is a combination of SDR and sensor deployment costs. For this paper, we assume SDR cost accounts for a quarter of the cost of a sensing node, and SDR housing, peripherals, and initial deployment accounting for the remaining cost of the node, for a total of $2800 per sensing node. This estimate is meant to be a starting point for discussion, rather than an exact value, and only encompasses the overhead cost of deploying the network. It does not account for the costs of continued maintenance.

The number of sensing nodes required to cover a given area is dependent on the maximum possible spacing between any two nodes in the network. In this section we propose that cost optimization of a distributed sensing network begins with modeling sensor maximum radius of detection, $r_{\max}$.

A. Modeling Sensor Maximum Radius of Detection

Minimum detectable signal level at each sensor is given by

$$P_{\text{Rmin}} = kTBF_n \times \text{SNR}_{\text{min}} \quad \text{[W]} \tag{1}$$

where k is the Boltzmann constant, T is temperature, B is equivalent noise bandwidth, F_n is noise figure, and SNR_{min} is the minimum signal-to-noise ratio required for detection. Received power at distance r, referenced at the sensor antenna terminal, can be estimated as

$$P_R(r) = \frac{P_T G_T G_R}{L_R(r) L_c} \quad \text{[W]} \tag{2}$$

where P_{T} is transmit power, G_T is transmitter gain, G_R is receiver gain, and L_c is clutter loss. Free space path loss is defined as

$$L_R(r) = \left(\frac{4\pi r f}{c}\right)^2 \quad \text{[dimensionless]} \tag{3}$$

where f is frequency and c is the speed of light in a vacuum. We use these equations to find $r_{\max}$ and model how $r_{\max}$ depends on system assumptions.

B. Modeling Network Deployment Cost

To model the cost of a CBRS sensing deployment, we begin by assuming 300 K temperature, 10 kHz equivalent noise bandwidth, 3 dB noise figure, and $G_T P_T$ = EIRP = 30 dBm, the maximum permissible transmit power for a Category A CBSD. Assuming the simplest case sensing deployment, G_R = 0 dB.When considering clutter, we use the value L_c = 30 dB, the 90th percentile of median clutter loss in a suburban environment as verified in Boulder, CO, at 3.5 GHz for a 400 m 3D clutter distance [10, see Fig. 7]. Assuming a 10 dB SNR_{min}, the resulting maximum radius of detection is 7.1 km.

A 25 km × 25 km deployment would be large enough to cover the city of Boulder, CO. Measuring CBSD signals over this area would require nine sensors, for a deployment cost of $25 200, assuming $2800 per sensing node. An illustration of this network's coverage is shown in Fig. 3.

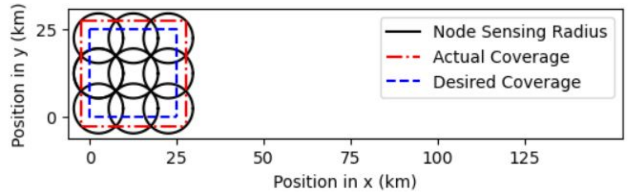

Fig. 3: Coverage of hypothetical sensing deployment.

IV. Summary

The ability to sense spectrum utilization over a wide area at minimal cost is critical to managing the increasingly crowded RF spectrum. This paper demonstrates how SDR characteristics can be used to design cost-optimized sensing networks and suggests that more work be done to make full use of this design framework. As discussed, SDR data sheets often lack noise figure information required to model sensing radius. We plan a future paper with SDR calibration measurements that can inform distributed sensing network design.

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