Spectrum Sharing with Rotating Radar: Implications for Cognitive Radio Rendezvous

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***Abstract*—To date, research on spectrum sharing has almost exclusively studied dynamic access limited to agility in time & frequency. Even prior work specifically on sharing with radar systems typically proposes switching to another frequency upon detection of radar activity. An opportunity exists for a more comprehensive reuse of spectrum in the space & time dimensions in the case of rotating radars. Drawing from measurements of an actual radar system, this paper studies how an ad hoc network of cognitive radios lacking a common control channel can discover one another—the rendezvous problem—while simultaneously coexisting with this class of radar.**

I. INTRODUCTION

The ability of dynamic spectrum access to recycle otherwise idle spectrum offers one means to satisfy the burgeoning demand for spectrum. Much of the prior literature in the field examines sharing in the TV band. Spectrum sharing with radar, by contrast, receives relatively scant attention. The *dynamic frequency selection* (DFS) option within IEEE 802.11(h) appears to be the only widespread, commercially-available approach: detection of radar pulses causes the network to switch to another frequency. Although some research structures waveforms to foster coexistence (e.g., [1]) the intent there isn't the dynamic adaptation to rotating radars sought here. One noteworthy paper [2] does recognize the intrinsic differences that spectrum sharing with rotating radar has compared to sharing with broadcasters, and the authors develop statistical models to forecast the traffic carrying capacity of a cellular service. With an infrastructure-based model, however, their design does not confront the same challenge during network formation as an ad hoc network lacking a common control channel network does. The task of independent CRs discovering one another and forming a network is known as the *rendezvous problem* [3].

To fully exploit spectrum sharing with a rotating radar the CR must accommodate the operating characteristics of radar systems, characteristics quite different than TV broadcasts. Even if all radar system locations and specifications could be retrieved from a database that information wouldn't tell a CR whether or not the radar antenna's main beam faced the CR at a given instant in time. Sensing needs to be part of the solution too. Moreover, the sensing must account for the fact that radars, unlike broadcast services, have very low duty cycle transmissions, often with a varying pulse repetition interval (PRI), and spend a large portion of time listening for faint returns. Also, even at times when there is no risk of harmful interference to the radar, the radar's high power (kW to MW) may deliver enough power in some sidelobes to preclude communications.

II. MEASUREMENTS

Measurements conducted for this research serve as a test stimulus to the system model introduced in the next section; the source is the airport surveillance radar (ASR) at Dulles. Even though safety of life considerations ultimately may preclude sharing with civil aviation radars, these measurements nonetheless serve as an exemplar of rotating radar signals. Fig. 1 (top panel) shows measured high power peaks corresponding to a 12.5 RPM revolution rate. The bottom panel shows a detailed view (1000× timescale) of one of these peaks in which both the individual pulses (mean of PRIs $\approx$1 ms) and shape of the antenna gain pattern as it sweeps past the fixed observer are clearly evident. The pulses themselves (plot omitted due to space) lasted $\approx$1 μs each. This measurement comes from a research grade software defined radio (SDR) that is a common platform for CR development; the SDR is an Ettus USRP N210 with a SBX transceiver card connected via a protective limiter (Mini-Circuits VLM-63-2W-S+) to a single, omnidirectional antenna.

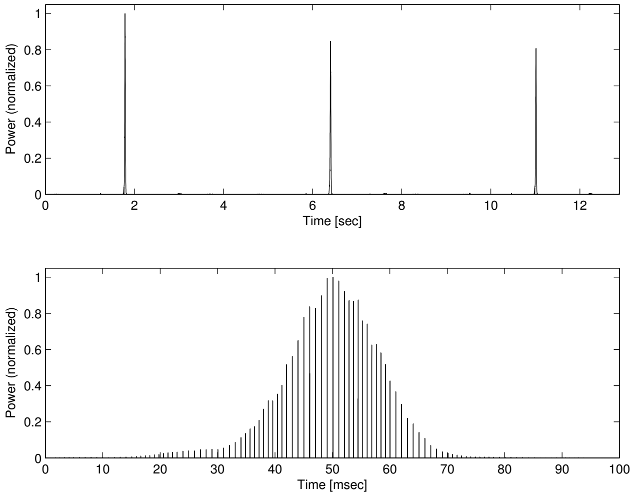

Fig. 1. Measurement of an ASR at Dulles.

III. System Model

Here all CRs incorporate GPS receivers for both geolocation and a common time reference. The geolocation keys the lookup of a factory-programmed database of radar facilities and their operating parameters as well as configuration of compatible spectrum sharing configuration. The scope of this analysis limits the geographic extent of the network to the scan region of a single radar system. The common time reference permits a simple form of rendezvous known as the synchronous model and, post rendezvous, facilitates timeslotted channel access among the CRs. Furthermore, the radio band is subdivided into frequency channels, and the CRs can hop to one channel per timeslot. A common trade-off for the spectrum agility of CRs is that their RF front ends may lack the selectivity of conventional wireless devices. Consequently, when the radar's main beam covers a CR's position this system model assumes the CR's receiver suffers saturation for all frequency channels in the band. Of course, for a CR sufficiently close to the radar even sidelobes can cause saturation. This analysis makes the simplifying assumption that all sidelobes are suppressed by least the 25 dB nominal specification for ASR-9 radar [4] and that this suppression suffices for the CR's receiver. A more comprehensive analysis than presented here could also examine the sidelobe-based path from the CR transmitter to the radar's receiver in order to evaluate the probability impairing the radar's performance. Before conducting the rendezvous, each CR senses the radio band until it measures the radar's rotation period, the period's time offset with respect to a global clock and the time duration of the main beam. From these measurements each CR knows in which timeslots it must be silent within a previously-agreed periodic *epoch*, a contiguous set of timeslots that collectively last one rotation period of the radar.

For the rendezvous algorithm itself the top-cited, state of the art work [3] follows a *sequence-based* approach in frequency hopping among the channels. Their mathematical analysis provides theoretical guarantees of rendezvous in ideal circumstances but hasn't accounted for timeslot blockage due to revolving radar. The specific technique evaluated here is the Modified Modular Clock Algorithm (MMCA) [3]. To summarize, in MMCA each CR starts on one of the frequency channels $[0, 1, \ldots, m)$ and selects a channel step rate, $r \in [0, m)$ and a prime number, $p \in [m, 2m]$. For a duration of up to $2p^2$ timeslots MMCA selects the next channel, c_{next}, based on the following rule: if $(c_{current}+r) \bmod (p) < m$ then use this value for c_{next}; otherwise, select c_{next} at random from $[0, m)$ channels. Once tuned to a frequency channel the CR emits a rendezvous request. The mechanics of channel access can be implemented in many ways (e.g., carrier sense multiple access with collision avoidance); here it is treated as reliable. If a CR does not complete rendezvous in $2p^2$ timeslots then it selects a new $\{r, p\}$ and repeats the channel hopping rule.

This study evaluates expected time to rendezvous (ETTR) for this system by simulation. The radar band is subdivided into a fixed number of channels (20) while the number of CRs is varied to produce a node-to-channel ratio ranging from $(\frac{1}{2}) \times \ldots 2\times$, and the timeslots last 10 ms. In each of the 10^3 experimental trials each CR sees a random time offset of the previously-recorded radar signal from the Dulles ASR. Any portion of the signal within 25 dB of the maximum peak forms the basis of blocked timeslots. Like most prior rendezvous studies, pairwise rendezvous of all CRs was the objective; this can be generalized to larger groups by having joined pairs search for other pairs. Each trial had an absolute time limit of 1 simulated minute.

IV. Results

Fig. 2 compares the ETTR in the presence of radar (boxplots) to the case without radar (shaded, overlay line). Both exhibit monotonically diminishing ETTR as the node-to-channel ratio increases. Due to the skewness of the distribution (heavy, positive tail) the plotted boxplot center bars and overlay line are median ETTR values. Their nearly indistinguishable medians provide evidence of the robustness of the rendezvous algorithm in this experiment. Additionally, plotting the maximum rendezvous time among the set of nodes in each trial (omitted for space reasons) shows qualitatively similar results with tails almost all within one epoch (here 480 timeslots). In summary, properly structured spectrum sharing techniques can enable network rendezvous in the presence of rotating radars.

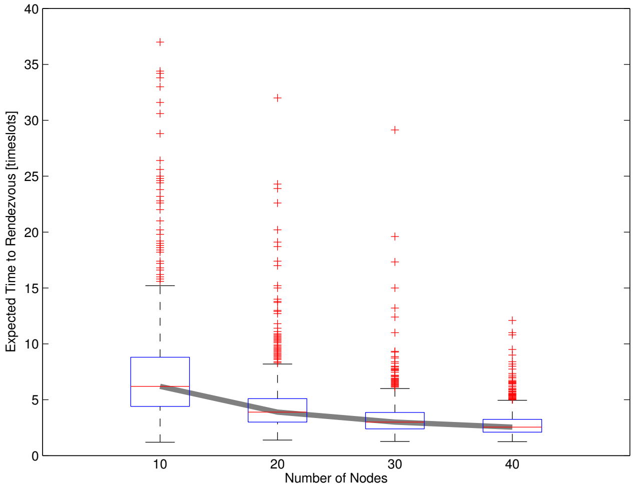

Fig. 2. Distribution of ETTR with Radar (boxplots) and Median ETTR without Radar (heavy, shaded line).

References

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