Demonstration of an Environment Sensing Capability Prototype for Shared Access with Rotating Radars

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***Abstract*—In this demonstration, we present a design of a multi-objective Environmental Sensing Capability (ESC) device that facilitates SA with ground-based fixed rotating radars. The proposed ESC device design 1) detects radar signals; 2) measures interference from SUs for radar protection; and 3) also measures SUs airtime utilization (ATU) in a channel. The ATU information can be used to help SUs to select channels with better spectrum utilization. We present an ESC-SAS network Architecture in which a SAS is supported by ESC to provide SA with rotating radar systems. The proposed network architecture can help reduce the size of currently proposed large exclusion zones around the rotating radar systems. We also implement a prototype of the proposed ESC device on a Xilinx Field-programmable gate array (FPGA). We evaluate the performance of the implemented ESC device and show that with close to hundred percent probability: 1) it can detect radar signals; 2) it can distinguish them from SU signals; and 3) it can detect airtime usage of SUs.**

I. Introduction

More than a decade of research has shown that sensing-based shared access (SA), where secondary users (SUs) monitor the environment to detect the primary user (PU) signals and operate whenever the band is empty, alone cannot guarantee efficient operation of SA-based systems [1]. This deficiency has generated intense research interest in the design of functional elements for SA-based systems that can enable an advanced sharing regime which effectively protects primary users (PUs) operations while maximizing secondary spectrum usage. In the context of SA in rotating radar spectrum, recent works in [2], [3], [4] have proposed system designs that consist of both sensing and database based components to facilitate spectrum sharing. The proposed system designs consist of four functional elements: 1) spectrum access system (SAS), which is a control database and an automated frequency assignment entity; 2) environmental sensing capability (ESC), which consists of multiple distributed devices used for detection/protection of incumbent radar systems; 3) network infrastructure (NI) nodes, such as access points, base stations and gateways; and 4) SU devices.

In this demonstration, we focus on an ESC-SAS based sharing approach in the frequency channels of ground-based fixed rotating radar systems. In our work, we design and prototype a sensor/measuring device, a network of such devices can enable an ESC to assist the SAS to allow an efficient use of the frequency channels of ground-based fixed rotating radar systems on a SA-basis. The proposed ESC can help reduce the size of currently proposed large exclusion zones around the rotating radar systems [2]. This in turn can allow a higher number of SU transmissions with the same level of interference protection to a radar system. In particular, we present a novel ESC algorithm which is used to: 1) detect the presence of a radars' transmissions; 2) measure interference from SUs for incumbent protection; and 3) measure SU airtime utilization (ATU) in a channel which can be used by a SAS to help improve SU spectrum utilization. A prototype of the proposed ESC device is also implemented on a Xilinx Field-programmable gate array (FPGA). The effectiveness of the proposed design and its FPGA-based implementation is tested under various scenarios.

II. Proposed ESC Device Design and Its Prototype

In our recent work [3], using real measurements of radar spectrum usage, MATLAB mapping toolbox, MySQL software and Wireless Open Access Research Platform (WARP) platform nodes [5], we combine powerful data, software and hardware related tools to implement a realtime SAS (database and access control server) assisted SA system between rotating radars and wireless communications. Broadly speaking, the SA system in [3] is based on a zone-based model which divides the area around a rotating radar into three zones, where the rotating radar itself is located at the center of the zones. In Zone 1, opportunistic secondary operation is strictly forbidden as it can cause interference on the incumbent radar. In Zone 2, REM-enabled temporal sharing takes place, in which the users (assisted by the REM) can transmit during the times when the radars main beam is pointing in another direction. Finally, in Zone 3, the users are free to use the spectrum, as they are outside the interference area of the radar.

In this paper, we build on our previous work in [3], and design/prototype a multi-objective ESC device to assist the SAS for SA in rotating radar channels. The proposed multi-objective ESC device not only detects the presence of radar transmissions and measures interference for incumbent protection but can also measure in parallel SU airtime utilization in a channel which can be used to help improve SU spectrum utilization. The proposed ESC device is one of a network of devices which are deployed at the boundary of Zone 1 of a radar. The proposed ESC can particularly facilitate interference-free temporal sharing in Zone 2 with the radar. By deploying interference measurement sensors at an approximate height of a typical four storey building, a SAS operator can be informed when and where the reference power threshold (defined by a regulatory body) is exceeded. In the proposed ESC, the SAS can also be notified about the measurements of secondary ATU. By obtaining ATU across different channels, the SAS can maximize channel usage efficiency by performing airtime usage-based load balancing across the channels.

A. Motivation for the FPGA-based ESC Device

Most challenging issues in implementing a multi-objective ESC are the speed and accuracy with which large scale I/Q samples of signals are required to be processed to perform multiple signal detection/measurement tasks. To address the challenges, we present a multi-objective ESC device design which is prototyped on the Wireless Open Access Research Platform (WARP) FPGA board. At the heart of the proposed ESC design is a Xilinx Virtex-family Pro FPGA. This family of FPGAs is very well suited for the real-time DSP-intensive operations required by the proposed multi-objective ESC. For example, a low-cost Xilinx FPGA with a sampling frequency of 40 MHz can process 32 samples of a radar pulse whose duration is 0.8μs. An FPGA can process large number of samples in real time to make multiple detection/measurement decisions in parallel. The proposed algorithm is implemented on the WARP FPGA board using the Xilinx System generator which provides the possibility of functional simulation even before the compilation of the designed model. Xilinx System

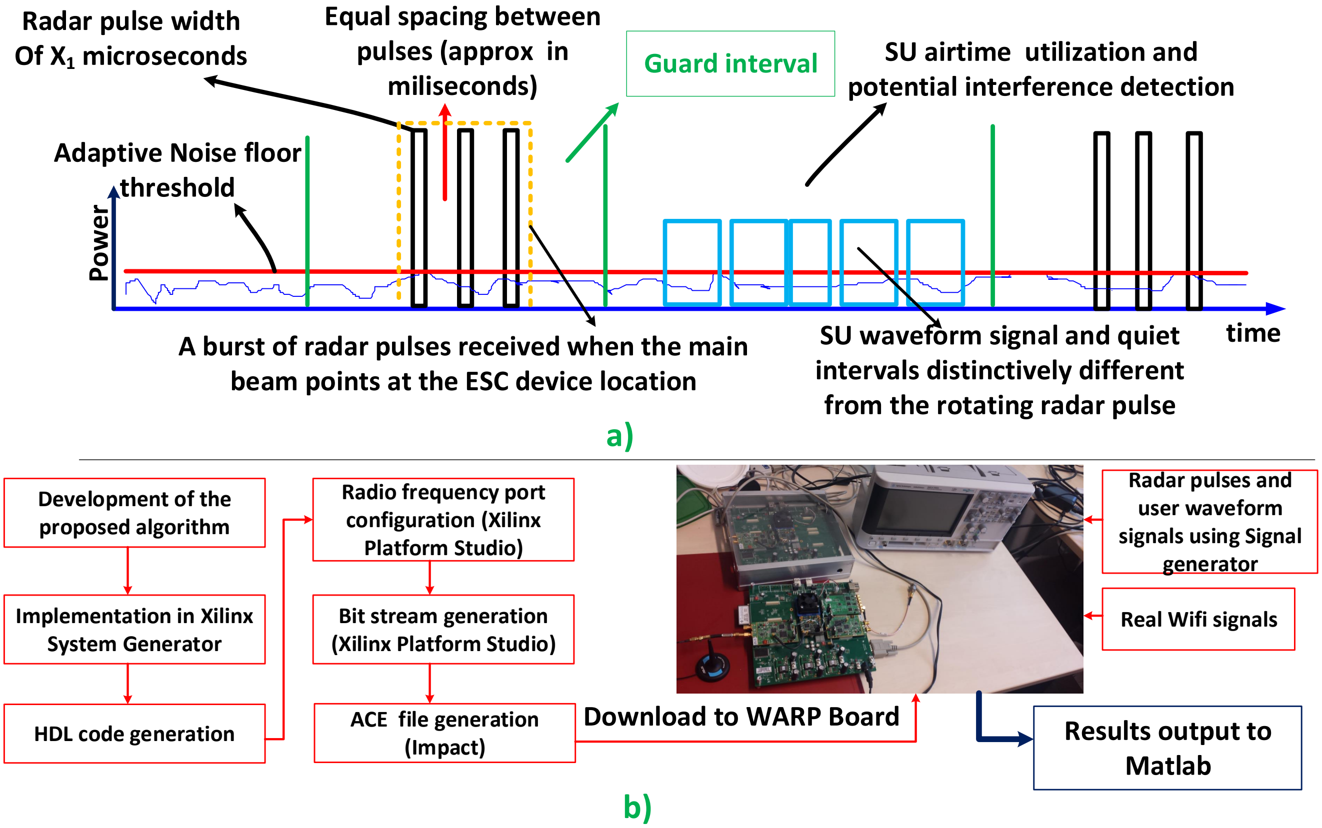

Fig. 1: a) Group of rotating radar and SU pulses under the Zone-based SA; b) Steps involved in implementation of the proposed ESC device on a WARP board.

Generator (XSG) provides a set of models (blocks) for several hardware operations that could be implemented on various Xilinx FPGAs. One of the advantages of XSG is the capability of generating HDL code from the implemented design.

B. Proposed Multi-objective ESC device algorithm

As illustrated in Fig. 1, the rotating radar signal includes a plurality of equally spaced pulses having magnitude that is significantly greater than magnitude of a SU signal transmitted using a typical unlicensed wireless access scheme. At a given location radar pulses are received periodically/quasi-periodically as a group of pulses with a particular size, each pulse has a particular duration, and also a particular pulse spacing between two pulses. The proposed algorithm exploits such distinctive feature of radar pulses to detect it and distinguish it from SUs signals. As different rotating radar systems are designed for specific applications, hence, their pulse duration, pulse spacing and the size of group of pulses tend to be different from one model to another.

In the proposed algorithm, a radars' pulse properties, such as the duration of each pulse, pulse spacing, and the size of group of pulses are provided to the ESC device for a particular radar in its vicinity. The ESC device performs the following four tasks simultaneously in real-time: 1) *Adaptive noise floor estimation (NFE):* it measures/updates the noise level to set a threshold level N_F for the signal detection; 2) *Detection of radar pulse:* it analyzes the received signal to determine if the signal exceeding the N_F contains radar signal; 3) *Interference Detection:* it analyzes the received signal to determine if the signal exceeds an interference threshold value I_{th} (defined by a regulatory body). If the radar signal is not declared and the signal exceeds the I_{th}, the ESC notifies the SAS, otherwise, when the radar signal is declared the SAS is not notified; and 4) *ATU measurement:* it measures the SUs ATU. If the radar signal is not detected, the ESC device periodically notifies the SAS, otherwise, the ATU is declared as the radars' ATU and the SAS is not notified.

The core idea of the proposed algorithm is as follows:

- In the proposed algorithm, the ESC device utilizes identifying data (an example of which is given in Table 1) to recognize a certain radar pulse and also to distinguish it from SU signal waveforms. The ESC device analyzes the received signal in real time to determine if the signal contains a radar pulse, if a radar pulse is detected it ignores the outcomes of *Interference* and *ATU* measurements for the specified times, otherwise, the outcomes are updated to the SAS as required.

The complete details of the proposed ESC device algorithm and its hardware implementation are available at [6]

REFERENCES

[1] S. Bhattarai, J. M. J. Park, B. Gao, K. Bian, and W. Lehr, "An overview of dynamic spectrum sharing: Ongoing initiatives, challenges, and a roadmap for future research," *IEEE Transactions on Cognitive Communications and Networking*, vol. 2, no. 2, pp. 110–128, 2016.

[2] M. Cotton, M. Maior, F. Sanders, E. Nelson, and D. Sicker. (March, 2012) Developing Forward Thinking Rules and Processes to Fully Exploit Spectrum Resources: An Evaluation of Radar Spectrum Use and Management. Accessed on: 17-10-2016. [Online]. Available: http://www.its.bldrdoc.gov/publications/2669.aspx

[3] Z. Khan, J. J. Lehtomaki, S. I. Iellamo, R. Vuohtoniemi, E. Hossain, and Z. Han, "IoT Connectivity in Radar Bands: A Shared Access Model Based on Spectrum Measurements," *IEEE Communications Magazine*, vol. 55, no. 2, pp. 88–96, 2017.

[4] F. H. Sanders, E. F. Drocella, and R. L. Sole, "Using On-Shore Detected Radar Signal Power for Interference Protection of Off-Shore Radar Receivers," National Telecommunications and Information Administration (NTIA), USA, Tech. Rep., March, 2016, Accessed on: 17-10-2016. [Online]. Available: https://www.its.bldrdoc.gov/publications/download/TR-16-521.pdf

[5] Rice University WARP project. [Online]. Available: http://warp.rice.edu/

[6] Z. Khan, J. J. Lehtomäki, E. Hossain, M. Latva-aho, and A. Marshall. Design and Prototype of a Multi-objective Environmental Sensing Capability for Shared Access with Rotating Radars. Accessed on: 17-10-2016. [Online]. Available: http://www.ee.oulu.fi/zaheer