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Request for Information on the National Spectrum Research and Development Plan

Ben Wu and Kevin Gifford

Interference Tracking and Categorization for

National Radio Dynamic Zones

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1. Motivation and Objectives

1.1 Motivation

Real-time spectrum sensing plays a key role for spectral resource allocation in national radio dynamic zones (NRDZ). The resource allocation problem can be summarized as enabling the usage of radio frequency spectrum for multiple systems at different (1) times, (2) frequencies, and (3) locations in space. Real-time spectrum sensing addresses the cognition of spectrum usage in time and frequency [1], [2]. In this proposed research, we will present a sensing system that accurately measures the location of an interference source (Fig. 1). With comprehensive cognition of time, frequency, and location, dynamic and efficient spectral allocation can be achieved in NRDZ*.

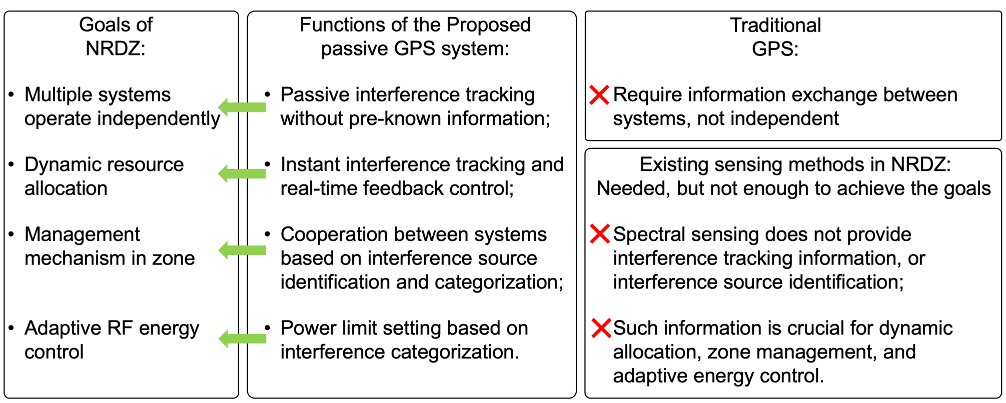

Fig. 1 Functions of the proposed system and how the functions meet the goals of NRDZ.

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This proposed research addresses “priority areas for spectrum research and development” in “Request for Information Notice”, especially areas of “spectrum resilience”, “dynamic spectrum access and management”, and “spectrum situational awareness at scale”.

The existing method for tracking interference sources is based on pre-known information shared or published by the spectrum users. For example, low earth orbit satellites generate interference to a radio telescope array, and the tracking information for low earth orbit satellites is shared to the radio telescope array. This does not meet the ultimate goal of independent operation in NRDZ. The goal of independent operation achieves ideal system robustness, so an NRDZ can manage any type of interference without pre-known information. In this proposed research, the sensors in NRDZ passively track the locations of the interference sources with neither pre-known information about the sources nor communication with the sources, which achieves complete independence.

1.2 Objective

The comprehensive information of time, frequency, and location of the interference source enable efficient use of all the possible resources of the radio frequency spectrum. The goal of this proposed research is to locate the interference source in sub-meter resolution and track the movement of the interference source. With accurate measurement of interference source locations, a receiver such as a radio telescope array can coordinate based on the location information. More importantly, tracking of movement of interference sources can provide key information to infer what type of system is generating the interference, such as a pedestrian, car, satellite, or drone, as well as the communication protocols they are using. The inference information will guide the receiver to coordinate future usage of the spectrum with the interference sources.

2. Method and Research Plan

2.1 Interference Tracking with a Passive GPS Model

In this proposed research, we developed a passive GPS model to accurately measure the location of an interference source. The Global Positioning System (GPS) has been deployed to provide geolocation information with sub-meter resolution [3]; however, the traditional GPS technology cannot be directly used for interference source tracking in NRDZ. With traditional GPS technology, satellites send signals to the target to measure the distance between satellite and the target (Fig. 2 left). To track an interference source in NRDZ, the behavior of sending measurement signals from the sensors to the interference source would generate additional interference which is unwanted in spectrum-controlled areas, such as observatories with radio telescope arrays.

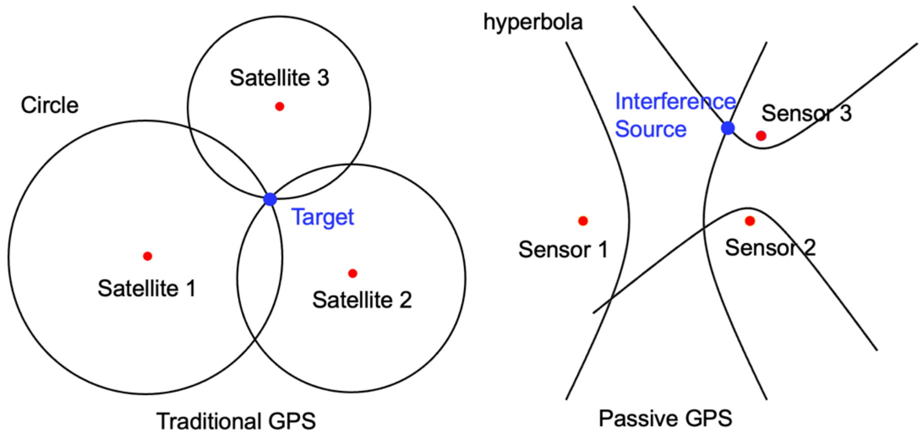

Fig. 2 Comparison between traditional GPS (left) and passive GPS in this proposed research (right)

To accurately measure the location of an interference source without sending signals from the sensors, we developed a passive GPS method (Fig. 2 right). In this method, all the sensors passively receive signals. At time t, interference source sends a signal. At time t_{m1}, sensor 1 measures the arrival time of the signal and it takes t_1 for the signal to transmit from the interference source to the sensor 1. With n sensors, we can have n different arrival times:

$$t - t_{m1} = t_1$$

$$t - t_{m2} = t_2$$

$$t - t_{mn} = t_n$$

Although t and t_1 are unknown, the difference of arrival times between two sensors can be measured with t_{m1} and t_{m2}, and calculated as:

$$t_1 - t_2 = t_{m2} - t_{m1}$$

With a known t_1- t_2, the interference source should be in a hyperbola curve defined by the two sensors, where the two sensors are located at the two focus points of the hyperbola. The distance between the two sensors can be measured and are defined as $2C$. The arrival time difference (t_1- t_2) defines the distance between two vertices for the hyperbola:

$$2A = (t_1 - t_2)\times c = (t_{m2} - t_{m1})\times c$$

Where c is the speed of light. The coordinate of the interference source (x, y) is determined by the hyperbola curve:

$$\frac{x^2}{A^2} - \frac{y^2}{B^2} = 1$$

Where $B^2 = C^2 - A^2$. Note: we use lower case c to represent the speed of light and upper case C to represent the focal length of the hyperbola.

With another pair of sensors (sensor 2 and sensor 3 in Fig. 2), another hyperbola curve is obtained, and the interference source is located at the intersection point between the two hyperbola curves. This method is similar to the traditional GPS in terms of finding intersection point between curves. The difference is that in traditional GPS, the satellites actively send signals, and measure the distances between satellites and the target. The location of the target is determined by the intersection of multiple round curves defined by the several distances. In this proposed method, the sensors passively receive signals, and the location is determined by the intersection of hyperbola curves. This is why we name our method “passive GPS”.

Although the two-dimensional case is discussed, this method can easily be expanded to three dimensions by adding another pair of sensors. With three-dimensional information, interference sources that are not on the surface of the Earth, such as satellites, drones, etc., can be located. In a three-dimensional application, a minimum of three pairs of sensors are needed (sensor 1 and 2; sensors 2 and 3; sensors 3 and 4).

2.2 Interference Identification

The passive GPS system provides location information and tracks the movement of the interference source. With the location information and movement speed/pattern, and by using deep learning, interference identification and categorization can be achieved. Interference will be categorized as originating from a pedestrian, motor vehicle, drone, satellite, etc. The interference categorization provides (1) instructive information for NRDZ to allocate spectrum resources and (2) feedback information to the passive GPS system about modulation format, which will further improve the resolution of the interference tracking.

3. Preliminary Results with Prototype System

In this section, we demonstrate a prototype system that locates the coordinate of the interference source with centimeter resolution based on the method presented in Section 2.1.

3.1 Experimental Setup

Fig. 3 shows the experimental setup of the prototype system. The system includes an interference source and 3 sensors. The interference signal is transmitted and received with antennas. The transmitting antenna sends out amplitude modulated pulses (Fig. 4 (a)) with carrier frequency of 863MHz (Fig. 4 (b)). The pulse repetition rate is 1MHz and pulse width is 200ns. The 3 sensors are synchronized to measure the difference in signal arrival time.

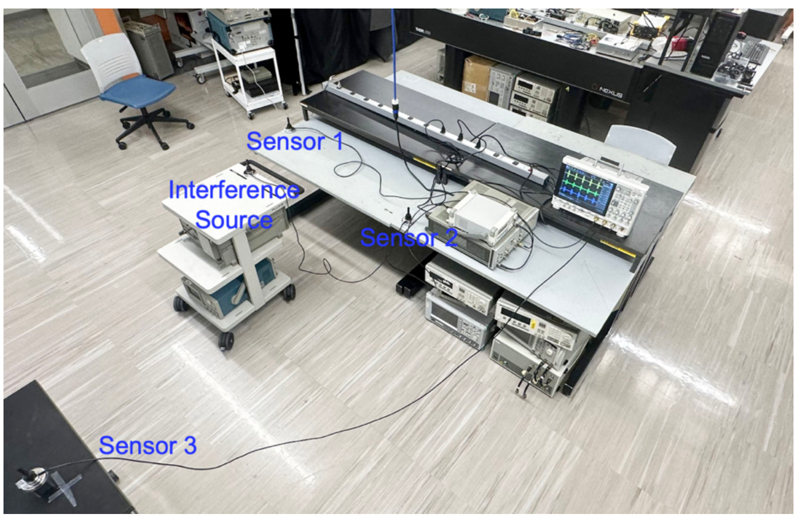

Fig. 3 Experimental setup of the passive GPS system.

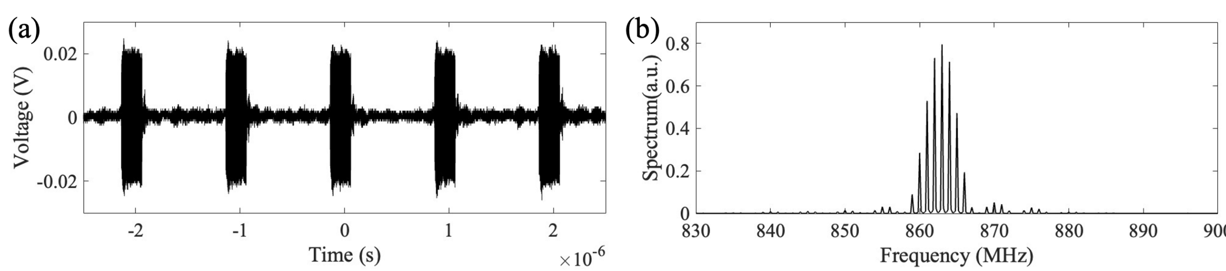

Fig. 4 Signal received from sensor 1 (a) Time domain signal (b) Spectrum of the signal.

3.2 Experimental Results and Analysis

The synchronized sensors measure the differences in signal arrival time between each sensor pair (Fig. 5). In this experiment, all the sensors are connected to the same oscilloscope, and signals from sensors are recorded by separate channels of the oscilloscope. In the field test, all the sensors are connected with optical fibers and synchronized with the same clock. Fig. 5 shows differences of signal arrival time (delay). The delay difference between Sensor 1 and Sensor 2, which is t_1- t_2, is measured as $1.6ns$, and the delay difference between Sensor 2 and Sensor 3, which is t_2- t_3, is measured as $2.7ns$.

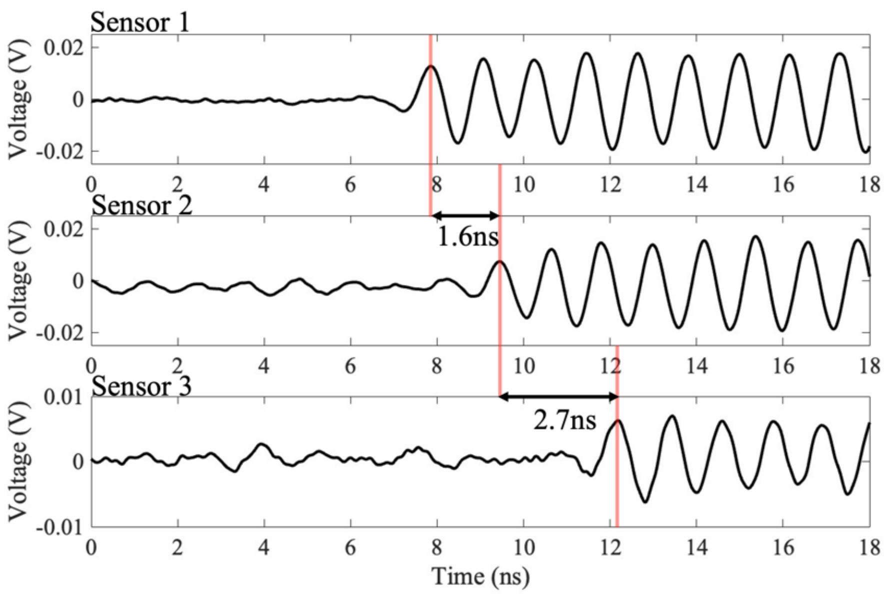

Fig. 5 Delay differences between 3 sensors.

With the delay differences and according to the theory in Section 2.1, the location of the interference source is determined by the intersection point of the hyperbola defined by Sensor 1 and Sensor 2 and the other hyperbola defined by Sensor 2 and Sensor 3 (Fig. 6 (a)). The red dots show the locations of the sensors. The blue dot shows the actual location of the interference source, measured by a tape ruler. Fig. 6 (a) shows that the intersection point of the two hyperbola curves overlaps with the blue dot, which means **the location of the interference source measured by the passive GPS method is the same as its actual location**. Fig. 6 (b) is an enlarged view of Fig. 6 (b) and demonstrates the accuracy of the measurement. The measurement result is 2cm from the actual location, which means the system achieves resolution in cm level.

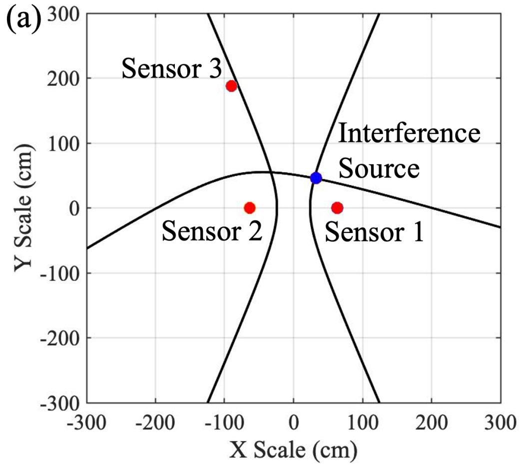

Fig. 6 Experimental measurement of the interference source location (b) is a zoomed-in view of (a)

Future work, which will be discussed with more details in Section 4, includes evaluating the passive GPS system in a larger geographical scale and distance. The scale of distance between the interference source and the sensors will meet the requirements of NRDZ. Longer distance decreases the signal to noise ratio (SNR) of the sensor receivers, which can be compensated for by (1) Applying an RF amplifier at the receiver. The current system uses a 10mW transmitter as the interference source without using any RF amplifier at the sensor receiver. (2) Leveraging the redundancy of the prototype system. The current system achieves cm resolution. Meter level resolution is enough to achieve the goal of interference tracking and identification, as discussed in Section 2.2. This means the prototype system has 2 orders of magnitude in terms of resolution redundancy. With this redundancy, the tracking system is functional at meter level resolution when the SNR drops by 10-20 dBm. (3) Adding more sensors. 3 pairs of sensors to is the minimum number of sensors to solve a three-dimensional problem. By adding more sensor pairs, the extra sensor will improve the resolution. This is very similar to traditional GPS, where 5-6 satellites are used for ideal resolution.

4. Implementation Plan

The implementation plan includes three steps: (1) Proof of concept, demonstrating that the passive GPS system works in the lab. **This step is finished as preliminary results**

in Section 3. (2) Outdoor test to evaluate the signal power and distance resolution of the system in a larger scale. The distance between sensors and interference generators will be in the range of hundreds of meters to kilometers. Software defined radios with portable power supplies will be used to perform the test. We will use free space optical communication links to provide a synchronization clock. PI Wu has built a test bed for free space optical communication links [4]. Fig. 7 shows the ongoing test system built by PI teams. This step will take about 3-6 months to finish.

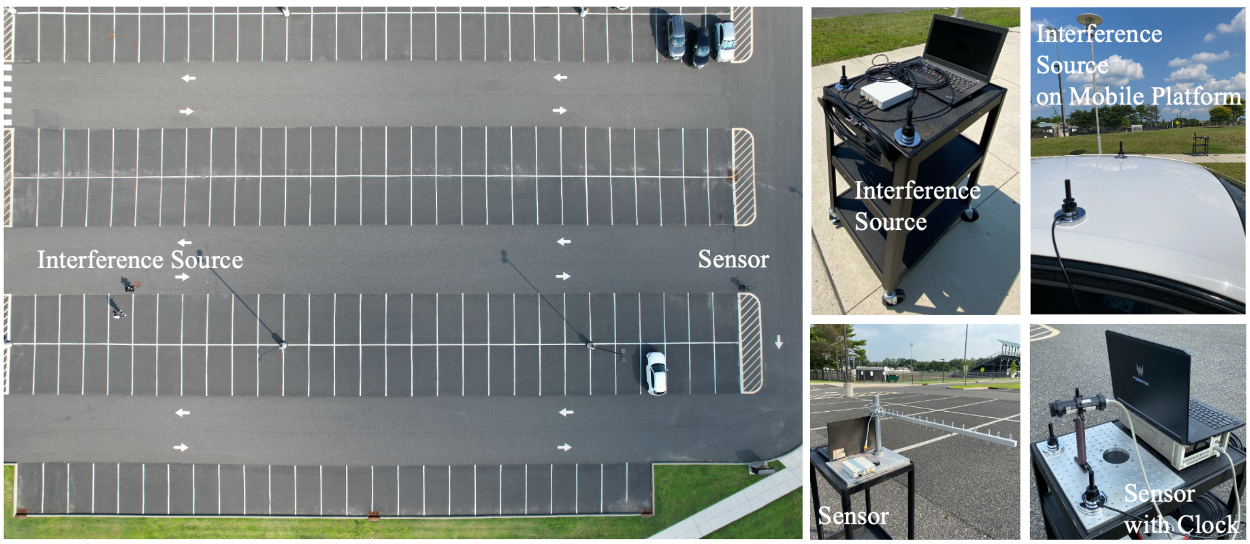

Fig. 7 Outdoor test bed of the passive GPS system that PIs have built.

(3) Field test at Hat Creek Radio Observatory. PI Kevin Gifford has built a sensor array at Hat Creek Radio Observatory [5]. The sensors use software defined radios, and have been tested to be able to measure the interference in both time and frequency domain. Fig. 8 shows the geographical location of five sensors. All the sensors are connected with optical fibers, which means that they can be synchronized with the same clock for accurate time delay measurement. We will test our passive GPS method with the sensor array at Hat Creek Radio Observatory. This step will take about 6-12 months to finish.

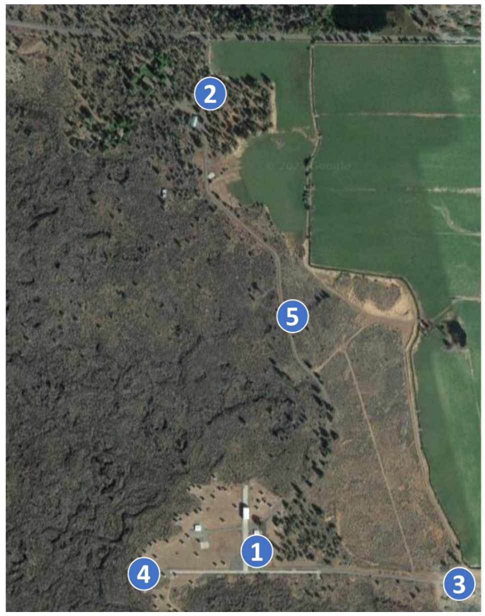

Fig. 8 Sensor array system in Hat Creek Radio Observatory that PI Gifford has built [5]. 5 sensors are shown with labels. Hat Creek Radio Observatory is located at the bottom of the figure.

5. Resources and Facilities

Our team has diverse expertise to secure the successful implementation of the proposed method and to perform field test within the planned time frame. PI Wu is an expert in interference management and has an active project from NSF Spectrum and Wireless Innovation enabled by Future Technologies (SWIFT) program. Project title: Collaborative Research: SWIFT: Wideband Spectrum Coexistence Enabled by Photonic Circuits: Cross-Layer Design and Implementation, with recent publications [6]–[8]. PI Wu has built a prototype system of the proposed method in his lab, and the functions of the system meet the goal of interference localization (Figs. 3-6). PI Gifford has multiple active projects for NRDZ and spectrum resources allocation [5], [9], [10], and has built an interference sensor system at Hat Creek Radio Observatory which is a key milestone for the field test of this planned research (Fig. 8).

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