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A Hybrid Scheme for Localizing Rogue Secondary User in a Mobile Cognitive Radio Network

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ABSTRACT
This paper presents a novel approach for localizing a Primary User (PU) emulator using a hybrid of the received signal strength indicator (RSSI) and the angle of arrival (AOA) methods. This was conceived to address the problem of primary user emulation (PUE) attack in Cognitive Radio (CR). A PUE attack occurs when a rogue Secondary user (RSU) mimics the spectral characteristics of a Primary user (PU) signal for selfish or malicious purpose. Hence, our hybrid scheme relies on the power received from the RSU to compute the distance between the RSU and Secondary User (SU) and the angle the SU makes with the RSU, which gives the exact location of the RSU. The simulation results further validate that our method effectively outperforms both individual techniques.
Keywords: *Cognitive, localization, primary, radio, spectrum, user.*

1. INTRODUCTION

Cognitive radio (CR) technology has been proposed as a means to address the problem of spectrum underutilization, which is an issue currently plaguing the wireless communications industry. A CR opportunistically makes use of the available white space without causing interference to the primary network [1]. One of the sources of white spaces being targeted for this application is the television (TV) spectrum. It is envisaged that certain CRs called rogue CRs (or primary user emulators) will likely usurp the available white space by mimicking the spectral characters of the primary user. To have a successful CR operation, there is need to identify and distinguish the primary user's signal from that of primary user emulator. This can be achieved via localizing the signal source to ascertain the transmitter's position and to compare it with the known position of the primary user (PU). Normally, a significant difference in their positions indicates rogue secondary user (RSU) presence.

Localization refers to the accurate estimation of the position of a node in physical space. Localization is classified into two main categories, which are the Range-Free and Range-Based Localization techniques. The Range-Free localization techniques do not depend on the use of angle and distance for localization, while the Range-Based techniques require angle and distance for localization [2, 3]. Thus, range-based algorithms compute the distance between nodes and use the principle of geometry to calculate the position of the focal node [3].

In this paper, we focus on the range-based localization techniques, and combine the Angle of Arrival (AOA) and the Received Signal strength Indicator (RSSI) techniques to accurately estimate the position of a PU emulator. The rest of the paper is structured as follows: Section 2 is the review of the related literature while section 3 gives explanations on RSSI and AOA for location estimation. Section 4 elucidates the proposed hybrid technique and section 5 concludes the paper.

2. RELATED WORK

Transmit power and the knowledge of the location of a primary transmitter are fundamental in cognitive radio operation as they facilitate sensing of white spaces by cognitive radio for their transmission without interfering with the primary user[4].
Various localization techniques for estimating node location abound in literature [5]. These localization techniques are classified into Range-free and Range-based Localization techniques. Because Range-based techniques are more accurate in estimating the location of a node than the Range-free techniques, they are highly employed in cognitive radio network. Angle of arrival (AOA), time of arrival (TOA), time difference of arrival (TDOA), and received signal strength indicator (RSSI) are the Range-Based localization techniques in literature [3]. These techniques have some shortcomings, although they have good estimation accuracy. Table 1 which presents a summary of Range-Based methods for detecting primary user emulator, clearly shows that only RSSI and AOA are apt for localizing primary user emulator [6].

Table 1: Suitability of Range-Based Methods for Localizing Primary user emulator.

Technique	Suitability	Reason
GPS	unsuitable	Attacker has to reveal itself
TOA	unsuitable	It requires cooperation of the attacker which attacker will not allow. Synchronization problem -Time delay
TDOA	unsuitable	It cannot handle tight synchronization among the participating nodes
RSSI	suitable	Accurate with or without cooperation of other nodes
AOA	suitable	Does not need the cooperation of other nodes

3. LOCALIZATION ALGORITHM

Typically, an emulator being a rogue hides its location from other secondary users by preventing mutual cooperation. Since RSSI and AOA localization methods do not need the cooperation of the emulator to achieve localization, they are adopted for our hybrid localization scheme in our work.

3.1 RECEIVED SIGNAL STRENGTH BASED LOCALIZATION

The Received Signal Strength Indicator (RSSI)-based localization technique is considered in our work because there exist a strong connection between the distance of a wireless link and the RSSI. If the signal strength travels a distance, d , its strength is inversely proportional to the distance travelled [7, 8].

$$RSSI \alpha \frac{1}{d^n} \quad (1)$$

$$d = \sqrt[n]{c_f \frac{p_t}{p_r}} \quad \mathbf{(2)}$$

where,
n = loss exponent, c_f = constant that depends on transceiver characteristics, p_t = transmitter signal power, p_r = Received signal power, d = Distance between the transmitter and the receiver

3.2 ANGLE -OF- ARRIVAL BASED LOCALIZATION

The Angle of arrival (AOA), also known as the Direction of Arrival (DOA) is a scheme used to estimate the location of nodes by computing the absolute or relative angles between neighboring nodes. The AOA is the angle between some reference direction (orientation) and the propagation direction of an incident wave. The orientation is a static direction across which the angle of arrival can be measured. The measurement in degrees is taken in the clockwise direction from the north. For the absolute AOA, the orientation should be 0^0 and it should point to the North, otherwise, it is a relative AOA. The direction of the neighboring node is found using an antenna array. A few of the anchor nodes are equipped with Global Positioning System (GPS). The un-localized nodes typically update the location information broadcasted by the anchor nodes along the way. The required location is computed after getting the information from at least three anchor nodes [9].

4. METHODOLOGY

The following assumptions are made in this work:

1. There is a minimum distance between the primary transmitter and all the secondary users. This distance, Dp in Fig 1, is referred to as primary exclusive region (PER) or keep-off-region.
2. Only primary users are permitted to transmit within the primary exclusive region.
3. The primary transmitter has a fixed position which is known to all the secondary users.
4. The secondary users are randomly placed within the grid
5. We consider free space propagation model from the primary and secondary transmitters with path-loss exponent of 2.
6. Except otherwise stated, if rogue secondary user transmits with the same power that the primary user transmits, then, the power received from malicious user by the secondary user is higher than that received from the primary transmitter.
7. Cognitive radios are mobile devices.
8. Some anchor nodes equipped with GPS give the distance between SUs
9. Energy detection mechanism is considered for the received power at each secondary user.

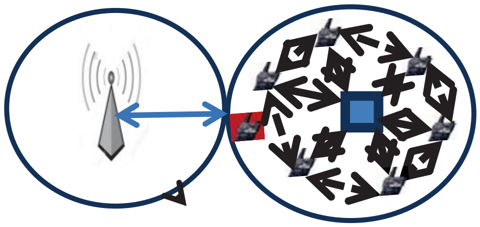

Figure 1 consists of a set of good secondary users (SUs), the primary user emulator (known as the rogue secondary user (RSU)), a base station (BS) and a primary transmitter (Ptx). The secondary users are randomly placed in a circular grid. Each secondary user is equipped with three directional antennas inclined to cover the angle of 180 degrees each. When signal is sensed in the network, all the secondary users get different received powers with the aid of their array of antennas. The direction (angle) of the antenna with the highest signal is considered to be the angle of arrival of the signal. Energy detection mechanism is considered for the received power at each secondary user when a signal is transmitted by either the PU or the RSU. The rogue secondary user masquerades itself as a primary transmitter as it mimics the spectral characteristics of the primary transmitter. The primary transmitter is at a distance of at least Dp (which is the primary exclusive region (PER)) from the secondary users. Only the primary user is allowed to operate within PER. The BS has detailed information about all the SUs and the primary transmitter. The free space model is used to estimate the distance between the transmitter and the respective secondary users [10, 11].

The proposed system estimates the location of a rogue transmitter from the available SU by using the RSS and the AOA to find the angle that the two SUs make with the transmitter and the distance between the two SUs and the transmitter as shown in figure 2.

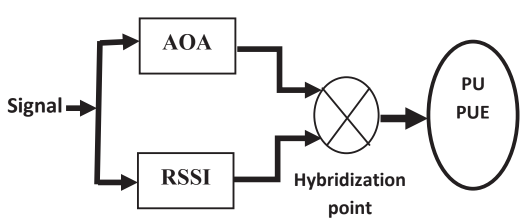

Figure 2: Hybrid of RSSI and AOA Localization Schemes

The following are the steps involved in the proposed algorithm:

Step 1: When the SUs sense the signal, the directional antenna gets the direction from which the signal strength is highest, and that direction is assumed the possible bearing to the signal transmitter.

Step 2: Each SU receives power separately and uses the free space propagation model to estimate the approximate distance of each SU from the transmitter.

Step 3: Once the SUs estimate their distances from the transmitter, then the anchor nodes estimate the distances between the SUs.

Step 4: After the information of distance is obtained, the angle that the two SUs make with the supposed transmitter is estimated and compared with the angle that the same pair of SUs make with the Primary transmitter. Any significant deviation in the angles indicates rouge SU.

Primary and rogue transmitters are respectively represented by A and E while SU1, SU2, and SU3 are B, C, and D respectively

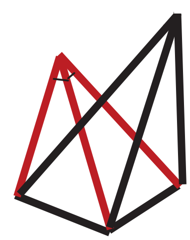

Figure 2: Triangulation of the received signal from both primary and rogue transmitters

We now consider triangle BCE, where E represents rogue secondary user, B and C respectively represent SU1 and SU2. The distance between RSU and SU1 is denoted by c while b is the distance between RSU and SU2. e is the distance between SU1 and SU2. Equation (3) gives the distance between SU1 and SU2.

$$e^2 = b^2 + c^2 - 2bc\cos\theta \quad (3)$$

From equation (3), we obtain equation (4)

$$\theta = \cos^{-}\left(\frac{b^2 + c^2 - e^2}{2bc}\right) \quad (4)$$

4.1 RECEIVED POWER

To get the received power, the free space propagation model is employed

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2} \quad (5)$$

where,

p_r and P_t are power received at the SU and transmit power of the transmitter respectively, G_t and G_r are the antenna gain of the transmitter and receiver respectively, λ is the wavelength of the transmitted signal while d, is the distance between the transmitter and the receiver.

However,

$$\lambda = \frac{c}{f},\ c = 3.0*10^8 m/s$$

$$P_r = \frac{P_t G_t G_r c^2}{(4\pi d f)^2} \quad (6)$$

Normalizing equation (6) to convert the received signal from watt to decibel yields (7):

$$P_r(\text{dB}) = P_t(\text{dB}) + G_t(\text{dB}) + G_r(\text{dB}) + 20\log(c) - 20\log(f) - 20\log(4\pi) - 20\log(d) \quad (7)$$

Since,

$c = 3.0*10^8 m/s$; $20\log(3.0*10^8) = 169.5$, and $20\log(4\lambda) = 21.98$

$$d = \exp\left[\left(P_t(\text{dB}) + G_t(\text{dB}) + G_r(\text{dB}) - P_r(\text{dB}) - 20\log(f) + 147.52\right)/20\right] \quad (8)$$

Equations (7) and (8) respectively give the received power at the secondary users and the distance between the transmitter and the secondary users.

4.2 RESULTS AND DISCUSSIONS

We consider the following values of the system parameters for our numerical computations.

Speed of light (Cspl) = 3.0e8m/s; pi = 3.1423; Primary User transmitter Gain (Gt) = 8dBi; Secondary Users receiver gain (Gr) = 12dBi; Transmission frequency (F) = 1.0e12; λ = Cspl / F; Primary user transmit power (5000W converted to dB), Rogue secondary user transmit power (500W converted to dB), Initial power received by secondary user A= -80dB (from primary transmitter), Initial power received by secondary user B= -83dB (from primary transmitter), Initial power received by secondary user A= -82dB (from rogue transmitter). Initial power received by secondary user B= -85dB (from primary transmitter). All transmit and received powers are in dB, angles in degrees, and distances in metres. P_{rB} and P_{rC} are the power received from primary transmitter at SUs B and C, respectively. E_{rB} is the power received at Secondary user B from rogue transmitter. E_{rC} is the power received secondary user C from the rogue transmitter. Apu and Ar are the respective angles that the secondary users B and C make with the primary transmitter and the rogue transmitter. D_{tx}_A is the distance between primary transmitter and the secondary user B while D_{tx}_B is the distance between primary transmitter and the secondary user C. D_{tx}_A_r and D_{tx}_B_r are the respective distance between rogue transmitter and secondary users B and C, while R is the distance between secondary users B and C.

It can be observed from the simulation result in table 2 that the angles that SUs A and B make with the primary transmitter and rogue transmitter at the various positions are different. The difference between angle A_r and angle A_{pu} shows that E is a rogue transmitter.

Table 2: Angles SUs make with the Primary transmitter and the RSU at different positions.

Dtx_B	Dtx_C	Dtx_B_r	Dtx_C_r	R	A_{PU}	Ar
168.068	237.402	211.585	298.872	87.287	16.191	4.283
168.070	237.405	211.587	298.875	101.288	21.301	11.727
168.075	237.412	211.594	298.884	117.290	27.394	17.922
168.077	237.415	211.596	298.888	121.291	28.848	19.277
168.080	237.420	211.600	298.894	127.293	30.994	21.229

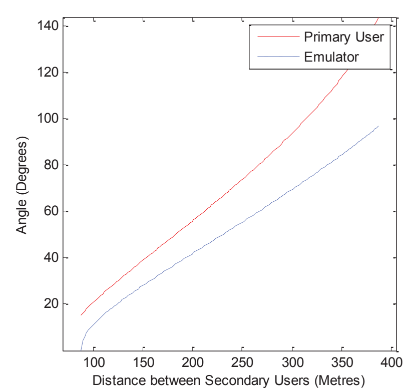

Figure. 3: Angle of User A and B with PU and RSU against Distance between SUs

From figure 3, the graph of PU and RSU (emulator) do not intersect. This shows that the two transmitters are not at the same location. It is also noted that as the distance between the SUs increases, there is a remarkable deviation that the angle SUs makes with the PU transmitter and the angle that the SUs makes with the RSU. This is because the wider the SUs are apart, the bigger the angle they make with the PU and RSU transmitters.

5. CONCLUSION

In this paper, we have presented a new method for detecting the primary user emulator in cognitive radio network using a hybrid of the RSS and AOA schemes. Our method works well in detecting the primary user emulators. According to the simulation results obtained, our technique is observed to have better performance as compared to the existing methods.

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