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A Hybrid Localization Scheme for Detection of Primary User Emulator in Cognitive Radio Networks

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Abstract: Cognitive radio (CR) is an enabling technology for combating the problem of spectrum scarcity in the wireless world; however, some security challenges are threatening this emerging technology. The major security challenge to the deployment of the cognitive radio network (CRN) is the primary user emulation attack (PUEA). Since the primary user emulator (PUE) mimics the primary user (PU) signal to cause havoc in the network, to distinguish its signal from that of the PU, knowledge of the exact position of the PUE in the CRN is required. One of the methods to detect PUEs is via Localization, of which there are two major categories: range-based and range-free. The range-based class is reportedly more accurate but with higher complexity. Among this category are Angle of arrival (AoA), which uses angular measurements to localise the PUE, and the received signal strength (RSS), which uses only distance to localize the PUE. To improve performance and reduce the complexity of range-based methods, this paper proposes a hybrid of AoA and RSS methods to localize PUEs in TV white space. This scheme computes the angle at which the PU signal reaches the SUs and the distance between the transmitter and SUs in the CRN. Since in a TV white space, the PU's location is known *a priori*, the computed AoA and the distance obtained from the RSS are thus used to determine the position of a PU signal transmitter. This position is compared with the location of the PU to ascertain the true source of the signal, thus detecting the PUE. The location estimation is carried out by the individual SUs. Computer simulations demonstrate that the hybrid scheme estimates the position of the PUE much faster and with a much lower root mean square error (RMSE) of 0.005, which greatly outperforms the methods considered individually. Thus, the hybrid scheme is faster, more accurate, and conserves energy better than considering the methods individually. This result is quite significant when attention is given to the fact that speed and accuracy are essential in the efficient operation of CRs and that energy-efficient operations are essential for wireless systems and especially in the currently looming global energy crisis.

Keywords: Angle, Cognitive, Localization, Primary User, Emulator.

1. Introduction

There is a high demand for radio spectrum as a result of sporadic deployment of newer wireless communication technologies [1]. Regrettably, this increasing demand has further culminated in a presumed scarcity of the limited radio spectrum. Nevertheless, recent studies have likewise found these supposed scarce spectrums to be underutilised, particularly stemming from the effect of the command and control method of spectrum allocation [2]. Cognitive Radio (CR) has been proposed to tackle the challenge of spectrum underutilization [3, 4].

A CR is a communication device capable of detecting spectrum holes and modifying its transmission parameters for dynamic and interference-free access to unoccupied licensed bands [5]. Cognitive radio networks (CRNs) are faced with many security challenges among which primary user emulation attacks (PUEAs) is the most problematic. A PUEA is said to arise when a scoundrel SU designated as primary user emulator (PUE) imitates the spectral characteristics of the primary user (PU) for mischievous purposes [6]. If left unaddressed, PUEAs can ultimately lead to flooding, denial of service, and possible collapse of the entire CRN [7]. To prevent this, PUEs should be detected and eliminated from CRN.

One of the most effective approaches for detecting and thus restricting the operation of a Primary User Emulator (PUE) is via the use of node localisation. In the case of television (TV) white spaces, because the secondary users (SU) must not operate within the primary exclusive region (PER) of the primary user (PU) [8], rogue signals can be distinguished from the authentic PU signal by their disparate locations. Localisation is a method of obtaining the location information of a node [9]. Localization techniques are mainly categorized into

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two: Range-free and Range-based localisation techniques [10]. Although range-based localisation schemes are more complex to apply than their range-free localisation counterparts, they are often preferred because of their higher accuracy. Typically, the Range-based localization technique is achieved using at least three SUs when the circles (or coverage areas) drawn around the SUs have a common intersection point [9]. The complexity of this technique could be reduced if two intersecting circles around two SUs are used for localization instead. Therefore, this work presents the localization of a PUE using a hybrid of received signal strength (RSS) and angle of arrival (AoA) from the perspective of two SUs. Computer simulations show that the hybrid scheme is an effective and less complex method for addressing the PUEA problem in CRNs. The rest of this manuscript is organized as follows: Section two presents a brief review of related works, whereas section three discusses the methodology. Section four presents results and discussion of results, while Section five concludes the paper.

2. Related Work

The range-based localization algorithms are computationally complex, more time consuming, and expensive to deploy, however having high accuracy. The range-free localization algorithms, on the other hand, are less complex, computationally simple, less time consuming, and cost-effective, albeit having less accuracy [11, 12].

Localization accuracy is a key requirement in detecting PUE in CRNs [13]. Consequently, most localization applications widely use range-based techniques for localization than range-free techniques. The angle of arrival (AoA), received signal strength (RSS), time difference of arrival (TDoA), and time of arrival (ToA) are the range-based techniques used for localization. They rely on angle and distance as the main parameters for localizing a node [14-16]. In ToA approach, the location of an un-localized node is estimated with the aid of the velocity and the time that radio signal transverses between the localized and un-localized nodes. Nevertheless, the ToA suffers from the problem of synchronization between the transmitted and received times of a signal [10, 17, 18]. ToA is upgraded to TDoA to account for synchronization problem in the ToA. TDoA handles the synchronization problem to a large degree, but it fails to handle the tight synchronization problem. Most synchronization accuracy is at most in the order of microseconds. This could lead to errors of several hundred metres. Tight synchronization occurs when synchronization accuracy is done in lesser time duration than microseconds. This leads to the elimination of errors and better performance of TDoA. It requires additional hardware, making it even more complex, in addition to having high financial cost [19, 23]. For AoA, the location of a node is determined by estimating the angle at which the signal arrives at the receiver without knowledge of the distance separating the transmitter from the receiver. [20]. Because AoA is complex to implement, financially intensive, and its accuracy decreases in multipath environments as the receiver gets farther from the transmitter [21, 22]. RSS method of localization localizes the transmitter by calculating the distance between the transmitter and the receiver without prior information about the received signal's angle of arrival. The RSS is easy to implement and relatively inexpensive [10, 16]. Except for the AoA and the RSS methods, other range-based techniques require the cooperation of localized and un-localized nodes to carry out localization process [23]. However, the PUE being a security threat conceals its location from other SUs by preventing cooperation between the SUs in the network. Hence, this work adopts the combination of AoA and RSS methods of localization to estimate the position of the PUE.

3. Methodology

The methodology for the proposed PUE detection is laid out in this section. It consists of descriptions of the system model and its operation.

A. System Model

As depicted in figure 1, the proposed CRN model is a cellular network operating in TV white space, comprising the primary user (PU) transmitter, the mobile switching centre (MSC), the secondary users (SUs), the secondary base stations (SBSs), and the primary user emulator (PUE).

According to the federal communications commission's (FCC's) regulation, the SUs must not operate within the primary exclusive region (PER). Hence, they are physically separated from the PU transmitter. Moreover, there must be a protected band which gives the minimum distance $d_{n(\Delta)}$, of SUs from the primary receiver. This is to shield the primary receiver from finite interference. SU should be capable of determining its location [8, 25, 26], and this information can be shared with other SUs. Therefore, SUs are aware of their locations, as well as the location of the PU and they use the location information to compute their respective distances from each other, from the PU and the relative angular measurement between each SU and the PU.

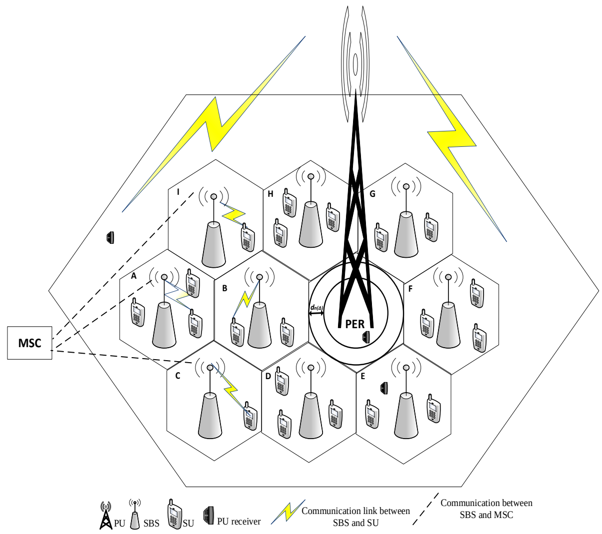

Figure 1. System Model

B. *No-Talk RegionUnits*

The no-talk region, r_n, shown in figure 2, consists of the primary exclusive region r_p, and additional protection band $d_{n(\Delta)}$, that prevents secondary user's signal from interfering with the primary receiver. SUs can transmit outside no-talk-region given by $r_n \in \Re$ using the white space defined by the function $I_D : \Re \rightarrow \{0,1\}$ [27].

$$I_D(x,y,f,t) = \begin{cases} 0, & \text{if } x,y \in r_n \\ 0, & \text{if } x,y \in \Re' \\ 1, & \text{if } x,y \in \Re \setminus r_n \end{cases} \tag{1}$$

Similarly, PUE can transmit from the positions defined as:

$$I_{PUE}(x,y,f,t) = \begin{cases} 0, & \text{if } x,y \in r_n \\ 1, & \text{if } x,y \in \Re \setminus r_n \\ 1, & \text{if } x,y \in \Re' \end{cases} \tag{2}$$

Where,

f is the frequency of transmission, t is the time of transmission, and x,y is a point in space that SU can transmit from.

Equations (3), (4), and (5) give the primary exclusive region, additional protection band, and the no-talk-region.

$$r_p = l_p^{-1}\left(p_T + G - \psi(r) - N_0 - \lambda\right) \tag{3}$$

$$d_n(\Delta) = l_p^{-1}\left(p_T + G - \psi(r) - N_0 - \lambda + \Delta_i\right) \tag{4}$$

$$r_n(\lambda, p_T, h_t, \Delta) = r_p(\lambda, p_T, h_t) + d_n(\Delta) \tag{5}$$

Where,

$d_n(\Delta)$ is further protection from PER, Δ_i is the protection margin, lp is the path-loss, $\Psi(r)$ is the fade margin, $r_p(\lambda, P_T, h_t)$ is the radius of the primary exclusive region, r_n is the no-talk-region while λ, P_T, h_t are wavelength, transmit power of the PU and antenna height respectively.

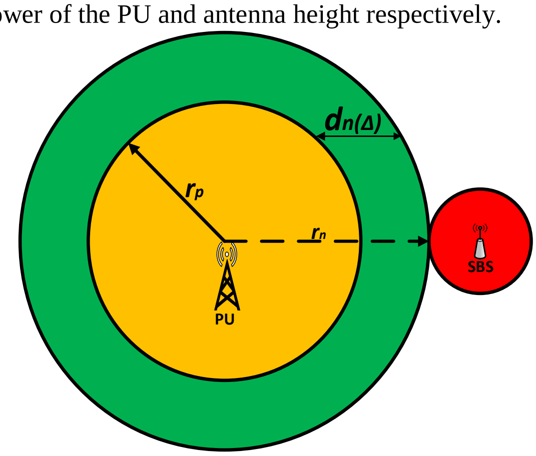

Figure 2. Digital Television Primary Exclusive Region and no-talk-margin

C. *Model Assumptions*

The assumptions considered in this work are summarized as follows:

i. The secondary users are all equipped with directional antennas to estimate the angle of arrival.
ii. All SUs and the PUEs are physically separated from the actual PU transmitter.
iii. The received power at each SU is different.
iv. Two SU nodes are used to localize the supposed PU.
v. The distance separating the PUE from the SU is obtained using the received signal strength.
vi. Each SU node estimates its distance to the PU and the angle it makes with the PU using the coordinates of the SUs and the PU.
vii. The SUs communicate with each other through the SBS.
viii. SUs and PUEs are all mobile devices.

D. Model Operation

When a signal that bears similar spectral characteristics to the PU is received, each SU computes its distance and the angle at which the signal is received from the transmitter. Each SU sends the location information to the SBS within its cell, which then broadcasts this information directly to the other SUs within that cell and to the SUs in other cells through their respective SBS via MSC. The computed location of the signal transmitter is compared with the known location of the legitimate PU [28]. Finally, SBS computes the location of the transmitter and communicates it to the SUs, which compare it with the known location of the PU and finally conclude whether the transmitter is the legitimate PU or not. During this time, SUs communicate by transmitting at very low transmit power below the noise floor of PU.

Figure 3 depicts a primary user emulation attack setup, where the PUE is transmitting, and its signal is being received by all the SUs in the network.

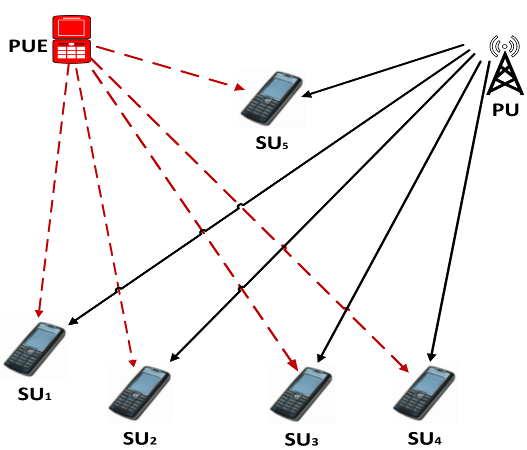

Figure 3. PUE Attack Launching Setup [29]

A typical localization scenario of the PUE is illustrated in Figure 3. The positions of secondary user 1 (SU_1) and secondary user 2 (SU_2), are x_1, y_1, and x_2,y_2 respectively. Similarly, r_1 and r_2 represent the radii of the coverage areas of SU_1 and SU_2, while x_a,y_a and x_b,y_b are the overlapping points of the coverage areas of SU_1 and SU_2. Line /PQ/ is the line joining the centres of SU_1 and SU_2, while angles ϕ and θ are the respective angles at which signal reaches SU_1 and SU_2 from the PU. Angles α_1 and α_2 depict the respective angles at which signal reaches the SU_1 and SU_2 from the PUE.

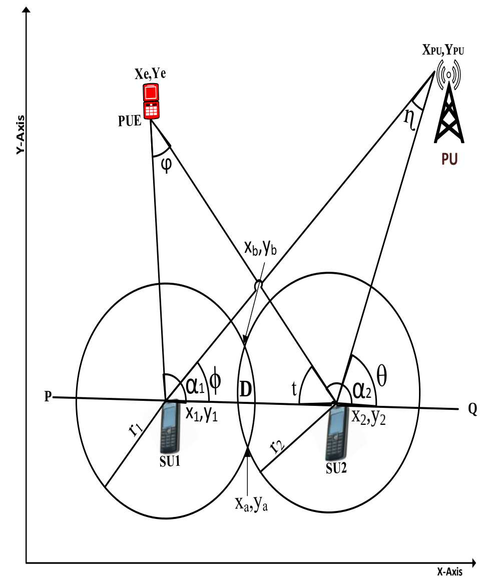

Figure 4. The two secondary users participating in the localization process

The legitimate PU is positioned at point $[X_{PU}, Y_{PU}]$, PUE is at point $[X_e, Y_e]$ while SUs are at positions $[x_i, y_i]$ where $i = 1, 2, \ldots\ldots N$. The two participating SUs are separated by the distance, D, which is given in equation (1) as:

$$D = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

(6)

The intersection points, (x_a,y_a) and (x_b,y_b) of the two SUs participating in localizing the PUE are given in equations (7) to (11) [9].

$$X_a = \frac{x_1 + x_2}{2} + \frac{(x_2 - x_1)(r_1^2 - r_2^2)}{2D^2} + 2\delta\left(\frac{y_2 - y_1}{D^2}\right) \quad (7)$$

$$Y_a = \frac{y_2 + y_1}{2} + \frac{(y_1 - y_2)(r^2_1 - r^2_2)}{2D^2} - 2\delta\left(\frac{x_1 - x_2}{D^2}\right) \quad (8)$$

$$X_b = \frac{x_1 + x_2}{2} + \frac{(x_2 - x_1)(r_1^2 - r_2^2)}{2D^2} - 2\delta\left(\frac{y_2 - y_1}{D^2}\right) \quad (9)$$

$$X_b = \frac{x_1 + x_2}{2} + \frac{(x_2 - x_1)(r_1^2 - r_2^2)}{2D^2} - 2\delta\left(\frac{y_2 - y_1}{D^2}\right) \quad (10)$$

$$\delta = \frac{1}{4}\sqrt{(D + r_1 + r_2)(D + r_1 - r_2)(D - r_1 + r_2)(-D + r_1 + r_2)} \quad (11)$$

The distance between the PU and the i^{th} SU is given in (12).

$$d_{i(PU)} = \sqrt{(X_{PU} - x_i)^2 + (Y_{PU} - y_i)^2} \quad (12)$$

The angle of arrival of the signal at SUs 1 and 2 from the PU are respectively given in equations (13) and (14) as:

$$\phi = \tan^{-1}\left(\frac{Y_{PU} - y_1}{X_{PU} - x_1}\right) \quad (13)$$

$$\theta = \tan^{-1}\left(\frac{Y_{PU} - y_2}{X_{PU} - x_2}\right) \quad (14)$$

In a transmission channel with losses, the transmit power is estimated as

$$p_r = p_t - (loss_{shadowing} + loss_{others}) \quad (15)$$

Here, p_t and p_r are the transmitted and received powers respectively, while $loss_{shadowing}$ and $loss_{others}$ are the losses due to shadowing and other losses in the communication channel respectively.

But,

$$p_{loss(d)} = loss_{shadowing} + loss_{others} \quad (16)$$

By substituting (16) into (15), we obtain the received power at i^{th} SU

$$\left(p_r\right)_i = p_t - p_{loss(d)} \quad (17)$$

$$\left(p_r\right) = \begin{pmatrix} (p_r)_{1,1} & (p_r)_{1,2} & \cdots & (p_r)_{1,j} \\ (p_r)_{2,1} & (p_r)_{2,2} & \cdots & (p_r)_{2,j} \\ \vdots & \cdots & \ddots & \vdots \\ (p_r)_{i,1} & (p_r)_{i,2} & \cdots & (p_r)_{i,j} \end{pmatrix} \quad (18)$$

But,

$$p_{loss(d)} = p_{loss(d_0)} + 10n\log(\frac{d}{d_0}) \text{ [30, 31]} \quad (19)$$

By substituting (19) into (17), we obtain

$$d = \exp\left(\frac{p_t - p_r - p_{loss(d0)}}{10n}\right) \quad (20)$$

Where,

p_t is the transmit power of PUE, p_r is the received power at SU, d is the distance between SU and PUE, $p_{loss(d0)}$ is the pathloss d_0 is the reference distance of 1m and loss exponent, n of 4, considering typical urban environments.

Due to the dynamics of the communication environment, the mean of several samples of the received power, P_r, is used to obtain a better estimate of the received power using (21)

$$p_{r(imean)} = \frac{1}{j}\sum_{j=1}^{j} p_{rij} \quad (21)$$

Here, $P_{r(imean)}$ represents the mean of the received power at the i^{th} SU and P_{rij} represents the j^{th} sample value of the P_r at the i^{th} SU in dBm.

$$d_i = \exp\left(\frac{p_t - p_{r(imean)} - p_{loss(d0)}}{10n}\right) \quad (22)$$

where,

d_i is the distance separating the transmitter from i^{th} SU, P_t the transmit power of the transmitter, and $P_{r(imean)}$ is the average received power at the i^{th} SU respectively, n is the path loss exponent defined for the propagation environment, while d_0 and $P_{loss(d0)}$ are the reference distance from which the line of propagation is assumed and the path loss within a reference distance respectively.

Equation (22) gives the distance between the PUE and the i^{th} SU.

For SUs 1 and 2 separated from each other by distance D, the PUE is separated from SU_1 with distance d_1, and SU_2 with d_2, the measured AoA at SU1 and SU2 from PUE is expressed as

$$\alpha_1 = arc\cos\left(\frac{D^2 + {d_1}^2 - {d_2}^2}{2Dd_1}\right) \quad (23)$$

$$t = arc\cos\left(\frac{D^2 + {d_2}^2 - {d_1}^2}{2Dd_2}\right) \quad (24)$$

$$\alpha_2 = 180 - t \quad (25)$$

By substituting (24) into (25), we obtain

$$\alpha_2 = 180 - \left(arc\cos\left(\frac{D^2 + d_2{}^2 - d_1{}^2}{2Dd_2} \right) \right) \quad (26)$$

For any two SUs participating in the localization of PUE, the distance and AoA received at point SU_i from PUE is given by

$$d_i\alpha_i = s_i\varphi_i + n_i \quad (27)$$

$$d\alpha = \begin{pmatrix} (d\alpha)_{1,1} & (d\alpha)_{1,2} & \cdots & (d\alpha)_{1,j} \\ (d\alpha)_{2,1} & (d\alpha)_{2,2} & \cdots & (d\alpha)_{2,j} \\ \vdots & \cdots & \ddots & \vdots \\ (d\alpha)_{i,1} & (d\alpha)_{i,2} & \cdots & (d\alpha)_{i,j} \end{pmatrix},$$

$$s\varphi = \begin{pmatrix} (s\varphi)_{1,1} & (s\varphi)_{1,2} & \cdots & (s\varphi)_{1,j} \\ (s\varphi)_{2,1} & (s\varphi)_{2,2} & \cdots & (s\varphi)_{2,j} \\ \vdots & \cdots & \ddots & \vdots \\ (s\varphi)_{i,1} & (s\varphi)_{i,2} & \cdots & (s\varphi)_{i,j} \end{pmatrix},$$

$$n = \begin{pmatrix} n_{1,1} & \mathrm{n}_{1,2} & \cdots & \mathrm{n}_{1,j} \\ n_{2,1} & n_{2,2} & \cdots & \mathrm{n}_{2,j} \\ \vdots & \vdots & \ddots & \vdots \\ n_{i,1} & \mathrm{n}_{i,2} & \cdots & \mathrm{n}_{i,j} \end{pmatrix} \quad (28)$$

$$Y_e - y_1 = (X_e - x_1)\tan\alpha_1 \quad (29)$$

$$Y_e - y_2 = (X_e - x_2)\tan\alpha_2 \quad (30)$$

$$X_e = \frac{x_1\tan\alpha_1 - x_2\tan\alpha_2 + y_2 - y_1}{\tan\alpha_1 - \tan\alpha_2} \quad (31)$$

$$Y_e = \tan\alpha_1\left(\frac{x_1\tan\alpha_1 - x_2\tan\alpha_2 + y_2 - y_1}{\tan\alpha_1 - \tan\alpha_2}\right)x_1\tan\alpha_1 + y1 \quad (32)$$

Equations (31) and (32) give the location of the PUE.

The flow process of our hybrid localization scheme is presented in Figure 5.

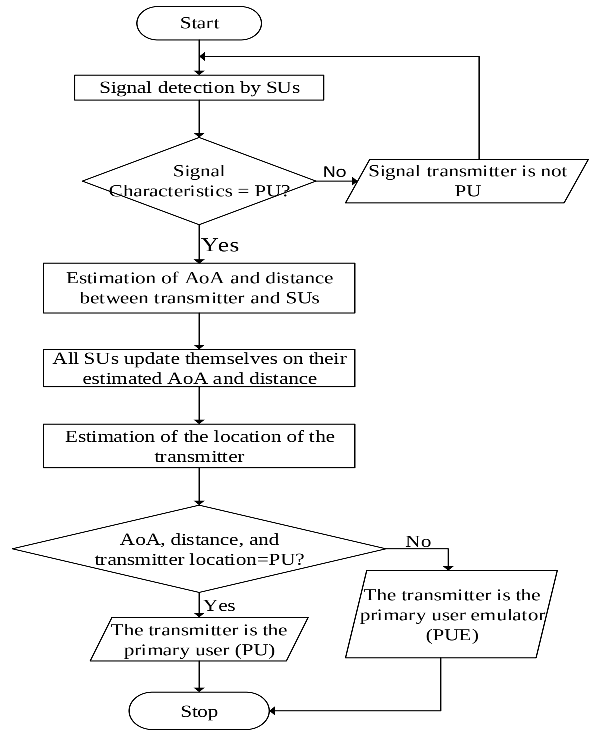

Figure 5. Hybrid localization flowchart

The Hybrid localization algorithm is thu summarized in the following steps:

1. Start
2. Secondary user (SU) receives signals from an unknown transmitter
3. Deduce the spectral characteristics (which are: pulse shaping, bandwidth, frame format, operating frequency, and modulation type) of the received signal
4. If the deduced spectral characteristics of the received signal are different from those of the primary user
5. Then
6. The transmitter is not the PU
7. Go to step two
8. Else
9. The transmitter is likely the PUE
10. Estimate euclidean distance from SUs to the transmitter and the AoA.
11. All SUs updates themselves with their AoA and distance to the transmitter
12. Estimate the position of the transmitter using AoA and the distance between SUs and transmitter
13. If the estimated distance from SU to the transmitter, AoA, and location of the transmitter

are equivalent to the known AoA, distance and the location of the PU
14. Then
15. The transmitter is the PU
16. Else
17. The transmitter is the PUE
18. End

The performance of our localization method was evaluated by comparing estimated locations with the actual locations using the root means square error (RMSE). Lower root means square error translates to better performance.

$$RMSE = \sqrt{\sum_{i=1}^{N} \frac{\left((L_{est})_i - (L_{real})_i \right)^2}{N}} \quad (33)$$

Where, L_{est} and L_{real} are respectively estimated and actual coordinates.

4. SIMULATION AND ANALYSIS

The simulation for the proposed hybrid method has been carried out using Matlab. The experimental layout is shown in figure 6. The primary user transmitter was fixed at X,Y (50,50) on a network area of 100m×100m, while the primary user emulator and secondary users were distributed randomly in the network. Secondary users 1 and 2 assumed initial positions of x_1, y_1 (19,22) and x_2, y_2 (24,23) respectively. The radius of the no-talk-region was 10m, radius of the coverage area of the PU was 50m, The transmit power of the PUE was set at 50dBm, the loss exponent, *n*, was set at 4 while the path loss within the reference distance, d_o, of 1m was set at 1dBm [30, 31]. All distances are given in metres (m), while all angles are in degrees. Due to the dynamics of the communication environment, equation (21) was used to obtain the mean of several samples of the received power, P_r, at every SU position to obtain a better estimate of the received power.

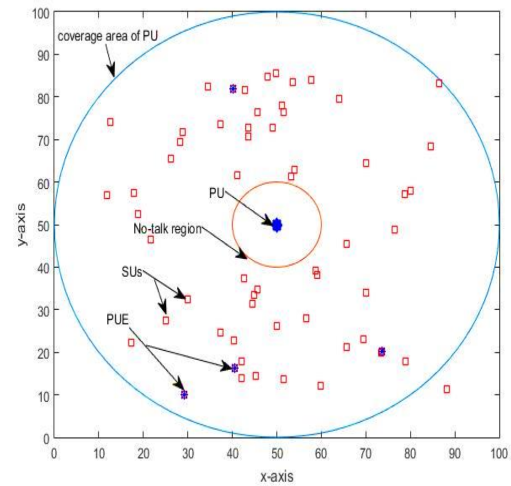

Figure 6. Positions of the primary user, secondary users, and primary user emulator

In figure 7a, the distance between SU_1 and the PU is compared to the distance between SU_1 and the PUE. It is observed that at different positions of SU_1, the distance between SU_1 and PU is different from the distance between SU_1 and PUE. Note that these results validate the correctness of the algebraic derivations and show that the computer simulation is tracking the correct positions of the nodes in the CRN.

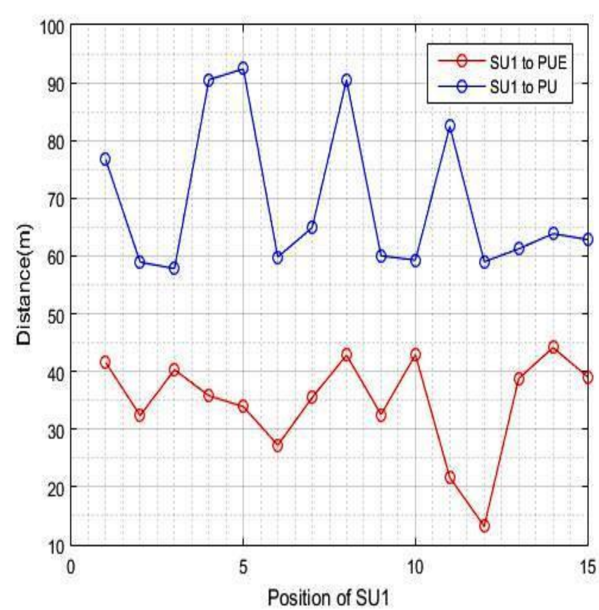

Figure 7a. Comparison of distance between SU_1 and PU with the distance between SU_1 and PUE

Similarly, in figure 7b, different positions of SU_2 were taken, and in each case, the distance between SU_2 and PU is compared with the distance between SU_2 and PUE. In all cases, the distance from SU_2 to the PU is different from the distance from SU_2 to the PUE.

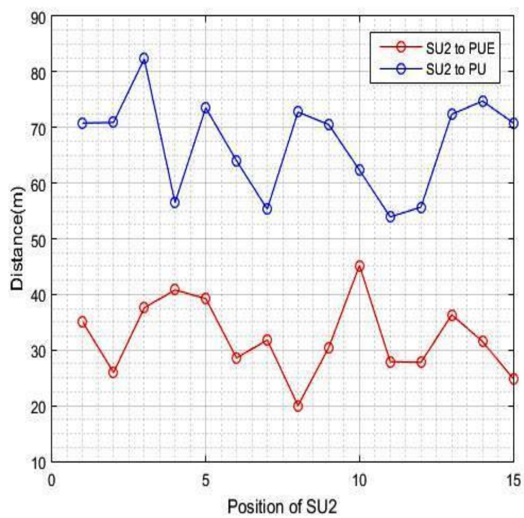

Figure 7b. Comparison of distance between SU_2 and PU with the distance between SU_2 and PUE

As observed in figure 8a, AoA of the signal at SU_1 from the legitimate PU is different from the AoA at SU_1 from PUE at sixteen different positions of SU_1. Also, when AoA of the signal at SU_2 from actual PU is compared with the AoA of the signal at SU_2 from PUE as shown in figure 8b, different AoAs were observed at all positions of SU_1 and SU_2.

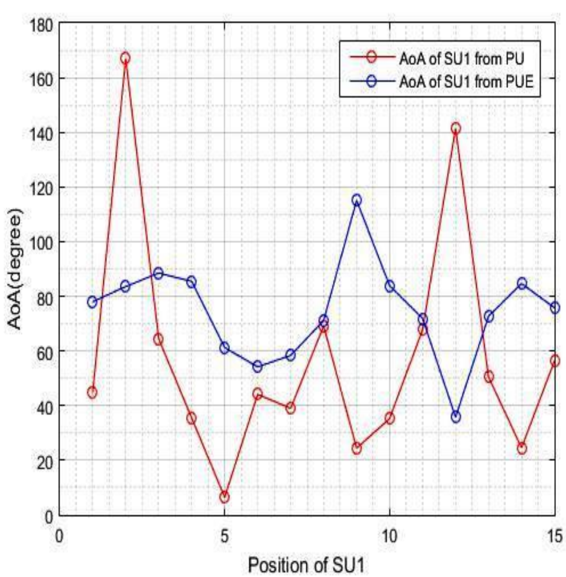

Figure 8a. Comparison of AoA of the signal at SU_1 from PU and PUE

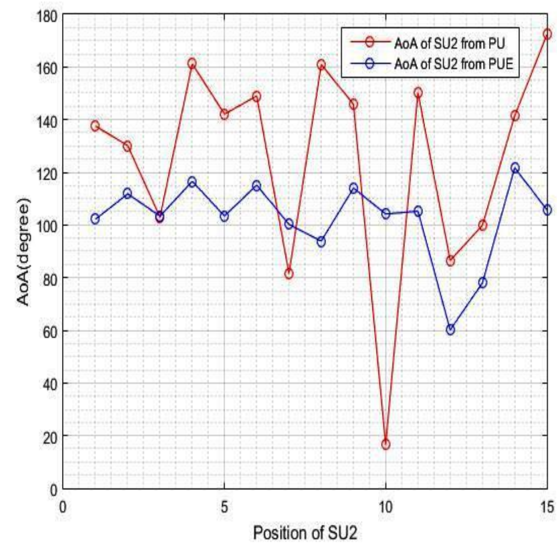

Figure 8b. Comparison of AoA of the signal at SU_2 from PU and PUE

A. Performance Analysis

The performance of the proposed hybrid of RSS and AoA, for localization of PUEs was measured using root mean square error (RMSE) as shown in figure 9. Notice that the RSS and AoA localization schemes both converge at the 50^{th} iteration with RMSE of 0.20 and 0.01 respectively. While the proposed hybrid scheme converges at the 20^{th} iteration with RMSE of 0.005. Therefore, the proposed hybrid scheme outperformed the RSS and AoA schemes respectively by a good margin both in speed and accuracy. The performance of the hybrid scheme is better than the performances of AoA and RSS reported in [21, 32] as presented in Table 1.

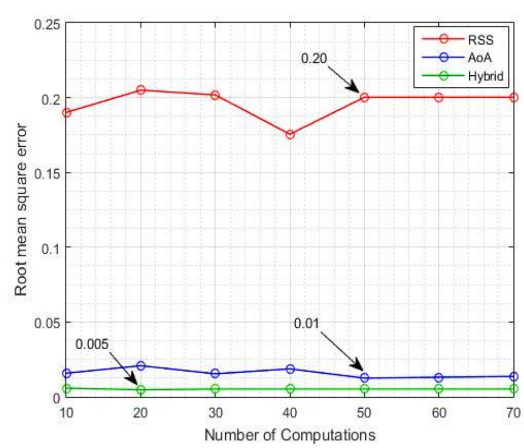

Figure 9. Performance of AoA, RSS and the proposed Hybrid

Table 1 is the comparison of our hybrid localization scheme with similar localization schemes in literature. The RSS and AoA schemes based on our algorithm performed better than RSS and AoA in [32] and [21] respectively. Moreover, our hybrid scheme demonstrates higher accuracy than both RSS and AoA as it exhibits the lowest RMSE of 0.005. Furthermore, our hybrid scheme takes a smaller number of iterations to attain convergence - thus, making it faster and energy efficient. These results are quite significant because good accuracy and speed is very important for the effective realization of cognitive radio technology. Again, considering the number of devices that will populate the wireless network of the future, the benefit of the added advantage of energy efficiency cannot be overemphasized.

TABLE 1. COMPARISON OF LOCALIZATION SCHEMES

Localization Scheme	Number of Iterations	RMSE
RSS [32]	50	0.220
AoA (DoA) [21]	30	0.012
RSS (our algorithm)	50	0.200
AoA (our algorithm)	50	0.010
The Hybrid of RSS and AoA	20	0.005

5. Conclusion

This work presents the need to use cognitive radio technology to effectively and dynamically manage spectrum. It pointed out that, though CR is a promising technology for opportunistic spectrum access, it has underlying challenges. One such challenge is the primary user emulation attack (PUEA). This attack could be inimical to the efficient operation of a cognitive radio network (CRN). The solution is to detect and restrict the PUE in the network. Best methods for detecting a PUE in CRN includes locating it and, at least, ignoring its transmissions. Therefore, an efficient localization technique is needed. The best localization techniques in literature are the range-based class of localization schemes, however, these are generally complex and costly. Therefore, a new scheme for localization of a primary user emulator (PUE) has been presented in this paper using a hybrid of received signal strength (RSS) and angle of arrival (AoA) localization schemes. The hybrid scheme has been demonstrated via computer simulations using just two secondary users to estimate the position of a PUE. The simulations validate that the proposed hybrid scheme localizes primary user emulator better and faster than the distinct application of the RSS and AoA localization techniques. It also has the added advantage of being more energy efficient, which is very beneficial in the current global energy crisis.

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