Proceedings on Big Data Analytics
& Innovation (Peer-Reviewed),
Volume 1, 2016, pp.192-198

A Survey of Range-Based Techniques for Localizing Primary User Emulators in Cognitive Radio Network

S.A. ADEBO, E.N. ONWUKA, A.J. ONUMANYI & A.S. USMAN
Federal University of Technology, Minna, Nigeria

ABSTRACT A problem currently facing the wireless communication industry is spectrum underutilization, wherein licensed Primary Users (PUs) only marginally use their bands in time and space. Consequently, Opportunistic Spectrum Sharing (OSS) has been proposed as a solution to this problem with Cognitive Radio (CR) being the enabling technology. CR describes the capability of a radio to dynamically and opportunistically access licensed spectrum without causing interference to the PU. While CR is being developed, one main security problem it faces is Primary User Emulation (PUE) attack. A PUE attack occurs when mischievous Secondary Users (SU), that is CRs, begin to emulate PU signals either to deny other SUs from gaining access to free bands or to simply acquire bandwidth for selfish purposes. In this regard, localization is considered as a solution, wherein the location of the PUE attacker is determined and compared to the location of the true PU transmitter and any significant deviation in their positions is indicative of a PUE attacker. Thus, this paper is a short note describing the different state-of-the-art localization techniques, elucidating their advantages and disadvantages. The approach adopted included identification of the various localization techniques for PUE identification, with subsequent analysis under the following metrics: accuracy, precision, computational complexity, cost, energy efficiency, and size of hardware. It was concluded that the Angle of Arrival and Received Signal Strength Indicator techniques do not require the cooperation of PUE for its detection, hence making these techniques most suitable for use. It is believed that this mini-review will be beneficial particularly for budding researchers seeking enlightenment in this research area.

Keywords: Cognitive Radio, Primary User, Localization, Angle of Arrival, Range

1. Introduction

Localization refers to the accurate determination of the position of a node in physical space. It is typically classified into two broad categories namely: Range-free and Range- Based Localization techniques. Range-Free localization techniques do not depend on the use of distance and angle for localization, while Range-based techniques use the distance and angle for localization (Alrajeh et al., 2013). In essence, the range-based algorithms compute the distance between nodes and use the principle of geometry to calculate the location of a focal node. These algorithms are used to compute range metrics such as Angle of Arrival (AOA), Time of Arrival (TOA), Time Difference of Arrival (TDOA), and Received Signal Strength

Indicator (RSSI) (Chen and Park, 2006). When implementing any localization technique, certain metrics such as accuracy, precision, computational complexity, cost, energy efficiency, and size of the hardware is considered because they easily elucidate the similarities and differences between these approaches, (Amundson and Koutsoukos, 2009). The different types of Range-Based techniques available in literature are the Time of Arrival (TOA), Time Difference of Arrival (TDOA), Angle of Arrival (AoA), and Received Signal Strength Indicator (RSSI). These are discussed in the following sections.

2. Time of Arrival

The velocity and time of arrival of the radio signals are used to calculate the location of the unlocalized transmitter in this localization method (Singh and Sharma, 2014). When a signal is transmitted from all nodes to their neighbours with the same predefined velocity, w, each node sends the received signal back to the transmitter. A node 'a' estimates its distance from its neighbour 'b' by using this formula:

$$Dis_{ab} = 2^{-1}\left(t^{a}_{rec} - t^{a}_{tra}\right) - \left(t^{b}_{rec} - t^{b}_{tra}\right) \quad (1)$$

where,

Dis_{ab} = distance between a and b t^{a}_{rec} = time of receiving signal for node 'a', t^{a}_{tra} = time of transmission of signal for node 'a', t^{b}_{rec} = time of receiving signal at node 'b', t^{b}_{tra} = time of transmission of signal at node 'b', t^{b}_{rec} = time of receiving of signal for node 'b', t^{b}_{tra} = time of transmission of signal for node 'b'. Time of Arrival (TOA) has two main limitations to its effectiveness (Srbinovska et al., 2011). These limitations are: a.) Synchronization at microsecond level between all sensor nodes: Roundtrip time was applied to surmount the problem of synchronization. Roundtrip propagation time measurements compute the difference between the time when a signal is sent by a sensor and the time when a signal returned by a second sensor is received at the original sensor. Even with the application of roundtrip propagation time, the problem of synchronization was not solved (Guvenc and Chong, 2009). b.) Internal delay required for handling the signal in the receiver sensor affects this method, which leads to inaccurate determination of the distance travelled by the signal (León et al., 2012). In a mobile-based approach, it is required that the transmitting node to be located collaborates with other nodes. This technique is suitable in wireless sensor networks where all nodes are friendly nodes. In a cognitive radio network (CRN) scenario where the objective is to locate attacker, this will not work because the attacker will not cooperate with other nodes to reveal its position (León et al., 2012).

3.Time difference of Arrival

Time Difference of arrival (TDOA) which is an upgrade of TOA estimates the location of an unlocalized transmitting node. In this method, the position of the sensor node is estimated by using the time difference of arrival of the radio and ultrasound signals at different sensor nodes. In this scenario, each node will have a microphone and a speaker, an anchor node is required to coordinate the measurements. When the anchor node transmits signal to other nodes in the network, it waits for some time lapse, after which the receiving node generates short high sound with the help of speaker (this marks the time the signal was received by it). The microphone saves the time it identifies the chirps. The unlocalized node uses this time information to determine the distance between the anchor node and itself. If there are two references, 'a' and 'b' the TDOA measurement can be transformed into a distance by the following formula:

$$Dis_{ab} = dis_a - dis_b = c(t_a - t_b) = c.t_{ab} \quad (2)$$

This technique requires two types of senders and receivers on each node and its location estimation is computationally intensive (Singh et al., 2012, Leelavathy and Sophia, 2014, Jin et al., 2009). Both TOA and TDOA have difficulty with measuring time resulting from synchronization of the devices involved. Hence the problem of synchronization by TOA was not also solved by TDOA.

4. Angle of arrival

Angle of Arrival (AOA) is the angle between some reference direction (orientation) and propagation direction of an incident wave. As a localization scheme, AOA is used to know the location of unlocalised sensor node by computing absolute or relative angles between neighbours. The measurement is in degree taken in clockwise direction from the north. For absolute AOA, the orientation should be 0^0 and it should point to the north; otherwise, it is a relative AOA (Kułakowski et al., 2010). The direction of neighbours is found by use antenna array and some anchor nodes equipped with compass and Global Positioning System (GPS). Unlocalised nodes update the location information broadcast by the anchor nodes along the way. Location is computed after getting the information from at least three anchor nodes. This approach is expensive to use in wide CRN since it requires additional hardware for transmitting and receiving location information (Heng and Gao, 2013).

5.received signal strength indicator

RSS-based localization technique arises from the fact that there exists 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 as given in equation (3) (Leelavathy and Sophia, 2014).

$$RSSI\, a\, \frac{1}{d^2} \quad (3)$$

Table 2: Suitability of Range-Based Methods for Detecting PUE

S/N	Technique	Suitability	Reason
1.	GPS	Unsuitable	Attacker has to reveal itself
2.	TOA	Unsuitable	It requires cooperation of the attacker and suffers synchronization
3.	TDOA	Unsuitable	It cannot handle tight synchronization among the participating nodes
4.	RSSI	Suitable	Accurate with or without cooperation
5.	AOA	Suitable	Does not need the cooperation of other nodes

It assumes those transmission power and path loss models are known and uses them to calculate the distance between the PU and the reference node (Chen and Park, 2006). Because of the dynamics of the indoor/outdoor environments, it is expected to have high error rate. This method is unsuitable for long distance network links. Specifically, given a transmitter-receiver pair, Received Signal Strength (RSS) can be modeled as a function of transmitted power and transmitted-receiver distance. Therefore, if a correct model is used and there are multiple observers taking RSS measurements, a transmitter location can be estimated using the model.

RSS-based technique is very effective in estimating the distance of the PUE from a reference node, but, there are some two issues that may affect its operation: Possible manipulation by malicious or multiple transmitters, and inaccuracy of the RSS measurement. These issues can be addressed if many RSS measurements are taken properly and the measured data are properly processed. Typically, as the distance between transmitter and receiver increases, RSS value decreases.(Pu et al., 2011).

To be able to use the approach above, two problems need to be addressed. a.) Path fade change over time and a PUE attacker may change its location or vary its transmission power frequently to stall localization, thereby causing drastic fluctuation in the RSS measurements within a short period of time. Averaging the measurement taken at different times cannot mitigate this problem since different RSS values abound for different measurements taken at different times. The panacea to this challenge is to take a “snapshot” of the RSS distribution in a given network. That requires the receiving nodes of a cognitive radio network (CRN) to take synchronized RSS measurements in a given band (Boukerche et al., 2007).

Short variation of distance causes high variation in the magnitude of the RSS (30dB to 40dB) (Liu et al., 2010). This poses challenge to deciding the location of PUs by just reading the raw data in a snapshot of RSS distribution. Since snapshot data is not free from uncertainty, the required data integrity is attainable using appropriate data smoothing technique so that the snapshot data can be used to solve localization problem. Data capturing techniques aims at eliminating noise from the snapshot data while capturing important patterns in raw data. Identifying the RSS measurements is possible once the variance in the raw RSS measurements is decreased through data smoothing methods such as Fourier filters, Loess fitting, Local averaging (Chen et al., 2008). A Summary of range-Based localization techniques is presented in Table 1while that of suitability of each range method for localizing the PUE is presented in Table 2.

Table 1: Comparison of Range-Based Localization Techniques

Technique	Accuracy	Precision	Computational Complexity	Cost	Energy Efficiency	Size of Hardware
GPS	High	High	Low	High	Low	Small
TOA	Medium	High	High	High	Low	Large
TDOA	High	Medium	High	High	High	Large
AOA	Low	Medium	High	High	Medium	Large
RSSI	High	Low	Low	Low	High	small

6. Discussion

Since cooperation of the participating nodes is needed for TOA localization technique, and an attacker will not cooperate with other nodes in detecting it, this localization technique is not suitable for detection of PUE. Although TDOA technique bypasses cooperation, it requires tight synchronization among the cooperating nodes, but it cannot handle such tight synchronization. GPS requires the attacker to reveal itself, thus, it is unsuitable for detecting PUE (D. Gumey, et al., 2008). Whereas AOA does not require the cooperation of other nodes as it measures the direction of signal at different nodes and computes its location by using simple triangulation method, RSSI is accurate within a short range (Guvenc et al., 2009).

7. Conclusion

Radio spectrum is a very valuable resource for wireless communication. CR system leads to spectrum usage efficiency and alleviation of spectrum scarcity. For CR to perform optimally, PUE's activities must be prevented. In this paper, we have discussed the four basic Range-Based PUE localization methods for detecting PUE. Based on the comparison of the four Range-Based localization techniques, it is evident that AOA and RSSI techniques do not require the cooperation of PUE to detect it although each of them has some merits over the other.

Correspondence

S.A. Adebo
Department of Telecommunications Engineering
Federal University of Technology
Minna, Nigeria
Email: adebosamuel@yahoo.com

References

ALRAJEH, N. A., BASHIR, M. & SHAMS, B. 2013. Localization techniques in wireless sensor networks. *International Journal of Distributed Sensor Networks,* 2013.

AMUNDSON, I. & KOUTSOUKOS, X. D. 2009. A survey on localization for mobile wireless sensor networks. *Mobile Entity Localization and Tracking in GPS-less Environments.* Springer.

BOUKERCHE, A., OLIVEIRA, H. A., NAKAMURA, E. F. & LOUREIRO, A. A. 2007. Localization systems for wireless sensor networks. *IEEE wireless Communications,* 14**,** 6-12.

CHEN, R. & PARK, J.-M. Year. Ensuring trustworthy spectrum sensing in cognitive radio networks. *In:* Networking Technologies for Software Defined Radio Networks, 2006. SDR'06.1 st IEEE Workshop on, 2006. IEEE, 110-119.

CHEN, R., PARK, J.-M. & REED, J. H. 2008. Defense against primary user emulation attacks in cognitive radio networks. *IEEE Journal on selected areas in communications,* 26**,** 25-37.

GUVENC, I. & CHONG, C.-C. 2009. A survey on TOA based wireless localization and NLOS mitigation techniques. *IEEE Communications Surveys & Tutorials,* 11**,** 107-124.

HENG, L. & GAO, G. X. 2013. Accuracy of Range-Based Cooperative Localization in Wireless Sensor Networks: A Lower Bound Analysis. *arXiv preprint arXiv:1305.7272*.

JIN, Z., ANAND, S. & SUBBALAKSHMI, K. 2009. Mitigating primary user emulation attacks in dynamic spectrum access networks using hypothesis testing. *ACM SIGMOBILE Mobile Computing and Communications Review,* 13**,** 74-85.

KUŁAKOWSKI, P., VALES-ALONSO, J., EGEA-LÓPEZ, E., LUDWIN, W. & GARCÍA-HARO, J. 2010. Angle-of-arrival localization based on antenna arrays for wireless sensor networks. *Computers & Electrical Engineering,* 36**,** 1181-1186.

LEELAVATHY, S. & SOPHIA, S. 2014. Providing Localization using Triangulation Method in Wireless Sensor Networks. *International journal of innovative technology and exploring engineering,* 4**,** 47-49.

LEÓN, O., HERNÁNDEZ-SERRANO, J. & SORIANO, M. 2012. Cooperative detection of primary user emulation attacks in CRNs. *Computer Networks,* 56**,** 3374 -3384.

LIU, Y., NING, P. & DAI, H. Year. Authenticating primary users' signals in cognitive radio networks via integrated cryptographic and wireless link signatures. *In:* 2010 IEEE Symposium on Security and Privacy, 2010. IEEE, 286-301.

PU, C.-C., PU, C.-H. & LEE, H.-J. 2011. *Indoor location tracking using received signal strength indicator*, INTECH Open Access Publisher.

SINGH, A. & SHARMA, A. 2014. A Survey of Various Defense Techniques to Detect Primary User Emulation Attacks. *International Journal of Current Engineering and Technology,* 4.

SINGH, B., SAHOO, S. K. & PRADHAN, S. R. 2012. Performance evaluation of anchor-based range-based localization systems in wireless sensor networks. *International Journal of Computer Applications,* 52.

SRBINOVSKA, M., DIMCEV, V., GAVROVSKI, C. & KOKOLANSKI, Z. 2011. Localization Techniques in Wireless Sensor Networks using Measurement of Received Signal Strength Indicator. *FACULTY OF ELECTRICAL ENGINEERING UNIVERSITY OF BANJA LUKA***,** 67.

SRBINOVSKA, M, DIMCEV, V, GAVROVSKI, C, & KOKOLANSKI, Z. (2011). Localization Techniques in Wireless Sensor Networks using Measurement of Received Signal Strength Indicator. *FACULTY OF ELECTRICAL ENGINEERING UNIVERSITY OF BANJA LUKA*, 67.