http://dx.doi.org/10.7236/JIIBC.2013.13.5.55
JIIBC 2013-5-7

인지무선시스템을 위한 전송 손실 지수 추정 기반의 기 사용자 위치 검출 기법

Localization of primary user for cognitive radios based on estimation of path-loss exponent

황안*, 구인수**

Hoang Anh, Insoo Koo

요 약 인지무선네트워크에서 기 사용자(primary user)의 위치를 정확하게 파악하는 것은 2차 사용자(secondary user)들의 스펙트럼 이용 효율 향상 및 적절한 전력제어를 통한 기 사용자에 대한 간섭을 야기하는 것을 회피하는데 사용될 수 있기 때문에 인지무선네트워크에서 매우 중요한 연구 주제이다. 노드의 위치를 추정하는 다양한 기법들 중, 수신신호세기(RSS) 기반의 위치 추정 기법은 추가적인 하드웨어 자원 없이 쉽게 구현할 수 있어 일반적으로 가장 많이 사용되는 기법으로 인지무선네트워크에서도 사용될 수 있다. 하지만, 수신신호세기 기반의 위치 추정에서 노드간 거리 측정은 수신된 신호 세기를 기반으로 이루어져 무선 채널 환경의 페이딩, 쉐도잉 그리고 장애물 등으로 인해서 거리 추정의 오차가 생긴다. 따라서 본 논문에서는 수신신호세기 기반으로 기 사용자의 위치 측정의 정확도를 향상시키기 위하여 전송 손실 지수(path loss exponent) 추정기반의 기 사용자 위치 검출 기법을 제안한다. 시뮬레이션 결과를 통해 제안된 방식이 기존 방식보다 기 사용자 위치 측정의 오차를 줄어 기 사용자에 대한 간섭률을 더 줄일 수 있음을 보였다.

Abstract In cognitive radio networks, acquirement of position information of primary user is very important to secondary network since localization information of primary users can be utilized for improving the spectrum efficiency of secondary network and for avoiding harmful interference to primary users by using proper power control. Among various location methods, Received Signal Strength (RSS)-based localization has been widely used for distance measurements in the location detection process despite its inherent inaccuracy because it can be easily implemented without any additional hardware cost. In the RSS-based localization, the distance is measured by the received signal strength, and distance error can be caused by many factors such as fading, shadowing and obstacle between two nodes. In the paper, therefore we propose a localization scheme based on estimation of path-loss exponent to localize the location of primary users more accurately. Through simulations, it is shown that the proposed scheme can provide less localization error and interference rate to primary users than other schemes.

Key Words : Primary user localization, path loss exponent, triangular method, angle of arrival, received signal strength, cognitive radio

---

*준회원, 울산대학교, 전기공학부
**정회원, 울산대학교, 전기공학부 (교신저자)
접수일자 : 2013년 9월 12일, 수정완료 : 2013년 10월 3일
게재확정일자 : 2013년 10월 11일

Received: 12 September, 2013 / Revised: 3 October, 2013 / Accepted: 11 October, 2013
**Corresponding Author: iskoo@ulsan.ac.kr
School of Electrical Engineering, University of Ulsan,, Korea

Ⅰ. Introduction

A principal of cognitive radio technology [1,8] is that the secondary users (SUs) can use the idle spectrum to communicate without creating harmful interference to primary users (PUs), which is a prerequisite because PUs are authorized for using the licensed band. The advantages of cognitive radio networks (CRNs) are higher utilization of the spectrum and lower cost, which leads to CRNs' having many practical applications, such as tracking PUs and assisting the communication of SUs when spectrum is a scarce resource. In a CRN that estimates the PU location, several distributed SUs estimate or compute a relevant quantity, like energy or spectrum-sensing decision, and report it to the cluster heads (CHs)[9]. Then, the CHs make a final decision about the presence or absence of a PU and estimate its location if present.

According to the information available, the localization system can be categorized into range-free and range-based algorithms [2]-[5]. In the range-free algorithm, the SUs make an independent decision on the presence or absence of the PU, without location information, and only transmit this one bit of information to the CH. The range-based algorithm includes the angle of arrival (AOA), direction of arrival (DOA), and received signal strength (RSS), which rely on having enough location information estimated by smart antenna techniques.

In this paper, we propose a localization scheme using the communication and cooperation between each group of SUs to calibrate the path loss exponent. After the sensing phase, in the proposed scheme, the path loss exponent of each channel between PU and SU will be estimated by the cooperation among SUs. The SU periodically sends a signal to other SUs, and it can calculate the angle of arrival from its neighbor SU and then further calculate the path loss exponent for that direction. After that, by using the temporary location of the PU, we can find the calibrated path loss exponent between each link of PU and SU.

The rest of the paper is constructed as follows. The general system model and background about RSS based method are presented in Section Ⅱ. In Section Ⅲ, we describe the calibration method to estimate path loss exponent in CRNs environment by applying AOA model in each calibration region of SUs. We also present a LS method to localize the location of PUs. The simulation results are demonstrated in Section Ⅳ. Finally the conclusion will be drawn in Section Ⅴ.

Ⅱ. System Model

In this paper, we consider a cognitive radio network consisting of SUs and PUs. Fig.1 shows the general system model with the PU in which Cluster Head (CH) and several SUs randomly distributed. Assume that the SUs' locations are known and the location of PUs, CHs and SUs are stationary during the localization process.

In the paper, the received signal strength (RSS) is assumed to be modeled by following log normal shadowing path loss model[6].

$$PL(d) = PL(d_0) + 10\gamma \log_{10}^{(d/d_0)} + \epsilon \ \ [dB] \quad (1)$$

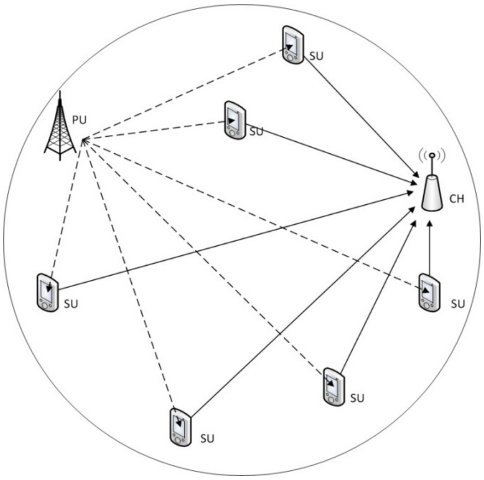

그림 1. 시스템 모델
Fig. 1. System model

where $PL(d)$ is the path loss at distance d from the primary transmitter. $PL(d_0)$ is the path loss at a standard distance d_0 and it is a fixed quantity and can be found using the free space model with is set to 1m in the small grid and 10m in the large grid $(\geq 1000m)$. ϵ is a random variable with a zero-mean Gaussian distribution and variance on a dB scale. γ is the path loss exponent. The path-loss exponent differs by environment and the Table.1 shows some path loss exponents obtained in some radio environments [6].

표 1. 채널 환경에 따른 경로 손실 지수[6]
Table 1. Some typical values of path loss exponent

Environment	path loss exponent (γ)
free space	2
shadowed urban area	3 to 5
urban area	2.7 to 3.5
in building line of sight	1.6 to 1.8
blocked by building	4 to 6
blocked by factories	2 to 3

Ⅲ. Proposed localization scheme based on estimation of the path loss exponent

In this section, we propose a localization scheme based on estimation of the path loss exponent in which a calibration method for estimating the path loss exponent is proposed since the path loss model depends on the power law for the path loss exponent such that a small error in the path loss exponent will produce a significant error in distance measuring.

Similar to the references [7,13], in the paper we use the AOA method as a calibration method in order to find the best temporal and spatial match for the path loss exponent around the SUs, instead of using an average value for the path loss exponent which may result in considerable error in measuring the distance during the localization process.

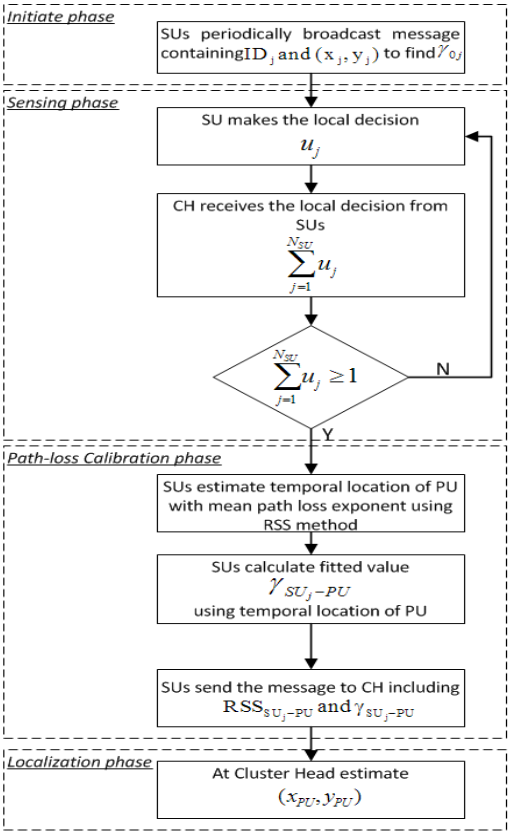

그림 2. 제안된 위치 검출 기법의 전체 흐름도
Fig. 2. Overall flowchart of the proposed scheme

The Fig. 2 shows overall flow chart of the proposed localization scheme for CRNs using the calibrated path loss exponent, which consists of Initiate Phase, Sensing Phase, Path loss Calibration Phase and Localization Phase.

1. Initiate Phase

In the phase SUs periodically broadcast messages containing their IDs and positions to all nodes in their transmission range; here, “broadcast” means on-hop broadcasting. That is, the message of a SU will be sent to other SUs within its transmission range. When an SU receives the messages, it records the RSS values in order to calculate the path loss of the power value, and it extracts the locations. Then, using the path loss value and the distance between any pair of SUs, the path loss exponent for that link can be found. In the flow chart shown in Fig.2, fro example, ID_j and (x_i, y_i) present the ID and position of the j^{th} SU respectively, and γ_{0j}presents the path loss exponent between the path of senders SU_0 and receiver SU_j.

2. Sensing Phase

In order to protect the PUs from harmful interference, the SUs have to sense the spectrum prior to their transmissions to make sure that it is available at that time instance. In this paper, we assume that the SUs employ the widely-used energy detection method to detect the PU's signal, due to the method's simplicity, speed, and excellent capability [10-11]. The principle of energy detection is based on the difference in energy between the PU transmission signal and the noise. The observed energy of the j^{th} SU is given as:

$$y_j = \sum_{k=1}^{n} |x_j(k)|^2 \tag{2}$$

where $x_j(k)$ is the k^{th} sample of the received signal at the j^{th} SU and N is the number of samples, $N = 2TW$, where T and W are the detection time and the signal bandwidth, respectively.

According to the status of the PU, the received signal at the j^{th} SU is given by:

$$x_j(t) = \begin{cases} n(t), & H_0 \\ h_j s(t) + n(t), & H_1 \end{cases} \tag{3}$$

where H_0 and H_1 represent the absence and presence of a PU, respectively, $s(t)$ denotes the signal transmitted by the PU, h_j is the channel gain between the j^{th} SU in the cluster and the PU, $n(t)$ denotes the additive noise at the SU.

Suppose that the noise in each sample is a Gaussian random variable with a mean zero and variance σ_n^2. As a result if the PU signal is absent, the sum of the squares of N Gaussian random variables y_j/σ_n^2 follows a central chi-square distribution with N degree of freedom and a non-centrality parameter $N\eta_j$:

$$y_j/\sigma_n^2 \sim \begin{cases} \chi_N^2 & H_0 \\ \chi_N^2(N\eta_j) & H_1 \end{cases} \tag{4}$$

where $\eta_j = \dfrac{E_s|H_j|^2}{N\sigma_n^2}$ is the SNR of the PU signal at the SU, and the quantity $E_s = \sum_{k=1}^{N} |s(k)|^2$ represents the transmitted signal energy over a sequence of N samples during each detection interval.

A local decision of the SU, u_j can be made as follows:

$$u_j = \begin{cases} H_1 & y_j \ge \lambda \\ H_0 & otherwise \end{cases} \tag{5}$$

where λ is the decision threshold of the SU.

With the given false alarm probability P_f, the threshold λ can be decided by:

$$P_f = P_r\{u_j \ge \lambda | H_0\} = Q(\frac{\lambda - N\sigma_n^2}{\sqrt{2N\sigma_n^4}}) \tag{6}$$

Then the detection probability of the k^{th} SU is calculated as follows:

$$\begin{aligned} P_d^j &= P_r\{u_j \ge \lambda | H_1\} \\ &= Q(\frac{\lambda - N(1+\eta)\sigma_n^2}{\sqrt{2N(1+2\eta)\sigma_n^4}}) \end{aligned} \tag{7}$$

where $Q(.)$ is the tail probability of the standard normal distribution (or called complementary cumulative distribution function) and is given by

$$Q(x) = \frac{1}{2\pi} \int_x^{\infty} e^{-\frac{t^2}{2}} dt \tag{8}$$

Assume that the channel to CH is perfect. The local decisions are collected at the cluster head, and then a final decision is taken. A final decision of the CH using OR rule [12] u_c can be made as follows:

$$u_c = \begin{cases} H_1 & \sum_{j=1}^{N_{SU}} u_j \ge 1 \\ H_0 & otherwise \end{cases} \tag{9}$$

where N_{SU} is the number of SUs in the cluster.

3. Path loss Calibration Phase

When a PU is present, its temporal location can be calculated by using the RSS method with at least 3 SUs and average path-loss exponent. However, the temporal location is imprecise, since the mean, rather than the calibrated, path-loss exponent is used to define the distances between the PU and its neighboring SUs. After obtaining the temporal location, the SU receives the signal from the PU in order to improve the precision of the location. One of the SUs, called the central SU, checks the angle of arrival by using the temporal location of the PU. Then, the path loss exponent for the link between the PU and the central SU is used, along with the distances between all pairs of SUs, to find the best-fit value of the path-loss exponent.

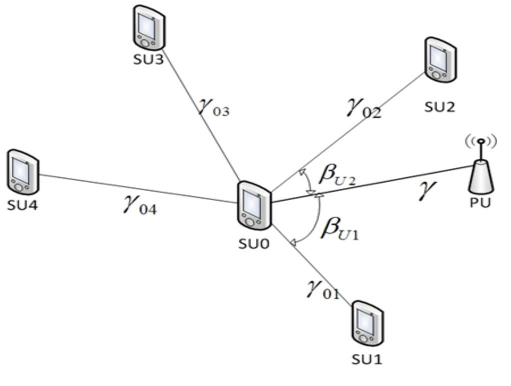

그림 3. 경로 손실 지수 추정 예
Fig. 3. Example for estimating path-loss exponent

Fig. 3 shows an example for estimating path-loss exponent in which the PU is in the sector formed by SU_0, SU_1 and SU_2. The SU_0 checks the angle of arrival based on the temporal location of the PU. To obtain the calibrated value of path loss exponent between link of PU to SU_0, the information of distance and path loss between links $SU_0 - SU_1$ and $SU_0 - SU_2$ are used. The best value of the path loss exponent for link between PU and is calculated by [13]:

$$\gamma = \frac{PL_{01}D_{01}\beta_{U1} + PL_{02}D_{02}\beta_{U2}}{D_{01}^2\beta_{U1} + D_{02}^2\beta_{U2}} \tag{10}$$

where PL_{01}, PL_{02} and D_{01}, D_{02} are path loss value and log-normal distance between links $SU_0 - SU_1$, $SU_0 - SU_2$, respectively. β_{U1} and β_{U2} are the angle between PU and SU_{01}, and the angle between PU and SU_{02} respectively.

4. Localization Phase

When the CH receives at least three messages including the calibrated path loss exponent and RSS value from SUs, finally it can calculate the precise location based on trilateration method with Weight Least Square (WLS) Error Estimation. The PU is assumed to have an interference range with radius r. Only the SUs inside the circle can detect the signals from the PU. The algorithm does not work when there are fewer than 3 nodes in the range.

Let the position of the PU (x_p, y_p), and the position of secondary user SUs randomly distributed at (x_1, y_1), (x_2, y_2), $\cdots$, $(x_j, y_y) \cdots (x_{N_{SU}}, y_{N_{SU}})$ in CRN, respectively. Then, we can find the distance D_{ij} between the i^{th} PU and the j^{th} SU after getting the calibration path-loss exponent γ_{ij} as following way: If we denote the distances between the i^{th} PU and all the SU as D_{i1}, D_{i2}, $\cdots$, D_{ij} $\cdots D_{iN_{SU}}$, then we have following equation;

$$\begin{cases} (x_p - x_1)^2 + (y_p - y_1)^2 = D_{p1}^2 \\ (x_p - x_2)^2 + (y_p - y_2)^2 = D_{p2}^2 \\ \qquad \vdots \\ (x_p - x_{N_{SU}})^2 + (y_p - y_{N_{SU}})^2 = D_{pN_{SU}}^2 \end{cases} \tag{11}$$

The Eqn.(11) can be re-written by subtracting all other lines by the first line , and further we have a matrix form as following:

$$\boldsymbol{A}\boldsymbol{X}=\boldsymbol{B} \tag{12}$$

where $\boldsymbol{X}=[x_p y_p]^T$,

$$\boldsymbol{A}=\begin{cases}2(x_1-x_2)+2(y_1-y_2)\\ 2(x_1-x_3)+2(y_1-y_3)\\ \quad\vdots\\ 2(x_1-x_{N_{SP}})+2(y_1-y_{N_{SP}})\end{cases}$$

$$\boldsymbol{B}=\begin{cases}D_{p2}^2-D_{p01}^2+(x_1^2-x_2^2+y_1^2-y_2^2)\\ D_{p3}^2-D_{p01}^2+(x_1^2-x_3^2+y_1^2-y_3^2)\\ \quad\vdots\\ D_{pN_{SU}}^2-D_{p01}^2+(x_1^2-x_{N_{SU}}^2+y_1^2-y_{N_{SU}}^2)\end{cases}$$

To get the best estimation of location of the primary user, the standard least squares (LS) method is applied in the paper, and we have best solution $\hat{\boldsymbol{X}}$ for LS method as following:

$$\hat{\boldsymbol{X}}=(\boldsymbol{A}^T\boldsymbol{A})^{-1}\boldsymbol{A}^T\boldsymbol{B} \tag{13}$$

Ⅳ. Simulation Results

In this section, simulation results are shown for a CRN in which secondary network including 5 independent CHs and 50 SUs and a primary network including 25 PUs distributed in a 100 x 100 meter square are considered as shown in Fig.4.

To sure that each PU can be localized, the maximum cooperation range of SUs in the network is set to 30m as shown in Fig.5. To emulate a real environment, we have partitioned the nodes' surroundings into six unequal sections with angles ranging from [30 45 55 65 75 90]. In the case that the angle between PU and closet SU is lower than 30 degree, the best calibrated value for this PU will be the path–loss exponent from that SU. We also have set up a simulation model in which the value path loss exponent is changed around each SU. The path loss exponent value of each section is randomly created in range between $\overline{\gamma}-\Delta_\gamma$ and $\overline{\gamma}+\Delta_\gamma$ where the mean value of path–loss exponent $\overline{\gamma}$ is set to 3 and the deviation of path–loss exponent Δ_γ is set to 0.5. The following other parameters are used; the false alarm probability P_f is 0.01, the variance of the Gaussian white noise process is 3dB, the SNR is 3dB and the transmission range of PUs is 35m. 50 samples are taken for calculating the received signal strength and 100 run times for performance evaluation.

For performance comparison in terms of accuracy of localization, we compare our scheme with the two other methods: Mean path–loss exponent method that utilized the mean value of path loss exponents and the Maximum Likelihood method[14] that utilized all path–loss exponents in–range SUs.

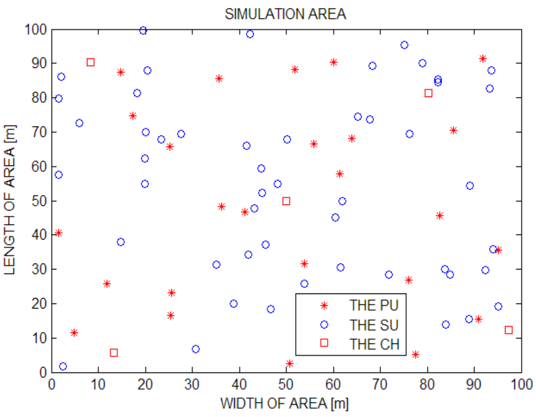

그림 4. 시뮬레이션을 위해 고려된 인지무선망
Fig. 4. The proposed CRN for simulation

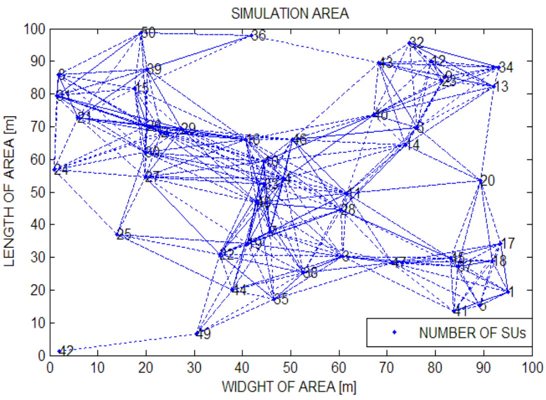

그림 5. 2차 사용자들 간 경로손실 지수 추정을 위한 링크 형성
Fig. 5. The cooperation link between SU nodes for estimating path loss exponent

Fig.6 shows the error in the PU localization with changes of maximum deviation of path-loss exponent in range . As the maximum deviation of path-loss exponent increases, the localization error is also increased. However, the proposed scheme much improves the precision compared with the other schemes. Also, the proposed is less sensitive to the changes of maximum deviation of path-loss exponent than the other localization schemes.

Fig.7 shows localization error according to the variance of Gaussian noise. From the figure, it is observed that Gaussian noise has little impact on localization schemes. That is, even when the variance of Gaussian noise changes significantly, the variation in location error is small. Fig.6 and 7, we observed that the localization error is mainly due to not Gaussian noise but the path-loss exponent.

Fig.8 shows that the interference rate to PU according to the maximum transmission range of SU. The interference to PU is defined to be occurred when the transmission range of the SU is overlapped with that of PU. As shown in the figure, interference rate to PU increases as the maximum transmission range of SU increases. However, the proposed method always outperforms the other schemes.

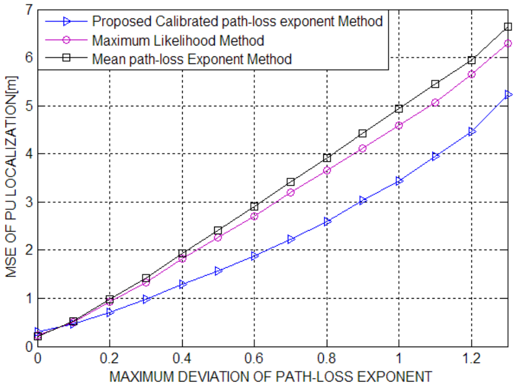

그림 6. 경로 손실 지수의 분산 변화에 따른 위치 측정 오차
Fig. 6. Localization error with changing of maximum deviation of path-loss exponent for different localization schemes

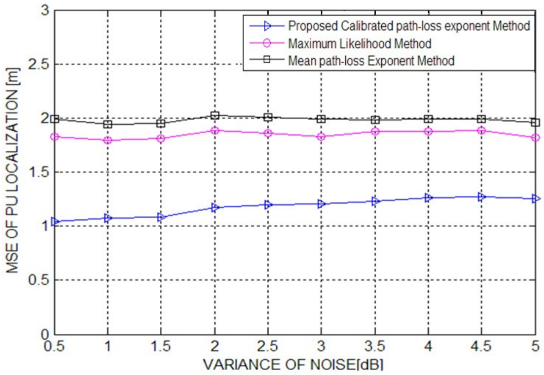

그림 7. 채널의 가우시안 잡음 분산에 따른 위치 측정 오차
Fig. 7. Localization error according to the variance of Gaussian noise

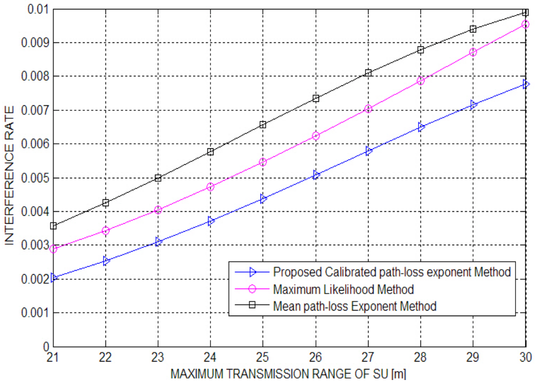

그림 8. 2차 사용자의 최대 전송 범위에 따른 기 사용자에 대한 간섭률
Fig. 8. The interference rate to PU according to the maximum transmission range of SU for different localization schemes

Ⅴ. Conclusion

In this paper, a localization algorithm based on RSS is proposed to solve the problem of locating the PUs for the CRNs. To improve the precision, instead of using the given path-loss exponent, a method to estimate the path loss exponent is studied. According to the characteristic of CRNs, the path loss exponent is determined by the SUs' communication. Finally, trilateration method is applied in order to realize the position of PU and LS method is utilized to estimate the error of PU location. Simulation shows that the proposed scheme can improve the localization precision obviously.

References

[1] S. Haykin, “Cognitive radio: Brain empowered wireless communications,” IEEE J. Sel. Areas Comm., vol. 23, no. 2, 2008

[2] A. Uchiyama, S. Fujii, K. Maeda, T. Umedu, H. Yamaguchi, and T. Hig -ashino, “Ad-hoc localization in urban district,” in Proc. IEEE INFOCOM, Anchorage, AK, May 2007, pp. 2306 - 2310

[3] D. Gong, Z Ma. Y. Li, W. Ches, and Z. Cao, “High geometric range free localization in opportunistic cognitive sensor network,” IEEE International Personal Commun., pp. 139-143, 2008

[4] N. Bulusu, J. Heidemann, and D, Estrin, “GPS-less Low Cost Outdoor Localization for Very Small Devices,” IEEE Personal Communications Magazine, vol. 7 no. 5, Oct., 2000

[5] Tian He, Chengdu Huang, Brian M.Blum, John A.Stankovic, and Tarek Abdelzaher, “Range-Free Localization Schemes for Large Scale Sensor Networks,” in Proceeding of ACM MOBICOM, 2003

[6] Tapan K.Sarkar, Zhong Ji, Kyungjung Kim, Abdellatif Medourf, and Magdalena Salazar-Palma, “A Survey of Various Propagation Models for Mobile Communication,” Antennas and Propagation Magazine, IEEE, vol. 45, pp. 51-82

[7] T.X. Cong, E. Kim, I. Koo, “RSS Based Localization Scheme Using angle-referred calibration in WSN”, Proc. ICIC, pp.1222-1233, 2008.

[8] N. Tung and I. Koo, "Fuzzy-based Dynamic Packet Scheduling Algorithm for Multimedia Cognitive Radios,” The Journal of The Institute of Internet, Broadcasting and Communication, Vol.12, No.3, pp.1-7, 2012. http://dx.doi.org/10.7236/JIWIT.2012.12.3.1

[9] N. Radhi, K. Aziz, S. Hamad and H.S. Al-Raweshidy, “Estimate primary user localization using cognitive radio networks,” International Conference on Innovations in Information Technology (2011) pp. 381-385

[10] P. Prasain, Y. Kim, and D. Choi, “A Survey on MAC Protocols for Cognitive Radio Networks,” Journal of Korean Institute of Information Technology, vol. 11, issue 8, pp. 121-133, 2013.

[11] M.A. Abdulsattar and Zahir A. Hussein, “Energy detection technique for spectrum sensing in Cognitive radio: A survey,” International Journal of Computer Networks & Communications, Vol.4, No.5, pp. 223-242

[12] M.A. Hossain, Md. Hossain and Md. Ibrahim Abdullah, “Performance analysis of Cooperative Spectrum sensing in Cognitive Radio,” International Journal of Innovation and Applied Studies Vol.1, No.2, pp. 236-245

[13] T.X Cong and Insoo Koo, “An RSS-based Localization Scheme Using Direction Calibration and Reliability Factor Information for WSN,” KSII Transactions on Internet and Information Systems Vol.4, No.1 (Feb. 2010).

[14] C. Kocks, S. Wang, G.H. Bruck and P. Jung, “Maximum likelihood localization estimation based on received signal strength,” International Symposium on Applied Sciences in Biomedical and Communication Technologies, 2010.

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MEST) (NRF-2013R1A2A2A05004535 and 2012R1A1A2038831)

저자 소개

황 안(준회원)

- 2008년 : (학사) Hanoi University of Technology, Vietnam(학사)
- 2013년 : 울산대학교 전기공학부(석사)

<주관심분야 :무선인지시스템, 위치검출, 스펙트럼 센싱>

구 인 수(정회원)

- 1996년 건국대학교 전자공학과 졸업 (학사)
- 1998년 광주과학기술원 정보통신공학과 졸업 (석사)
- 2002년 광주과학기술원 정보통신공학과 졸업 (박사)
- 2005년~현재 울산대학교 전기공학부 교수

<주관심분야 : 차세대 통신 시스템, 무선 센서네트워크>