**Journal of Theoretical and Applied Information Technology**
31st July 2015. Vol.77. No.3

ISSN: **1992-8645** www.jatit.org E-ISSN: **1817-3195**

# CRAMER RAO BOUNDS FOR PRIMARY USER LOCALIZATION USING HYBRID TOA/DOA TECHNIQUE IN COGNITIVE RADIOS

**[1]C.S.PREETHAM, [2]Dr. M SIVA GANGA PRASAD, [3]A.SUSMITHA, [3]S.PRASANTH, [3]M.R.KISHORE, [3]A.ESWAR**
[1] Research Scholar, Dept of ECE, K L University, Vaddeswaram, Guntur, AP, India.
[2] Professor, Dept of ECE, K L University, Vaddeswaram, Guntur, AP, India.
[3] UG Student, ECE, K L University, Vaddeswaram, Guntur, AP, India.
E-mail: [1]cspreetham@kluniversity.in, [2]msivagangaprasad@kluniversity.in, [3]alurisusmitha1@gmail.com,
[3]prasanth4424@gmail.com, [3]kishoremunaga@gmail.com, [3]eswar4400@gmail.com

## ABSTRACT

Cognitive Radio (CR) is of great interest to technologists because of significantly increasing the spectrum efficiency. The Secondary user (SU) which is the unlicensed user must constantly study the actions of Primary user (PU), which is the licensed user. The location information of PU can enable several key functions of CR networks, such as aiding spectrum policy enforcement, intelligent location aware routing, and better spatial temporal sensing. Time of Arrival, Directions of Arrival and Received Signal Strength are three categories of research that is being done previously in the field of passive localization. These categories are done based on how the sensors obtain location estimation and on the type of measurements shared between the sensors. Cramer-rao bound establishes the lower limit on how much information about an unknown probability distribution parameter can a set of measurement carries. In this paper we obtain the Cramer-rao bounds for a novel hybrid Direction of arrival (DOA)/Time of arrival (TOA) based algorithm in cognitive radios networks and the performance is analyzed and compared for various primary user location estimation techniques such as RSS-CRB, Joint-CRB optimal, and Joint-CRB music.

**Key words:** *PU Localization; Cognitive radio network; Cramer-Rao bounds; DOA; TOA.*

## 1. INTRODUCTION

A communication system needs sufficient operational environment information, like propagation characteristics and spectral resources. The Cognitive radio (CR) networks have unique abilities such as location, environment, spectrum awareness to obtain accurate information regarding environment, location and spectrum [1]. This paper provides a comprehensive review of implementing these concepts. In addition to this, other characteristics of CR technology such as propagating channel, transmission, reception and dynamic spectrum utilization are discussed. The cognitive radio capabilities for accurate operating environment characterization are discussed. This emphasis is crucial to efficient radar systems, communications and localization.

In this paper the accuracy that is achievable by primary user localization algorithms that utilize Direction of Arrival (DOA) and Time of Arrival (TOA) jointly is analyzed, by calculating Cramer Rao Bounds to obtain the variance. The works that are done previously in this field assume that DOA estimation error variance is independent of Received Signal Strength or as a fixed constant and evaluate the CramerRao-Bounds for DOA only, RSS only and RSS/DoA localization techniques. The CRB-bounds for Hybrid-TOA/DOA based licensed user localization techniques are derived based on DOA-estimation error variance mathematical model, as a function of TOA to the given CR placements. The bounds derived are compared with other localization algorithms and analyzed few key components like number of samples and antennas, number of nodes, achievable accuracy, correlation distance and channel shadowing variance.

The paper focuses mainly on characterization of performance achievable by the proposed hybrid TOA/DOA based localization, using either or both DOA and TOA for any unbiased estimator, by obtaining the CRB-lower bound on estimation accuracy. The localization method based on RSS only is discussed in [2]-[4] and the CRB is calculated assuming a shadowing channel that is correlated and independent. The CRB bounds for the DOA only based localization is discussed in several papers [5]–[10] .CRB for RSS/DOA based localization is discussed in [11].

## 2. COGNITIVE RADIO

The concept of Cognitive-radio is built upon software defined radio technology, currently spectrum sensing is the most focused area of research in the cognitive radio field, especially the TV band white spaces. Achieving higher throughput in WLAN, extension of transmission distance and emergency are the important cognitive radio spectrum sensing applications.
The cognitive radios have four important functions which are given below

### 2.1 Spectrum Sensing

This is the ability of CR for detecting spectrum that is unused and allow sharing it with other users preventing any harmful interference to other primary users.
Sensing of whitespaces is an important requirement in CR network, detection of primary user is an effective method for detecting white spaces. In Spectrum sensing three types of techniques are available.

#### 2.1.1 Cooperative Detection

In these methods the information is incorporated from multiple cognitive radios for detecting the primary user jointly and performs spectrum sensing.

#### 2.1.2 Transmitter Detection

CR should have the ability to detect in a certain spectrum whether signal of the PU transmitter is available locally or not. Some of the proposed approaches for this are

i. Energy Detection
ii. Matched Filter Detection
iii. Interference based detection

### 2.2 Spectrum Management

The cognitive radios must meet the requirements of communicating users by selecting the best spectrum available.[12] The Cognitive radios need the following management functions to satisfy the required quality-of-service over all the spectrum bands available.

i. spectrum analysis
ii. spectrum decision

### 2.3 Spectrum Sharing

In open spectrum usage spectrum sharing is one of the major challenges. It is the task of offering a fair spectrum scheduling method for the users.

### 2.4 Spectrum Mobility

This is the process performed when the CR exchanges its operating frequency. When the channel that the CR is previously using is being reoccupied by the PU then the best frequency available must be chosen in a dynamic manner, for transition to a better spectrum, providing the communication requirements seamlessly during this transition.

## 3.PASSIVE LOCALIZATION METHODS

### 3.1 Received Signal Strength

RSS is most capable for measurements because of low cost and implementation is simple in hardware. It is one of the best propagation models in passive localization methods and to measure distance between the transmitter and the receiver. At the receiver the magnitude of the signal power is measured by using RSS.

### 3.2 Time Of Arrival

In Time of Arrival method the distance between two devices is derived, when signal propagation speed is known priori, by measuring time taken for one way propagation between the devices. When the signal propagation speed is given by S, time of signal sent at sender is given by $t_1$, time of signal received at receiver is given by $t_2$ and the distance d between the devices is given by $d = s(t_2 - t_1)$. The mobile units can be localized by knowing the absolute position of reference units along with calculated distance between the devices. The PU localization estimate can be seen ideally as point of interception of circumferences centered on radius of estimated distance to mobile unit and reference units. In reality, due to the presence of shadowing and multipath fading, instead of one exact localization point an area of uncertainty is found.

In TOA based techniques the estimation of correct position we need all the network devices (reference units and mobile) to be synchronized and also the timestamp information of the packet transmitted. TOA techniques have high hardware complexity and yet offer high accuracy.

### 3.3 Direction Of Arrival

The array based direction of arrival PU localization algorithms are classified into four types; they are subspace based technique, conventional techniques, integrated techniques and maximum likelihood techniques. The subspace based techniques exploit Eigen structure of input data matrix and these are high resolution suboptimal methods. The conventional technique requires huge number of elements to obtain high resolution and they are based on classical beam forming methods. Maximum likelihood methods are computationally very intensive and can perform well even in the conditions where SNR is low. The integrated techniques are combination of subspace based techniques with property restoral techniques. Hardware complexity is high to accommodate antenna arrays and hence suitable for implementation at base station. It avoids multipath effect and shadowing occurs in RSS algorithm.

## 4. SYSTEM MODEL:

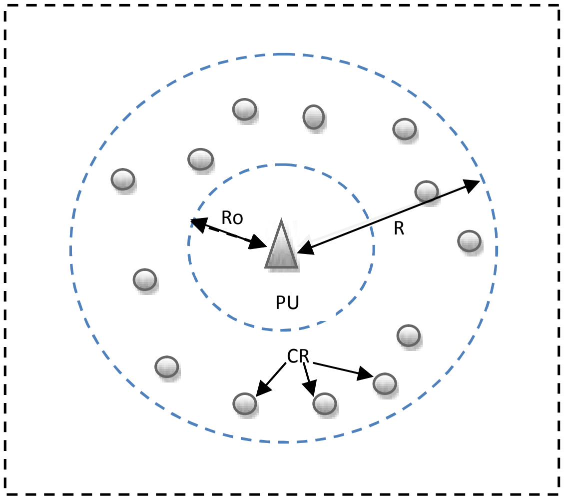

Fig. 1. system model

We expect the Cognitive Radios that can hear the primary user form a circle with radius R and are consistently set in the range, as demonstrated in Fig.1. The Cognitive Radios are set freely inside range, which shows independency among sets of $\theta_n$ and $d_n$ , all $\theta_n$'s, and all $d_n$'s . Let $R_0$ is the radius of forbidden region and primary user located at the center of circle.

## 5. HYBRID-TOA/DOA ESTIMATION FOR CRB

A far-field target source is considered for the transmission of plane wave along with a sensor which contains the uniform linear array with an N-element to receive. AWGN channel with line of sight is considered as transmitted channel. The transmitted signal with unit energy $\int |s(t)|^2 d \ = 1$ is represented by $s(t)$ .

The baseband EM wave received at the antenna of N element is stacked into a vector

$$r(t) = [r_0(t), r_1(t), \ldots\ldots, r_{N-1}(t)]^T \quad (1)$$

This considers equation

$$r(t) = a(\theta) A\, s(t - \tau) + n(t) \quad (2)$$

Where, A represents distance dependent channel gain, $\tau$ represents the time delay from the target to the primary user location and $n(t)$ represents the independent noise elements the AWGN vector mean zero, each of $N_0/2$ power spectral density and zero mean. The array signature vector can be narrated by,

$$a(\theta) = [1, e^{-j2\pi \quad c \quad \theta/\lambda}, \ldots., e^{-j2\pi(N-1)d \quad c \quad \theta/\lambda}]^T \quad (3)$$

Here, d represents the antenna element distance, λ represents plane wave signal wavelength and θ is directional of arrival.

Irrespective of whether $A$ is known or unknown, the model of the signal in the CRB for $\tau - \theta$ can be demonstrated the same. So, joint estimation of $\tau - \theta$ is to be concentrated. In AWGN prospective, the received signal's probability density function (pdf) dependent on time delay and direction of arrivals.

$$p(r; \theta, \tau) = \frac{1}{Q} e \quad \left\{ -\frac{1}{N_0} \int \| r(t) - a(\theta) A \ (t - \tau) \|^2 d \ \right\} \quad (4)$$

Here, Q represents a constant. In like manner, joint-ToA/DoA maximum-likely-hood (ML) evaluations can be estimated by mutually seeking over (τ-θ) to maximize p(r; θ, τ). The exploration gets reduced to 2D sliding connection as

$$(\hat{\tau} - \ddot{\theta}) = a \quad \max_{\tau,\theta} R \ \{ \int r^H(t) a(\theta) A \ (t - \tau) d \ \} \quad (5)$$

This combined ML estimation is fair, and asymptotically touch the bounds of cramer-rao for $\tau - \theta$ specified in $C_{\tau,\theta} = F^{-1}$[6] , here F represents the FIM defined as

$$F := E\{[\nabla_{\tau,\theta} \ln p(r;\theta,\tau)][\nabla_{\tau,\theta} \ln p(r;\theta,\tau)]^T\}$$

$$F = \begin{pmatrix} F_\tau & F_\tau \\ F_\tau & F_\theta \end{pmatrix} \quad (6)$$

After defining some algebraic derivations $\gamma_s := A^2/N_0$ as SNR (signal to noise ratio), we derive

$$F_\tau = 8\pi^2 N\gamma_s \int |S(f)^2| f^2 d \quad (7)$$

$$F_\theta = \frac{8\pi^2 d^2 \gamma_s S \quad ^2\theta}{\lambda^2} \frac{(N-1)N(2N-1)}{6} \quad (8)$$

$$F_\tau = -\frac{8\pi^2 d\gamma_s S \quad \theta}{\lambda} \frac{N(N-1)}{2} \int f|S(f)|^2 d \quad (9)$$

Let the mean square effective band-width of the unit energy signal s (t) is denoted by $W^2 = \int 4\pi^2 f|S(f)|^2 d$ .zero for real valued s (t) is denoted by $F_\tau$ .The evaluation of TOA and DOA with CRB gives the result as

$$C_\tau = [F^{-1}]_{(1,1)} = \frac{1}{2N\gamma_s W^2} \quad (10)$$

$$C_\theta = [F^{-1}]_{(2,2)} \quad (11)$$

$$C_\theta = \frac{3\lambda^2}{4\pi^2 d^2 \gamma_s S \quad ^2\theta (N-1)N(2N-1)} \quad (12)$$

Evidently, the Cramerrao-bounds of ToA are predominantly resolved by the signal bandwidth W, in this DoA is influenced by array arrangement specifications N and d.

### 5.1 CRB for RSS

To determine fisher information matrix (F.I.M) $F_{\bar{\emptyset}}$ for the RSS only, then first unequivocally express the logarithm of the probability distribution function as

$$\log p(\bar{\emptyset}/\ell_p) = -\log[(2\pi)^{N/2}(d \quad \Omega_s)^{1/2}] - \frac{1}{2}(\bar{\emptyset}-\bar{\emptyset})^T \Omega_s^{-1}(\bar{\emptyset}-\bar{\emptyset}) \quad (13)$$

Then the given RSS-only FIM is

$$F_{\hat{\emptyset}} = \frac{1}{2} E_{\hat{\emptyset}}\left[\frac{\partial^2}{\partial l^2}(\hat{\emptyset}-\bar{\emptyset})^T \Omega_s^{-1}(\hat{\emptyset}-\bar{\emptyset})\right]$$

The components of $F_{\bar{\emptyset}}$ are inferred

$$\{F_{\hat{-}|\bar{\emptyset}}\}_{11} = \sum_{n=1}^{N} \frac{\Delta y_n^2}{d_n^4}\{\frac{\sim \cos^2 \theta\%_n)}{d_n^{¥}} + 2\tan^2 \theta_n\}$$

$$\{F_{\hat{\emptyset}}\}_{22} = \frac{\partial(\hat{\emptyset}-\bar{\emptyset})}{\partial y_P}^T \Omega_s^{-1} \frac{\partial(\hat{\emptyset}-\bar{\emptyset})]}{\partial y_P}$$

$$= \in ¥^2 \Delta y^T D^{-2} \Omega_s^{-1} D^{-2} \Delta y$$

$$\{F_{\hat{\emptyset}}\}_{12} = \{F_{\hat{\emptyset}}\}_{21} \frac{\partial(\hat{\emptyset}-\bar{\emptyset})}{\partial x_P}^T \Omega_s^{-1} \frac{\partial(\hat{\emptyset}-\bar{\emptyset})]}{\partial y_P}$$

$$= \in ¥^2 \Delta x^T D^{-2} \Omega_s^{-1} D^{-2} \Delta y$$

Here $\varepsilon = 100 / (\log 10)^2$, matrices and vector are represented as

$$D \triangleq d \quad (d_1, d_2, \ldots, d_N) \quad (14)$$
$$\Delta x = [\Delta x_1, \Delta x_2, \ldots\ldots, \Delta x_N]^T,$$
$$\Delta y = [\Delta y_1, \Delta y_2, \ldots\ldots, \Delta y_N]^T,$$
$$\Delta x_n = x_p - x_n \text{ And } \Delta y_n = y_p - y_n.$$

Itemized determinations are given in Appendix A. To get a minimal outflow of $F_{\bar{\emptyset}}$, how about we characterize $L = [\Delta x, \Delta y]^T$ and $\Lambda = \frac{1}{\varepsilon\gamma^2} D^2 \Omega_s D^2$. In this way, it is direct to confirm that the RSS only primary user localization for FIM and RMSE are represented by

$$F_{\bar{\emptyset}} = L\Lambda^{-1}L^T$$

$$R_{R,F} \geq \sqrt{\{F_{\bar{\emptyset}}^{-1}\}_1 + \{F_{\bar{\emptyset}}^{-1}\}_2} \quad (15)$$

Here R, F represents the RSS only limit for fixed placements.

### 5.2 MUSIC ALGORITHM FOR JOINT-CRB

In this area by utilizing error variance from $\sigma^2_{n,M}$ , we infer the joint-CRB with DoA estimation considered by MUSIC calculation, considered one of the efficient methods of DoA estimation.

$F_{\bar{\theta}/\bar{\emptyset}}$ Is determined by supplanting $f_C \quad (\bar{\emptyset}_n)$ (12) with $f_M \quad (\bar{\emptyset}_n)$ given by ( ). Applying the outcomes in equation, can obtain $F_{\bar{\theta}/\bar{\emptyset}} = P\Delta P^T$ , Here $\Delta = d \quad (\delta_1, \delta_2, \ldots\ldots, \delta_N)$ and

$$\delta_n = \frac{1}{d_n^4}\left\{\frac{c \quad ^2\bar{\theta}_n}{p}\left[\frac{\varepsilon_L P_T \varepsilon^{\sigma^2_n/(2\varepsilon)}}{d_n^Y} - \frac{P_M}{N_a} + \frac{P_M^2}{N_a^2} E_{\bar{\emptyset}}\left(\frac{1}{\varphi_n + \frac{P_M}{N_a}}\right)\right] + 2t \quad ^2\bar{\theta}_n\right\} \quad (16)$$

Since Fisher Information Matrix for the RSS-only is autonomous of DoA calculation, the joint FIM and the comparing RMSE utilizing MUSIC calculation are considered by

$$R_{J,F,M} \geq \sqrt{\{F_{J,F,M}^{-1}\}_1 + \{F_{J,F,M}^{-1}\}_2} \quad (17)$$

$$F_{J,F,M} = P\Delta P^T + L\Delta^{-1}L^T \quad (18)$$

Here R, F represents the RSS only limit for fixed placements.

## 6. SIMULATION RESULTS:

**6.1 Results of RMSE for RSS** –CRB comp, RSS-CRB asymptotic, Joint CRB MUSIC, Joint CRB comp, ToA/DoA with varying Ro/R ratio. We represent the numerical results to study the performance of localization and also to verify the derived CRB's for channel conditions, array parameters and different node density. We observe that the variation of RMSE is an accurate function of various parameters of channel and array.

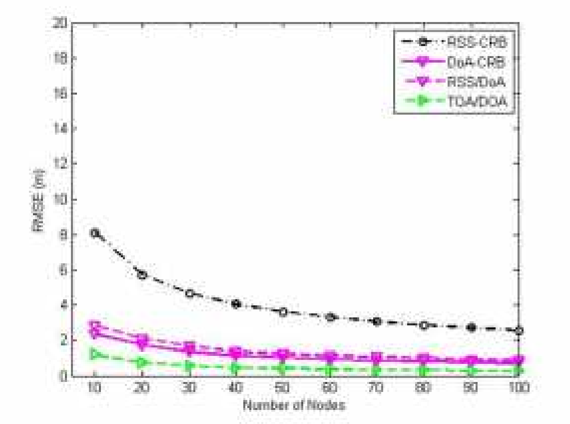

Fig. 2a. Variation Of Number Of Nodes Vs. RMSE For Ro/R=0.1

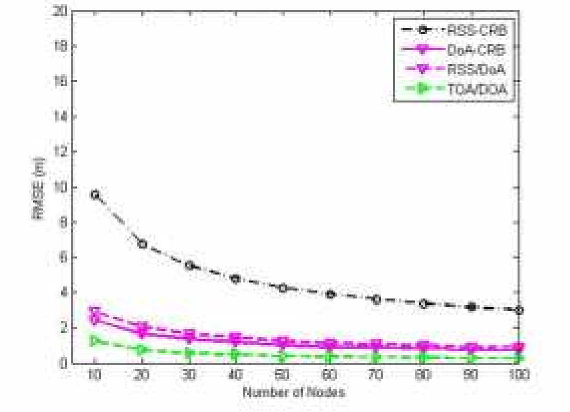

Fig. 2b. Variation Of Number Of Nodes Vs. RMSE For Ro/R=0.2

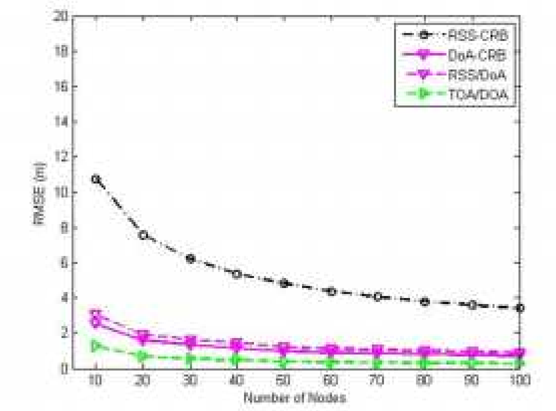

Fig. 2c.Variation Of RMSE Vs Number Of Node For Ro/R=0.3

Among all we observe that the values of Ro/R play an important role .RMSE increases as we increase Ro due to excluding the nodes that are closer to the primary user. As the value of Ro/R changes the RMSE of RSS CRB asymptotic varies largely as shown in the figures 2a,2b,2c.Fig 2a represents the RMSE for nodes ranging upto 10 to 100 for Ro/R=0.1, Fig 2b represents the RMSE for nodes ranging upto 10 to 100 for Ro/R=0.2, Fig 2c represents the RMSE for nodes ranging upto 10 to 100 for Ro/R=0.3 when the shadowing variable is considered to be 6.

**6.2 Results of RMSE for RSS** – CRB comp, RSS-CRB asymptotic, Joint CRB MUSIC, Joint CRB comp, ToA/DoA with varying number-of-CRs in an un-correlated shadowing environment

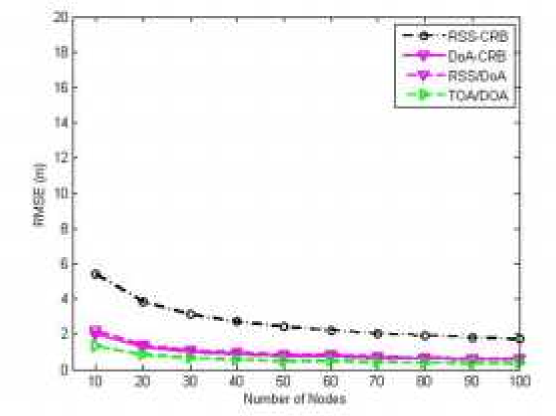

Fig. 3a.Variation Of Number Of Nodes Vs. RMSE Shadowing Variable Sigma=4

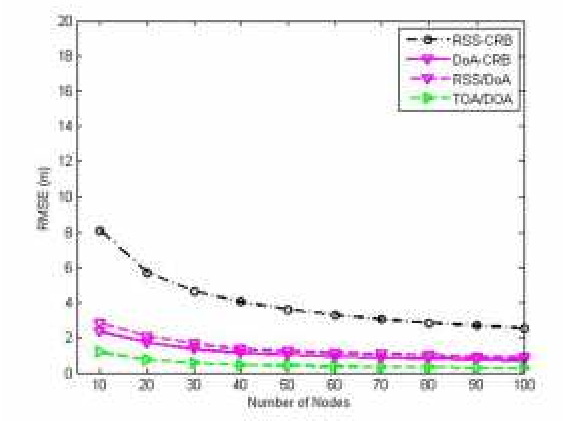

*Fig. 3b. Variation Of Number Of Nodes Vs. RMSE For Shadowing Variable Sigma=6*

The impact of shadowing on the RSS –CRB comp, RSS-CRB asymptotic, Joint CRB MUSIC, Joint CRB comp, ToA/DoA are presented in the fig 3a,3b,3c. We observe that as shadowing increases ,RMSE also increases. This is because the Lognormal of a probability distribution function of RSS spreads out when the shadowing increases. In case of large shadowing cases to obtain a better accuracy we need to assign higher weights to CR's with better DoA measurements.

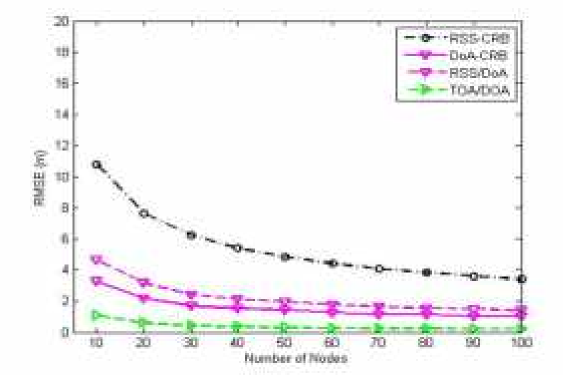

*Fig. 3c. Variation Of Number Of Nodes Vs. RMSE For Shadowing Variable Sigma=8*

Shadowing refers to the rapid fluctuations in the power levels of signal due to presence of obstacles between a Transmitter and a Receiver. Fig 3a represents the RMSE for nodes ranging up to 10 to 100 when the shadowing variable is considered to be 4. Fig 3b represents the RMSE for nodes ranging up to 10 to 100 when the shadowing variable is considered to be 6

Fig 3c represents the RMSE for nodes ranging up to 10 to 100 when the shadowing variable is considered to be 8.The performance loss caused by the RSS-CRB comp is more than the RSS-CRB asymptotic. In general the shadowing variable range is taken from 2 to 10 db .here we have considered the range of shadowing variable from 4 to 8 db.

**6.3 Results of RMSE for** RSS –CRB comp ,RSS-CRB asymptotic, Joint CRB MUSIC, Joint CRB comp, ToA/DOA with varying number of CRs ,for different array orientation in an uncorrelated shadowing environment (sigma=6). The effect of array orientation on RSS -CRB comp ,RSS-CRB asymptotic, Joint CRB MUSIC, Joint CRB comp, ToA/DOA are presented in the fig 4a,4b,4c. we observe that as the value of theta changes only the RMSE of RSS/DoA and ToA/DoA changes leaving the RSS-CRB undisturbed indicating RSS doesn't depend on the value of theta or the array orientation. Fig 4a represents the RMSE for nodes ranging up to 10 to 100 when the array orientation theta is considered to be 30. Fig 4b represents the RMSE for nodes ranging up to 10 to 100 when the array orientation theta is considered to be 60.

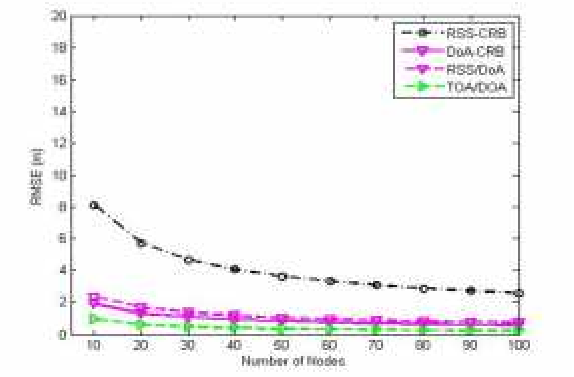

*Fig. 4a. Variation Of Number Of Nodes Vs. RMSE For Θ=30*

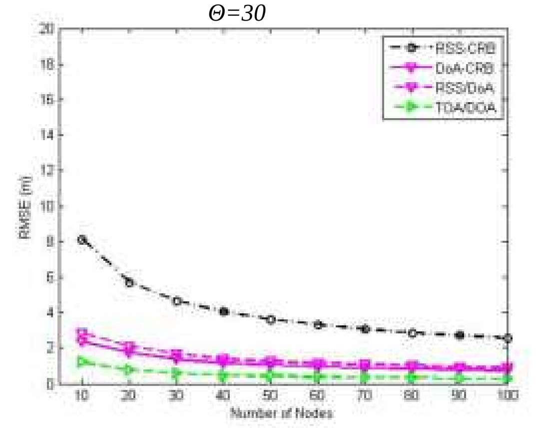

Fig. 4b. variation of number of nodes vs. RMSE for θ =6

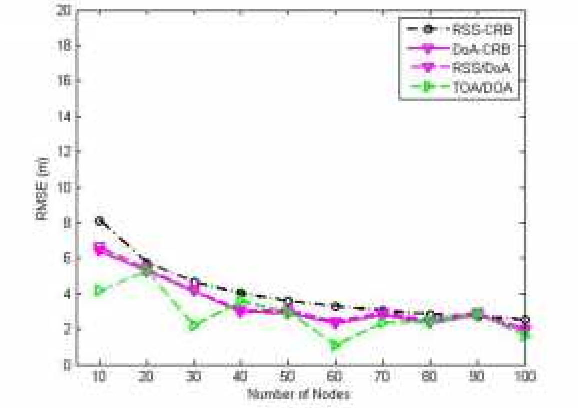

*Fig. 4c. Variation Of Number Of Nodes Vs. RMSE For Θ =90*

Fig 4c represents the RMSE for nodes ranging upto 10 to 100 when the array orientation theta is considered to be 90.we observe that the RMSE will be less when the primary user or a transmitter and secondary user or a receiver are facing toward each other so RMSE for array orientation of 90 is more when compared to 30, 60 degrees.

## 7. CONCLUSION

In this paper we introduce an analytical work for the performance achievement of Joint ToA/DoA for localization of PU's in cognitive radio network. Firstly we derive the CRB for a fixed CR replacement for RSS,DoA,RSS/DoA,ToA/DoA based primary user localization. Due to the effect of shadowing and multipath RSS is less accurate when compared to ToA and DoA. so we go for the combined approach of RSS/DoA and ToA/DoA. Hybrid approach of ToA/DoA gives less error when compared to the RSS/DoA which can be clearly observed from the obtained results.

It is observed that the achievable RMSE gets decreased with the increase of shadowing. Also the RMSE varies with the Array orientation. Maximum performance can be yielded when the transmitter and receiver are facing towards each other. so we obtain low RMSE in case of array orientation of 30,60 than compared to 90 degrees. RMSE also depends on the value R0 and R. Here we have altered the Ro/R ratio by changing only Ro and R is kept as constant. As Ro increases RMSE increases due to excluding of the CR's closer to the primary user. Derivation of CRB for practical and more complex channel variations, for different CR placement will be considered as a future work.

## REFERENCE

[1] A Ghasemi, ES Sousa, Spectrum sensing in cognitive radio networks:Requirements, challenges and design trade-offs. IEEE Commun Mag. 46(4),32–39, 2008.

[2] J Mitola, GQ Maguire, Cognitive radio: making software radios more personal. IEEE Personal Commun. 6(4), 13, 1999.

[3] S Haykin, Cognitive radio: Brain-empowered wireless communication. IEEE J Sel Areas Commun. 23, 201–220, 2005

[4] FK Jondral, Software-defined radio-basics and evolution to cognitive radio. EURASIP J Wirel Commun Netw. 2005, 275–283, 2005.

[5] Sherman, M.; Mody, A.N.; Martinez, R.; Rodriguez, C.; Reddy, R., "IEEE Standards Supporting Cognitive Radio and Networks, Dynamic Spectrum Access, and Coexistence," *Communications Magazine, IEEE*, vol.46, no.7, pp.72,79, July 2008

[6] Lu Lu*, Xiangwei Zhou, Uzoma Onunkwo and Geoffrey Ye Li, "Ten years of research in spectrum sensing and sharing in cognitive radio" EURASIP Journal on Wireless Communications and Networking 2012, 2012:28

[7] Srinivasa, S.; Jafar, S.A., "COGNITIVE RADIOS FOR DYNAMIC SPECTRUM ACCESS - The Throughput Potential of Cognitive Radio: A Theoretical Perspective, " *Communications Magazine, IEEE* , vol.45, no.5, pp.73,79, May 2007.

[8] Werner, J.; Hakkarainen, A.; Valkama, M., "Cramer-Rao Bounds for Hybrid RSS-DOA Based Emitter Location and Transmit Power Estimation in Cognitive Radio Systems," *Vehicular Technology Conference (VTC Fall), 2013 IEEE 78th* , vol., no., pp.1,7, 2-5 Sept. 2013

[9] Chen Feng; Au, W.S.A.; Valaee, S.; Zhenhui Tan, "Received-Signal-Strength-Based Indoor Positioning Using Compressive Sensing," *Mobile Computing, IEEE Transactions on* , vol.11, no.12, pp.1983,1993, Dec. 2012

[10] Qinghua Wang; Balasingham, I.; Miaomiao Zhang; Xin Huang, "Improving RSS-Based Ranging in LOS-NLOS Scenario Using GMMs," *Communications Letters, IEEE* , vol.15, no.10, pp.1065,1067, October 2011.

[11] Akyildiz, I.F.; Won-Yeol Lee; Vuran, Mehmet C.; Mohanty, S., "A survey on spectrum management in cognitive radio networks," *Communications Magazine, IEEE* ,

vol.46, no.4, pp.40,48, April 2008 doi: 10.1109/MCOM.2008.4481339.

[12] C.S.Preetham and M.Siva Ganga Prasad, "Relay, power and subchannel allocations for underlay non LOS OFDM-based cognitive networks under interference temperature," Signal Processing And Communication Engineering Systems (SPACES), 2015 IEEE International Conference on, pp.205-209, 2015.

[13] S Haykin, DJ Thomson, JH Reed, Spectrum sensing for cognitive radio. Proc IEEE. 97(5), 849–877, 2010 .

[14] F. Mrabtia, M. Elhajjamib, M. Zouaka,” Performance analysis of joint DOA/TOA estimator” , Signal Processing 84 (2004) 1359 – 1365.

[15] Catovic, A.; Sahinoglu, Z., "The Cramer-Rao bounds of hybrid TOA/RSS and TDOA/RSS location estimation schemes," *Communications Letters, IEEE* , vol.8, no.10, pp.626,628,Oct. 2004 doi: 10.1109/LCOMM.2004.835319.