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System Architecture & Performance Analysis of Ultra-Wide Band Cognitive Interrogators Network Using RFID for Indoor Location Tracking

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Abstract

Remote monitoring of mobile objects in domestic environment can be done by using cognitive interrogator network (CIN) where Ultra-wide band radio frequency identification (UWB-RFID) technology may be utilized for accurate indoor location and object tracking. CIN architecture, in which the central base station (BS)constantly and judiciously customize the illumination modes of the distributed transceivers in response to the system's changing knowledge of the channel conditions and object movements. The analytical results of the locating probability and time-of-arrival (TOA) estimation uncertainty for a large-scale CIN with randomly distributed interrogators are derived based upon the implemented cognitive intelligences. Different interference conditions are also considered as a problem faced by CIN and the corresponding results are mentioned.

Keywords: *Cognitive radio Network (CRN), Cognitive interrogator network (CIN), Ultra-wide band radio frequency identification (UWB-RFID)*

1. Introduction

OVER the past several decades there has been an exhaustive research on designing efficient radar illumination strategies for target detection and tracking applications. Wireless radar sensor network is emerging as an enabling technology for applications such as border surveillance, intrusion monitoring for unauthorized movement of targets around critical facilities. Surveillance applications, *i.e.*, real-time detection, tracking and classification of instruction, require mission critical networking capabilities in wireless sensor networks. Cognitive radar network(CRN), a new arrangement for optimizing the performance of distributed sensor networks within non-stationary and interference-limited environments is used in indoor location as well as object tracking [1-3]. In a CRN, a numerous radars collaborate together to provide the overall sensing system with the competencies of being aware of its outside world by using previous measurements as well as learning through interactions with the environment, and wisely and adaptively tailoring the operation of its transceivers in response to the channel variations in real-time. A sophisticated RFID interrogator(reader)with integrating sensing and signal processing capability is considered [4]. Electromagnetic (EM) wave transmitted from each reader(interrogator)detect an object or location by interacting with passive RFID tag attached with that object or location [5]. Detection accuracy may be improved by using Ultra Wide Band tags due to the high accuracy of UWB-based time-of-arrival(TOA)estimation. A battery-free and chip-less UWB-RFID tag with desirable scattering characteristics is artificially recognized and magnified through modulated backscatter at the tag antenna [6, 7].

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Cognitive-interrogator-network (CIN), comprising of cognitive radar network (CRN) and Ultra-Wide Band (UWB)Radio Frequency Identification (RFID) is used for detection of indoor location along with tracking of mobile objects. In summary, the CIN features three important cognitive operations based on the understanding gained from the standard radar-returns from the UWB-RFID tags(a)adaptive and constant allocation of limited transmit power among the activated interrogators;(b)smart illumination of the environment through antenna beam-steering at the interrogators distributed within a direction-selective circular sector;(c)adjusting the set of stimulated interrogators to achieve the optimized location detection probability and positioning accuracy. This paper will focus on the system architecture and the influence of the various cognitive mechanism on the probability of localization and TOA estimation adjustment. Effort of noise and its corresponding handling procedures using Nakagami Distribution, two way faded envelope effect and gaussian distribution *etc.*, are also considered [8-10].

Signals, contained from different tags, can interfere with each other in addition, destructive or in multiplicative way, with different probability density function [11]. Ultra-Wide Band (UWB)RFID is operated within the frequency range of 3.5GHz and 28GHz and at that high frequency penetration power may be more in domestic's buildings and thus it's useful in short range communication within a closed indoor location. This paper is arranged as below CIN is explained in Section 2. Two way faded envelope effect is considered in Section 3. High frequency noise component effect is considered in Section 4 interference effects are considered in Section 5. Conclusion is considered in Section 6.

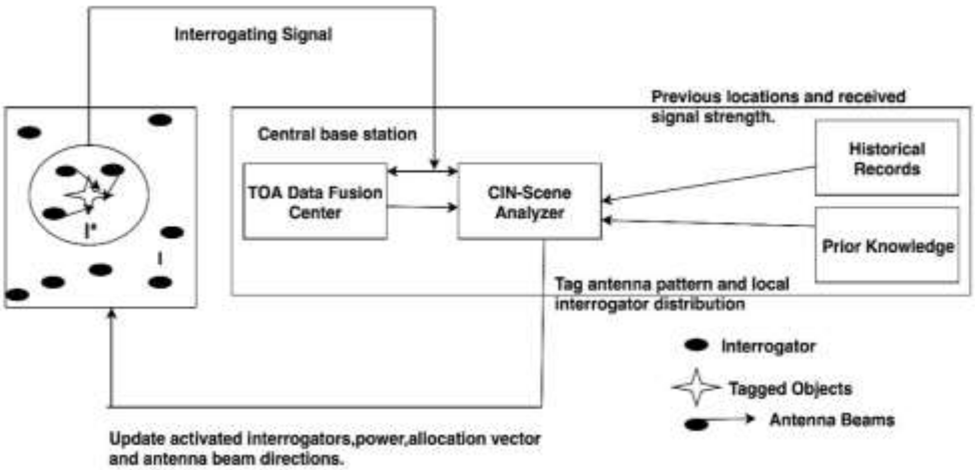

Figure 1. Block Diagram of CIN Network

2. CIN Description

CIN exists in a region R with an area A with M interrogating network I= $[I_1, I_2, \ldots, I_M]$ are arranged within R. The distribution location information is available at central base station (CBS). Now to detect an object it's assumed that N number of interrogators $I^* \subseteq$I are enough, such that power is limited to P_t .N number of active interrogators are denoted by I^* =$[I_1^*, I_2^*, \ldots, I_N^*]$.The diagram of block is mentioned in Figure 1. The active interrogators radiate an electromagnetic convergent beam towards the tagged object and from that object an electromagnetic beam is radiated towards the interrogator. The above-mentioned process is known as Line of Sight (LOS). Now interrogators send the information towards the central base station (CBS). In central base station collects the Time of Arrival (TOA) information, τ_{I^*} = $[\tau_1, \tau_2, \ldots, \tau_{\bar{N}}]$($\bar{N} \leq$N) along with power P_{I^*} = $[P_{t,1}, P_{t,2} \ldots, P_{t,N}]$allotted to individual object and location. The information's are then analyzed at CIN-scene analyzer with previous knowledge of historical records and prior knowledge. If the location of objects is changed then corresponding I^*,P_{I^*} information's are changed and update the corresponding information. The electromagnetic wave transmitted and received from the interrogator traversed through medium with high frequency range within 3.5GHZ and 28 GHZ so there may be a chance of corruption of the information and if information is affected the proper location detection is not possible. So, to remove that noise a noise eliminating filter is used in this paper. Also, electromagnetic wave is radiated from one more than interrogator so there may be a chance of interference so a process is explained in this paper by which interference can be reduced.

3. Faded Envelope Effect

Faded envelope is of two types (A)Path Loss Analysis and (B)Time of Arrival (TOA) Analysis.

3.1. Path Loss Analysis

Cognitive interrogator network (CIN) is contained of two parts such as downlink(interrogator→tag) and uplink (tag→ interrogator) [7]. So, the received power at the tag from the interrogator can be expressed below:

$$P_{d,n}(\mathrm{f})=\alpha_1 * P_{t,n}(\mathrm{f})*|U_n(f)|^2*G_n(\mathrm{f})*g_n(\mathrm{f})*(\frac{c}{4\pi f d_n})^2 \quad (1A)$$

where α_1 is the frequency independent and identically distributed(i.i.d)unit mean small scale fading of downlink segments random variable factor.is the transmitted power which is allotted to I_n^*. $|U_n(f)|^2$is power spectrum of normalized ultra-wide band(UWB) signal u_n(t) which is transmitted from I_n^*. $G_n$is the gain of antenna of I_n^* in direction of tag, g_n is the gain of tag antenna to the direction of I_n^*. $d_n$is the separation unit among nth interrogator and tag, c is the velocity of light=3×10^8meter/Second.

The power received at the interrogator from the tag is expressed below

$$P_{u,n}(\mathrm{f})=\alpha_2*|\gamma_n(f)|^2*G_n(\mathrm{f})*g_n(\mathrm{f})*(\frac{c}{4\pi f d_n})^2 \quad (1B)$$

where $\gamma_n(f)$ is the reflection coefficient α_2 is the frequency independent and identically distributed (i.i.d) unit mean small scale fading of uplink segments random variable factor rest of the terms are explained above. Thus, the received power $P_{r,n}$(f) *i.e.*, is multiplication of downlink power $P_{d,n}$(f) and uplink power $P_{u,n}$(f). So,

$$P_{r,n}(\mathrm{f})= P_{d,n}(\mathrm{f})* P_{u,n}(\mathrm{f}) \quad (1)$$

Signal amplitude X =$\sqrt{\alpha}$,$\alpha\epsilon\{\alpha_1,\alpha_2\}$is described by Nakagami distribution with parameter m, where m=1 denotes Rayleigh fading=½ denotes one sided gaussian fading, m=∞ denotes no fading.

$$f_X(\mathrm{X})=\frac{2m^m}{\Gamma(m)}X^{2m-1}\exp(-\mathrm{m}X^2) \quad (2)$$

Gamma distribution with shape parameter is given by:

$$f_\alpha(\alpha)=\frac{m^m}{\Gamma(m)}\alpha^{m-1}\exp(-\mathrm{m}\alpha) \quad (3)$$

Where Γ(.) is the Gamma function

Probability density function(pdf) of the two-way faded envelope A=X_1X_2=$\sqrt{\alpha_1}\sqrt{\alpha_2}$ is derived in [9] for pdf of the product of two random variables is given by:

$$f_A(\mathrm{A})=\int_0^\infty f_{X_1}(X_1)f_{\frac{A}{X_1}}(\frac{A}{X_1})\frac{1}{X_1}\mathrm{d}X_1$$

$$=\int_0^\infty \frac{4m^{2m}A^{2m-1}}{X_1|\Gamma(m)|^2}\exp(-\mathrm{m}X^2-\mathrm{m}\frac{A^2}{X_1^2})\mathrm{d}X_1 \quad (4)$$

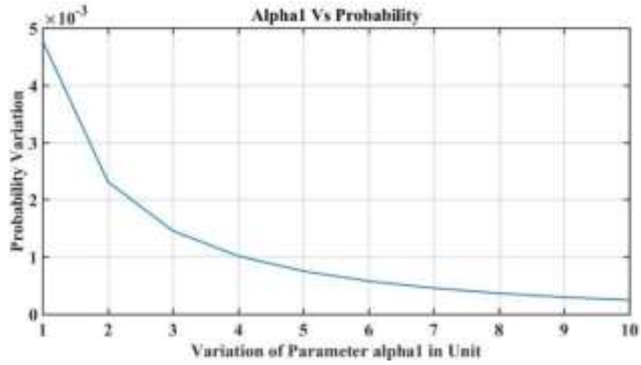

Figure 2. Variation of alpha1 Vs Probability of Detection

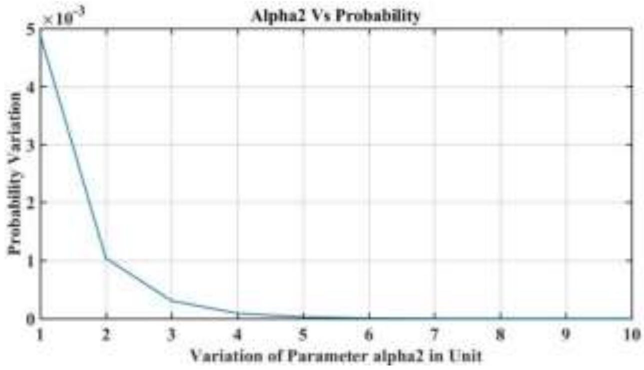

Figure 3. Variation of alpha2 Vs Probability of Detection

From Figure 2 & 3 it can be concluded that variation(increase) of alpha1 & alpha2 the probability of detection is reduced.

3.2. Time of Arrival (TOA) Probability Detection

In this case not considering multipath effect only direct Line of Sight (LOS) is considered. The received signal at nth interrogator is shown below:

$$\mathrm{r(t)}=\mathrm{A}\sqrt{\Omega}_{r,s}\mathrm{s}(\mathrm{t}-\tau_n)+\mathrm{N(t)} \quad (5)$$

Where $\Omega_{r,n}$ is the mean path gain of the received signal which can be expressed as below:

$$\Omega_{r,n}=\mathrm{E}\{\int_{\Delta f} P_{r,n}(\mathrm{f})\mathrm{df}\} \quad (6)$$

, $\tau_n=\frac{2d_n}{c}$ is the path delay of the signal, N(t) is additive white gaussian noise (AWGN) with zero mean and variance σ_0^2 and s(t)is the UWB pulse received of signal power.

Now if discrete time interval is considered that is in different time interval k=0,1,……..,K and time τ_n can be expressed as τ_n=k× $\Delta\tau$ with $\Delta\tau$ is the sampling time interval, so equation (5) is modified below:

$$r_k=\mathrm{A}\sqrt{\Omega}_{r,s}\delta(\mathrm{k}-K_n)+N_k \quad (7)$$

Where $K_n \approx \lceil\frac{\tau_n}{\Delta\tau}\rceil$, $\lceil.\rceil$ is the ceiling function. TOA is calculated by correlator or match filter receivers.so

$$K_n = \underset{k}{argmax}\, r_k \quad (8)$$

The probability of highest peak at exact delay is given by

$$\Pr(\widetilde{K_n}=K_n)=\Pr(N_k \leq A\sqrt{\Omega}_{r,s}+N_{K_n})$$

$$=\int_{-\infty}^{\infty}\int_{0}^{\infty} \Pr(N_k \leq A\sqrt{\Omega}_{r,s}+N_{K_n}|(A,N_{K_n})*f_A(A)f_N(N_{K_n})dAdN_{K_n} \quad (9)$$

$$,\forall k \neq K_n$$

Where Pr(.) is the probability of detection substitute equation (4) in the equation (9) probability of exact TOA estimation can be found as

$$\Pr(\widetilde{K_n}=K_n)=\int_{-\infty}^{\infty}\int_{0}^{\infty}\int_{0}^{\infty}[½(1+\mathrm{erf}(\frac{A\sqrt{\Omega}_{r,s}+N_{K_n}}{\sqrt{2}\sigma_0}))]^K \times \frac{4m^{2m}A^{2m-1}}{X_1\,\sigma_0\sqrt{2\pi}|\Gamma(m)|^2}\exp(-\frac{N_{K_n}^2}{2\sigma_0^2}- mX^2 - m\frac{A^2}{X_1^2})dX_1dAdN_{K_n} \quad (10)$$

Equation (9) is affected by noise components so the amplitude is less in Figure (4). Now, if a high pass filter is applied with transfer function H(jω) $=\frac{2}{(j\omega)^{-1}}$ is applied then noise component is eliminated and probability of TOA is high as shown in Figure (5).

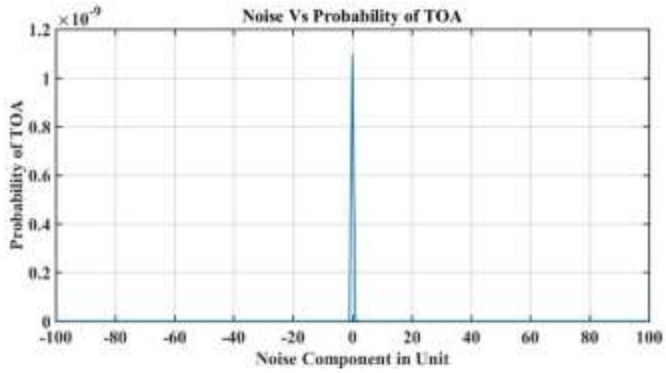

Figure 4. Noise Vs Probability of TOA

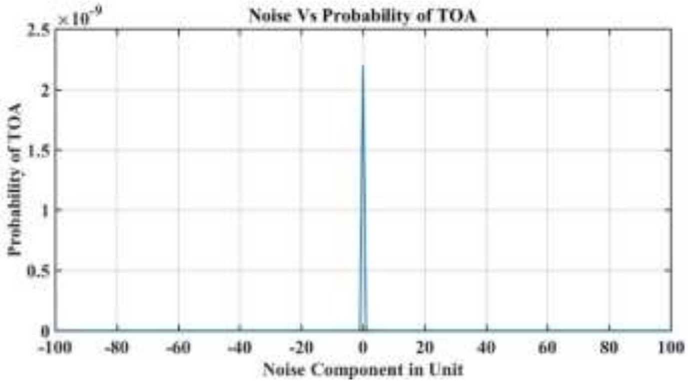

Figure 5. Noise Vs Probability of TOA

4. High Frequency Noise Component Effect

Using WiSE(Wireless System Engineering) model channel parameters can be designed in small environments [8].

Hence, Path loss is denoted by [8]

$$PL=[A*\log(d/d_0)+B]+S \quad (11)$$

Where A & B are fitting parameter of the mean path loss;d_0 is known reference path distance generally it's taken as 1; S is the deviation from the mean which is known by terms such as scatter points and shadow fading. The above formula can be proved from curve fitting. A, the fitting parameter is 28.9 and 42.2 at 28 GHz and 3.5GHz respectively [8]. Another fitting parameter B is considered 73.8 and 32.4 at frequency 28GHz and 3.5GHz respectively [8]. The median value for S is 8.2dB and 9.8dB at 28GHz and 3.5GHz respectively [8].

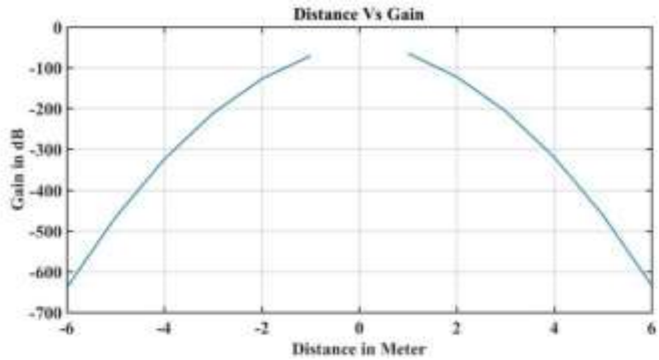

Figure 6. Gain of Signal Amplitude Due to Path Loss

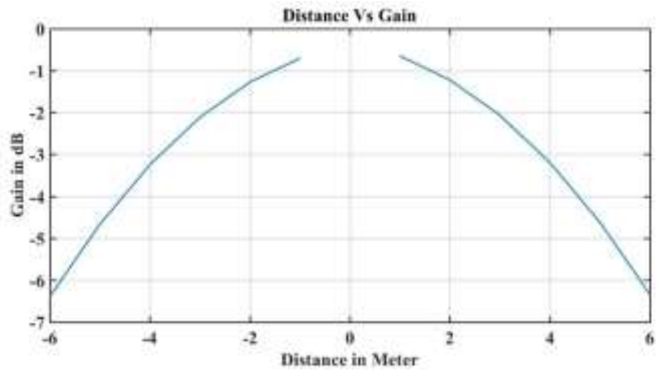

Figure 7. Improved Gain of Signal Amplitude Due to Filter

5. Interference Effect

Probability distribution function (PDF) of Nakagami distribution is given by:

$$p_\alpha(\mathrm{x})=\frac{2m^m x^{2m-1}}{\Gamma(m)\Omega_p^m}\exp\{-\frac{mx^2}{\Omega_p}\} \quad (12)$$

Where Ω_p=E[α^2], E is expectation parameter,σ is variance m is Nakagami distribution parameter[11].Now if m=$1/2$ then it's known as PDF of Gaussian distribution which can be written as[11]:

$$f_x(\mathrm{x})=\frac{1}{\sqrt{2\pi\sigma^2}}e^{-(x-\mu)^2/2\sigma^2} \quad (13)$$

Signal which is contained information was generated from different UHF RFID's can interfere with each other, for simplicity two signal is considered.

Probability density function is affected when two signals are interfered with each other.

Two signal x and y are considered, they both are random variable and interfere constructively that is z=x + y where z is resultant of x and y.

Distribution of z is given by

F_z(z)=P{x+y≤z} $=\int_{y=-\infty}^{\infty}\int_{x=-\infty}^{z-y} f_{xy}$(x,y)dxdy
$=\int_{-\infty}^{\infty} f_{xy}$(z-y,y)dy (14)

Where f(x,y) is joint probability density function of x and y and is given by

$$f(x,y)=\frac{1}{2\pi\sigma^2}e^{-(x^2+y^2)/2\sigma^2} \quad (15)$$

Variance σ is considered to be 1 for simplicity

After replace value of f(x,y) in the equation (14) from the equation (15) the equation is given by:

$$f(x,y)=\frac{1}{2}\times\int_{-\infty}^{\infty}\frac{1}{2\pi}e^{-[(z-y)^2+y^2]/2}dy$$
$$=\frac{1}{2}\times\frac{1}{2\sqrt{\pi}}e^{-z^2/4} \quad (16)$$

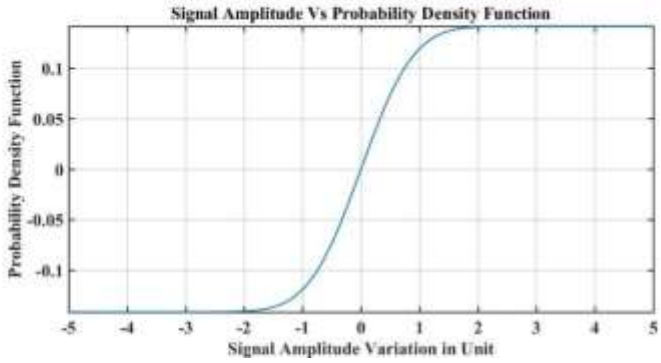

Figure 8. Signal Amplitude Vs Probability Density Function

In the equation (16) both x & y are both dependent variable.

Now, if x & y are both independent variable then distribution function is given byf_{xy}(x,y)=f_x(x)× f_y(y).

Where f_x(x)=$\frac{1}{2\pi}e^{-x^2/2}$ & f_y(y)= $\frac{1}{2\pi}e^{-y^2/2}$. The joint probability density function is given by:

$$f_z(z)=\int_0^z f_x(z-y)f_y(y)dy$$
$$=\int_0^z[\frac{1}{2\pi}e^{-(z-y)^2/2}]\times[\frac{1}{2\pi}e^{-y^2/2}]dy$$
$$=\frac{\sqrt{\pi}\,e^{-z^2/2}\mathrm{erf}(\frac{\sqrt{2}\,z}{\sqrt{3}})}{2\sqrt{6}}+\frac{\sqrt{\pi}e^{-z^2/3}}{2\sqrt{6}} \quad (17)$$

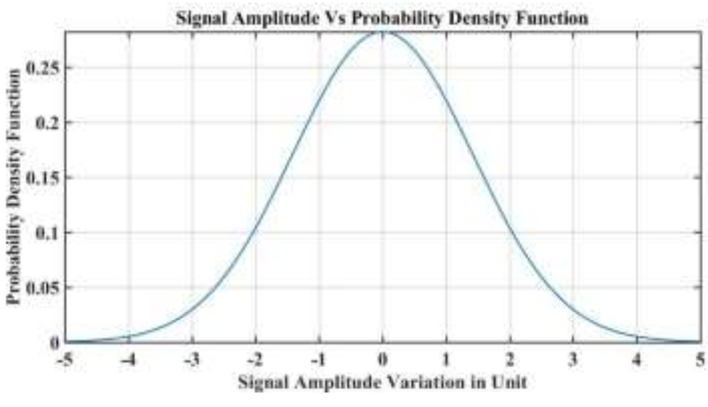

Figure 9. Signal Amplitude Vs Probability Density Function

Single random variable probability density function is shown in Figure (8) and constructive interference is displayed in Figure (9). Independent random variable interference is displayed in Figure (10).

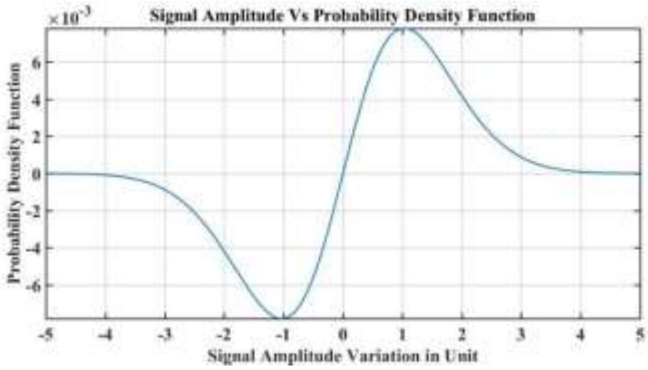

Figure 10. Signal Amplitude Vs Probability Density Function

Now if distribution of x and y is given by as following:

f_x(x)=$\lambda e^{-\lambda x}$ and f_y(y)=λ$e^{-\lambda y}$,so the joint probability density function is given by:

$$f_z(z)=\int_0^z f_x(x) \times f_y(y)dx=\int_0^z \lambda^2 e^{-\lambda(x+y)}dx$$
$$=z\lambda^2 e^{-\lambda z} \quad (18)$$

Equation (18) is plotted in Figure (11)

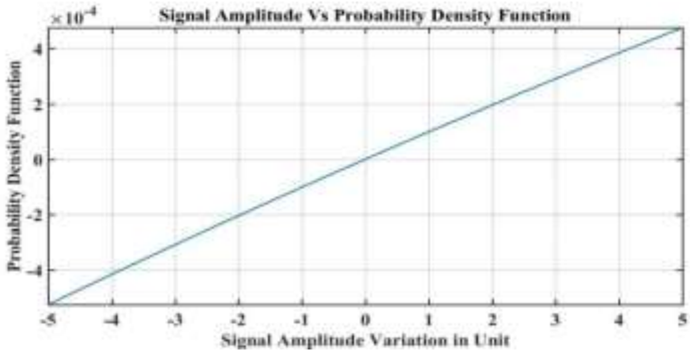

Figure 11. Signal Amplitude Vs Probability Density Function

The variation of λ is displayed in Figure (12), where the signal attenuated totally after certain threshold λ.

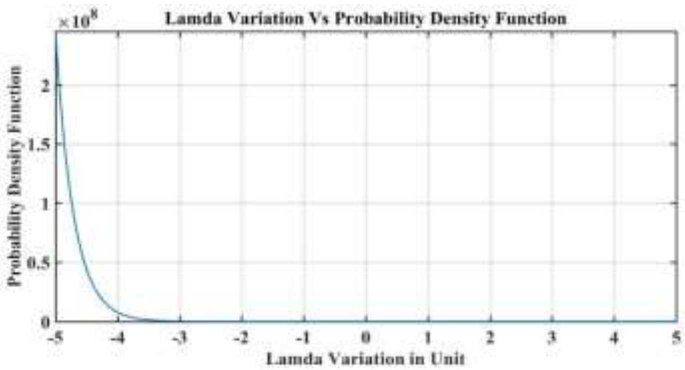

Figure 12. Lamda Variation Vs Probability Density Function

Now, if two signal/information is generated from UHF RFID interfere destructively that is z=x-y

The distribution function is given by:

$F_z(z)=P(x-y\leq z)=\int_{y=-\infty}^{\infty}\int_{x=-\infty}^{z+y} f_{xy}(x,y)dxdy$

$=\int_{0}^{\infty} f_{xy}(z+y,y)dy$ for $z\geq 0$ and (19)

$=\int_{-z}^{\infty} f_{xy}(z+y,y)dy$ for $z<0$ (20)

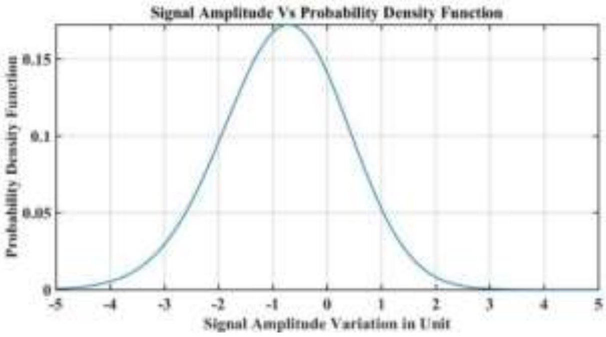

Figure 13. Signal Amplitude Vs Probability Density Function

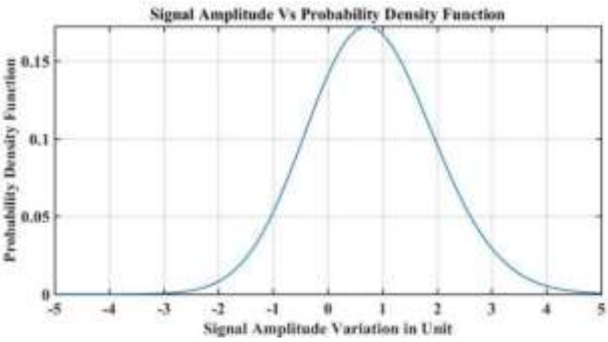

Figure 14. Signal Amplitude Vs Probability Density Function

Plot of equation (19) & (20) is plotted in Figure (13) & 14 respectively. The ratio of two signal/information is given by:z=$^{x}/_{y}$,so probability density function is given by:

$f_z(z)=\int_{y=0}^{\infty} y f_{xy}(yz,y)dy=\frac{1}{2\pi}\int_{y=0}^{\infty} e^{-[(yz)^2+y^2]/2}$

$=\frac{1}{4\sqrt{2\pi}}\times\frac{1}{\sqrt{2z^2+1}}$ (21)

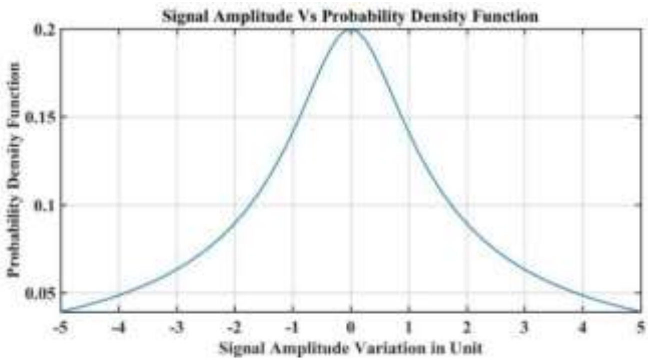

Figure 15. Signal Amplitude Vs Probability Density Function

Plot of equation (21) is displayed in the Figure (15).

6. Conclusion

The potential benefits of applying an UWB-based CIN in remote monitoring of mobile subjects in indoor environments are investigated thoroughly. Discussions on target positioning and tracking capabilities through CIN system-level synthetization are also made. The influence of applying a circular sector to account for the directional pattern of tag antenna is demonstrated. The sensing region is a sector with central angle, where the main direction of the sector employing a sectorized shape instead of a "dumb" circle as the probing area deteriorates the performance of target localization, but remarkably reduces the TOA estimation uncertainty.

References

[1] Y. Chen and P. Rapajic, “Ultra-Wideband Cognitive Interrogator Network for indoor Location Tracking-Part I: System Architecture and Network Performance Analysis”, Proc. PIMRC 2008. IEEE 19th International Symposium on Personal, Indoor and Mobile Radio Communications, **(2008)**.

[2] S. Haykin, “Cognitive radar: A way of the future”, IEEE Signal Process. Mag., vol. 23, no. 1, **(2006)**, pp. 30-40.

[3] S. Haykin, “Cognitive radar networks”, Proc. 2005 IEEE International Workshop on Computational Advances in Multi-Sensor Adaptive Processing, **(2005)** December, pp. 1-3.

[4] V. Chawla and D. S. Ha, “An overview of passive RFID”, IEEE Applications and Practice, **(2007)** September, pp. 11-17.

[5] P. Wilson, D. Prashanth and H. Aghajan, “Utilizing RFID signaling scheme for localization of stationary objects and speed estimation of mobile objects”, Proc. 2007 IEEE International Conf. RFID, **(2007)** March, pp. 94-99.

[6] S. Hu, C. L. Law and W. Dou, “Petaloid antenna for passive UWB-RFID tags”, IET Electr. Lett, vol. 43, no. 22, **(2007)** October.

[7] D. Kim, M. A. Ingram and W. W. Smith Jr., “Measurements of small scale fading and path loss for long range RF tags”, IEEE Trans. Antennas Propag., vol. 51, no. 8, **(2003)**, pp. 1740-1749.

[8] A. Ö zge Kaya, D. Calin and H. Vishwanathan, “28GHZ and 3.5GHz Wireless Channels: Fading, Delay and Angular Dispersion”, https://www.researchgate.net/publication/303108736, **(2016)** April.

[9] A. F. Molisch, D. Cassioli and C. C. Chong, “A comprehensive standardized model for ultra wideband propagation channels”, IEEE Trans. Antennas Propagat., vol. 54, no. 11, **(2006)**, pp. 3151-3166.

[10] V. K. Rohatgi, “An Introduction to Probability Theory Mathematical Statistics”, Wiley, New York, **(1976)**.

[11] A. Papoulis and S. Unnikrishan, “Pilai Probability, Random Variables, and Stochastic Process”, Tata McGraw Hill Education Private Limited, New Delhi, **(2012)**.

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