Performance Analysis of Energy Detection over Composite $\kappa - \mu$ Shadowed Fading Channels

HUANG He, ZHAO Chenglin
Key lab of Universal Wireless Communications of Ministry of Education, Beijing University of Posts and Telecommunications, Beijing 100876, China

Abstract- Energy detection is a reliable non-coherent signal processing technology of spectrum sensing of cognitive radio networks, which thanks to its low complexity, no requirement of priori received information and fast sensing ability etc. Since the excellent performance of energy detection would be actually affected by physical multipath fading, this paper is concentrating on characteristics analysis of energy detection over composite $\kappa - \mu$ shadowed fading channels. The small-scale and line-of-sight $\kappa - \mu$ fading distribution consists of particular examples such as Rayleigh, Hoyt, Nakagami-m and one sided Gaussian distributions. Based on this, we derive the probability density function of signal envelope and signal-to-noise ratio of the composite $\kappa - \mu$ shadowed fading channels, which could accurately present the line-of-sight shadowed fading characterization. Subsequently the exact close-form expressions with infinite series formulation for the appropriate detection probability have been firstly extended to estimate detection capacity of the above-mentioned model by adopting Inverse Gaussian asymptotic distribution. In addition, the absolute truncation error is deduced for evaluating minimum detection efficiency. The established model can be also applied in detection estimation with non-integral fading parameters. Last but not least, the analytical results and quantification performance are approved by numerically evaluation with MATHEMATICA and MATLAB as the power variables of dominant components changes.

Keywords- energy detection, composite shadowed fading channels, $\kappa - \mu$ fading channels, cognitive radios, radar system

I. Introduction

Energy detection (ED) is the emerging efficient and popular spectrum sensing (SS) skill in cognitive radio networks (CRs) and ultra wide-band (UWB) systems, which has the advantage in low-complexity, non-coherent detection and implementation simplicity. The received and sampled signal energy levels in an observation time window have been compared to the predefined energy threshold of ED radiometer to determine whether the unknown signal is present or absent[1-5].

Urkowitz firstly investigated the issue of unknown signal detection over a flat band-limited Gaussian noise channel and focused on the binary hypothesis-testing problem for deriving the performance expressions of the probability of detection $P_d$ and the probability of false alarm $P_f$ by applying energy radiometer. The critical variable statistics ($P_d$ and $P_f$) respectively obey the central chi-square and non-central chi-square distribution[1]. After that, due to the excellent properties of ED, Kostylev considered ED means extensively associated with classical fading channels such as Rayleigh, Rician and Nakagami-m etc in radar systems and UWB communications, but only integer values are
adopted in fading channels\textsuperscript{[6-9]}. Next, Alouini et al. algebraically derived the close-form expressions for the average probability of detection or miss detection \( P_d \) ( \( P_e = 1 - P_d \) ) over single-channel and multi-channel fading scenarios\textsuperscript{[7]}. Next, ED that was performed in fading channels with merging mode of versatile gains as maximal ratio combining (MRC), selection combining (SC) and equal gain combining (EGC) had been analyzed in \([10-17]\) to identify the presence or absence of deterministic signal and activity state of authorized users. Hence, it is reasonably meaningful to operate ED method in the presence of fading channels, which could widely mitigate the current spectrum scarcity and improve the utilization of allocated spectrum resource in the wireless communications.

On the other hand, the generalized fading pattern \( \kappa-\mu \) distribution has provided adequate small-scale characterization for multipath line-of-sight (LOS) communication environment, it includes special cases as Nakagami-m, Rayleigh, Rician and one-sided Gaussian distributions, then \( \kappa-\mu \) extreme distribution could be deduced to accurately characterize mobile radio propagation under severe fading conditions\textsuperscript{[18-21]}. Furthermore, remarkable fading models \( \alpha-\mu, \eta-\mu, \alpha-\kappa-\mu \) etc were proposed subsequently to taken into account that providing adequate fittings to field measurements is highly effective in multipath fading channels\textsuperscript{[22-24]}. However, fading models that are discussed above often occur with shadowing effects and could not be availably represented with multipath shadowing feature, it is necessary to introduce composite shadowed pattern to explore the actual shadowed statistical characterization. Based on this, several composite fading channels applied to ED have been recently represented as Nakagami-m/ shadowed, \( \kappa-\mu \) /shadowed, \( \eta-\mu \) /shadowed in Ref.\textsuperscript{[25-31]}. Moreover, to a certain extent log-normal distribution can replace the gamma distribution for more effective shadowing effect to better evaluate the shadow degree\textsuperscript{[30]}, but implement is rather intractable because of inconvenient algebraic representation. Therefore, it is meaningful to overcome the shortage of the log-normal shadowed model\textsuperscript{[31-38]} and analyze the performance of ED that is performed in generalized shadowed channels.

Motivated by the statement above, a new framework of the formulation of composite \( \kappa-\mu \) shadowed distribution has been developed to reveal the performance of ED over LOS shadowed fading channels. Besides, novel probability density function (p.d.f.) expressions of average probability of detection are derived in physical fading model. The extended patterns are compared with each other as actual parameters alter. To achieve better detection capacity, fading parameters of \( \kappa-\mu \) distribution change in different average SNR status. Moreover, the inferred analysis of truncation error is derived in this paper.

The remainder of this work is organized as follows: the ED model and the \( \kappa-\mu \) channels model are described in section II. The performance of ED which is operated over composite \( \kappa-\mu \) shadowed channels is analyzed in section III and section IV. Numerical results are provided in section V, while closing remarks are given in section VI.

\section*{II. System and Channel Models}

\subsection*{1. The ED model}

The ED pattern can be assumed to be the binary hypothesis-testing problem in Eq.\textsuperscript{(1)} to determine the absence or presence of unknown wireless signal ( \( H_0 \): signal is absent; \( H_1 \): signal is present)\textsuperscript{[11]},

\[ H_0: y(t) = n(t) \]
\[ H_1: y(t) = h \cdot s(t) + n(t) \]  \hspace{1cm} (1)

where \( y(t) \) denotes the received signal, \( n(t) \) is zero-mean complex additive white Gaussian
noise (AWGN), $h$ denotes the wireless channel gain, $s(t)$ is the transmitted primary signal. By denoting the time bandwidth product as $\omega = TW$, \( T \) is time interval and $W$ is the single-sided signal bandwidth, the received signal test statistics follow that,

$$
Y \sim \begin{bmatrix} X_0^2; & H_0 \\ X_0^2(2\gamma); & H_1 \end{bmatrix}
$$

where $X_0^2$ is a central chi-square distribution with degrees of freedom $2\omega$, likewise $X_0^2(2\gamma)$ is a non-central chi-square distribution with degrees of freedom $2\omega$ and a non-centrality parameter $2\gamma$.

Accordingly we could compute $P_e$ and $P_b$ as,

$$
P_e = P_t(y > \lambda | H_0) = Q \left( \frac{\sqrt{\lambda} - \sqrt{2\gamma}}{\gamma} \right) 
$$

and

$$
P_b = P_t(y > \lambda | H_1) = \frac{\Gamma(u, \frac{\lambda}{2})}{\Gamma(u)}
$$

where $Q(a,b)$ is the $u$-th order generalized Marcum Q-function, $\Gamma(\cdot)$ is the Gamma function which is defined by the integral $\Gamma(x) = \int_0^\infty e^{-t} \, dt$ and $\Gamma(a,\cdot)$ is the incomplete Gamma function which is defined by the integral $\Gamma(a,x) = \int_x^\infty e^{-t} \, dt$.

$\gamma$ denotes the SNR, $\lambda$ is the ED threshold, corresponding the p.d.f. of $y(t)$ can be expressed as\[^{1,2,6,18}\],

$$
f_y(y) = \begin{bmatrix}
\frac{1}{2^\gamma \Gamma(\frac{\gamma}{2})} y^{\frac{\gamma}{2} - 1} \\
\frac{1}{2^\gamma \Gamma(\frac{\gamma}{2})} y^{\frac{\gamma}{2} - 1} I_{\gamma}(\sqrt{2\gamma} y); & H_1
\end{bmatrix}
$$

where $I_{\gamma}$ is the first kind modified Bessel function with the order $\frac{\gamma}{2} - 1$ which is defined by $I_{\gamma}(x) = \frac{1}{2} \cos(\pi \gamma) e^{x \cos(\pi \gamma) \sin(\pi \gamma) d\theta}$.

### 2. The $\kappa-\mu$ channels model

The $\kappa-\mu$ distribution is a generic fading distribution that illustrates small-scale and line-of-sight (LOS) fading circumstance, it considers signal of clusters of multipath waves to be propagated in a non-homogeneous environment. The clusters of multipath waves are assumed to have scattered waves with identical powers, but within each cluster a dominant component is found, which presents an arbitrary power. The parameter $\kappa(\kappa>0)$ is the ratio between the total power of the dominant components and the total power of the scattered waves, parameter $\mu(\mu>0)$ is the related variable of multipath clusters. For the power of a fading signal $W = R^2$ and normalized power $\Omega = W / E(W)$, the corresponding p.d.f. is given by Ref.[19] as,

$$
f_{\mu}(\omega) = \frac{\mu(1 + \kappa)^{\frac{\omega}{2}}}{\kappa^{\frac{\omega}{2}} \exp(\mu \omega)} \cdot \omega^{\frac{\omega}{2} - 1} \exp(-\mu(1 + \kappa)\omega^\gamma).
$$

Especially, Rician distribution is obtained for $\mu = 1$ and Nakagami-m distribution for $\kappa \rightarrow 0$, whereas the Rayleigh distribution attained for $\mu = 1$ and $\kappa \rightarrow 0$ and the one sided Gaussian distribution for $\mu = 0.5$ and $\kappa \rightarrow 0\,[19]$.

### III. Detection over Composite Fading Channel

#### 1. Composite $\kappa-\mu$ shadowed channels

According to the basic principles of composite shadowed statistical distribution, the p.d.f. of composite $\kappa-\mu$ shadowed channels can be represented as,

$$
p_{\kappa-\mu}(r) = \int_{0}^{\infty} p_{\kappa-\mu}(r|y) \cdot p_{\mu}(y) \, dy
$$

For a fading signal with envelop $R$, \( r = \sqrt{E(R^2)} \) ( $E(\cdot)$ is the expectation and $r$ is the root mean square value) and $y = \frac{r}{\sigma}$, with Ref.[19], Eq.(10) and Eq.(6), the $\kappa-\mu$ distribution can be shown as,

$$
p_{\kappa-\mu}(r|y) = \frac{2\mu(1+\kappa)^{\frac{\gamma}{2}}}{\kappa^{\frac{\gamma}{2}} \exp(\mu \gamma)} \cdot \frac{r^\gamma}{\gamma!} \exp(-\mu(1+\kappa)\gamma) \cdot I_\gamma(2\mu \sqrt{\kappa(1+\kappa)\gamma})
$$

besides, the lognormal shadowing distribution is given by Ref.[32],

$$
p_{\mu}(y) = \frac{\xi}{\sqrt{2\pi} \sigma y} \exp\left(-\frac{10\log y - \mu)^2}{2\sigma^2}\right)
$$

$\mu$ and $\sigma$ are the mean and standard deviation of lognormal random variable $\log y$, constant $\xi$ is $4.342$. In order to obtain more computational expression, it was referred in Ref.[33] that Inverse Gaussian (IG) distribution can represent a better substitute for the lognormal shadowing
distribution as,
\[ \eta = \frac{\exp(\mu)}{2\sinh(\sigma^2/2)} \theta = \exp(\mu + \sigma^2/2) \]  
(10)
then Eq.(7) can be expressed with Eq.(10) as,
\[ p_{c_{\text{sin}^2}}(r) = \frac{2\pi}{\lambda^2} \frac{\mu(1 + \kappa)}{\kappa^2} \exp(\mu\kappa) \int_r^\infty \tau^2 \cdot \frac{1}{\tau^2} \exp \left( -\mu(1 + \kappa) \frac{\tau^2}{\gamma^2} \right) \]  
(11)
\[ I_\mu(2\mu, [\kappa(1 + \kappa)] \frac{r^2}{\gamma^2}) \]

2. Average probability of detection
For communication scene over \( \kappa-\mu \) shadowed fading channels, the average detection probability is obtained by averaging Eq.(3) with p.d.f. of SNR statistics as,
\[ T_{\text{snr}^2} = \int_0^\infty Q^\text{pr}(\sqrt{2}\gamma, \sqrt{\lambda}) p_{c_{\text{sin}^2}}(r) dy \]  
(12)
with Eq.(11), Eq.(13), Ref.[32, Eq.(2.3)] and Ref.[33, Eq.(12)] can be expressed as,
\[ T_{\text{snr}^2} = A \sum_{n=0}^{\infty} \frac{\Gamma(l + n, \frac{\lambda}{2})}{\Gamma(l + 1)\Gamma(l + n)} \exp\left( \frac{\mu\lambda}{2} \right) \int_0^\infty \exp(-\gamma) \cdot \]  
(14)
\[ \left( \frac{\gamma^2}{\lambda^2} - \gamma^2 \cdot \exp(-\frac{\eta y}{2\theta} - \frac{1}{2} \gamma^2 - \mu(1 + \kappa) \frac{\theta^2}{2} \right) \]  
\[ I_\mu(2\mu, [\kappa(1 + \kappa)] \frac{r^2}{\gamma^2}) \]  
(15)
by means of Ref.[36, Eq.(9.220.2)], Eq.(15) can be deduced as,
\[ I_\mu(2\mu, [\kappa(1 + \kappa)] \frac{r^2}{\gamma^2}) \]
\[ (\frac{\gamma^2}{\lambda^2} - \gamma^2) \cdot M_{\mu, \frac{\theta^2}{2}}(\frac{\mu(1 + \kappa) \theta^2}{\gamma^2} + \mu(1 + \kappa) \theta^2) \]  
\[ (\frac{\gamma^2}{\lambda^2} + \mu(1 + \kappa) \theta^2 \gamma^2) \]
\[ \Gamma(l + \mu) \frac{\gamma^{l+\mu}}{2l(\gamma^2 + \mu(1 + \kappa) \theta^2)} \]  
(16)
\[ \left( \frac{\gamma^2}{\lambda^2} + \mu(1 + \kappa) \theta^2 \gamma^2 \right) \cdot M_{\mu, \frac{\theta^2}{2}}(\frac{\mu(1 + \kappa) \theta^2}{\gamma^2} + \mu(1 + \kappa) \theta^2) \]  
\[ \Gamma(l + \mu) \frac{\gamma^{l+\mu}}{2l(\gamma^2 + \mu(1 + \kappa) \theta^2)} \]
where \( F_{(a;c,b;k)} \) is the Kummer's Confluent Hypergeometric function\cite{37}, substitute Eq.(16) into Eq.(12) we get,
\[ T_{\text{snr}^2} = B \cdot \gamma^2 \frac{\Gamma(l + \mu)}{2l(\gamma^2 + \mu(1 + \kappa) \theta^2)} \]  
(17)
performing generalized integral transformation for Eq.(17), we obtain,
\[ T_{\text{snr}^2} = B \cdot \gamma^2 \frac{\Gamma(l + \mu)}{2l(\gamma^2 + \mu(1 + \kappa) \theta^2)} \]  
(18)
then we get,
\[ T_{\text{snr}^2} = B \cdot \gamma^2 \frac{\Gamma(l + \mu)}{2l(\gamma^2 + \mu(1 + \kappa) \theta^2)} \]  
(19)
especially, the Kummer's Confluent Hypergeometric function is given by with Ref.[37],
\[ \sum_{n=0}^{\infty} \frac{(l + \mu)_n}{n!} = \frac{\mu(1 + \kappa) \theta^2}{\gamma^2 + \mu(1 + \kappa) \theta^2} \]  
(20)
where \( (\mu)_n = \Gamma(\mu + n)/\Gamma(\mu) \) is the Pochhammer symbol\cite{37}. We define \( f = \mu(1 + \kappa) \theta^2 \) and \( I_z \) is expressed as,
\[ I_z = \sum_{n=0}^{\infty} \frac{(l + \mu)_n}{n!} M_{\mu, \frac{\theta^2}{2}}(\frac{\mu(1 + \kappa) \theta^2}{\gamma^2} + \mu(1 + \kappa) \theta^2) \]  
(21)

further, we expand negative integer binomial function for Eq.(21) from Ref.[41, Eq.(12)], then we obtain,
\[ I_z = \sum_{n=0}^{\infty} \sum_{m=0}^{\infty} D(n) \left( \frac{1}{l+1} \right) \left( \frac{1}{l} \right) \]  
(22)
where we have,
\[ \frac{a}{b} = \frac{a!}{(a-b)!} \]  
(23)
ref. [36, Eq.(3.471.9)], \( I_z \) can be
deduced as,
\[
I_z = \sum_{i=1}^{j} D(n-i) i^{-1} \left( - \frac{1}{i} \right) \left( 1 - \frac{\mu - \sigma}{\sigma} \right) \left( 1 - \frac{\mu - \sigma}{\sigma} \right)
\]
(24)

\[
\left( \mu(1+\theta)\gamma \cdot \left( \theta - \frac{\gamma}{\gamma^2} - \frac{\gamma}{\gamma^2} \right) - K_{\gamma+} \left( \frac{\gamma}{\gamma^2} \right) \right)
\]
where \( K_{\gamma}(x) \) is the modified Bessel function of the second kind. Stated thus, the detection probability of composite \( \kappa - \mu \) shadowed channels can be expressed with Ref.[11-13,15-16,20-23] as,
\[
\mathcal{F}_{\text{Kerr}}^{\text{Kerr}} = \left( \frac{\pi}{\pi} \right) \left( \frac{\pi}{\pi} \right) \exp(\mu \kappa) \exp(\mu \kappa) \exp(\mu \kappa)
\]
operating simply Eq.(25), we can obtain as,
\[
\mathcal{F}_{\text{Kerr}}^{\text{Kerr}} = \frac{2}{2} \left( \frac{\pi}{\pi} \right) \left( \frac{\pi}{\pi} \right) \exp(\mu \kappa) \exp(\mu \kappa) \exp(\mu \kappa)
\]
numerically results
(25)

\[
\left( \frac{\pi}{\pi} \right) \left( \frac{\pi}{\pi} \right) \exp(\mu \kappa) \exp(\mu \kappa) \exp(\mu \kappa)
\]

furthermore, we simplify Eq.(26) by using generalized Confluent Hypergeometric function as,
\[
\mathcal{F}_{\text{Kerr}}^{\text{Kerr}} = \left( \frac{\pi}{\pi} \right) \left( \frac{\pi}{\pi} \right) \exp(\mu \kappa) \exp(\mu \kappa) \exp(\mu \kappa)
\]

IV. Analysis of Truncation Error

In wireless communications it is abnormally important to derive efficient and available representations for close-form algebraic expressions over complicated multi-channel fading scenarios, such as truncation error, power capacity and detective reliability etc. Truncation error bounds of detection performance of composite shadowed channels can show accurate finite series appearance which is account for communication transmission failure limit. Consequently, we discuss the truncation error towards composite \( \kappa - \mu \) shadowed channels from Eq.(27), then we get the truncation error expression as,
\[
\mathcal{F}_{\text{Kerr}}^{\text{Kerr}} = \frac{2}{2} \left( \frac{\pi}{\pi} \right) \left( \frac{\pi}{\pi} \right) \exp(\mu \kappa) \exp(\mu \kappa) \exp(\mu \kappa)
\]
according to Ref.[38, Eq.(57) and Eq.(58)], we gain the upper bound limit for finite summation series with Confluent Hypergeometric function \( I_{\text{Hyp}} \) as,
\[
\mathcal{F}_{\text{Kerr}}^{\text{Kerr}} = \frac{2}{2} \left( \frac{\pi}{\pi} \right) \left( \frac{\pi}{\pi} \right) \exp(\mu \kappa) \exp(\mu \kappa) \exp(\mu \kappa)
\]
moreover, on the basis of Ref.[39, Eq.(8) and Eq.(9)], the absolute truncation error of the infinite summation series can be obtained as,
\[
\mathcal{F}_{\text{Kerr}}^{\text{Kerr}} = \frac{2}{2} \left( \frac{\pi}{\pi} \right) \left( \frac{\pi}{\pi} \right) \exp(\mu \kappa) \exp(\mu \kappa) \exp(\mu \kappa)
\]
V. Numerical Results

Having derived the novel analytic expressions for the average probability of detection, this section is devoted to the specific
analysis of the behavior of ED over composite $\kappa - \mu$ Shadowed channels with MATLAB, MAPLE and MATHEMATICA\(^{[42]}\). The corresponding performance is evaluated for different scenarios of interest through average detection probability $P_d$ versus $\gamma$, in addition, the effect of the fading parameters and the observation time bandwidth product on the value of detection model list above is numerically quantified. For this reason, Fig.1 to Fig.4 illustrate composite $\kappa - \mu$ shadowed/IG distribution for $\eta = 10$, $\theta = 1$\(^{[43]}\) and different fading values. As can be see, Fig.1 shows better average detection probability for larger values of $\kappa$ and $\mu$. This is because the detector presents better detection capability for higher $\kappa$ and $\mu$ as more power of the dominant components can be received. For example, for the case of $\gamma = 10$ dB, $\kappa = 0.8$ and $\mu = 0.8$, the $P_d$ is 100% higher than the case of $\kappa = 0.5$ and $\mu = 0.7$. Likewise, when $\kappa = 1.0$ and $\mu = 0.9$, the $P_d$ is nearly 125% higher than the case for $\kappa = 0.8$ and $\mu = 0.8$.

![](Fig.1.png)

Fig.1. Average probability of detection versus average SNR for composite $\kappa - \mu$ shadowed channels with $\eta = 5$, $P_s = 2.8 \times 10^{-4}$ and different values of $\kappa$ and $\mu$.

It is also very important to quantify the effect of the fading parameters on the model performance explicitly. For this purpose, Fig.2 and Fig.3 appear the behavior of $P_d$ versus $\mu$ (for fixed $\gamma = 4$, $\kappa = 0.1$) and $\kappa$ (for fixed $\gamma = 5$, $\mu = 0.4$) respectively. It is objective that if we select higher $\kappa$ and $\mu$ as $\gamma$ increases, the better $P_d$ could be obtained. We can observe the significant deviation of $P_d$ even for small variations of $\mu$ in Fig.2, but $P_d$ alter slowly as $\kappa$ continuously increase in Fig.3. Clearly, for $\gamma = 9$ dB, it indicates that $P_d = 0.247$ and $P_d = 0.935$ when $\mu = 0.7$ and $\mu = 0.9$ for fixed $\kappa = 0.1$ separately in Fig.2, in addition, for $\mu = 0.8$, the $P_d$ for $\gamma = 9$ is nearly 160% higher than the case for $\gamma = 6$. Likewise, in Fig.3 it is explicitly revealed that $P_d$ is not sensitive when $\kappa$ is 0 to 9, but severe variations for $\kappa = 9$ to $\kappa = 13$ when $\gamma = 6$, moreover, on a basis of comparing the two fading parameters on detection probability, it is evident that the impact of $\mu$ is more significant than the effect of $\kappa$, furthermore, when $\gamma = 6$, the $P_d$ could be availably improved for selecting appropriate fading parameters.

![Fig.2.png](https://via.placeholder.com/150)

Fig.2. Average probability of detection versus $\mu$ for composite $\kappa - \mu$ shadowed channels with $\eta = 4$, $P_s = 3.2 \times 10^{-5}$, $\kappa = 0.1$ and different values of average SNR

![Fig.3.png](https://via.placeholder.com/150)

Fig.3 Average probability of detection versus $\kappa$ for composite $\kappa - \mu$ shadowed channels with $\eta = 5$, $P_s = 2.8 \times 10^{-4}$, $\mu = 0.4$ and different values of average SNR.

Finally, Fig.4 shows the curves of the absolute truncation error $E_{\gamma=0.01}^{|s|}$ versus number of terms in the composite $\kappa - \mu$ shadowed channels with different fading parameters. It could be seen that the energy detector has lower truncation
error rate as truncation number increases, and the $|E_{\log |E|}|$ can be evidently decreased if truncation number $\geq 8$, for example, the $|E_{\log |E|}|$ is nearly 0.02.

![Figure 4](image_url)

Fig.4 Absolute truncation error versus number of terms for composite $\kappa - \mu$ shadowed channels with SNR=9, $\kappa = 0.7$, $\mu = 0.8$ and different values of the observation time bandwidth product $u$.

VI. Conclusion

This work is devoted to the formulation and derivation of the detection pattern of the composite $\kappa - \mu$ shadowed/IG distribution. This model can be used in generalized LOS and small-scale fading channels for multipath shadowing effects. Novel analytical expressions of detection model have been derived for composite $\kappa - \mu$ shadowed channels. Importantly, the detection capability of the fading channels is able to be exactly estimated with different non-integer values of fading parameters, and even small range increased variations for the ratio between the total power of the dominant components and the total power of the scattered waves will substantially improve the corresponding detection performance under appropriate SNR condition. As a result, the offered results can be used for quantifying the composite LOS and shadowed fading channels with ED in SS which can contribute to cognitive radio systems in wireless communication.

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