# Energy Detection of Unknown Signals over Composite multipath/shadowing Fading Channels

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***Abstract*— In this paper, the performance analysis of an energy detector is exploited over composite multipath/shadowing fading channels, which is modeled by Rayleigh-lognormal (RL) distribution. Based on an approximate channel model which was recently proposed by the author, the RL envelope probability density function (pdf) is approximated by a finite sum of weighted Rayleigh pdfs. Relying on this interesting feature, the performance of energy detector over RL fading channel is investigated and approximate closed-form expression is derived for the detection probability ($P_d$). Further, results are extended to diversity reception case, where selection diversity (SC) technique is adopted to improve the detection performance. Selection Diversity is one of the most simplest diversity techniques, in which, the receiver simply picks the signal with the largest SNR among the received signals. In this regard, an approximate closed-form expression is derived for the pdf of the resulting signal-to-noise ratio (SNR) of SC receiver. Using this approximated pdf, an analytical closed-form expression is derived for the $P_d$ of energy detector with SC diversity. The presented analysis is validated by numerical and simulation results.**

***Index Terms*— Energy detection, Rayleigh-lognormal distribution, Selection combining, composite fading channel.**

## I. INTRODUCTION

Currently, there is an increasing interest of energy detection of unknown signals. As an obvious example, detection of primary user signals is one of the key challenges in cognitive radio networks. Due to the spectrum scarcity in wireless networks, low-priority secondary users try to access the spectrum of primary users (licensed users) once the primary users are sensed to be idle over their allocated spectrum band [1], [2]. A common method for detection of unknown signals in noise is energy detection (a.k.a. radiometry) [3-5]. An energy detector measures the energy of an incoming signal and compares it to an appropriately selected threshold to determine the presence of a transmitted signal. Energy detector does not require any prior knowledge of the transmitted signal and fading channel; and hence, it can be found also in practical communication systems such as radar detection and orthogonal frequency division multiplexing (OFDM) applications. Low-complexity and

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non-coherent energy detection has thus been applied in ultra-wideband (UWB) wireless communication networks [6], [7].

The detection of an unknown deterministic signal in the presence of additive white Gaussian noise (AWGN) is analytically formulated in [5] for a flat and band-limited Gaussian channel. Based on the results in [5], performance metrics of energy detector including the detection probability and false alarm probability have been derived in closed-form over AWGN channel in [8]. Performance analysis of energy detector for Rayleigh, Rice and Nakagami fading channels has been investigated in [8] and [9] as two independent works with different analytical approaches. Further, energy detection under different diversity receptions such as maximal ratio combining (MRC), selection combining (SC), switch-and-stay combining (SSC), square-law combining (SLC), square-law selection (SLS) and equal gain combining (EGC) has been analyzed in [10]] over different multipath fading channels.

In many real life propagation links, multipath fading and shadowing occur simultaneously, yielding a composite fading environment which can be modeled efficiently by Rayleigh-lognormal (RL) distribution [11]. The analysis based on the RL distribution is always not easy because of its complicated integral form [12]. No closed-form expression on the performance of the energy detector in the composite Rayleigh fading and shadowing is studied in the existing literature.

To fill this gap, in this paper, the performance of energy detector over composite multipath/shadowing fading channel, which is modeled by the RL distribution, is analyzed and novel, approximate closed form expressions are provided for the energy detector performance metrics. This analysis is based on a new RL approximate model which was proposed recently by the author in [13, sec. 3, pp. 18]. The proposed model is analytically tractable and makes it possible to approximate the signal envelop pdf by a finite sum of weighted Rayleigh pdfs. Then, based on this interesting feature, the detection performance of energy detector over RL fading channel is investigated and approximate closed form expression is derived for the detection probability. Moreover, to improve the detection performance, the selection diversity (SC) scheme is adopted. In SC diversity scheme, the branch with the highest instantaneous signal-to-noise ratio (SNR) is selected among $L$ available. For this case, first, it is shown that the pdf of the signal-to-noise (SNR) at the output of the SC receiver can be approximated accurately by a finite linear combination of exponential functions. The derived approximate pdf accurately estimates the pdf of the SNR for arbitrary values of diversity order ($L$). Then, based on the presented results, an approximate closed-form expression is derived for the average detection probability of the energy detector over RL fading channel with SC diversity. Numerical results presented in this paper show that the derived approximate expressions for detection probability is very accurate for arbitrary values of diversity order and a wide range of channel conditions, and hence, it can serve as a simple and reliable method to estimate detection performance of energy detector over composite fading channels.

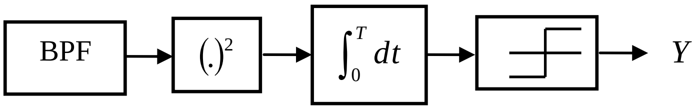


Fig.1. Block diagram of an energy detector

The remainder of the paper is organized as follows. In section II, the system model is introduced. In section III the RL channel model is described. Section IV and V include the results of performance analysis of energy detector over RL fading channel with no diversity as well as with employing SC diversity schemes.. Finally, concluding remarks are provided in Section VI.

## II. SYSTEM MODEL AND NOTATIONS

To be consistent, the major notations which will be used in the paper are summarized in Table I. Fig. 1 depicts the block-diagram of an energy detector. Let *S(t)* be the primary user signal that is transmitted over a channel with gain α and additive zero-mean white Gaussian noise *n(t)*. In this paper, α is assumed to be a RL-distributed random variable. Let *W* denote the signal bandwidth, and *T* be the observation time over which signal samples are collected, so chosen that the time-bandwidth product, *u*=*TW*, is an integer. The goal is to determine whether a signal is

Table I: Notation list

| | |
|---|---|
| *s*(t) | Signal waveform |
| *n*(t) | Noise waveform which is modeled as a zero-mean white Gaussian random process |
| $N_0$ | One-sided noise power spectral density $E_s = \int_0^T s^2(t)\,dt$ |
| $E_s$ | Signal energy, i.e., |
| *u* | Time bandwidth product |
| $H_0$ | Hypothesis 0 corresponding to no signal transmitted |
| $H_1$ | Hypothesis 1 corresponding to signal transmitted |
| $P_{d\|\gamma}$ | probability of detection *conditioned* on the instantaneous SNR |
| $P_{d,SC}$ | Probability of detection with selection combining diversity over Rayleigh-lognormal fading channel |
| $P_f$ | Probability of false alarm |
| $\chi_\alpha^2$ | A central chi-square variable with α degrees of freedom |
| $\chi_\alpha^2(\beta)$ | A no central chi-square variable with α degrees of freedom and no centrality parameter $\beta$ |
| $\lambda$ | Energy threshold used by the energy detector |
| $\gamma$ | Signal-to-noise ratio (SNR) |
| $\bar{\gamma}$ | Average signal-to-noise ratio |

present (hypothesis $H_1$) or not(hypothesis $H_0$). Under these two hypotheses, the received signal is given by

$$r(t) = \begin{cases} n(t) & : \quad H_0 \\ \alpha s(t) + n(t) : & H_1 \end{cases} \tag{1}$$

The output of the integrator in Fig.1 is denoted by $Y$, which serves as decision statistics. Following the results which have been presented in [6], $Y$ may be shown to have the following distribution

$$Y \sim \begin{cases} \chi^2_{2u} & : \quad H_0 \\ \chi^2_{2u}(2\gamma) : & H_1 \end{cases} \tag{2}$$

The probabilities of detection and false alarm are given by the following formulas [8],

$$P_{d|\gamma} = \Pr\left(Y > \lambda \;\middle|\; H_1\right) = Q_u\left(\sqrt{2\gamma}, \sqrt{\lambda}\right) \tag{3}$$

$$P_f = \Pr\left(Y > \lambda \;\middle|\; H_0\right) = \frac{\Gamma\left(u, \frac{\lambda}{2}\right)}{\Gamma(u)} \tag{4}$$

where Γ(.) and Γ(.,.) are complete and incomplete gamma functions respectively and $Q_u(.,.)$ is the generalized Marcum $Q$-function [11]. As expected, $P_f$ is independent of $\gamma$ since under $H_o$ there is no primary signal present.

In this paper, we are interesting to investigate the performance of energy detector over RL fading channel. So, the average probability of detection over RL channel, $P_d$, may be derived by averaging (3) over fading statistics,

$$P_d = \int_0^\infty Q_u\left(\sqrt{2\gamma}, \sqrt{\lambda}\right) f_\gamma(\gamma) d\gamma \tag{5}$$

where $f_g(g)$ is the pdf of SNR over RL composite multipath/ shadowing fading channel.

The RL distribution has been widely employed for capturing the phenomenon of fading and shadowing aspects in wireless channels [9]. The RL distribution is described as

$$f_\alpha(\alpha) = \int_0^\infty f_{\alpha|\Omega}(\alpha|\Omega) f_\Omega(\Omega) d\Omega \tag{6}$$

The conditional density for $f_{\alpha|\Omega}(\alpha|\Omega)$ denotes the Rayleigh distribution

$$f_{\alpha|\Omega}(\alpha|\Omega) = \frac{2\alpha}{\Omega} \exp\left(-\frac{\alpha^2}{\Omega}\right) \quad , \quad \alpha \geq 0 \tag{7}$$

where the parameter $\Omega = E[\alpha^2]$ is assumed to be a random variable having a lognormal distribution with parameters μ and σ as follow

$$f_{\Omega}(\Omega;\mu,\sigma)=\frac{1}{\sqrt{2\pi}\sigma\Omega}\exp\left(-\frac{(Ln(\Omega)-\mu)^2}{2\sigma^2}\right) \quad , \quad \Omega\geq 0 \tag{8}$$

where $\mu$ is the mean and $\sigma$ is the standard deviation of *Ln(Ω)*, where *Ln(.)* is the logarithm to the base *e*. The mean ($\mu_L$) and the variance ($\sigma^2_L$) of the log normally-distributed random variable $\Omega$ can be described in terms of $\mu$ and $\sigma$ as $\exp(\mu+\sigma^2/2)$ and $\left(\exp(\sigma^2)-1\right)\exp\left(2\mu+\sigma^2\right)$, respectively.

Accordingly the explicit pdf of RL distribution can be derived by averaging $f_{\alpha|\Omega}(\alpha|\Omega)$ in (7) with respect to $f_{\Omega}(\Omega;\mu,\sigma)$ in (8) as follow

$$\begin{aligned} f_{\alpha}(\alpha) &= E_{\Omega}[f_{\alpha|\Omega}(\alpha|\Omega)] \\ &= \int_0^{\infty}\frac{2\alpha}{\Omega}\exp\left(-\frac{\alpha^2}{\Omega}\right)\frac{1}{\sqrt{2\pi}\sigma\Omega}\exp\left(-\frac{(Ln(\Omega)-\mu)^2}{2\sigma^2}\right)d\Omega \end{aligned} \tag{9}$$

III. Proposed Channel Model

Unfortunately, $f_{\alpha}(\alpha)$ in (9) is not available in closed form and this makes the RL distribution difficult to work with [12]. Very recently, in [10] an approximation method was proposed that makes it possible to bypass this problem. The proposed model is analytically tractable and makes it possible to accurately approximate the signal envelop pdf by a finite sum of weighted Rayleigh pdfs as follows

$$\begin{aligned} f_{\alpha}(\alpha) \approx{}& \frac{2}{3}\left\{\frac{2\alpha}{\mu_L}\exp\left(-\frac{\alpha^2}{\mu_L}\right)\right\}+\frac{1}{6}\left\{\frac{2\alpha}{\mu_L+\sqrt{3}\sigma_L}\exp\left(-\frac{\alpha^2}{\mu_L+\sqrt{3}\sigma_L}\right)\right\} \\ &+\frac{1}{6}\left\{\frac{2\alpha}{\mu_L-\sqrt{3}\sigma_L}\exp\left(-\frac{\alpha^2}{\mu_L-\sqrt{3}\sigma_L}\right)\right\} \end{aligned} \tag{10}$$

These interesting feature facilities the performance analysis of energy detector over RL composite fading channel. From (10) it is easy to verify that $E[\alpha^2]=\mu_L$. The SNR in the composite multipath/shadowing fading channel can be described as $\gamma=\alpha^2\frac{E_s}{N_0}$, so the average SNR can be calculated as

$$\bar{\gamma}=E[\alpha^2]\frac{E_s}{N_0}=\mu_L\frac{E_s}{N_0} \tag{11}$$

Using (10) and considering the definition of $\gamma=\alpha^2\frac{E_s}{N_0}$, the pdf of the SNR, $\gamma$, can be derived as follow

$$f_\gamma(\gamma) = \frac{2}{3}\left\{\frac{1}{\bar{\gamma}}\exp\left(-\frac{\gamma}{\bar{\gamma}}\right)\right\} + \frac{1}{6}\left\{\frac{1}{\bar{\gamma}}\frac{\mu_L}{\mu_L + \sqrt{3}\sigma}\exp\left(-\frac{\gamma}{\bar{\gamma}\frac{\mu_L + \sqrt{3}\sigma}{\mu_L}}\right)\right\} +$$
$$\frac{1}{6}\left\{\frac{1}{\bar{\gamma}}\frac{\mu_L}{\mu_L - \sqrt{3}\sigma}\exp\left(-\frac{\gamma}{\bar{\gamma}_{RL}\frac{\mu_L - \sqrt{3}\sigma}{\mu_L}}\right)\right\} \tag{12}$$

By defining

$$\begin{cases} \bar{\gamma}_a = \bar{\gamma}\dfrac{\mu_L + \sqrt{3}\sigma}{\mu_L} \\ \bar{\gamma}_b = \bar{\gamma}\dfrac{\mu_L - \sqrt{3}\sigma}{\mu_L} \end{cases} \tag{13}$$

equation (12) can be simplified to

$$f_\gamma(\gamma) = \frac{2}{3}\left\{\frac{1}{\bar{\gamma}}\exp\left(-\frac{\gamma}{\bar{\gamma}}\right)\right\} + \frac{1}{6}\left\{\frac{1}{\bar{\gamma}_a}\exp\left(-\frac{\gamma}{\bar{\gamma}_a}\right)\right\} + \frac{1}{6}\left\{\frac{1}{\bar{\gamma}_b}\exp\left(-\frac{\gamma}{\bar{\gamma}_b}\right)\right\} \tag{14}$$

Considering the definition of the cdf of random variable $\gamma$ as $F_\gamma(\gamma) = \int_0^\gamma f_\gamma(\gamma)\, d\gamma$, and by using (14), $F_\gamma(\gamma)$ can be approximated as follow

$$F_\gamma(\gamma) = 1 - \frac{2}{3}\exp\left(-\frac{\gamma}{\bar{\gamma}}\right) - \frac{1}{6}\exp\left(-\frac{\gamma}{\bar{\gamma}_a}\right) - \frac{1}{6}\exp\left(-\frac{\gamma}{\bar{\gamma}_b}\right) \tag{15}$$

## IV. Detection Probability over RL fading channel with no Diversity

In this section, we derive the average detection probability over RL fading channel. In this regard, by inserting from (14) into (5), we will have

$$P_d = \int_0^\infty Q_u\left(\sqrt{2\gamma},\sqrt{\lambda}\right) f_\gamma(\gamma)\,d\gamma$$
$$= \frac{2}{3}\left\{\frac{1}{\bar{\gamma}}\int_0^\infty Q_u\left(\sqrt{2\gamma},\sqrt{\lambda}\right)\exp\left(-\frac{\gamma}{\bar{\gamma}}\right)d\gamma\right\} + \frac{1}{6}\left\{\frac{1}{\bar{\gamma}_a}\int_0^\infty Q_u\left(\sqrt{2\gamma},\sqrt{\lambda}\right)\exp\left(-\frac{\gamma}{\bar{\gamma}_a}\right)d\gamma\right\} +$$
$$\frac{1}{6}\left\{\frac{1}{\bar{\gamma}_b}\int_0^\infty Q_u\left(\sqrt{2\gamma},\sqrt{\lambda}\right)\exp\left(-\frac{\gamma}{\bar{\gamma}_b}\right)d\gamma\right\} \quad (16)$$

Calculation of $P_d$ in (16) needs the calculation of integrals in the general form as follow

$$\vartheta(u,\lambda,x) = \int_0^\infty Q_u\left(\sqrt{2\gamma},\sqrt{\lambda}\right)\exp\left(-\frac{\gamma}{x}\right)d\gamma \quad (17)$$

which has a known closed-form as [6, Eq. (16)]

$$\vartheta(u,\lambda,x) = x\exp\left(-\frac{\lambda}{2}\right)\sum_{k=0}^{u-2}\frac{1}{n!}\left(\frac{\lambda}{2}\right)^n + x\left(\frac{1+x}{x}\right)^{u-1}\left[\exp\left(-\frac{\lambda}{2(1+x)}\right) - \exp\left(-\frac{\lambda}{2}\right)\sum_{k=0}^{u-2}\frac{1}{n!}\frac{\lambda x}{2(1+x)}\right] \quad (18)$$

Hence, $P_d$ in (16) can be described in an analytical closed-form as

$$P_d = \frac{2}{3}\frac{1}{\bar{\gamma}}\vartheta(u,\lambda,\bar{\gamma}) + \frac{1}{6}\frac{1}{\bar{\gamma}_a}\vartheta(u,\lambda,\bar{\gamma}_a) + \frac{1}{6}\frac{1}{\bar{\gamma}_b}\vartheta(u,\lambda,\bar{\gamma}_b) \quad (19)$$

V. Detection Probability with Selection Diversity

In this section, the energy detection performance is addressed when SC diversity scheme is employed. In the SC diversity scheme, the branch with maximum SNR, $\gamma_{\max}$, is to be selected. The PDF of $\gamma_{\max}$ is known to be given by

$$f_{\gamma_{\max}}(\gamma) = L\, f_{RL}(\gamma)\left[F_{RL}(\gamma)\right]^{L-1} \quad (20)$$

Inserting (17) and (20) in (25), $f_{\gamma_{\max}}(\gamma)$ can be described as

$$f_{\gamma_{\max}}(\gamma) = L\left[\frac{2}{3}\left\{\frac{1}{\bar{\gamma}}\exp\left(-\frac{\gamma}{\bar{\gamma}}\right)\right\} + \frac{1}{6}\left\{\frac{1}{\bar{\gamma}_a}\exp\left(-\frac{\gamma}{\bar{\gamma}_a}\right)\right\} + \frac{1}{6}\left\{\frac{1}{\bar{\gamma}_b}\exp\left(-\frac{\gamma}{\bar{\gamma}_b}\right)\right\}\right]$$
$$\times\left[1 - \frac{2}{3}\exp\left(-\frac{\gamma}{\bar{\gamma}}\right) - \frac{1}{6}\exp\left(-\frac{\gamma}{\bar{\gamma}_a}\right) - \frac{1}{6}\exp\left(-\frac{\gamma}{\bar{\gamma}_b}\right)\right]^{L-1} \quad (21)$$

Using the multinomial identity [12, eq. (24.1/2)], (26) yields to

(22)

$$f_{\gamma_{\max}}(\gamma) = L\left[\frac{2}{3}\left\{\frac{1}{\bar{\gamma}}\exp\left(-\frac{\gamma}{\bar{\gamma}}\right)\right\} + \frac{1}{6}\left\{\frac{1}{\bar{\gamma}_a}\exp\left(-\frac{\gamma}{\bar{\gamma}_a}\right)\right\} + \frac{1}{6}\left\{\frac{1}{\bar{\gamma}_b}\exp\left(-\frac{\gamma}{\bar{\gamma}_b}\right)\right\}\right]$$
$$\times \sum_{\substack{k_1,k_2,k_3,k_4 \\ k_1+k_2+k_3+k_4=L-1}} \binom{L-1}{k_1,k_2,k_3,k_4}\left(-\frac{2}{3}\right)^{k_2}\left(-\frac{1}{6}\right)^{k_3+k_4}\exp\left(-\left(\frac{k_2}{\bar{\gamma}}+\frac{k_3}{\bar{\gamma}_a}+\frac{k_4}{\bar{\gamma}_b}\right)\gamma\right)$$

By defining $H(\gamma,\beta)$ as

$$H(\gamma,\beta) = \sum_{\substack{k_1,k_2,k_3,k_4 \\ k_1+k_2+k_3+k_4=L-1}} \binom{L-1}{k_1,k_2,k_3,k_4}\left(-\frac{2}{3}\right)^{k_2}\left(-\frac{1}{6}\right)^{k_3+k_4}\beta\exp\left[-\left(\frac{k_2}{\bar{\gamma}}+\frac{k_3}{\bar{\gamma}_a}+\frac{k4}{\bar{\gamma}_b}+\beta\right)\gamma\right] \quad (23)$$

Equation (27) can be described in closed-form as

$$f_{\gamma_{\max}}(\gamma) = L\left[\frac{2}{3}H\left(\gamma,\frac{1}{\bar{\gamma}}\right) + \frac{1}{6}H\left(\gamma,\frac{1}{\bar{\gamma}_a}\right) + \frac{1}{6}H\left(\gamma,\frac{1}{\bar{\gamma}_b}\right)\right] \quad (24)$$

Fig.2 shows the approximate PDF (Eq. (24)) of the resulting SNR corresponding to the SC diversity scheme over RL fading channel compared with the simulation results. Interestingly, Fig.2 shows the good accuracy of the approximate pdf. In the following, this approximate pdf will be used to derive a closed-form expression for the average BER.

In the following, the approximate pdf in (24) will be used to derive a closed-form expression for the average detection probability when the SC diversity scheme is adopted. Using the approximated pdf, the detection probability in (5) can be calculated as

$$\begin{aligned} P_{d,SC} &= \int_0^\infty Q_u\left(\sqrt{2\gamma},\sqrt{\lambda}\right) f_{\gamma_{\max},RL}(\gamma)\,d\gamma \\ &= L\left\{\ \frac{2}{3}\left\{\int_0^\infty Q_u\left(\sqrt{2\gamma},\sqrt{\lambda}\right)H\left(\gamma,\frac{1}{\bar{\gamma}}\right)d\gamma\right\} + \frac{1}{6}\left\{\int_0^\infty Q_u\left(\sqrt{2\gamma},\sqrt{\lambda}\right)H\left(\gamma,\frac{1}{\bar{\gamma}_a}\right)d\gamma\right\} + \right. \\ &\quad \left. \frac{1}{6}\left\{\int_0^\infty Q_u\left(\sqrt{2\gamma},\sqrt{\lambda}\right)H\left(\gamma,\frac{1}{\bar{\gamma}_b}\right)d\gamma\right\}\ \right\} \end{aligned} \quad (25)$$

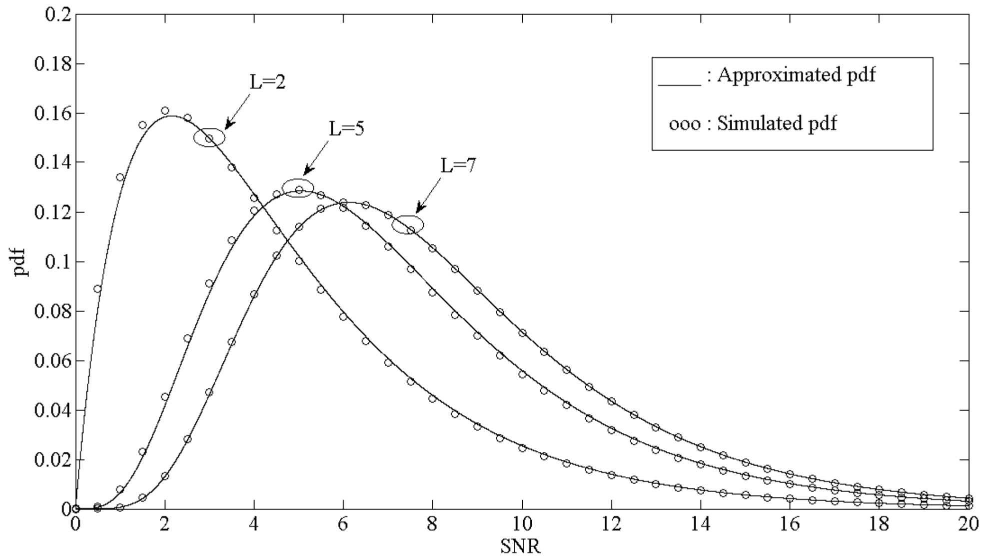


Fig.2. pdf of the resulting SNR corresponding to the SC diversity scheme over RL fading channel under light shadowing condition.

Inserting $H(\gamma,\beta)$ from (23) into (25), it can be rewritten as

$$P_{d,SC} = L \sum_{\substack{k_1,k_2,k_3,k_4 \\ k_1+k_2+k_3+k_4=L-1}} \binom{L-1}{k_1,k_2,k_3,k_4} \left(-\frac{2}{3}\right)^{k_2} \left(-\frac{1}{6}\right)^{k_3+k_4} \times$$
$$\left\{ \frac{2}{3}\frac{1}{\gamma}\int_0^\infty Q_u\left(\sqrt{2\gamma},\sqrt{\lambda}\right)\exp\left[-(\frac{k_2}{\gamma}+\frac{k_3}{\gamma_a}+\frac{k4}{\gamma_b}+\frac{1}{\gamma})\gamma\right]d\gamma + \right.$$
$$\frac{1}{6}\frac{1}{\gamma_a}\int_0^\infty Q_u\left(\sqrt{2\gamma},\sqrt{\lambda}\right)\exp\left[-(\frac{k_2}{\gamma}+\frac{k_3}{\gamma_a}+\frac{k4}{\gamma_b}+\frac{1}{\gamma_a})\gamma\right]d\gamma +$$
$$\left. \frac{1}{6}\frac{1}{\gamma_b}\int_0^\infty Q_u\left(\sqrt{2\gamma},\sqrt{\lambda}\right)\exp\left[-(\frac{k_2}{\gamma}+\frac{k_3}{\gamma_a}+\frac{k4}{\gamma_b}+\frac{1}{\gamma_b})\gamma\right]d\gamma \right\} \tag{26}$$

As can be deduced from (26), to derive closed-form expression for $P_{d,SC}$, it is required to solve integrals in the general form of $\int_0^\infty Q_u\left(\sqrt{2\gamma},\sqrt{\lambda}\right)\exp\left(-\frac{\gamma}{x}\right)d\gamma$, which can be evaluated in terms of $\vartheta(u,\lambda,x)$ (Eq. (18)) as follow

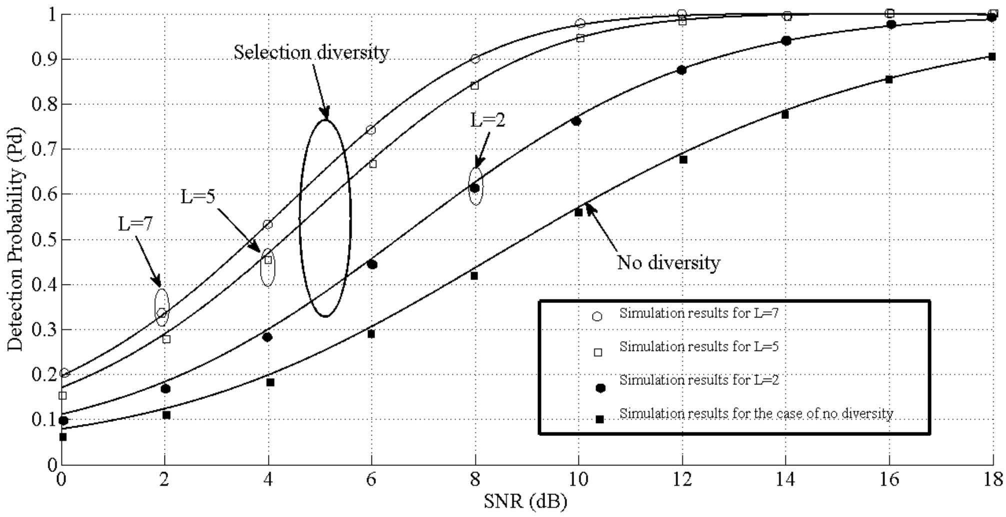


Fig. 3. Detection performance (analytical and simulation results) with selection diversity over RL fading channel with light shadowing for $P_f = 0.001, u = 5$

$$P_{d,SC} = L \sum_{\substack{k_1,k_2,k_3,k_4 \\ k_1+k_2+k_3+k_4=L-1}} \binom{L-1}{k_1,k_2,k_3,k_4} \left(-\frac{2}{3}\right)^{k_2} \left(-\frac{1}{6}\right)^{k_3+k_4} \times$$

$$\left\{ \frac{2}{3}\frac{1}{\gamma} \vartheta\left(u,\lambda,\frac{1}{\frac{k_2}{\gamma}+\frac{k_3}{\gamma_a}+\frac{k4}{\gamma_b}+\frac{1}{\gamma}}\right) + \frac{1}{6}\frac{1}{\gamma_a} \vartheta\left(u,\lambda,\frac{1}{\frac{k_2}{\gamma}+\frac{k_3}{\gamma_a}+\frac{k_4}{\gamma_b}+\frac{1}{\gamma_a}}\right)\right.$$

$$\left. + \frac{1}{6}\frac{1}{\gamma_b} \vartheta\left(u,\lambda,\frac{1}{\frac{k_2}{\gamma}+\frac{k_3}{\gamma_a}+\frac{k_4}{\gamma_b}+\frac{1}{\gamma_b}}\right) \right\} \tag{27}$$

The efficiency of employing the SC diversity scheme is illustrated in Fig.3 for a pre-specified probability of false-alarm, $P_f = 0.001$ at given SNR. For a fixed value of the time-bandwidth product, $u = 5$. To verify the accuracy of the derived analytical results, simulation results also depicted in Fig. 3. As can be deduced from Fig. 3, the accuracy of the derived expressions improves with the increasing of the diversity order (*L*). Moreover, the improvement in the detection achieved through the diversity gains offered by SC processing in energy detection is evident. For example, at SNR=8 dB, the detection probability increases from 0.43 (for the case of no diversity) to 0.6 (for the case of *L*=2) and this gain increases to 0.85 and 0.9 for the case of *L*=5 and 7, respectively. In Fig. 4, the same results are depicted for the case of $P_f = 0.01$.

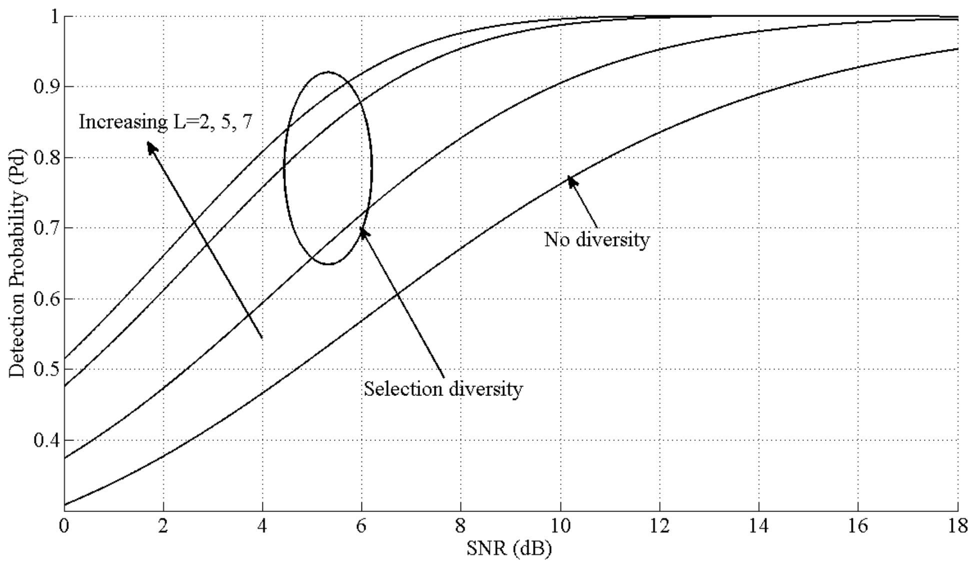


Fig. 4. Detection performance with selection diversity over RL fading channel with light shadowing for $P_f = 0.01, u = 5$

## VI. CONCLUSION

In this paper an analytical approach presented for performance analysis of an energy detector over RL fading channel. Based on a proposed analytically tractable channel mode, closed-form expressions provided for the probability of detection over RL fading channel. Moreover, the detection performance gain using SC diversity scheme was analyzed and approximate closed-form expression was provided for the detection probability of energy detector employing SC diversity scheme.

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