Energy Detection with Diversity Combining Over K_G Fading For Cognitive VANET

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***Abstract*—Continuous evaluation in Vehicular Ad-hoc Networks (VANET) will contribute to spectrum scarcity problem in near future. Cognitive radio (CR) system aims to provide opportunistic access and adapt the available frequency resources instead of conventional static spectrum allocation. Spectrum sensing is one of the most demanding aspects in CR design and implementation. Low signal to noise ratio (SNR) and fading effects posed limitations to deploying CR in realistic propagation scenario with fast and fine sensing features. Energy detection(ED) based spectrum sensing is a viable choice for many vehicle-to-vehicle (V2V) and vehicle-to-roadside infrastructure (V2I) communications. In this paper, we consider the performance of ED over composite Generalized-K (K_G) fading to deal with combined large and small scale fading in VANET. Diversity combining using Maximal ratio Combining (MRC) and Selective Combining (SC) over K_G fading channel are investigated. A novel tractable expression for Energy detection based average detection probability for optimal MRC diversity combining scheme is derived and closed form possibility is analyzed for SC. Both numerical and simulation models are examined for practical low to moderate shadow fading conditions. The results highlight the notable impact of shadowing spread and fading severity on detection performance and meliorating effects of employing combining techniques.**

I. Introduction

Fast and reliable vehicular communication is the key requirement of Vehicular Ad hoc Networks including vehicle-to-vehicle (V2V) and vehicle to-road-side infrastructure (V2I) real time communications. As fully autonomous vehicles development greatly enhanced the motivation for VANET implementation. This emerging scheme not only promise increased road safety benefits by employing pre-crash systems but also proposed enhanced mobility by reducing congestion and improved comfort [1]. However, dynamic nature and high mobility of vehicles are primary constraints categorized most performance limiting factors for realistic vehicular communication channel and propagation modeling [2].

Cognitive Radio (CR) is an innovative and most compelling solution having tremendous possibility to improve spectrum efficiency and quality of services through shared utilization [3]. Cognitive VANET in near future will take advantage of licensed spectrum utilization by allocation of unused spectrum pool to cognitive users (Secondary Users) for V2I or V2V communication. For that purpose, a vehicle in cognitive VANET system will observe first any particular spectrum which is idle for a long duration before accessing it [4]. With this intentions, that detection mechanism must be an artifact scheme, which senses the primary user (Licensed Users) signal presence with high detection possibility, while maintaining the erroneous exploration extremely small.

Several schemes are employed to expeditiously detect the presence of primary transmitter. Some well-known spectrum sensing techniques are Energy Detection, Matched Filter Detection and Cyclostationary Feature Detection. Each method possesses distinctive and diverse features which are suitable in various environment conditions. Among these, ED is of particular focus because of its implementation simplicity and potential to detect any shape of waveforms with intrinsic privacy. For the discovery of unascertained deterministic signal debased by Gaussian Noise, Energy detector primarily appeared in the classical contribution of Urkowitz [5]. ED is the simplest efficient technique that essentially computes a running average of the signal power over a window of pre-specified spectrum length and also does not demand any preceding information of signals which is to be detected. Concurrently, when knowledge of primary user signal is not possible, energy detector for spectrum sensing is the optimal choice for cognitive radio. However, the ability of an energy detector to classify between noise and signal is very compromising. Furthermore, the spatial and transient variations of wireless signal are also major contributing factors in sensing deterioration using energy detection technique.

ED based spectrum sensing in cognitive VANET suffers performance loss during varying propagation environment, shadowing from large vehicles and frequency selective channels characteristics. However, as a matter of fact an energy detector can collect the multipath energy very easily by means of a simple integrator without any channel estimation. The timing accuracy is also acceptable and the Bit Error Rate (BER) is not largely affected due to synchronization errors. In wireless Systems long and short term conditions of multipath fading appear concurrently, various investigations and estimations propose that combined or diversified probability distribution model is more appropriate to accurately describe the shadow-fading conditions in VANET. The performance evaluation of energy detectors with composite fading channels and various shadow fading environments has been focused in literature [6]–[9] and the references therein.

In this paper, we concentrate mainly our work to K_G fading channel. Since in Generalized K_G shadow-fading composite model, average power variations i.e., shadowing is exhibited by Gamma distribution and small-scale random deviations in the envelope of the received signal is characterized by Nakagami-m distribution. We extended the work by analyzing the impact of diversity reception by using the same probability density function (PDF) approach and alternative series representation of Marcum-Q function. we derive expressions for ED based average detection probability considering MRC and SC combining techniques. Our analytical results are confirmed through comparison with Monte Carlo simulations. For multiple antenna branches at the receiver, detector performances are numerically quantified followed by their simulation counterparts for various diversity strategies VANET.

The rest of this paper is outlined as follows. Section II gives the description of the system model comprised of ED sensing statistics used in the analysis followed. Diversity reception analysis is carried out in Section III. The numerical and simulation results are presented in Section IV, followed by the Section V which concludes the whole paper.

II. System Model

A simplified diagram of a energy detector is shown in Fig. 1. The basic operative structure requires a filter, squaring device, an integrator and a comparator. Over a deterministic and stationary signal model with white Gaussian noise having noise spectral density N_0, the primary user signal $x(t)$ with channel gain $h(t)$ is applied to band pass filter (BPF) using carrier frequency f_c and signal bandwidth W. To opt for the bandwidth of interest and reduce the noise at this point, the noise has a band-limited, flat spectral density at the output of the filter. Subsequently, to evaluate the power of the received signal, the output of BPF is squared and then integrated over observation time interval T to estimate the energy of received signal at the detector. The amount of samples u for individual element of received signal is to select as an integer i.e., u=TW. The output signal Y from the integrator for AWGN for specified T is given as

$$Y = \frac{1}{N_0}\int_{t-T}^{t} |x(\tau)|^2 \, d\tau \tag{1}$$

Lastly, Y is matched to a given specific threshold λ to determine the presence of a primary signal H_1 or its absence i.e., H_0. The threshold λ value is consistent with output Y considering the statistical attributes when ambient noise is existent appearing from the receiver itself or from environing RF interference.

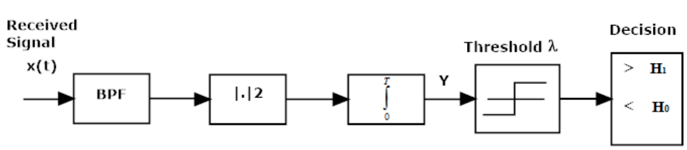

Fig. 1. Block diagram of Energy Detector.

The precise tractable equations for probabilities of detection $(\overline{P_d})$, false alarm (P_f), and missed detection (P_m) over AWGN channel are given by [10]

$$\overline{P_d} = \tilde{P}\{Y > \lambda | H_1\} = Q_u(\sqrt{2\gamma}, \sqrt{\lambda}) \tag{2}$$

where $\tilde{P}$ is the probability of an expectation and $Q_M(.,.)$ is generalized M^{th} order Marcum-Q operator that is determined in its integral form as [11]

$$Q_M(\alpha,\beta) = \int_{\alpha}^{\beta} \frac{t^M}{\alpha^{M-1}} \, e^{-\frac{t^2+\alpha^2}{2}} \, I_{M-1}(\alpha t)dt \tag{3}$$

where $I_{M-1}(.)$ is the modified Bessel function of $(M-1)^{th}$ order. The probability of false alarm is expressed as

$$\begin{aligned} P_f &= \tilde{P}\{Y > \lambda | H_0\} \\ &= \frac{\Gamma\left(u, \frac{\lambda}{2}\right)}{\Gamma(u)} \end{aligned} \tag{4}$$

here $\Gamma(.,.)$ is an upper incomplete gamma function which is defined as $\Gamma(m,n) = \int_n^{\infty} t^{m-1} e^{-t} \, dt$. Similarly, the probability of missed detection can be evaluated as

$$\begin{aligned} P_m &= 1 - \tilde{P}\{Y > \lambda | H_1\} \\ &= 1 - Q_u(\sqrt{2\gamma}, \sqrt{\lambda}) \end{aligned} \tag{5}$$

Threshold λ which is defined SNR for detector is computed for a defined P_f using (4). Whereas conventional optimality principle, Neyman-Pearson routine exploits $\overline{P_d}$ for assigned P_f and equivalent to $LR(Y)$ designated as the likelihood ratio test (LRT) of Y. As a matter of fact, the NLOS environment is considered among primary transmitter and secondary (Cognitive) user. Hence, the experienced primary signal is a superposition of various NLOS multiple replica signals and is well approximated to Gaussian random variables according to the central limit theorem. In our assumption or exploration, if the primary user signal and noise both are considered as Gaussian processes, energy detector can acquire any chosen $\overline{P_d}$ and P_f instantaneously, therefore the threshold λ is optimum.

Another essential distinctive series form of M^{th} order Marcum-Q is shown in (6) as given by [11]

$$\begin{aligned} Q_M\left(\alpha,\beta\right) &= \textstyle\sum_{n=0}^{\infty} exp\left(-\frac{\alpha^2}{2}\right) \frac{(\alpha^2/2)^n}{n!} \\ & \textstyle\sum_{k=0}^{n+M-1} exp\left(-\frac{\beta^2}{2}\right) \frac{(\beta^2/2)^k}{k!} \end{aligned} \tag{6}$$

by equating the variables (6) with (2) we can get the modified form as

$$Q_u(\sqrt{2\gamma}, \sqrt{\lambda}) = \sum_{n=0}^{\infty} \frac{\gamma^n e^{-\gamma}}{n!} \sum_{k=0}^{n+u-1} \frac{e^{\frac{-\lambda}{2}}}{k!} \left(\frac{\lambda}{2}\right)^k \tag{7}$$

Subsequently, after utilizing the series expression in (6), γ will have just exponentials and powers (possibly with special functions), which can be analyzed from (7). Besides the prevention of Bessel function present in (6), this form also permit us to deal with Marcum-Q function averaging with PDF's of γ, that may involve special functions.

III. Diversity Combining

To recuperate the sensing information and achieve the diversity gain, signals at multiple antenna branches are combined at the cost of intricacy of the receiver. Hence, the transmitted signal is conveyed through various channels which are entailed to combine at the receiver. As far as these channels are believed independent, there is a very high probability that the presence of the primary signal is sensed correctly.

However, our goal is to present the evaluation of $\overline{P}_{d,c}$ at the maximal ratio and selective combiners over i.i.d. Generalized-K (K_G) composite fading branches using Energy detection. For this, the PDF approach is applied in which PDF of SNR at the combiner output $f_{\gamma,c}(\gamma)$ is first determined. Later, averaging (2) over the obtained PDF furnishes the final result.

$$\overline{P}_{d,c} = \int_{\gamma} Q_u(\sqrt{2\gamma}, \sqrt{\lambda_i}) f_{\gamma,c}(\gamma) d\gamma \qquad (8)$$

A. Maximal Ratio Combining

Irrespective of the nature of fading, in an interference free environment, MRC is an optimal combining method which involves perfect knowledge of amplitudes and phases of channel fading. In this generic technique, the stronger signal is strengthen while the weaker one is abated. Firstly, the multiple signal are co-phased and weighted accordingly to the SNR of individual channel. Finally, all the branch signals are linearly combined and the MRC output signal for L diversity branches is given by

$$y_{mrc}(t) = \sum_{l=1}^{L} h_l^* \; r_l(t) \qquad (9)$$

where h_l^* is the complex conjugation of impulse response and $r_l(t)$ is the received signal at the l^{th} branch. Hence, the aggregated SNR per symbol is expressed as

$$\gamma_{mrc} = \sum_{l=1}^{L} \gamma_l \qquad (10)$$

In K_G composite fading, the small scale variations are Nakagami-m distributed and the closed-form tractable equation for the PDF of the sum of such L i.i.d arbitrary variables is not existed. However, it can specifically be estimated by additional Nakagami-m distribution with fading parameter Lm [11, pp.340]. Therefore, the PDF of MRC output $f_{\gamma,mrc}(\gamma)$ for L i.i.d. K_G faded diversity branches is expressed as

$$f_{\gamma,mrc,K_G}(\gamma) = \frac{2}{\Gamma(Lm)\Gamma(m_0)} \left(\frac{c_0}{2}\right)^{m_0+Lm} \gamma^{(\frac{m_0+Lm}{2})-1} K_{m_0-Lm}(c_0\sqrt{\gamma})$$
$$\gamma > 0, m > 0, m_0 > 0, L \geq 1 \qquad (11)$$

where $\Gamma(.)$ is the gamma function, m represents the Nakagami fading parameter, m_0 is the order of Gamma PDF which reflects the shadowing severity. Scaling parameter $c_0 = 2\sqrt{\frac{mm_0}{\overline{\gamma}_0}}$ is related to SNR γ and $K_{m_0-Lm}(.)$ is the modified Bessel function of order $(m_0 - Lm)$.

Thus, on substitution of (11) and (7) in (8), MRC centered probability for average detection over K_G shadow-fading $\overline{P}_{d,mrc,K_G}$ is obtained in (12).

$$\overline{P}_{d,mrc,K_G} = \frac{2\ e^{\frac{c_0^2}{8}}}{c_0\Gamma(Lm)\Gamma(m_0)} \left(\frac{c_0}{2}\right)^{m_0+Lm} \times \sum_{n=0}^{\infty} \frac{\Gamma(n+m_0)\Gamma(n+Lm)}{n!}$$
$$\times W_{\frac{1-2n-m_0-Lm}{2}, \frac{m_0-Lm}{2}}\left(\frac{c_0^2}{4}\right) \sum_{j=0}^{n+u-1} \frac{e^{\frac{-\lambda}{2}}}{j!} \left(\frac{\lambda}{2}\right)^j \qquad (12)$$

where $W_{-\mu,\nu}$ is defied as Whittaker function. Using series representation of incomplete Gamma function obtained from [12, eq. (8.352.4), pp.900], the second sign of summation in (12) can be modified. Now, the expression (12) can be written as

$$\overline{P}_{d,mrc,K_G} = \frac{2\ e^{\frac{c_0^2}{8}}}{c_0\Gamma(Lm)\Gamma(m_0)} \left(\frac{c_0}{2}\right)^{m_0+Lm} \times \sum_{n=0}^{\infty} \frac{\Gamma(n+m_0)\Gamma(n+Lm)}{n!}$$
$$\times W_{\frac{1-2n-m_0-Lm}{2}, \frac{m_0-Lm}{2}}\left(\frac{c_0^2}{4}\right) \times \frac{\Gamma(n+u, \frac{\lambda}{2})}{\Gamma(n+u)} \qquad (13)$$

The expression provide in (13) for average detection probability in K_G composite fading channel is new and tractable general result. The series form of Whittaker function can be implemented easily in software package MATHEMATICA. Further, the error result in truncating the infinite summation series by finite N terms required to compute $\overline{P}_{d,mrc,K_G}$ to a given figure of accuracy can be obtained numerically.

B. Selection Combining

In contrast to MRC which handles all diversity branches, SC only treats the branch with the highest SNR. Hence, the fading amplitude, phase and delay of the selected branch is processed as

$$\gamma_{sc} = \arg \max_{l \in (1,..,L)} \gamma_l \qquad (14)$$

According to [13], the PDF of the output SNR for L diversity branches at SC is given by

$$f_{\gamma,sc}(\gamma) = L[F_\gamma(\gamma)]^{L-1} f_\gamma(\gamma) \qquad (15)$$

In case of K_G composite fading, the CDF of output SNR is achieved by integrating [8, eq (14)] which equals to

$$F_{\gamma,KG}(\gamma) = \frac{\Gamma(m-m_0)(\frac{\gamma c_0^2}{4})^{m_0}}{\gamma(m)\Gamma(m_0+1)} {}_1F_2(m_0; 1-m+m_0, 1+m_0; \tfrac{\gamma c_0^2}{4})$$
$$+ \frac{\Gamma(m_0-m)(\frac{\gamma c_0^2}{4})^{m}}{\gamma(m_0)\Gamma(m+1)} {}_1F_2(m; 1-m_0+m, 1+m; \tfrac{\gamma c_0^2}{4}) \qquad (16)$$

Using (11), the PDF of SNR at SC output $f_{\gamma,sc,KG}(\gamma)$ can be defined as

$$f_{\gamma,sc,KG}(\gamma) = L[F_{\gamma,KG}(\gamma)]^{L-1} \frac{2}{\Gamma(m)\Gamma(m_0)} \left(\frac{c_0}{2}\right)^{m_0+m}$$
$$\gamma^{(\frac{m_0+m}{2})-1}\ K_{m_0-m}(c_0\sqrt{\gamma}) \qquad (17)$$

Thus, on substitution of (17) in (8) and following the similar steps, we solve SC based average detection probability over K_G fading $\overline{P}_{d,sc,KG}$ as

$$\overline{P}_{d,sc,KG} = \frac{2L}{\Gamma(m)\Gamma(m_0)}\left(\frac{c_0}{2}\right)^{m_0+m} \sum_{n=0}^{\infty}\int_0^{\infty}\frac{[F_{\gamma,KG}(\gamma)]^{L-1}}{n!} \times\gamma^{\frac{2n+m_0+m-2}{2}}e^{-\gamma}\ K_{m_0-m}(c_0\sqrt{\gamma})\frac{\Gamma(n+u,\frac{\lambda}{2})}{\Gamma(n+u)} \qquad (18)$$

The above equation does not lead to a closed-form solution and hence the results are found numerically and through simulations.

IV. Results and Discussions

On the basis of tractable expressions (13) and (18), average detection probability with diversity combining over K_G fading, analytical (Ana) and simulation (Sim) results are obtained over varying SNR. The performance analysis is presented for $L = 2, 3$ diversity branches when fading parameter $m = 1$, shadowing severity m_0 =1.64, time bandwidth product $u = 2$ and probability of false alarm is set as P_f= 0.01.

Fig.2 shows the MRC detector performance over the number of diversity branches for K_G composite fading. The dual and triple branch diversity detectors performance in comparison to no diversity scheme could be observed. The highest diversity gain at L=3 is noticed from no diversity fading case. In support, the corresponding simulation results are also provided which overlap the analytical counterparts. The performance of SC diversity combined energy detector is presented along with simulation results in Fig. 3. The performance gain of two and three branch diversity receivers compared to no diversity system is significant at higher SNR regions.

It has already been revealed that the underlying fading and shadowing severely degrade the detection performance. Although, diversity combining techniques at the receiver help to combat against such issues, but an energy detector is unable to attain the required performance limits particularly in low SNR regions. Several investigations has shown that over many practical ranges of m, m_0, u and P_f, ED offers a good performance at γ above 5 dB. Indeed it is rational, if the CU receiver designer is agreed to bear slight reduction in performance at higher values, since at higher values, P_d operates near unity.

The performance comparison of SC with MRC for L =2, 3 diversity branches is depicted in Fig. 4. It is evident that MRC provides best diversity gain related to SC. Furthermore, the MRC gain is improved and outclass SC diversity scheme when number of branches are increased.

V. Conclusion

In this paper, the performance analysis of ED based spectrum sensing with diversity reception techniques is investigated for cognitive vehicular communication experiencing K_G shadow-fading condition. To overcome the deteriorating performance over inherent fading effects the receiver diversity combining techniques are considered and respective modified detector performances are evaluated. In order to avoid mathematical exertions faced in evaluating integrals of Marcum-Q function with the PDF base approach, alternative series representations are applied. Further, MRC and SC diversity combining schemes using multiple antenna at the receiver are considered and tractable expressions for average detection probability at the for K_G composite fading channel are obtained. Later, numerical results are demonstrated with Monte Carlo simulation support. In either case, MRC proves to render better detection capability as compared to SC, which is more apparent at larger value of L diversity branches. Hence, improved energy detection results are arrived for K_G distributed channel for cognitive VANET. These spatial diversity frameworks can be effectively deployed to overwhelm the low SNR region problems in tunnels or as in other conventional fading and shadowing scenarios.

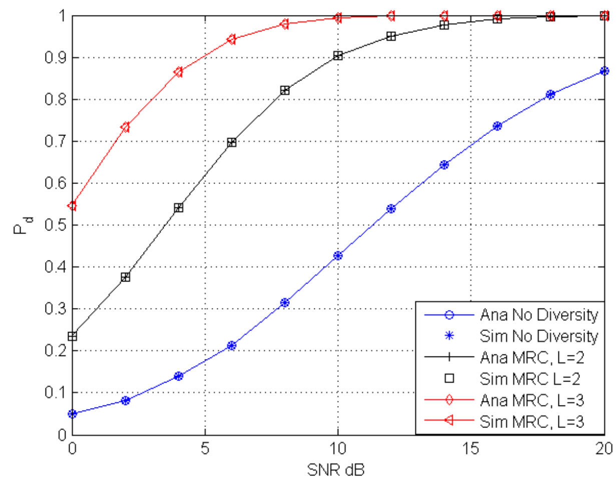

Fig. 2. Average probability of detection for MRC combining for L=2, 3 diversity branches, selecting time bandwidth product u=2, fading parameter m=1, shadowing severity m_0=1.64 while keeping false alarm probability P_f=0.01

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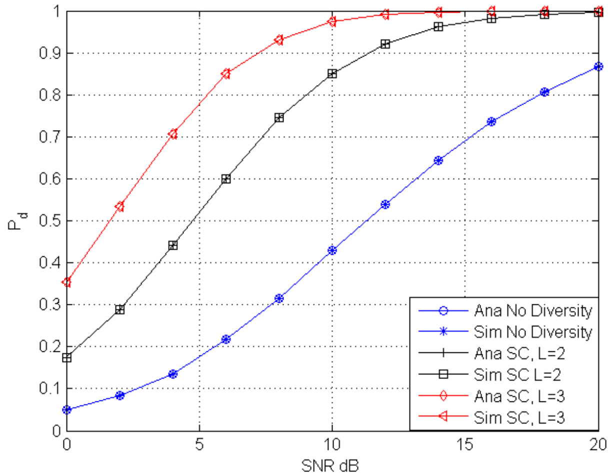

Fig. 3. Average probability of detection for SC combining for L=2, 3 diversity branches, selecting u=2, m=1, m_0=1.64 and P_f=0.01.

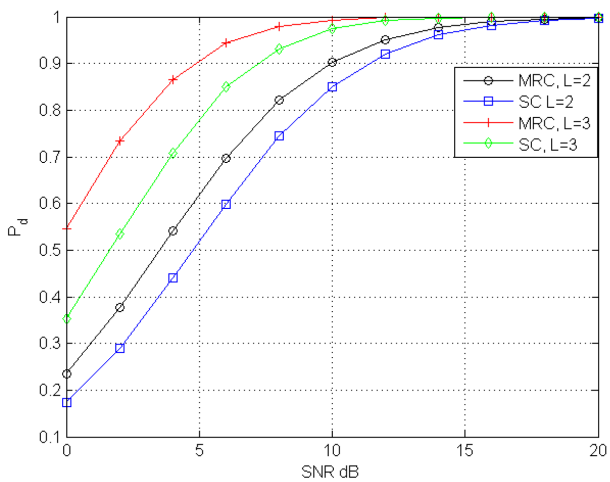

Fig. 4. Detection Probability comparison of MRC and SC combining for L diversity branches, taking u=2, m=1, m_0=1.64 and P_f=0.01.

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