Performance of the Cognitive Coexistence System Networks Using the Interference Cancellation Method in Nakagami Channel

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***Abstract*—The aggregate interference distribution in cognitive radio networks is studied in a precise and analytical way using the popular Poisson Point Process model. In this paper, we use interference distribution in Nakagami channel ad hoc network to obtain performance metrics such as outage probability and transmission capacity in cognitive radio networks. The analysis is further extended to include interference cancellation and more specifically the nearest interferer cancellation . The outage probability and transmission capacity is shown to improve by the interference cancellation method. The results from simulation which verify the proposed interference cancellation performance in Nakagami channel are shown as well.**

***Keywords*—Interference Cancellation(IC), Nakagami Fading, Nearest Interferers, Cognitive Radio(CR).**

I. Introduction

Owing to the inefficiency in the spectrum usage of current wireless systems, there exist a significant bulk of research activities in cognitive radio. That it is permissible for a cognitive user to share the spectrum with primary users provided that the interference is beneath a threshold is one of the ideas in cognitive radio is in case of the underlay spectrum sharing method [1]. In wireless networks, a cognitive user can take advantage of either the time, frequency, and space. Hence, while spatial resue is cognizant of cognitive radio solutions, it is one of the most significant options in utilizing this type of cognitive network [2]. Depending on whether the neighboring primary users are not in use (vacant), cognitive users may transmit but at primary users harmful interference can be caused by the signals of several secondary users. As a result, in order for the interference temperature metric to be satisfied, there is a need to characterize the aggregate interference [2].

This paper deals with general cognitive network scenarios and focuses on Nakagami channel where the spatial distribution of users follows the Poisson law. We assume that the locations of PUs and CRs follow two independent Poisson point processes. The advantages and validity of using spatial Poisson process for modeling the locations of the wireless devices have been mentioned in many articles. In [3], it is assumed that the user locations vary depending on time, and determine the average performance over a large population of users for a class of random networks. Stochastic geometry, a field which focuses on studying random spatial patterns, offers a striking way of analyzing large networks. A spatial point process model makes for constructing the spatial points, which represent the locations of users. In case there is no previous knowledge, the user locations are often assumed independent and completely random. The spatial Poisson process is thus a natural and a popular choice in such situations because, on the assumption that a user is inside a region, the PDF of its location is conditionally uniform over the same region [4].

II. Related Work

Point process theory has been successfully applied to wireless network analysis in the last two decades. Recently, with the flourishing condition of research on cognitive radio, point process models have found applications to cognitive networks. In [5], A stochastic geometry-based mathematical model for coexistence in networks composed of both narrowband and ultra-wideband wireless nodes has been considered. In [6], the capacity trade-off between the coexisting cellular uplink and mobile ad hoc networks under spectrum underlay and spectrum overlay was analyzed on the basis of the transmission capacity of a network with Poisson interferers. [7] studied power control in cognitive networks and simultaneously characterized the impacts of the transmission power of secondary users on the occurrence of spectrum opportunities and the reliability of opportunity detection qualitatively. [8] made use of spatial statistics to improve the performance of cognitive radio networks. Although there already exists bulk of research on cognitive networks, only very few papers have focused on the aggregate interference caused by multiple secondary users, together with the interference that the primary users cause among themselves in the Poisson point process setup which is what has been taken into close consideration in the current study. Some scholars, $e.g.$ [9] and [10] modeled the aggregate interference from the cognitive users outside the primary exclusion regions in fading channel, but both papers only took a single primary receiver instead of multiple primary transmitters and receivers into account. In [11], it was derived that the maximum primary and secondary transmitter densities give outage constraints for the overlaid network with multiple primary and cognitive users, but they considered a non-fading channel and no exclusion regions.

The rest of the paper is organized as follows: section III presents the system model; section IV formula and analyses the method; section V presents the simulation results; and section VI summarizes the conclusions.

III. System Model

We consider a cognitive radio network which contains a primary users receiver located at the origin and many secondary users transmitters (nodes) on a plane as figure 1. The secondary user randomly located in the plane according to a Poisson point process (PPP) of the density $\lambda[\text{nodes/m}^2]$. Interference from the SU nodes outside the circle of a certain radius R_{max} due to pathloss is assumed to be negligible.

We assume desire signal, interference and noise to be indpendent. The received power in PU in origin can be represnted as

$$P_{Pu} = P_d + \sum_{i=0}^{N} I_i + \omega_0 \tag{1}$$

Where P_d is desire signal, I_i is interference coming from i-th SU. N is a Poisson random variable which denotes the number of nodes in the ring between circles of the radii R_{min} and R_{max}. The power recieved in reciever antenna, P_r comes from power in transmit antenna, P_t relation between the two can be represented as [12]

$$P_r = P_t R^{-\alpha} \delta G_t G_r \tag{2}$$

where R is the distance between transmitter and receiver, parameter α is the path loss exponent, δ is power channel fading coefficient, G_t is transmitter antenna gain and G_r is receiver antenna gain. For simplicity, we assume the transmitter and receiver antenna to be isotropic with unity gain and all SU's transmit at the same constant power level P_s, so that the power at the receiver antenna input comes from a SU $P_r = P_s R^{-\alpha}\delta$. In non-fading situation, recieved power is $P_r = P_s R^{-\alpha}$, only distance affects on the recieved power. In this paper we assume that the recieved power will be affected by Nakagami-m fading and distance. So the recieved power follows as

$$P_r = P_s R^{-\alpha} \delta \tag{3}$$

Where δ has Nakagami distributaion with m and Ω parameters and probability density function (pdf) is [13]

$$f(x; m, \Omega) = \frac{2m^m}{\Gamma(m)\Omega^m} x^{2m-1} \exp\left(-\frac{\Omega}{m}x^2\right) \tag{4}$$

Using Nakagami distribution other fading *e.g,* Rayliegh and Rician fading can be represented.

IV. Formula and Analyses

Throughout the paper we have employed *transmission capacity* (TC) and *outage probability* (OP) as the primary performance metrics. The TC was introduced in [14] and is defined as the maximum number of successful communication links that can be accommodated per unit area, subject to a specified constraint on the OP relative to a target signal to interference plus noise ratio, (SINR)[1]. TC therefore quantifies

[1]In the present paper, instead of using SNIR in receivers INR has been utilized to analyze the outage probability.

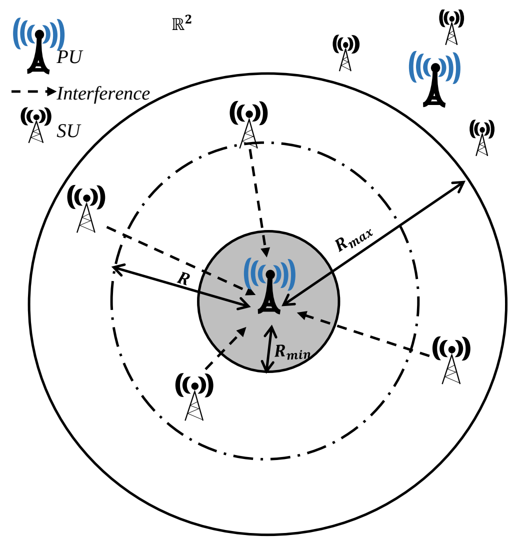

Fig. 1: The Geometry of the Cognitive Radio Networks with Primary Users and Secondery Users. R_{max} is Maximum Range for Sensing and R_{min} is Minimum Range to avoid interference to PU.

the area spectral efficiency in an cognitive adhoc network from an outage perspective.

In this regard, when the SINR is less than a certain threshold η, there is a significant performance degradation in a wireless link and it is considered to be in outage. The aggeragate interference power $I_{ag} = \sum_i I_i$ exceeds the threshold I_{th}, so the outage probability is

$$P_{out} = \Pr\big\{\text{SNIR} < \eta\big\} = \Pr\big\{I_{ag} \geq I_{th}\big\} \tag{5}$$

Defining the interference-to-noise ratio (INR) as

$$\gamma = I_{ag}/\omega_0 \tag{6}$$

its threshold value is $\zeta = I_{th}/\omega_0$, so the outage probability can be expressed as

$$P_{out} = \Pr\big\{\gamma > \zeta\big\} = 1 - F(\zeta) \tag{7}$$

where $F(\zeta)$ is the cumulative distribution function (CDF) of the INR. Under the adopted channel model, P_{out} also serves as a complementary CDF (CCDF) of the aggregate interference I_{ag}. The outage probability is an important performance metric for wireless system design. It can be related by other performance metrics such as frame error rate.

A. Interference Cancellation Method

In this section, we use interference cancellation method in [15], and apply Nakagami channel model in this method. When $\zeta \to \infty$, the outage probability from aggregate interference $P_{out} = \Pr\{\sum_i I_{ig} > \zeta\omega_0\}$ is dominated by the nearest node interference [15]:

$$\begin{aligned} P_{out} &= \Pr\big\{I_{ag} > \zeta\omega_0\big\} \\ &= \Pr\big\{I_{1g} > \zeta\omega_0\big\}\big(1 + o(1)\big) \\ &= N_0\zeta^{-2/\alpha}M_1(d).\big(1 + o(1)\big) \end{aligned} \tag{8}$$

where $M_k(d) = \int_d^\infty \big(g^{2/\alpha} - d^{2/\alpha}\big)^k f_g(g)dg$ is a biased moment of g of order $2k/\alpha$ and $o(.)$ is the small o function [16]. $M_1(d)$ includes the impact of both the forbidden region and fading. $F_g(x)$ is the CDF of the fading factor. Using equation (4) in equation (8) the following equation (9)

$$\begin{aligned} P_{out}^k &= \sum_{i=0}^{k} C_k^i(-1)^i d^{2i/\alpha}\int_d^\infty g^{2(k-i)/\alpha} \\ &\qquad \times \frac{2m^m}{\Gamma(m)\Omega^m}g^{2m-1}\exp\left(-\frac{m}{\Omega}g^2\right)dg \\ &= \sum_{i=0}^{k} C_k^i(-1)^i d^{2i/\alpha}\frac{2m^m}{\Gamma(m)\Omega^m} \\ &\qquad \times \int_d^\infty g^{2(k-i)/\alpha+2m-1}\exp\left(-\frac{m}{\Omega}g^2\right)dg \\ &= \sum_{i=0}^{k} C_k^i(-1)^i d^{2i/\alpha}\frac{1}{\Gamma(m)} \\ &\qquad \times \frac{\Gamma\left((k-i)/\alpha + m, \frac{m}{\Omega}d^2\right)}{2\left(\frac{m}{\Omega}\right)^{(k-i)/\alpha}} \end{aligned} \tag{9}$$

where $C_k^i = k!/(i!(k-i)!)$ is the binomial coefficient; and $\Gamma(a,x) = \int_x^\infty t^{a-1}e^{-t}dt$ is incomplete Gamma function. In particular, when $k = 1$, *i.e.*, no interference cancellation occurs.

$$P_{out}^1 = 1/\Gamma(m)\Big\{ (\frac{m}{\Omega})^{-\alpha}\Gamma(1/\alpha + m, md^2/\Omega) - d^{2/\alpha}\Gamma(m, md^2/\Omega)\Big\} \tag{10}$$

B. Transmission Capacity

Two or more wireless networks are said to coexist if they can operate in the same location without causing significant interference to one another. Coexistence is then related to mutual interference among systems. Transmission capacity with the interfernce cancellation for coexistence is obtained using the previous section. TC is defined as the maximum number of successful communication links that can be accommodated per unit area. In the presented model, TC which is defined for PU and CR cause interfernce to PU transmission. At first, we defined the probability of successful tansmission as [17]

$$P_{success}^k = 1 - P_{out}^k \tag{11}$$

The probability of successful transmission with interference cancellation show the probability of successful transmission in a link with removing interference of k nearset user, so in the presented model, we can obtain TC with interference cancellation method and can be written as

$$\tau^k = \lambda P_{success}^k \tag{12}$$

where λ is the spatial density of primary user nodes. We expect if the number of cancel user increases $i.e$, $k \rightarrow \infty$, the throughput of network improves.

V. Simulation

In this section, the extensive simulation and theoretical results with a wide range of system parameters are given. We use Matlab to run the Monte Carlo simulations. In all simulations, we generate random geometry of the CR network based on Poisson point process for each run, and the parameters are given in the figure captions. We fixed $R_{max} = 1000m$, and the noise power after normalization is $-90dB$ in figure 2 and $-80dB$ in figure 3. The radius of the forbidden region R_{min}

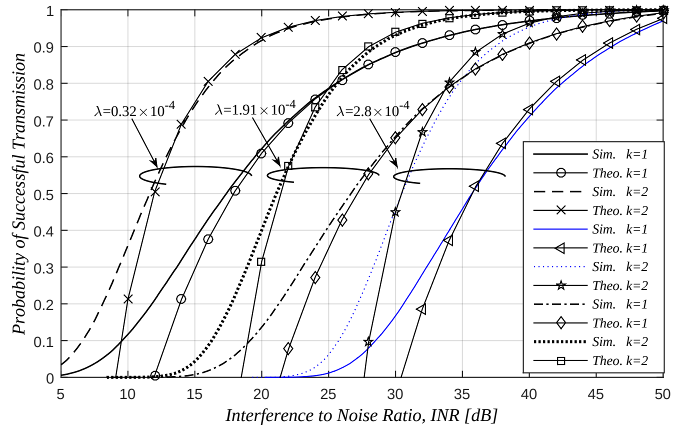

Fig. 2: Probability of successful transmission capacity according to interference to noise ratio with different spatial density. Parameters are set : $m = 1, \Omega = 1, R_{min} = 10, R_{max} = 10^3, \alpha = 4$.

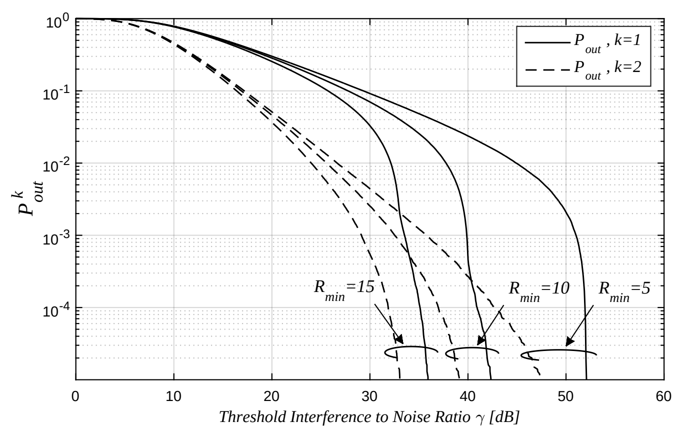

Fig. 3: Outage probability, P_{out}^k, of k nearest users cancelled according to thershold interfernce to noise ratio with different forbidden region, R_{min}. Parameters are set: $m = 1, \Omega = 0.5, R_{max} = 10^3, \alpha = 4, \lambda = 1 \times 10^{-4}$ and noise power is $N_0 = -80dB$.

and the density of active SU nodes λ are variable for different cases. The results are based on 10^6 runs.

In figure 2, $P_{success}$ curve is generated by the Monte Carlo simulation results of the outage probability causing by aggregate interference for two cases: without secondary user interference cancellation and nearest interference cancellation or in other words $k = \{1, 2\}$. The theoretical results are given based on equation (9) for cases as mentioned.

In figure 2, the probability of successful transmission capacity versus interference to noise ratio with different spatial density of secondary user has been shown. If interference from the nearest SU is cancelled, the spectral efficiency improves and the performance gain can be obtained. If the spatial density of SU increases the interference in PU, the spatial density of SU has to be controlled in space, time and frequency region.

Figure 3 depicts the outage probability of PU according to interference to noise ratio with different fobidden region. It can be expected that by increasing R_{min}, interfrence decreases, so the probability of outage improves, but by increasing the forbidden region, spectral efficiency of secondary user decreases. Therefore, in design cognitive coexistence network the trade off between different metrics must be considered.

VI. Conclusion

This paper aims at improving the spectral efficiency in primary users by interference cancellation of the nearest secondary user in nakagami channel. As shown in this paper, by using interference cacellation, the spectrum trasmission capacity of coexistence system can be improved. Finally, by removing the nearest interference can be obtain the performance gain in coexistence system can be obtained.

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References

[1] A. Goldsmith, S. A. Jafar, I. Maric, and S. Srinivasa, "Breaking spectrum gridlock with cognitive radios: an information theoretic perspective,"*Proc. IEEE,* vol. 97, no. 5, pp. 894914, May 2009.
L. Berlemann, S. Mangold, *Cognitive Radio and Dynamic Spectrum Access*, Wiley, 2009.

[2] S. Haykin, "Cognitive Radio: Brain-empowered Wireless Communications," *IEEE J. Sel. Area Comm.*, pp. 201-220, 2005.

[3] E. S. Sousa, "Performance of a spread spectrum packet radio network link in a Poisson field of interferers,"*IEEE Trans. Inf. Theory,* vol. 38, no. 6, pp. 17431754, Nov. 1992.

[4] M. Haenggi, J. G. Andrews, F. Baccelli, O. Dousse, and M. Franceschetti, "Stochastic geometry and random graphs for the analysis and design of wireless networks," *IEEE J. Sel. Areas Commun.*, vol. 27, no. 7, pp. 10291046, Sep. 2009.

[5] P. C. Pinto, A. Giorgetti, M. Z. Win, and M. Chiani, "A stochastic geometry approach to coexistence in heterogeneous wireless networks," *IEEE J. Sel. Areas Commun.,* vol. 27, no. 7, pp. 12681282, Sep. 2009.

[6] K. Huang, V. K. N. Lau, and Y. Chen, "Spectrum sharing between cellular and mobile ad hoc networks: transmission-capacity trade-off," *IEEE J. Sel. Areas Commun.,* vol. 27, no. 7, pp. 12561267, Sep. 2009.

[7] W. Ren, Q. Zhao, and A. Swami, "Power control in cognitive radio networks: how to cross a multi-lane highway,"*IEEE J. Sel. Areas Commun.,* vol. 27, no. 7, pp. 12831296, Sep. 2009.

[8] J. Riihijarvi and P. Mahonen, "Exploiting spatial statistics of primary and secondary users towards improved cognitive radio networks,"in *Proc. 2008 CrownCom,* pp. 17.

[9] X. Hong, C. X. Wang, and J. Thompson, "Interference modeling of cognitive radio networks,"in *Proc. 2008 IEEE Vehicular Technology Conference Spring*, pp. 1114.

[10] A. Ghasemi and E. S. Sousa, "Interference aggregation in spectrumsensing cognitive wireless networks,"*IEEE J. Sel. Topics Signal Process.,* vol. 2, no. 1, pp. 4156, Feb. 2008.

[11] C. Yin, L. Gao, T. Liu, and S. Cui, "Transmission capacities for overlaid wireless ad hoc networks with outage constraints,"in *Proc. 2009 IEEE International Conference on Communications,* pp. 15.

[12] G. L. Stuber, *Principles of Mobile Communication,* 2nd ed. Boston: Kluwer, 2001.

[13] E. Pajala, T. Isotalo, A. Lakhzouri and E. S. Lohan "An improved simulation model for Nakagami-m fading channels for satellite positioning applications", *Proc. 2006 WPNC.*,

[14] J. Blomer and N. Jindal, "Transmission capacity of wireless ad hoc networks: Successive interference cancellation vs. joint detection,"in *IEEE International Conference on Communications*, pp. 1-5, june, 2009.

[15] Y. Wen, S. Loyka, and A. Yongacoglu, "Asymptotic analysis of interference in cognitive radio networks," *IEEE Journal on Selected Areas in Communications,* vol. 30, no. 10, Nov. 2012.

[16] F. W. J. Olver, *Asymptotics and special functions.* New York: Academic Press, 1997.

[17] S. Weber, J. G. Andrews, X. Yang, and G. De Veciana, "Transmission Capacity of Wireless Ad hoc Networks with Successive Interference Cancellation," *IEEE Trans. Inf. Theory*, vol. 53, no. 8, pp. 2799-2814, Aug. 2007.

[18] D. Stoyan, W. Kendall, J. Mecke, and L. Ruschendorf, *Stochastic Geometry and its Applications*, Wiley Chichester, 1987.

[19] J. G. Andrews, R. K. Ganti, M. Haenggi, N. Jindal, and S. Weber, "A Primer on Spatial Modeling and Analysis in Wireless Networks," *IEEE Commun. Mag.*, vol. 48, no. 11, pp. 156-163, Nov. 2010.

[20] K. Huang, J. Andrews, D. Guo, R. Heath, and R. Berry, "Spatial Interference Cancellation for Multiantenna Mobile Ad Hoc Networks,"*IEEE Transactions on Information Theory,* vol. 58, no. 3, pp. 1660-1676, march 2012.

[21] T. Cover, "Broadcast Channels," *IEEE Transactions on Information Theory,* vol. 18, no. 1, pp. 2-14, jan 1972.

[22] F. Baccelli, A. El Gamal, and D. Tse, "Interference Networks with Point-to-Point Codes," *IEEE Transactions on Information Theory,* vol. 57, no. 5, pp. 2582-2596, May 2011.

[23] T. M. Cover, J. A. Thomas, *Elements of Information Theory*, New York: John Wiley and Sons, Inc., 1991.

[24] A. Zanella and M. Zorzi, "Theoretical Analysis of the Capture Probability in Wireless Systems with Multiple Packet Reception Capabilities," *IEEE Transactions on Communications*, vol. 60, no. 4, pp. 1058 -1071, April 2012.

[25] J. Andrews and T. Meng, "Optimum power control for successive interference cancellation with imperfect channel estimation," *IEEE Transactions on Wireless Communications*, vol. 2, no. 2, pp. 375-383, mar., 2003.

[26] M. Haenggi, J. G. Andrews, F. Baccelli, O. Dousse, and M. Franceschetti, "Stochastic geometry and random graphs for the analysis and design of wireless networks," *IEEE Journal on Selected Areas in Communications*, vol. 27, no. 7, pp.1029-1046, Sep. 2009.

[27] A. Viterbi, "Very low rate convolutional codes for maximum theoretical performance of spread-spectrum multiple-access channels," *IEEE Journal on Selected Areas in Communications*, vol. 8, no. 4, pp. 641-649, 1990.

[28] N. Abramson, "The Aloha system-Another alternative for computer communication," *Proc. AFIPS*, pp. 295-298, 1970.

[29] S. Ghez, S. Verd, and S. Schartz, "Stability properties of slotted Aloha with multipacket reception capability," *IEEE Trans. Autom. Control*, vol. 33, no. 7, pp. 640-649, Jul. 1988.

[30] F. Baccelli, B. Blaszczyszyn, and P. Muhlethaler, “An Aloha protocol for multihop mobile wireless networks,” *IEEE Trans. Inf. Theory,* vol. 52, no. 2, pp. 421-436, Feb. 2006.

[31] J. Lee, J. G. Andrews, and D. Hong, “Spectrum-Sharing Transmission Capacity,” *IEEE Trans. Wireless Commun.*, vol. 10, no. 9, pp. 3053-3063, Sep. 2011.

[32] J. Lee, J. G. Andrews, and D. Hong, “Spectrum-Sharing Transmission Capacity with Interference Cancellation,” *IEEE Trans. Wireless Commun.*, vol. 10, no. 9, pp. 3053-3063, Sep. 2013.