Cognitive Radio Spectrum Sharing with Linear Interference Cancellation Method

Akbar Heydari
Department of Electrical Engineering
Shahid Beheshti University, Tehran
Email:Heydariakbar00@gmail.com

Kazem Heydari
Department of Electrical Engineering
Tarbiat Modares University, Tehran
Email:K.Haydari@gmail.com

***Abstract*—This paper attempts to improve the efficiency of spectrum sharing systems. In this regard, we consider a model of spectrum sharing system. In the proposed model, interference from other coexisting systems may reduce the efficiency of spectrum sharing system. To improve the efficiency and the performance of spectrum sharing system, we describe the use of cancellation in which each system can cancel interference from other coexisting systems. Performance of interference cancellation method is measured by coefficients of cancellation. Using these coefficients, we evaluate the network behavior and observe that the performance spectrum sharing system can be improved using an interference cancellation method. We evaluate system performance in terms of different parameters such as power transmit coexistence systems, outage probability constraint, spatial density and the pathloss component. Finally, we observe that with interference cancellation, underlay method has a better performance then overlay method in spectrum sharing systems.**

Keywords—Spectrum Sharing, Interference Cancellation (IC), Coefficient of Cancellation, Cognitive Radio(CR).

I. INTRODUCTION

In the past decade, understanding large wireless network capacity has increased considerably, but perhaps still comprises more questions than answers, especially for realistic models. Spectrum sharing protocols can allow various wireless systems to access and share overlapping spectrum on an opportunistic basis [1]. The potential gains in terms of total spectral efficiency are large, since wasted spectrum can be put to use. However, the risks are equally important to consider, since inappropriate opportunistic access strategies can undermine the reliability of all the constituent systems [2].

A key aspect of opportunistic access is the density and location of users for a given system, which drives the demand for the spectral resources as well as driving the amount of interference that the system causes to other users [3]. The exact interference level will depend on the precise relative positions of the various transmitters and receivers, which in general are random, but the interference caused by each transmitter will fall off with distance and so denser systems will cause more interference [4].

II. RELATED WORK AND MOTIVATION

As contemporary wireless systems are becoming increasingly interference-limited, there is an ascending interest in using advanced interference mitigation techniques to improve the network performance in addition to the conventional approach of treating interference as background noise [5]-[6]. One important approach is successive interference cancellation (SIC) that was first introduced in [7], the idea of SIC is to decode different users sequentially, i.e., the interference due to the decoded users is subtracted before decoding other users. Although SIC is not always the optimal multiple access scheme in wireless networks [8]-[9], it is especially amenable to implementation and does attain boundaries of the capacity regions in multiuser systems in many cases [10].

Conventional performance analyses of SIC do not take into account the spatial distribution of the users. The transmitters are either assumed to reside at given locations with deterministic path loss, see, e.g., [11] and the references therein, or assumed subject to centralized power control which to a large extent compensates for the channel randomness [12]. To establish advanced models that take into account the spatial distribution of the users, recent papers attempt to analyze the performance of SIC using tools from stochastic geometry [13]. In this context, a guard-zone based approximation is often used to model the effect of interference cancellation due to the well-acknowledged difficulty in tackling the problem directly [5]. According to this approximation, the interferers inside a guard-zone centered at the receiver are assumed cancelled, and the size of the guard-zone is used to model the SIC capability. Despite many interesting results obtained by this approximation, it does not provide enough insights on the effect of received power ordering from different transmitters, which is essential for successive decoding [14]. For example, if there are two or more (active) transmitters at the same distance to the receiver, it is very likely that none of them can be decoded given the fact that the decoding requires a reasonable SINR, e.g., no less than one, while the guard-zone model would assume they all can be decoded if they are in the guard zone. Therefore, the guard-zone approach provides a good approximation only for cancelling one or at most two interferers. Furthermore, most of the work in this line of research considers Rayleigh fading and/or uniformly distributed networks. In this paper, by tools of cognitive radio that have linear interference cancellation, interference caused by own network and other network is cancelled in receiver.

III. SYSTEM MODEL AND METRICS

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. In order to model Interference and coexistence, figure 1 is cosidered for system model. This figure involves all wanted and unwanted interactions between systems.

The system model follows the Aloha model. Aloha describes the independent transmission in time slots. Aloha is a widely deployed and studied access protocol. The initial paper presenting Aloha was published in [15] and Aloha is now used in most cellular networks to request access. A lot of both theoretical and practical studies have been carried out to improve Aloha. A model introduced in [16] for slotted Aloha with multipacket reception capability in a widely referenced, which introduced a well-accepted model for Aloha in a network with spatial reuse.

Let the receiver (cognitive radio) be located at the origin of coordinates, o, that is not affected in principle [5]. The active transmitters (cognitive radio and primary users) located in the zone can be represented by PPP[1] that $\prod_k = \left\{\left(X_k^{(i)}, \hbar_k^{(i)}\right\}\right) \subset \mathbb{R}^d$ $(\forall k \in \Phi)$, where, $X_k^{(i)}$ is the location of transmitter i in system k to o, $\hbar_k^{(i)}$ is the iid (power) fading coefficient associated with the link from transmitter i in system k to o, and $d(=2)$ is the number of dimensions of the space. Note that Φ can be represented as a pair of independent poisson point processes representing transmitters of coexistence spectrum sharing systems.

Since the interference at the receiver of system k is generated by transmitting nodes in both other systems and its own system, the signal to interference-plus-noise ratio (SINR) becomes

$$\mathrm{SINR}_k = \frac{p_k \hbar_k^{(D)} R_k^{-\alpha}}{\sum_{j\in\phi}\sum_{X_j^{(i)}\in\prod_j^o} p_j \hbar_j^{(i)} |X_j^{(i)}|^{-\alpha} + \omega_o}; \quad (\forall k \in \Phi) \tag{1}$$

where, p_k transmits power from system k, R_k is distance of desire link, $|X_j^{(i)}|$ is distance transmitter i in system j from o, α is pathloss component and ω_o is AWGN noise. By normalizing interference with equation (2) and neglecting AWGN noise, equation (1) can be rewritten as (3)

$$I_{kj} = \frac{p_j}{p_k} \sum_{X_j^{(i)}\in\prod_j^o} \hbar_j^{(i)} |X_j^{(i)}|^{-\alpha} \tag{2}$$

$$\mathrm{SIR}_k = \frac{\hbar_k^{(D)} R_k^{-\alpha}}{I_k}; \quad (\forall k \in \phi) \tag{3}$$

For reliable comminucation, the interference should be minimized to satisfy the smallest allowable value of SIR at the receiver to guarantee its QoS, i.e $\mathrm{SIR}_k \geq \upsilon_k$. Thereby the probability of successful transmission can be defined [17]

$$\begin{aligned} &\mathbb{P}(SIR_k \geq \upsilon_k) = \mathbb{P}\{\hbar_k^{(D)} \geq \upsilon_k R_k^{\alpha} I_k\} \\ &= \int_0^{\infty} \mathbb{P}\{\hbar_k^{(D)} \geq \upsilon_k R_k^{\alpha} I\} f_{I_x}(I) dI = \psi_{I_k}(R_k^{\alpha}\upsilon_k) \end{aligned} \tag{4}$$

where $\psi_{I_k}(R_k^{\alpha}\upsilon_k)$ is a Laplace transform of the PDF of aggregate interference, I_k and in presented model [17]-[18],

$$I_k = \sum_{j\epsilon\Phi} I_{kj} \tag{5}$$

because I_{kj} is independent and by taking [18] into consideration, the probability of successful transmission is obtained as

$$\mathbb{P}(SIR_k \geq \upsilon_k) = \exp\left(-\zeta_k \sum_{j\in\Phi} \gamma_{kj}\lambda_j\right) \tag{6}$$

The outage probability for each coexistence system can be obtained using the probability of successful transmission as

$$P_j^o(\Lambda) = 1 - \exp\left(-\zeta_k \sum_{j\in\Phi} \gamma_{kj}\lambda_j\right) \leq \epsilon \tag{7}$$

---

[1] Poisson Point Process

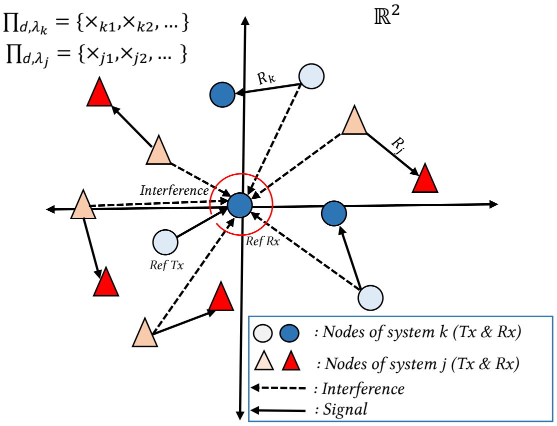

Fig. 1: Spectrum Sharing System Model between Coexietence Systems, Desire Receiver Locate in $(0, 0)$

Where

$$\zeta_k = (2\pi/\alpha)\Gamma(2/\alpha)\Gamma(1 - 2/\alpha)R_k^2 \upsilon_k^2$$

$\gamma_{kj} = (p_j/p_k)^{2/\alpha}$, λ_j spatial density of j coexistence system and ϵ is vector of outage constraint for each coexistence systems. For example, outage constraint just for coexistence system k, can be written

$$P_k^o(\lambda_k) = 1 - \exp\{-\zeta_k \lambda_k\} \leq \epsilon_k \tag{8}$$

We use interference cancellation method in [19] in the presented model and finally, show that the interference cancellation method improves spectral effiency. The author in [19] obtained coefficient of cancellation interference. This coefficient shows performance of the interference cancellation method and can be represented as

$$\rho_{kj}^{IC} = \frac{\text{Ln}(\psi_{I_{kj}}^{IC}(R_k^\alpha \upsilon_k))}{\text{Ln}(\psi_{I_{kj}}(R_k^\alpha \upsilon_k))}, \quad 0 \leq \rho_{kj}^{IC} \leq 1 \tag{9}$$

This coefficient, ρ_{kj}^{IC}, is between zero and one. If this coefficient is close to zero, the interfrence cancellation method has the best performance and if it is close to one, the interference cancellation method has less performance. This interference cancellation method adopted for two cases: 1) coefficient of strong interferer cancellation and 2) coefficient of close interferer cancellation. In strong interference cancellation, whose received powers are greater than a threshold χ is cancelled. In case two, the receiver cancels the close interferer which dominates the total interference [19].

In our model, the spatial density of two coexistence system's λ_1 and λ_2 with regard to outage constraints in both coexistence system with the interference cancellation method is selected and can be represented as [19]

$$\begin{aligned} &\mathcal{C}_1^{IC} : (\rho_{11}\lambda_1 + \gamma_{12}\rho_{12}\lambda_2)u(\lambda_1) \leq \bar{\lambda}_1 \\ &\mathcal{C}_2^{IC} : (\rho_{21}\gamma_{12}^{-1}\lambda_1 + \rho_{22}\lambda_2)u(\lambda_2) \leq \bar{\lambda}_2 \\ &\lambda_1 \geq 0 \text{ , } \lambda_2 \geq 0 \end{aligned} \tag{10}$$

By redefining the spectrum-sharing transmission capacity (S-TC) of system k with the interference cancellation [19]

$$\tau_k = \lambda_k \exp\left(-\zeta_k \sum_{j\epsilon\phi} \gamma_{kj}\lambda_j\rho_{kj}\right) \text{ ;} \tag{11}$$

Therefore, sum transmission capacity of coexistence system with interference cancellation can be written as

$$f_\tau(\Lambda) = \tau_1^{IC} + \tau_2^{IC} \tag{12}$$

In equation (12), spatial density of coexistence system's is chosen by equation (10). Therefore, outage constraint puts constraint in sum transmission capacity.

IV. SIMULATION AND NUMERICAL RESULTS

In this section simulation and numerical results are explained. This simulation is obtained by regarding rayleigh fading and PPP distribution of transmitter coexistence systems. This simulation runs for 100 time slotted and $N = 10000$ channel realization for each link and spatial density of system one is $\lambda = 8 \times 10^{-4}$. The other parameter in simulation and numerical are set as $\alpha = 4$, $R_1 = 5$, $R_2 = 7$, $\upsilon_1 = \upsilon_2 = 0.9$, $p_2/p_1 = 2$, $\sigma_1^2 = 5\text{dB}$, $\sigma_2^2 = 3\text{dB}$. In states, it will be informed when these parameter are changed.

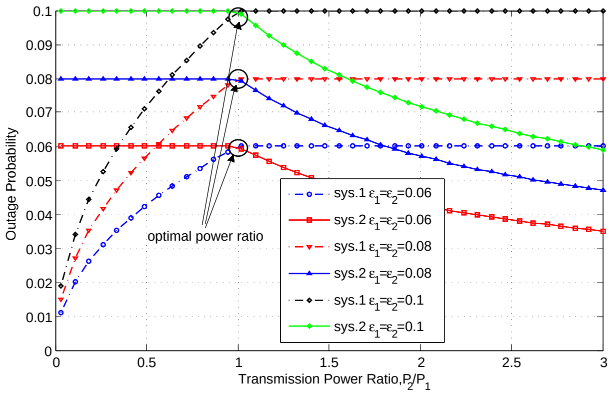

Fig. 2: Outage Probability without interference cacellation method of two coexistence system that outage constraints is set $\epsilon_1 = \epsilon_2 = [0.06\ 0.08\ 0.1]$ and optimal power ratio is shown.

In figure 2, outage probability without interference cacellation method of two coexistence system for outage constraints and optimal power ratio is shown. As shown in figure 2 in point optimal power ratio, two coexistence systems have fairness sharing from spectrum and overall efficiency is improved. If transmission power ratio is lower or higher than this point, the overall spectrum efficiency is reduced. The other important point in figure 2 is that by increasing outage constraint, the outage probability increases as well and as a result the overall spectrum efficiency is reduced.

Figure 3 depicts simulation and numerical result of the coefficient of cancellation of strong inreference cancellation according to the cancellation threshold χ with different amounts of residual interference z. As shown in this figure, when cancellation thershold increases, due to increasing interference, the coefficient of strong interferer cancellation increases as well. The simulation verifies the validity of presentations. In case the thershold is excessive, the coefficient of cancellation increases slowly until it reaches one. For example in $z = 1$ increase or decrease of the thershold has no effect on coefficient of strong cancellation because none of the interferers has been removed. By decreasing z, the performance of spectrum sharing between coexistence system is improved. As shown in figure (3) in small thershold and small z, coefficient of cancellation is close to zero that is a perfect state in interference cancellation.

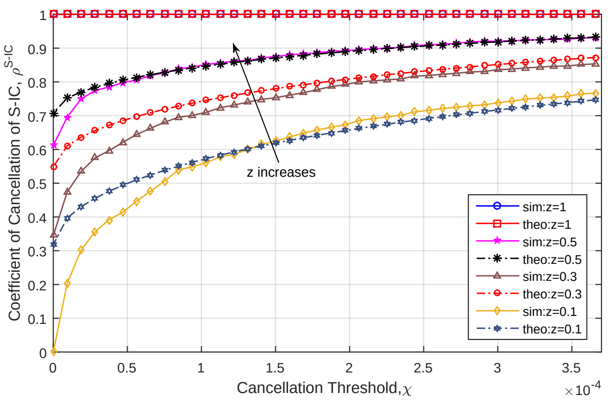

Fig. 3: The coefficient of cancellation of strong inreference cancellation according to the cancellation threshold χ with different amounts of residual interference z.

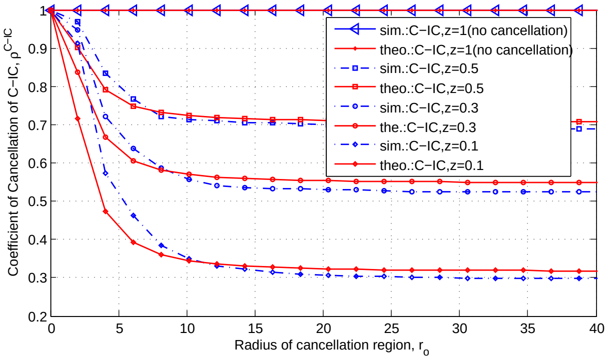

Fig. 4: The coefficient of cancellation close interference cacellation according to the radius of cancellation region r_o with different amounts of residual interference z.

Figure 4 represented the coefficient of cancellation close interference cancellation according to the radius of cancellation region r_o with different amounts of residual interference z. As shown in this figure, if radius increases, due to eliminating many of the interferers, coefficient of close interference cancellation is decreased and the performance of spectrum sharing is improved. On the other hand, by increasing resudial interference, due to elimination of less interference, coefficient of close increases and performance decreases. For example, $z = 1$ has low performance and $z = 0.1$ has high performance in spectrum sharing. Signification interference caused by user that located in close to receiver so as shown in figure 4, the curves have steep and then have low slope, because in frist signification interference has been removed and then interference in long distances experiences more loss.

Figure 5 shows the coefficient of cancellation strong interference cacellation according to the pathloss component α with different amounts of residual interference z. At frist, the curves have descending behavior and then have increasing behavior. In the descending zone, due to increasing pathloss component,

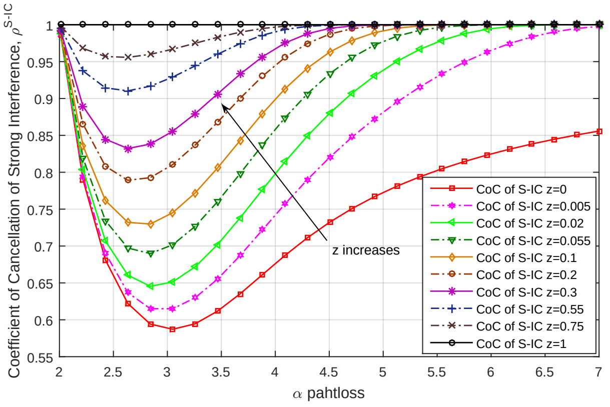

Fig. 5: The coefficient of cancellation strong interference cacellation according to the pathloss component α with different amounts of residual interference z.

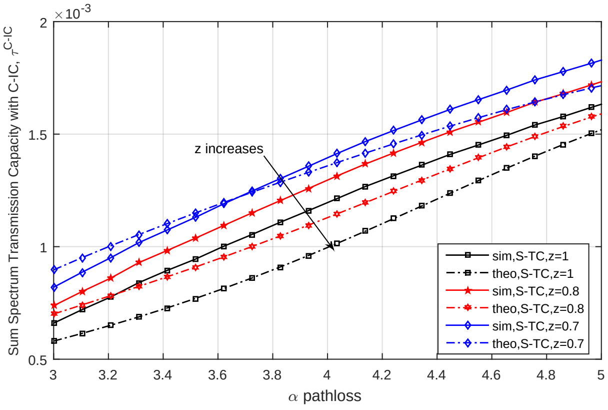

Fig. 6: Sum Spectrum Transmission Capacity with strong cancellation method according to the pathloss component, α, with different amounts of residual interference z

α, interference experiences more loss, so performance of the spectrum sharing increases. When strong interferer recieved below thershold, aggregate interferrence increases, so performance of spectrum sharing decreases.

Figure 6 shows simulation and numerical results of sum spectrum transmission capacity with close cancellation method according to the pathloss component, α, with different amounts of residual interference z. As shown in this figure, by increasing α, overall performance of spectrum sharing between two coexistence systems is improved, because interference from transmitters of two coexistence systems exerimence more loss. Increasing residual interference also improved performance. The simulation verified this results. Figure 7 shows the Sum Spectrum Transmission Capacity with the interference cancellation method according to outage probability constraint of system 1, ϵ_1, with different amounts of coefficients of cancellation ρ_{12}. The results can be verified in [5] for spectrum tramission capacity versus outage constraint. In this figure, if outage constraint increases, sum spctrum-sharing can be analyzed in two phases. In frist phase, by increasing outage constraint, the sum spectrum sharing increases and in phase two, by exceeding outage constraint from previous pahse, sum spectrum-sharing decreases.

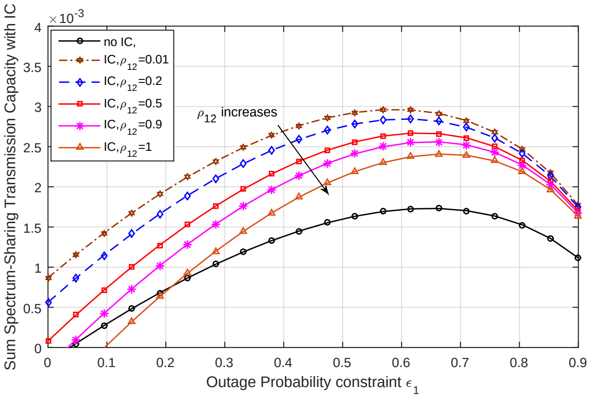

Fig. 7: The Sum Spectrum Transmission Capacity with interference cancellation method according to outage probability constraint of system 1, ϵ_1, with different amounts of coefficients of cancellation ρ_{12}

Figure 8 sums the spectrum transmission capacity according to power of system k, p_k, with different amounts of residual interference z. As shown in this figure, by increasing p_k, the overall spectrum efficiency decreases, because by increasing transmitted power in system k, interference from own system is increased. If the transmitted power exceeds from the thershold level, interferer is cancelled, as a result, the overall spectrum sharing performance is increased. It can be expected if all p_k is exceeded from the thershold level, the sum spectrum sharing has uniform behavior. In the other side, if the residual interference decreases, efficiency of spectrum will improve. Therefore, in the design wireless network component power must be taken into account.

Figure 9 shows the outage probability of system 1 according to coefficient of cancellation with diffrenet power ratio coexistence systems. In this figure, if the transmitted power of system 1 in comparison with the transmitted power of system 2 is increased, spectrum sharing performance increases too, because system 1 experiences loss interference. On the other side, if the coefficient of cancellation is close to one, the

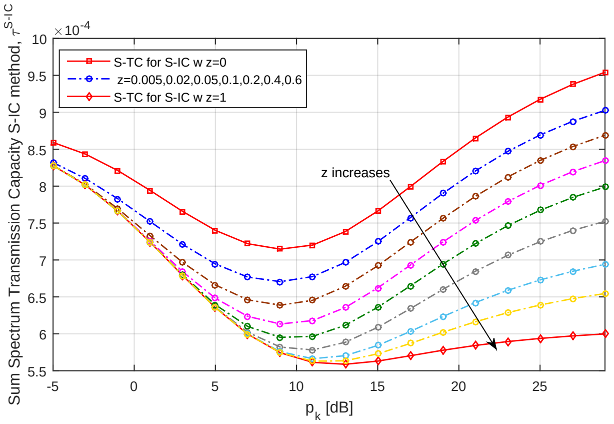

Fig. 8: Sum Spectrum Transmission Capacity according to power of system k, p_k, with different amounts of residual interference z.

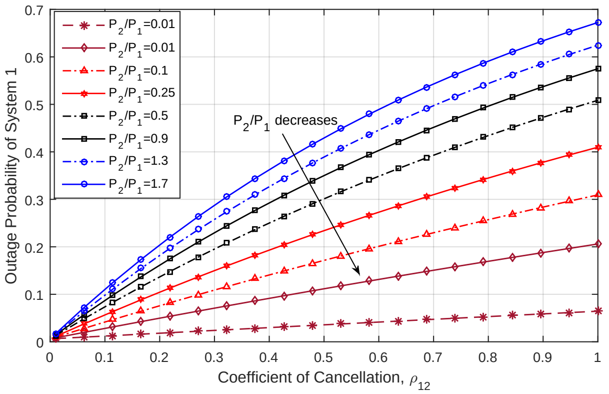

Fig. 9: The outage probability of system 1 according to coefficient of cancellation with diffrenet power ratio coexistence systems. parrameters set:$(R_1 = 3, R_2 = 2.5, \upsilon_2 = \upsilon_1 = 3, \alpha = 4, \epsilon_2 = \epsilon_1 = 0.1, \rho_{21} = 0.1, \rho_{22} = \rho_{11} = 0.2)$

outage probability system one increases and if this coefficient is reduced, the outage probability decreases.

V. CONCLUSION

The current paper aims at improving the efficiency of spectrum sharing systems by linear interference cancellation. As shown, the overall spectrum sharing transmission capacity of coexistence systems in cognitive radio can be improved using interference cancellation. Finally, the effect of a couple of parameters in the overall spectrum sharing has been presented by simulation and numerical results.

ACKNOWLEDGMENT

The A.Heydari wishes to thank Yunes Heydari for many helpful discussions and for continous encoragement. He also wishes to thank Abdulbaset Saeedian due to his carfully reading the manuscript and providing helpful comments.

REFERENCES

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

[4] 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.

[5] 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.

[6] 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.

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

[8] 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.

[9] 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.

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

[11] 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.

[12] 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.

[13] 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.

[14] 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.

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

[16] 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.

[17] 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.

[18] 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.

[19] 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.