



Cairo University

NOVEL RESULTS FOR THE PERFORMANCE OF
AMPLIFY AND FORWARD AND COGNITIVE RADIO
SYSTEMS THROUGH VARIOUS COMMUNICATION
CHANNEL SCENARIOS

By

Ebtehal Hassan Abdel Fattah El-Bahaie

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY
in
Electronics and Communications Engineering

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Title of Thesis:

Novel Results For The Performance Of Amplify And Forward And Cognitive Radio Systems Through Various Communication Channel Scenarios

Key Words:

Amplify and Forward; Nakagami fading ; Lognormal shadowing; Gauss Hermite polynomial; Cognitive Radio

Summary:

This thesis includes three contributions. The first is accurate numerical results for the BER of a dual hop AF system with independent or correlated interferer in Nakagami fading channels. The second contribution is the evaluation of the BER and ergodic capacity for a dual hop AF system in a Nakagami fading plus Lognormal shadowing environment. Lognormal shadowing is represented by the Hermite polynomial. The third contribution is the exact analytical results for a cognitive radio system for two cases when the secondary users (SUs) are directly connected to the fusion centre and when the SUs are far from the fusion centre in Nakagami fading and Lognormal shadowing channels.

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I would like to thank my supervisor Prof. Emad Al-Hussaini for his continuous support and dedication throughout this research.

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Dedication

To my mother

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List of Publications

- 1- Ebtehal H. El-Bahaie, Emad K. Al-Hussaini, "Performance of Dual Hop Relay System in the Presence of a Correlated Interferer Through Nakagami Fading Channel ", Wireless Personal Communication, vol. 84, no. 2, 2015, pp: 1401-1415
- 2- Ebtehal H. El-Bahaie, Emad K. Al-Hussaini , "Novel results for the performance of single and double stages cognitive radio systems through Nakagami m fading and log-normal shadowing ", Telecommunication systems, 2017, pp: 1-9

List of Abbreviations

| | |
|------|-----------------------------------|
| AF | Amplify and Forward |
| AWGN | Additive white Gaussian Noise |
| BER | Bit Error Rate |
| BPSK | Binary Phase shift keying |
| CAF | Cyclic autocorrelation function |
| CDF | Cumulative Distribution function |
| CF | Compress and Forward |
| CR | Cognitive Radio |
| CSD | Cyclic spectral density |
| CSI | Channel state information |
| D | Destination node |
| DF | Decode and Forward |
| FCC | Federal Communications Commission |
| FDM | Frequency division multiplexing |
| IM | Inter-modulation |
| ISI | Inter symbol interference |
| MAI | Multiple access interference |
| MRC | Maximal Ratio Combining |
| PDF | Probability density function |
| PSD | Power Spectral Density |
| PU | Primary Use |
| R | Relay node |
| S | Source node |
| SDR | Software defined radio |

| | |
|-----|-----------------------|
| SU | Secondary User |
| SNR | Signal to noise ratio |
| WSS | Wide sense stationary |
| VF | Voice frequency |

List of symbols

| | |
|-------------------------|---|
| a | modulation parameter |
| d | distance traveled by the radio wave |
| $E\{\}$ | Expected value |
| E_1 | The energy of the transmitted signal at the source |
| E_2 | The energy of the transmitted signal at the relay |
| E_{h_l} | The energy of the interferer at the first hop (link) |
| E_{g_l} | The energy of the interferer at the second hop (link) |
| $F_{\gamma_t}(\cdot)$ | Cumulative distribution function of γ_t |
| $f_{\gamma_t}(\cdot)$ | Probability density function of γ_t |
| ${}_1F_1(\cdot, \dots)$ | Confluent hyper-geometric function |
| G | The amplification factor at the relay |
| g_k | Fading gain of the interferer ' k ' |
| H_0 | The hypothesis problem that indicates signal absence |
| H_1 | The hypothesis problem that indicates signal presence |
| h_j | Fading gain of the interferer ' j ' |
| h_{kl} | Channel gain k and l |
| h_k | Composite Nakagami fading-lognormal shadowing coefficient |
| $I_0(\cdot)$ | Modified Bessel function of order zero |
| $I_\nu(\cdot)$ | Modified Bessel function of the first kind of order ν |
| K_i | Order of the Hermite polynomial for the i^{th} link |
| $K_0(\cdot)$ | Zero order modified Bessel function of the 2 nd kind. |
| $K_\nu(\cdot)$ | ν^{th} order modified Bessel function of the 2 nd kind |
| L | Number of interferers at the first link |
| L_k | Laguerre polynomial of degree k |

| | |
|-------------------------|--|
| M | Number of secondary users |
| m | fading depth |
| m_h | Fading parameters for the desired signal at the first hop (link) |
| m_{h_i} | Fading parameter for the interfering signal at the first hop (link) |
| m_g | Fading parameter for the desired signal at the second hop |
| m_{g_i} | Fading parameter for the interfering signal at the second hop |
| m_i | Nakagmi fading parameter at the i^{th} link |
| m_{s_i} | Shadowing severity parameter for the i^{th} link |
| N | Number of interferers at the second link |
| N_d | Number of antennas at the destination node |
| N_r | Number of antennas at the relay node |
| N_s | Number of samples of the received signal |
| N_{0_i} | Variance of the zero mean AWGN at the i^{th} node |
| $n_{kl}(t)$ | AWGN process with zero mean and one-sided power spectral density N_0 |
| n_k | Gaussian distributed noise with zero mean and variance σ_n^2 |
| P_d | Probability of detection |
| $P_{d_{M_1}} = P_{d_1}$ | Probability of detection at the secondary user |
| $P_{d_{NL_1}}$ | Average probability of detection for the composite Nakagami lognormal (NL) channel at the end of the first link and at each SU |
| $P_{d_{NL_2}}$ | Average Probability of detection for each SU at the end of the second faded and shadowed link |
| P_e | The average bit error rate |
| P_f | Probability of false alarm |
| $P_{f_{M_1}} = P_{f_1}$ | Probability of false alarm at the secondary user |
| $P_{f_{NL_2}}$ | Probability of false alarm for each SU at the end of the second faded and shadowed link |
| P_D | Overall probability of detection at the fusion centre |