# Artificial Noise for In-Home and Broadband PLC Systems: An Initial Discussion

Gustavo M. Campos, Pedro H. Sartorello, Mateus de L. Filomeno, Ândrei Camponogara, and Moisés V. Ribeiro

***Abstract*— This paper discusses improvements in the information security of in-home and broadband power line communication systems. To achieve this, we introduce artificial noise, designed based on the degrees of freedom of the cyclic prefix, for impairing the eavesdropper's decoding capacity without adversely affecting the legitimate receiver. Numerical outcomes derived from measured data indicate that the artificial noise is more effective in jamming when the eavesdropper is closer to the legitimate transmitter.**

***Keywords*— Artificial noise, physical layer security, power line communication.**

## I. Introduction

The introduction of orthogonal frequency-division multiplexing (OFDM) has solidified power line communication (PLC)'s status as a viable technology for data communication in indoor and outdoor environments. This is chiefly due to using existing electrical power infrastructure, significantly curtailing the costs associated with data network implementation. However, the inherent broadcast nature of electric power systems raises concerns regarding the security and privacy of information exchanged between PLC devices. For instance, Camponogara *et al.* [1] showed that a passive eavesdropper may threaten the security of in-home and broadband PLC systems.

In this context, physical layer security (PLS) has emerged as an effective strategy for bolstering information security by capitalizing on diversity across time, frequency, and space domains. Wiretap code rates for maximizing effective secrecy throughput were investigated in [2]. Another practical approach to achieving secure communication is the injection of artificial noise (AN). This AN is intelligently generated by the legitimate transmitter (Alice) in a manner that it does not degrade the signal-to-noise-ratio (SNR) of the legitimate receiver (Bob), yet effectively disrupts the SNR of any passive eavesdropper (Eve) nearby.

This research was supported in part by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) under Grant 001, Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) under grants 404068/2020-0 and 314741/2020-8, Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG) under grants APQ-03609-17, TEC-PPM 00787-18, and APQ-04623-22, and Instituto Nacional de Energia Elétrica (INERGE).

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In [3], the authors, considering a single-input single output (SISO) system under an OFDM scheme, investigated the use of the degrees of freedom introduced by the cyclic prefix (CP) to design the AN. Notably, this specific approach has not yet been assessed in the context of PLC systems. To fill this research gap, the present paper evaluates whether AN—generated based on the degrees of freedom of CP—can enhance the security of in-home and broadband PLC systems under the presence of passive eavesdroppers.

## II. System Model

Let $\mathbf{X}_i \in \mathbb{C}^{N\times 1}$ be the $i^{\text{th}}$ OFDM transmitted block, in the discrete-frequency domain, whose elements obey the Hermitian symmetry baseband transmission [3]. In this sense, $\mathbb{E}\{\mathbf{X}_i\mathbf{X}_i^\dagger\} = \mathbf{\Lambda}_{\sigma^2_{\mathbf{x}}}, \forall i$, such that $\text{Tr}(\mathbf{\Lambda}_{\sigma^2_{\mathbf{x}}}) = P_{\mathbf{x}}N$, where $\mathbb{E}\{\cdot\}$ is the expectation operator, $\text{Tr}(\cdot)$ denotes the trace operator, and $P_{\mathbf{x}}$ is the total power assigned to the transmitted block. In the discrete-time domain, the real-valued transmitted block may be therefore represented as

$$\mathbf{x}_i = \mathbf{\Psi}_{\text{T}}\mathbf{F}^\dagger\mathbf{X}_i, \tag{1}$$

where $\mathbf{F} \in \mathbb{C}^{N\times N}$ denotes the normalized version of the $N$-length discrete Fourier transform (DFT) matrix and $(\cdot)^\dagger$ is the conjugate transpose operator. Also, the matrix $\mathbf{\Psi}_{\text{T}} = [\mathbf{E}^T_{N_{\text{cp}}\times N}\mathbf{I}_N]^T$ is responsible for the CP insertion, thus $N_{\text{cp}}$ is the CP-length and $\mathbf{E}_{N_{\text{cp}}\times N} = [\mathbf{0}_{N_{\text{cp}}\times(N-N_{\text{cp}})}\mathbf{I}_{N_{\text{cp}}}]$, with $\mathbf{0}_{a\times b}$ standing for an $(a \times b)$-size matrix of zeros and $\mathbf{I}_a$ representing an $a$-size identity matrix; $(\cdot)^T$ denotes the transpose operator.

Alice sends $\mathbf{x}_i$ plus an artificial noise $\mathbf{a}_i \in \mathbb{R}^{(N+N_{\text{cp}})\times 1}$ through a linear and time-invariant broadcast channel, reaching users Bob and Eve respectively denoted by "b" and "e". Also, $\mathbb{E}\{\mathbf{a}_i\mathbf{a}_i^\dagger\} = \mathbf{\Lambda}_{\sigma^2_{\mathbf{a}}}, \forall i$, such that $\text{Tr}(\mathbf{\Lambda}_{\sigma^2_{\mathbf{a}}}) = P_{\mathbf{a}}(N + N_{\text{cp}})$, in which $P_{\mathbf{a}}$ is the total power assigned to the artificial noise. Therefore, the $i^{\text{th}}$ discrete-time domain received block is

$$\mathbf{y}_i^l = \mathbf{H}^l(\mathbf{x}_i + \mathbf{a}_i) + \mathbf{w}_i^l, \qquad \forall l \in \{\text{b}, \text{e}\}, \tag{2}$$

in which $\mathbf{H}^l \in \mathbb{R}^{(N+N_{\text{cp}})\times(N+N_{\text{cp}})}$ represents the Toeplitz channel matrix [3] associated with the $l^{\text{th}}$ user, whereas $\mathbf{w}_i^l \in \mathbb{R}^{(N+N_{\text{cp}})\times 1}$ indicates the additive white Gaussian noise vector affecting the $i^{\text{th}}$ block and $l^{\text{th}}$ user. Thus $\mathbb{E}\{\mathbf{w}_i\mathbf{w}_i^\dagger\} = \mathbf{\Lambda}_{\sigma^2_{\mathbf{w}}}, \forall i$, such that $\text{Tr}(\mathbf{\Lambda}_{\sigma^2_{\mathbf{w}}}) = P_{\mathbf{w}}(N+N_{\text{cp}})$, with $P_{\mathbf{w}}$ denoting the noise power. The inverse operations to those performed at the transmitter are carried out at the receiver side. As a result, the $i^{\text{th}}$ block received by the $l^{\text{th}}$ user can be expressed in the discrete-frequency domain as $\mathbf{Y}_i^l = \mathbf{F}\mathbf{\Psi}_{\text{R}}\mathbf{y}_i^l$, with the matrix $\mathbf{\Psi}_{\text{R}} = [\mathbf{0}_{N\times N_{\text{cp}}}\mathbf{I}_N]$ being responsible for the CP removal.

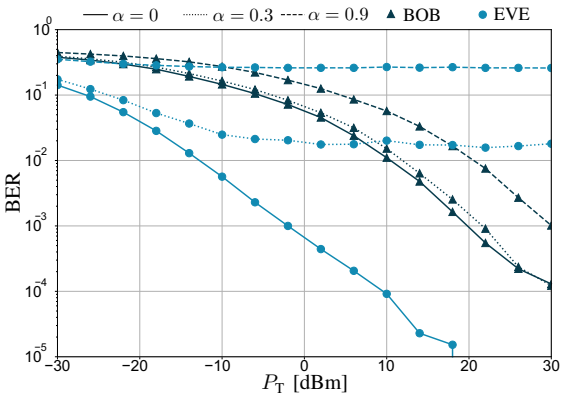


Fig. 1. BER vs $P_T$ for Eve and Bob under distinct $\alpha$ values when Eve is near Alice.

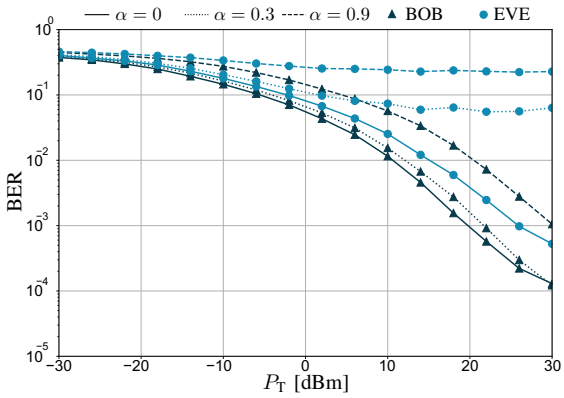


Fig. 2. BER vs $P_T$ for Eve and Bob under distinct $\alpha$ values when Eve is near Bob.

## III. Artificial Noise Design

Alice designs $\mathbf{a}_i$ to worsen Eve's SNR but not Bob's. For this purpose, she exploits the degrees of freedom introduced by the CP. According to [3], $\mathbf{a}_i = \mathbf{V}^{\mathrm{b}}\mathbf{d}_i$, such that $\mathbf{d}_i \in \mathbb{R}^{N_{\mathrm{cp}}\times 1}$ is a vector of Gaussian random variables while $\mathbf{V}^{\mathrm{b}} \in \mathbb{R}^{(N+N_{\mathrm{cp}})\times N_{\mathrm{cp}}}$ indicates the null space of $\mathbf{\Psi}_{\mathrm{R}}\mathbf{H}^{\mathrm{b}}$ (Bob's channel) and can be obtained from singular value decomposition. Therefore, Alice needs to know the coefficients of Bob's channel impulse response, which can be obtained e.g. from a feedback channel, and $\mathbf{\Psi}_{\mathrm{R}}\mathbf{H}^{\mathrm{b}}\mathbf{V}^{\mathrm{b}} = \mathbf{0}_{N\times N_{\mathrm{cp}}}$. Consequently, the discrete-frequency domain representations of the $i^{\mathrm{th}}$ block received by Bob and Eve are respectively given by

$$\mathbf{Y}_i^{\mathrm{b}} = \mathbf{F}\mathbf{\Psi}_{\mathrm{R}}\mathbf{H}^{\mathrm{b}}\mathbf{x}_i + \mathbf{F}\mathbf{\Psi}_{\mathrm{R}}\mathbf{w}_i^{\mathrm{b}} \tag{3}$$

and

$$\mathbf{Y}_i^{\mathrm{e}} = \mathbf{F}\mathbf{\Psi}_{\mathrm{R}}\mathbf{H}^{\mathrm{e}}\mathbf{x}_i + \mathbf{F}\mathbf{\Psi}_{\mathrm{R}}\mathbf{H}^{\mathrm{e}}\mathbf{V}^{\mathrm{b}}\mathbf{d}_i + \mathbf{F}\mathbf{\Psi}_{\mathrm{R}}\mathbf{w}_i^{\mathrm{e}}. \tag{4}$$

Note that the resulting received block by Eve has a further noise term, i.e, $\mathbf{F}\mathbf{\Psi}_{\mathrm{R}}\mathbf{H}^{\mathrm{e}}\mathbf{V}^{\mathrm{b}}\mathbf{d}_i$, that will detriment its SNR. In the next section, we numerically evaluate the impact of this extra noise term on the performance of Bob and Eve in two distinct configurations (i.e., Eve close to Alice and Eve close to Bob).

## IV. Numerical Results

In this section, we consider a Monte Carlo simulation with the transmission of $2^{17}$ bits modulated in 4-order quadrature amplitude modulation (4-QAM). In this regard, an OFDM scheme with $N = 4096$ and $N_{\mathrm{cp}} = 512$ samples is treated. Also, we considered channel impulse responses of in-home and broadband ($1, 7-100$ MHz) PLC systems acquired from a measurement campaign [4]. In this context, two scenarios were simulated: one for Eve near Alice and another for Eve near Bob. The numerical approach for the total transmission power is $P_{\mathrm{T}} = P_{\mathbf{x}} + P_{\mathbf{a}}$, such that $P_{\mathbf{x}} = \alpha P_{\mathrm{T}}$ and $P_{\mathbf{a}} = (1-\alpha)P_{\mathrm{T}}$, with $\alpha \in [0, 1]$. We assume uniform power allocation, thus $\mathbf{\Lambda}_{\sigma_{\mathbf{x}}^2} = \mathbf{I}_N P_{\mathbf{x}}/N$ and $\mathbf{\Lambda}_{\sigma_{\mathbf{a}}^2} = \mathbf{I}_N P_{\mathbf{a}}/(N + N_{\mathrm{cp}})$. Additionally, the noise for in-home PLC environments is modeled as additive white gaussian noise (AWGN) with $P_{\mathrm{w}} = 10^{-8}$ [5].

In Fig. 1, for Eve in proximity to Alice, we compare the bit error rate (BER) of Bob and Eve, considering different values of $\alpha$. For $\alpha = 0$ (no AN injection), Eve's BER is naturally lower than Bob's. However, as the AN power increases, Bob's BER slightly increases since the total available power has to be divided into signal and AN. On the other hand, it severely impacts Eve's BER so that it is higher than Bob's for $P_{\mathrm{T}} \geq 10$ dBm if $\alpha = 0.3$ and for $P_{\mathrm{T}} \geq -10$ dBm if $\alpha = 0.9$.

We consider Eve close to Bob in Fig. 2. In this scenario, Bob's BER is lower than Eve's if $\alpha = 0$, i.e., Bob's channel is inherently better than Eve's. As $\alpha$ increases, the BER values of Bob and Eve also increase. However, due to the correlation of PLC channels for near receivers, the impact of the AN is less expressive to Eve in this scenario.

## V. Conclusions

From a perspective of information security, this paper has investigated the effects of introducing AN, designed based on the degrees of freedom of the CP, to in-home and broadband PLC systems. The numerical analysis, in terms of BER, suggests that AN can significantly degrade the performance of a passive eavesdropper located in proximity to the legitimate transmitter, leading to an elevated BER for the eavesdropper. However, it is noteworthy that when the eavesdropper is situated closer to the legitimate receiver, the effectiveness of AN diminishes, causing only a minor increase in Eve's BER. Overall, employing AN-based jamming techniques appears to be a promising approach to bolster the PLS of in-home and broadband PLC systems. As futures works, we can analyze other PLS parameters and scenarios

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