Effect of Epidemic Interference on the Performance of M-ASK, M-PSK and M-QAM Modulation Schemes

Joel E. Cordeiro Jr, Marcelo S. Alencar, Marina V. Yashina, and Alexander G. Tatashev

***Abstract*—This article presents a study on the performance of different digital modulation systems in the presence of epidemic interference. This type of interference is caused by the fast increase in the number of users in a system at a given time. The epidemic interference can be modeled as a non-stationary stochastic process, which presents random power levels over time. In a previous work, the authors assessed the effect of the epidemic interference on the performance of BPSK, QPSK, and M-QAM systems. The present paper extends the previous results for M-ASK and M-PSK systems. Furthermore, numerical results from Monte Carlo simulations are presented for all evaluated digital modulation systems.**

***Index Terms*—Lognormal interference, epidemic interference, non-stationary interference, mobile communications, digital modulation, average error probability.**

I. Introduction

Interference can be a serious impairment in cellular mobile communications, in which the spectrum frequency is a limited and scarce resource. The division of the coverage site in multiple cells is a good strategy to deal with the radio spectrum scarcity, because it enables the reuse of frequency channels in different cells. Thus, it is possible to serve more users, cover large geographical areas and reduce energy consumption [1], [2]. Nevertheless, the transmitted signals in a given cell can be received as interference in another cell that reuses the same frequency [3]. The interference level on cellular communication systems depends on many factors, such as, the number of users, the transmission power, and the inter-cell distance. High levels of interference can drastically decrease the wireless channel capacity.

In order to simplify the analysis, many studies model the interference in communication systems as a zero-mean stationary Gaussian random process. But, for dynamic systems, the interference power can change quickly over time. In this case, the stationary model does not apply, and it is necessary to model the interference as a non-stationary random process. The fifth-generation cellular systems (5G) bring several new features, such as small cells, massive connections, communications for high-speed vehicles, and Device-to-Device (D2D) communications, [4]–[6]. In this way, new cellular environments will be more dynamic. If the number of devices varies in short periods, the generated interference will be non-stationary.

Epidemic interference is type of non-stationary effect, which arises when many users arrive simultaneously at the system, leading to a fast increase in interference levels. The epidemic interference can reduce the performance of receivers designed to operate with stationary interference only. Recently, it has been shown that the power of the epidemic interference is a Lognormal distributed random process [7], which confirms its non-stationary property.

This paper extends the results presented in [8], which evaluates the effect of the epidemic interference on the performance of Binary Phase Shift Keying (BPSK), Quaternary Phase-Shift Keying (QPSK) e M-ary Quadrature Amplitude Modulation (M-QAM). In this work, expressions are presented for the average error probability functions of digital modulation systems, including M-ary Amplitude-Shift Keying (M-ASK) and M-ary Phase-Shift Keying (M-PSK). To verify the correctness of expressions, numerical results obtained from Monte Carlo simulation are presented for all evaluated digital modulation systems.

Section II briefly discusses the related study of interference in communications systems. Section III describes the performance measures used and the stochastic model of epidemic interference. In Section IV, the error probability functions are derived for different digital modulation schemes in the presence of the epidemic interference. The results are presented and discussed in Section V. The numerical results obtained by Monte Carlo simulation are also presented. Section VI presents the main conclusions of the study.

II. Related Works

The problem of non-stationary interference has been approached in different ways. In [9], the performance of convolutional codes is evaluated in the presence of non-stationary noise. Interference is modeled as a Gaussian process with random variance. In addition, numerical results are presented, including a scenario in which the power of the interference has

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J. E. Cordeiro Jr is with the Federal Institute of Education, Science and Technology Baiano and Federal University of Bahia, Salvador, Brazil (e-mail: joel.cordeiro@ifbaiano.edu.br)

M. S. Alencar is with the Institute for Advanced Studies in Communications, Campina Grande, Brazil (e-mail: malencar@iecom.org.br)

M. V. Yashina and A. G. Tatashev are with the Moscow Automobile and Road Construction State Technical University, Moscow, Russia (e-mails: mv.yashina@madi.ru, a-tatashev@yandex.ru)

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Lognormal distribution. It has been shown that when the interference power has a long tail asymmetric distribution, which causes a large performance degradation of the system. In [10], the authors assess the performance of multiple-input multiple-output (MIMO) antenna systems with orthogonal frequency division multiple access OFDMA) systems for channels with correlated fading and non-stationary interference.

Random non-stationary interference has variable power that depends on time. This type of interference is commonly modeled as a random signal with normal distribution and random variance. Pally and Beex [11] propose to mitigate non-stationary interference using the subtraction of the estimation of the modulated signal. In [12], a method of mitigating interference between OFDM carriers is evaluated, in vehicular network environments. The considered interference is non-stationary due to the shading effect present in the channel.

One type of non-stationary interference that occurs in communications systems is the co-channel interference, which has been modeled as a random process with Lognormal power [13]–[15]. In this case, the total interference is formed as the sum of several signals with Lognormal power distribution. In [16], [17] the authors present efficient methods to calculate the approximate Probability Density Function (PDF) of the sum of variables with Lognormal distribution. Cardieri and Rappaport [18] propose generalized methods for the sum of Lognormal random variables, with different mean values and standard deviations.

Systems subject to Lognormal interference are studied in different environments [19]–[21]. Moreover, the Lognormal distribution is also used to model fading channel effects [22]. Because of the Lognormal distribution properties, the error analysis for Lognormal interference, such as epidemic interference, can be modeled based on Lognormal fading studies. In [23], a closed-form approximation of the average probability of error over a Lognormal fading channel is presented. Other approximations for the average probability of error have been proposed in [24]–[27].

The epidemic interference has been studied in [7], the Lognormal power distribution has been obtained by stochastic integration. In [8], the authors evaluate the error performance of digital systems subject to epidemic interference. The present work extends this analysis to the M-ASK and M-PSK systems.

III. Performance Measures

This section presents some measures to evaluate the performance of communication systems that are subject to non-stationary stochastic interference.

A. Average SINR

Because of channel fading, the transmitted signal power undergoes random changes, which imply the randomness of the Signal-to-Interference-plus-Noise Ratio (SINR) [3]. Therefore, it is useful to analyze the average SINR, given by

$$\overline{\gamma} = \mathrm{E}[\Gamma] = \int_0^\infty \gamma p_\Gamma(\gamma) d\gamma, \tag{1}$$

in which $\mathrm{E}[\cdot]$ is the expected value operator and p_Γ represents the PDF of the random SINR Γ.

B. Outage Probability

The increase in the interference level, plus channel noise, reduces the SINR and increases the detection error probability, which reduces the data transmission rate and the channel capacity.

The transmission rate must be above a certain level, to satisfy the quality of service requirements, otherwise the service could be interrupted. The chance of this event is given by the Outage Probability (OP). It can be considered as the probability that the SINR remains below a certain threshold γ_l [3]. Therefore,

$$P_O(\gamma_l) = \Pr(\Gamma \leq \gamma_l) = \int_0^{\gamma_l} p_\Gamma(\gamma) d\gamma. \tag{2}$$

The OP is computed using the SINR Cumulative Probability Function (CPF).

C. Average Error Probability

The error probability of a communication system is, usually, a function of the SINR. If the SINR is random, it is possible to define the average error probability as,

$$P_E(\overline{\gamma}) = \int_0^\infty P(E|\gamma) p_\Gamma(\gamma) d\gamma \tag{3}$$

in which $P(E|\gamma)$ is the Symbol Error Probability (SEP), or the Bit Error Probability (BEP) conditioned to a certain value of γ [28].

Depending on the conditional probability function used, $P_E(\overline{\gamma})$ will be the Average Symbol Error Probability (ASEP) or the Average Bit Error Probability (ABEP). The integration interval is only defined for positive values, because the SINR is always positive.

D. Performance of Digital Modulation Systems

Several digital modulation systems have been studied in the literature, for different environments. The exact, or approximate, expressions for the error probability of some schemes have been published [29].

Considering coherent and ideal detection, and supposing that the transmitted and receiver are synchronized in phase, the SEP for M-ASK is given by

$$P_{MASK}(\gamma_s) = 2\left(1 - \frac{1}{M}\right) Q\left(\sqrt{\frac{6\gamma_s}{M^2-1}}\right), \tag{4}$$

in which γ_s is the SINR per transmitted symbol. For equiprobable symbols with equal energy, the SINR per bit is $\gamma_b = \gamma_s / \log_2 M$. If the Gray code mapping is used, the M-ASK BEP is

$$P_{MASK}(\gamma_b) = \frac{2}{\log_2 M}\left(1 - \frac{1}{M}\right) Q\left(\sqrt{\frac{6 \log_2 M \gamma_b}{M^2-1}}\right). \tag{5}$$

For the Binary PSK (BPSK) or 2-PSK scheme, the SEP is given by

$$P_{BPSK}(\gamma_s) = Q\left(\sqrt{2\gamma_s}\right). \tag{6}$$

For BPSK, which has two symbols, the number of bits per symbol is $\log_2 2 = 1$. Therefore, the SINR per bit, γ_b, equals γ_s and the BEP is given by the Function 6.

The SEP for the Quaternary PSK (QPSK) or 4-PSK system is given by

$$P_{QPSK}(\gamma_s) = 2Q\left(\sqrt{\gamma_s}\right) - Q^2\left(\sqrt{\gamma_s}\right). \tag{7}$$

The QPSK has four possible symbols, therefore each symbol carries two bits, and $\gamma_s = \log_2 4\gamma_b$. The QPSK BEP is

$$P_{QPSK}(\gamma_b) = Q\left(\sqrt{\gamma_s}\right) = Q\left(\sqrt{2\gamma_b}\right), \tag{8}$$

which equals the BPSK BEP [3].

For M larger than four, the SEP and BEP of M-PSK can be approximated, respectively, by

$$P_{MPSK}(\gamma_s) = 2Q\left(\sqrt{2\gamma_s}\sin\frac{\pi}{M}\right) \tag{9}$$

and

$$P_{MPSK}(\gamma_b) = \frac{2}{\log_2 M} Q\left(\sqrt{2\log_2 M\gamma_b}\sin\frac{\pi}{M}\right). \tag{10}$$

Most mobile cellular communication systems use M-QAM modulation. For $M = 4$, the SEP and the BEP are the same as the QPSK scheme. For the general case, in which $M \geq 4$ [29], the SEP is

$$\begin{aligned} P_{MQAM}(\gamma_s) = 4 \Bigg[& \left(1 - \frac{1}{\sqrt{M}}\right) Q\left(\sqrt{\frac{3\gamma_s}{M-1}}\right) + \\ & - \left(1 - \frac{1}{\sqrt{M}}\right)^2 Q^2\left(\sqrt{\frac{3\gamma_s}{M-1}}\right)\Bigg]. \end{aligned} \tag{11}$$

The computation of the BER for higher order schemes can be tedious, and depends on the mapping between the bits and the symbols. Considering the use of Gray code, an approximate expression for the BER of the M-QAM scheme is presented in [28],

$$\begin{aligned} P_{MQAM}(\gamma_b) \approx & \left(1 - \frac{1}{\sqrt{M}}\right)\left(\frac{4}{\log_2 M}\right) \times \\ & \times \sum_{i=0}^{\sqrt{M}/2-1} Q\left((2i+1)\sqrt{\frac{3\log_2 M}{M-1}\gamma_b}\right). \end{aligned} \tag{12}$$

E. Epidemic Interference

Cellular communication systems enter an epidemic state when most users decide to place calls at the same time. In this situation, the interference in the system can be modeled as a non-stationary stochastic process. Therefore, its statistical averages, or moments, also vary over time.

The traditional correlation analysis is not adequate to deal with that type of problem. In this case, stochastic differentiation is a useful tool to model the phenomenon. This makes it possible to obtain a problem formulation, for the modeling of the interference, based on a stochastic differential equation.

In a recent study [7], the epidemic interference was modeled as a non-stationary stochastic process, that was analyzed utilizing stochastic integration. The results show that the interference power has a Lognormal distribution, given by

$$p_W(w) = \frac{1}{w\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{\ln(w) - \ln(P_0)}{\sigma}\right)^2}, \tag{13}$$

in which P_0 represents the observed power at the beginning of the observation interval. The cumulative probability function is given by

$$P_W(w) = \begin{cases} 0, & n < 0 \\ 1 - Q\left(\frac{\ln(w) - \mu}{\sigma}\right), & n \geq 0 \end{cases}. \tag{14}$$

F. Average Error Probability for Lognormal SINR

As presented in Section III-D, a number of expressions for the error probability involve the Q function. Therefore, using the Expressions 3 and Lognormal PDF $p_\Gamma(\gamma)$, the computation of the ASEP and ABEP results in the integrals

$$I_Q = \int_0^\infty Q(a\sqrt{\gamma}) p_\Gamma(\gamma) d\gamma \text{ and}$$
$$I_{Q^2} = \int_0^\infty Q(a\sqrt{\gamma})^2 p_\Gamma(\gamma) d\gamma,$$

for a constant a. Using the Gauss-Hermite quadrature method, presented in [28] and described in the Appendix of [8], it is possible to compute these integrals as follows

$$I_Q = \frac{1}{\sqrt{2\pi}} \sum_{i=1}^{n} w_i Q\left(a\sqrt{e^{\sigma x_i + \mu}}\right) \text{ and} \tag{15}$$

$$I_{Q^2} = \frac{1}{\sqrt{2\pi}} \sum_{i=1}^{n} w_i Q^2\left(a\sqrt{e^{\sigma x_i + \mu}}\right), \tag{16}$$

in which x_i are the roots of the n-order Hermite polynomials, and w_i are the associated weight factors. These parameters can be obtained from a table or numerically.

IV. Performance Analysis of Systems Subject to Lognormal SINR

Based on the stochastic model presented in [7], expressions for OP, ASEP and ABEP are derived. For simplicity, the small AWGN noise is not taken into account, because it is a stationary process with constant power that does not modify the PDF of the SINR. In order to analyze only the interference effect, a unity gain channel without attenuation is considered. Therefore, the received signal is $r(t) = s(t) + i(t)$, in which $s(t)$ and $i(t)$ represent the transmitted signal and the epidemic interference, respectively.

The SINR is defined as, $\Gamma(t) = \frac{S}{W(t)}$, in which S is the signal constant power and $W(t)$ is the random process that models the epidemic interference power. The SINR probability distribution can be obtained from the transformation of PDF 13. Thus,

$$p_\Gamma(\gamma) = \frac{p_W(S/\gamma)}{|d\gamma/dw|} = \frac{1}{\gamma\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left[\frac{\ln\gamma - \ln\gamma_0}{\sigma}\right]^2}, \tag{17}$$

in which $\gamma_0 = S/P_0$ represents the SINR, observed at the beginning of the measurement interval.

A. Outage Probability

The channel outage probability is given by the SINR cumulative probability, as a function of the threshold γ_l,

$$P_O(\gamma_l) = \int_0^{\gamma_l} p_\Gamma(\gamma) d\gamma = 1 - Q\left(\frac{\ln \gamma_l - \ln \gamma_0}{\sigma}\right). \quad (18)$$

Observe that P_O is an increasing function, which implies that an increase in the minimum SINR requirement causes a growth in the probability of transmission interruptions.

B. Error Probability

This section presents the error probability of a system that is subject to epidemic interference, using the ASEP and ABEP for the M-ASK, M-PSK and M-QAM modulation schemes. For this purpose, the Expression 3 is used, in which $P(E|\gamma)$ is replaced by the respective SEP and BEP functions presented in Section III-D, and the PDF given by (17). In the following expressions, the subscript s and b indicate that the error probability functions are computed per symbol and per bit, respectively.

1) M-ASK: For the M-ASK signal, the error probability conditioned to the SINR is given by the Functions 4 and 5. Using the same method applied to the computation of Integral 15, the ASEP and ABEP can be computed as

$$\begin{aligned} P_s(\overline{\gamma_s}) &= \int_0^\infty P_{MASK}(\gamma_s) p_\Gamma(\gamma_s) d\gamma_s \\ &= \sqrt{\frac{2}{\pi}}\left(1 - \frac{1}{M}\right) \times \\ &\times \sum_{i=1}^n w_i Q\left(\sqrt{\frac{6}{M^2-1} e^{\sigma x_i + \ln \gamma_{0(s)}}}\right) \end{aligned} \quad (19)$$

and

$$\begin{aligned} P_b(\overline{\gamma_b}) &= \int_0^\infty P_{MASK}(\gamma_b) p_\Gamma(\gamma_b) d\gamma_b \\ &= \frac{1}{\log_2 M}\sqrt{\frac{2}{\pi}}\left(1 - \frac{1}{M}\right) \times \\ &\times \sum_{i=1}^n w_i Q\left(\sqrt{\frac{6\log_2 M}{M^2-1} e^{\sigma x_i + \ln \gamma_{0(b)}}}\right), \end{aligned} \quad (20)$$

respectively.

2) BPSK: From SEP given by (6), the ASEP of BPSK signal can be computed as

$$\begin{aligned} P_s(\overline{\gamma_s}) &= \int_0^\infty P_{BPSK}(\gamma_s) p_\Gamma(\gamma_s) d\gamma_s \\ &= \frac{1}{\sqrt{2\pi}} \sum_{i=1}^n w_i Q\left(\sqrt{2e^{\sigma x_i + \ln \gamma_{0(s)}}}\right). \end{aligned} \quad (21)$$

In the BPSK case, the SINR per symbol equals the SINR per bit. Besides, the SEP and the BEP are given by the Function 6. This way, the ABEP for the BPSK scheme is

$$P_b(\overline{\gamma_b}) = P_s(\overline{\gamma_s}). \quad (22)$$

3) QPSK: For the QPSK signal, the error probability, conditioned to the SINR, is given by Function 7. The QPSK ASEP is obtained following the same steps used in computing the Integrals 15 and 16,

$$\begin{aligned} P_s(\overline{\gamma_s}) &= \int_0^\infty P_{QPSK}(\gamma_s) p_\Gamma(\gamma_s) d\gamma_s \\ &= \frac{1}{\sqrt{2\pi}} \sum_{i=1}^n w_i \left[2Q\left(\sqrt{e^{\sigma x_i + \ln \gamma_{0(s)}}}\right) + \right. \\ &\left. -Q\left(\sqrt{e^{\sigma x_i + \ln \gamma_{0(s)}}}\right)\right]. \end{aligned} \quad (23)$$

In the QPSK case, $\gamma_s = 2\gamma_b$ and the BEP is given by the Function 8. Therefore, the ABEP for both QPSK and BPSK are given by (22).

4) M-PSK: From (9), for $M > 4$ the ASEP of M-PSK scheme can be computed as

$$\begin{aligned} P_s(\overline{\gamma_s}) &= \int_0^\infty P_{MPSK}(\gamma_s) p_\Gamma(\gamma_s) d\gamma_s \\ &= \sqrt{\frac{2}{\pi}} \sum_{i=1}^n w_i Q\left(\sqrt{2e^{\sigma x_i + \ln \gamma_{0(s)}}} \sin\frac{\pi}{M}\right). \end{aligned} \quad (24)$$

Similarly, from (10), the ABEP of M-PSK is given by

$$\begin{aligned} P_b(\overline{\gamma_b}) &= \int_0^\infty P_{MPSK}(\gamma_b) p_\Gamma(\gamma_b) d\gamma_b \\ &= \frac{1}{\log_2 M}\sqrt{\frac{2}{\pi}} \sum_{i=1}^n w_i \times \\ &\times Q\left(\sqrt{2\log_2 M e^{\sigma x_i + \ln \gamma_{0(b)}}} \sin\frac{\pi}{M}\right). \end{aligned} \quad (25)$$

5) M-QAM: In analogy to the computation of the BPSK and QPSK expressions, the Integrals 15, 16, and the Function 11, are used to obtain the ASEP expression for the M-QAM system. Thus,

$$\begin{aligned} &P_s(\overline{\gamma_s}) = \int_0^\infty P_{MQAM}(\gamma_s) p_\Gamma(\gamma_s) d\gamma_s \\ &= \frac{4}{\sqrt{2\pi}} \sum_{i=1}^n w_i \left[\left(1 - \frac{1}{\sqrt{M}}\right) Q\left(\sqrt{\frac{3}{M-1} e^{\sigma x_i + \ln \gamma_{0(s)}}}\right) + \right. \\ &\left. -\left(1 - \frac{1}{\sqrt{M}}\right)^2 Q^2\left(\sqrt{\frac{3}{M-1} e^{\sigma x_i + \ln \gamma_{0(s)}}}\right)\right]. \end{aligned} \quad (26)$$

For the M-QAM scheme, one has $\gamma_s = \log_2 M \gamma_b$ and the BEP is approximated by the Expression 12. Therefore, the ABEP is

$$\begin{aligned} &P_b(\overline{\gamma_b}) = \int_0^\infty P_{MQAM}(\gamma_b) p_\Gamma(\gamma_b) d\gamma_b \\ &= \frac{4}{\sqrt{2\pi}\log_2 M}\left(1 - \frac{1}{\sqrt{M}}\right) \times \\ &\times \sum_{i=1}^n w_i \left[\sum_{j=0}^{\sqrt{M}/2-1} Q\left((2j+1)\sqrt{\frac{3\log_2 M}{M-1} e^{\sigma x_i + \ln \gamma_{0(s)}}}\right)\right]. \end{aligned} \quad (27)$$

It can be observed that, for the case $M = 4$, the ASEP and ABEP are equal for the QPSK scheme.

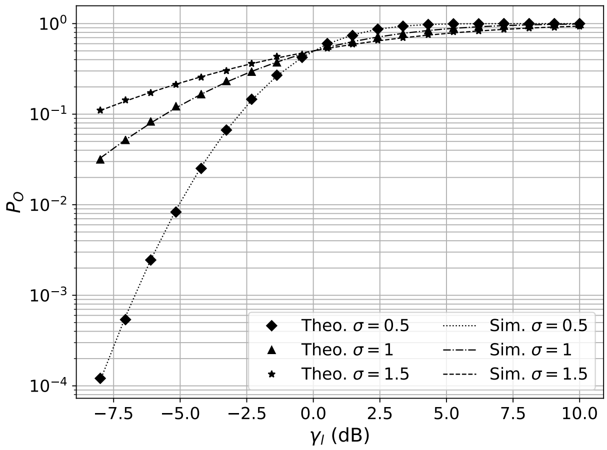

Fig. 1. Comparing the theoretical curves for OP with those obtained by Monte Carlo simulation.

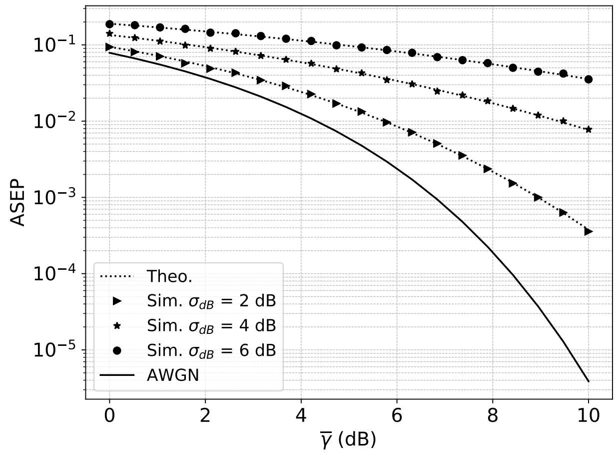

Fig. 2. ASEP curves for a BPSK system, for different values of σ_{dB}.

The previous expressions for ABEP and ASEP are based on the average SINR, in which $\overline{\gamma}$ is implicit in the Q function argument, by means of the parameters σ and γ_0.

C. Monte Carlo Simulations

To confirm the exactitude of the presented expressions, computer simulations were carried out using the Monte Carlo method. The simulations were obtained varying the values of the parameter σ.

For each simulated point 1000 error interruption events were considered, for the OP case, or 1000 symbol error events were considered for the computation of ASEP for the 8-ASK, BPSK, QPSK, 16-PSK and 64-QAM schemes. In the simulations, the epidemic interference is modeled as a Gaussian signal with random variance with Lognormal distribution.

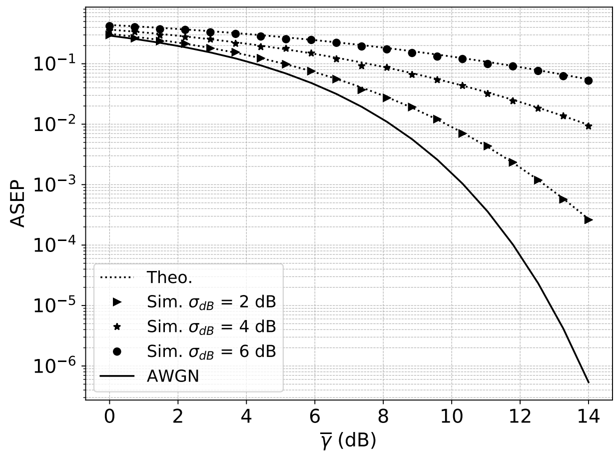

Fig. 3. ASEP curves for a QPSK system, for different values of σ_{dB}.

V. Numerical Results

The probability functions presented in Section IV allow the performance evaluation of digital communication systems subject to epidemic interference. This section presents numerical results and performance graphs for the OP, ASEP and ABEP of the 8-ASK, BPSK, QPSK, 16-PSK and 64-QAM schemes. Besides the theoretical curves, the numerical results were also obtained using Monte Carlo simulation.

A. Outage Probability

The results obtained by simulation are compared to the theoretical curves from Formula 18 and presented in Figure 1. Note that, when $\gamma_l > 1$, a higher value for σ decreases the chance of an outage event. On the other hand, when the threshold is smaller that one, lower values for σ imply a smaller OP.

B. Average Error Probability

The effect of the epidemic interference in a BPSK system can be evaluated by the average error probability, given by Expression 21. Figure 2 shows the ASEP curves for BPSK, comparing different values of the interference parameter σ em decibel ($\sigma_{dB} = \sigma \ln 10/10$). As a reference, the curve for the SEP of the BPSK system, subject to AWGN, is also shown.

It is possible to observe that the epidemic interference increases the channel error probability. Besides, higher values of σ_{dB} lead to higher error rates. It is worth observing that the plotted curves in Figure 2 are the same for the ASEP of the BPSK schemes, and the ABEP for the QPSK system.

The ASEP curves for the QPSK system are presented in Figure 3, for different values of σ. A reference plot for the AWGN channel, for the QPSK scheme, is also shown. As in the BPSK case, the epidemic interference increases the symbol error rate. In the same way, the theoretical and simulated curves for 16-PSK are shown in Figure 4.

The ASK results are represented by the curves of the 8-ASK scheme shown in Figure 5. The simulated points are consistent with the theoretical curves calculated by Expression 19.

The theoretical and simulated curves for a 64-QAM system

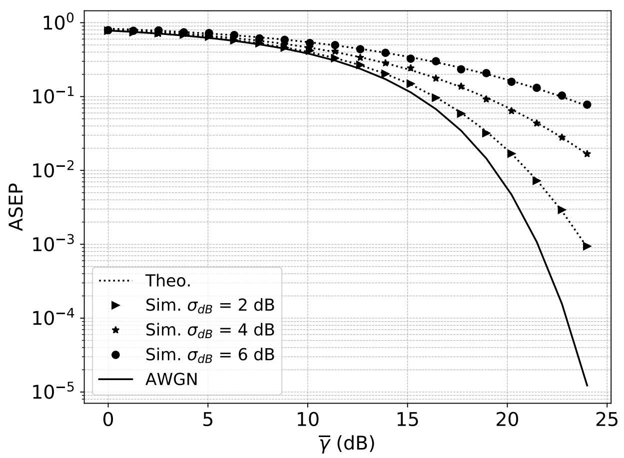

Fig. 4. ASEP curves for a 16-PSK system, for different values of σ_{dB}.

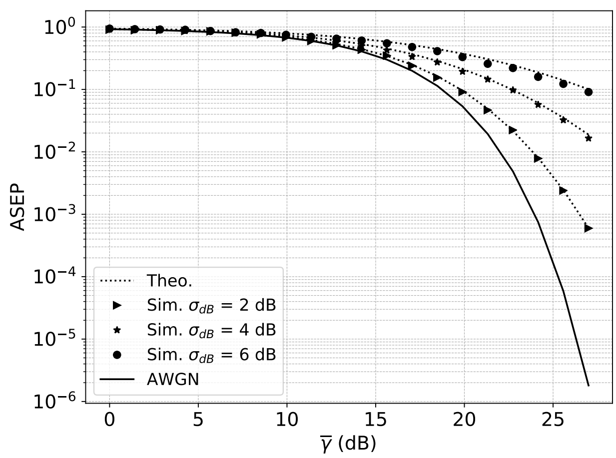

Fig. 6. ASEP curves for a 64-QAM system, for different values of σ_{dB}.

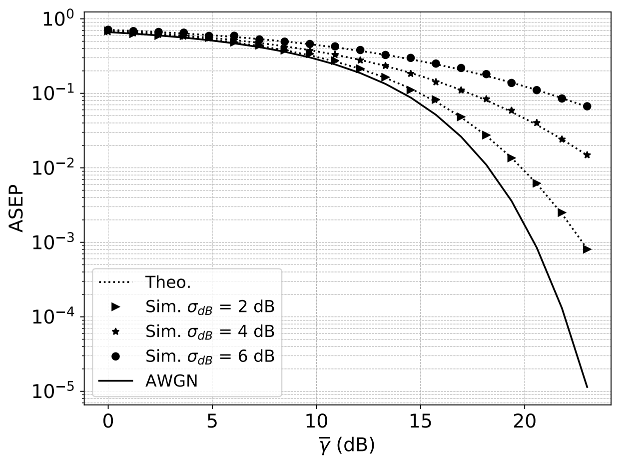

Fig. 5. ASEP curves for a 8-ASK system, for different values of σ_{dB}.

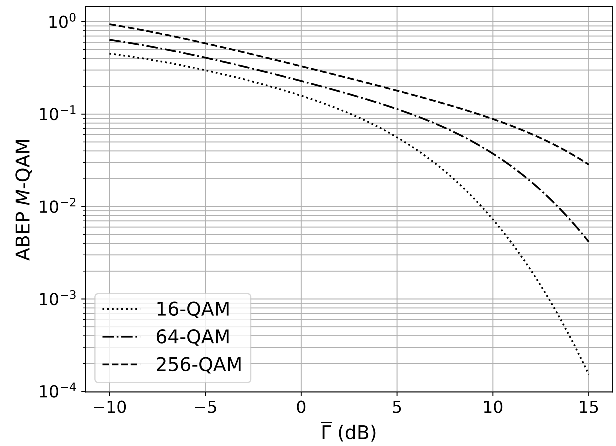

Fig. 7. ABEP curves for a QAM system, of order 16, 64 and 256.

are presented in Figure 6. Similar to the previous cases, increasing σ_{dB} increases the error probability.

A comparison of ABEP for QAM systems, of order 16, 64 and 256, is shown in Figure 7, in which the parameter σ is fixed to 0.5. One can verify that the scheme with more symbols presents higher error probability in the presence of epidemic interference. For an average SINR of 10 dB, the 16-QAM ABEP is approximately 0.01, while the 256-QAM presents an ABEP of 0.1.

VI. Conclusions

This article presented a mathematical model to compute the performance of a digital communication system that includes the effect of interference accumulation, caused by a sudden increase of users in a digital cellular system, also called an information outbreak or epidemic interference.

This results in a Lognormal distribution for the interference, which is a heavy tail distribution. The authors derived expressions for the outage probability, as well as, for the error probability of M-ASK, M-PSK and M-QAM modulation schemes.

By means of those expressions, it has been verified that the epidemic interference increases the error rate for all modulation schemes. For the presented results, the epidemic interference increases the error probability even for high SINR cases.

There is also an increase in the outage probability of the analysed systems. In the near future, the authors plan to develop mathematical and computational models for channel ergodic capacity.

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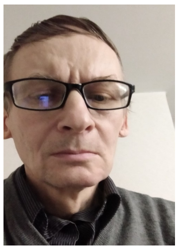
Joel E. Cordeiro Jr received his Bachelor Degree in Exact and Technological Sciences (2013) and Bachelor Degree in Computer Engineering (2016), from the Federal University of Recôncavo da Bahia (UFRB), Brazil. He received his Master Degree in Electrical Engineering from the Federal University of Campina Grande (UFCG), Brazil, in 2018. He was a substitute professor of data processing at the UFRB, Brazil (2014–2016). He is currently information technology analyst at the Bahian Federal Institute of Education, Science and Technology (IF Baiano) and doctoral student at the Federal University of Bahia. His research interests include network security, information theory and radio multiple access.

Marcelo S. Alencar was born in Serrita, Brazil in 1957. He received his Bachelor Degree in Electrical Engineering, from the Federal University of Pernambuco (UFPE), Brazil, 1980, his Master Degree in Electrical Engineering, from the Federal University of Paraiba (UFPB), Brazil, 1988 and his Ph.D. from the University of Waterloo, Department of Electrical and Computer Engineering, Canada, 1993. He is Emeritus Member of the Brazilian Telecommunications Society (SBrT), and IEEE Senior Member. He worked for the Department of Electrical Engineering, Federal University of Paraiba, as Full Professor. From 2003 to 2017, he was Chair Professor at the Department of Electrical Engineering, Federal University of Campina Grande, Brazil. Between 1982 and 1984, he worked for the State University of Santa Catarina (UDESC). from 2017 to 2019 he was with the Federal University of Bahia. He also worked for Senai Cimatec, Salvador, for MCI-Embratel, and for the University of Toronto, as visiting professor. He is founder and President of the Institute for Advanced Studies in Communications (Iecom). He has been awarded several scholarships and grants, from the Brazilian National Council for Scientific and Technological Research (CNPq), two grants from the IEEE Foundation, scholarships from the University of Waterloo and from the Federal University of Paraiba. He received an achievement award for contributions to the SBrT, an award from the city of Campina Grande, during its 150th anniversary, an award from the Medicine College of the Federal University of Campina Grande (UFCG), and an achievement award from the College of Engineering of the Federal University of Pernambuco, during its 110th year celebration. He published over 500 engineering and scientific papers and 28 books. He also wrote chapters for 12 books. Marcelo S. Alencar has contributed in different capacities to the following scientific journals: Editor of the Journal of the Brazilian Telecommunication Society; Member of the International Editorial Board of the Journal of Communications Software and Systems (JCOMSS), published by the Croatian Communication and Information Society (CCIS); Member of the Editorial Board of the Journal of Networks (JNW), published by Academy Publisher. He was founder and Editor-in-Chief of the Journal of Communication and Information Systems (JCIS), a joint edition of the IEEE Communications Society (ComSoc) and SBrT. He also served on the Board of Directors of SBrT and on the SBMO Council. He is a Registered Professional Engineer, for two decades he was a columnist for the traditional Brazilian newspaper Jornal do Commercio, and he was Vice-President External Relations of SBrT. Marcelo S. Alencar is a laureate of the prestigious 2014 Attilio Giarola Medal, by the Brazilian Microwave and Optoelectronics Society (SBMO).

Marina V. Yashina is professor and a head of Higher Mathematics Department of the Moscow Automobile and Road Construction Technical University (Russia), and a professor of Mathematical Cybernetics and IT Department of the Moscow Technical University of Communications and Informatics (Russia). From 1974 till 1979, she was an undergraduate student of the Lomonosov Moscow State University, Mechanical-Mathematical Faculty (Russia). She had received her Ph.D. (Math) degree from the Lomonosov Moscow State University (Russia) in 1989, and her Dr. Sc. (Tech.) from the Moscow Automobile and Road Construction Technical University (Russia) in 2000. She is the author of more than 150 research publications related to dynamical systems, mathematical modeling of complex socio-technical systems, intelligent transport systems and cybernetics.



Alexander G. Tatashev was born on February 15, 1955, in Moscow, Russia. From 1973 till 1978 he was an undergraduate student of the Moscow Physical Technical Institute, Russia. From 1978 till 1995, he worked at the Scientific Research Institute of Communications and Control Systems. From 1995 till the present, he is with the Moscow Automobile and Road Technical University. Since 2003 he is professor of this university. He is the author of more than 100 research publications related to queuing theory, mathematical modeling, discrete dynamical systems and related subjects.