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Modeling and Simulation of *L*-branch Selection Combining Diversity Receiver in Nakagami-*m* Environment using Matlab

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Abstract – In this paper, motivated by the fact that wireless channels are exposed to fading, *L*-branch selection combining (SC) diversity receiver operating over Nakagami-*m* fading environment in the presence of cochannel interference (CCI) is modeled and simulated using program package Matlab. Level crossing rate (LCR), as second order statistic, is chosen to indicate performance measure. Simulation results show great agreement with earlier published numerical results.

Keywords – Fading, Selection combining diversity, Level crossing rate, Sum-of-sinusoids-based simulator.

I. INTRODUCTION

In cellular mobile radio systems, the main causes for the performance degradation are fading due to multipath propagation and cochannel interference (CCI) due to frequency reuse [1]. In the open technical literature, several statistical models are used to describe fading in wireless environments. The most frequently used distributions are Rayleigh, Nakagami-*m*, Rician and Weibull.

Space diversity techniques, which combine input signals from multiple receive antennas, are the well known techniques that can be used to alleviate the effects of degradations [2]. Diversity improvement is achieved without increasing transmission power and bandwidth, but at the expense of increased system complexity and moderate increase in receive power consumption. The most popular ones are maximal-ratio combining (MRC), equal-gain combining (EGC), and selection combining (SC) [3]. MRC and EGC require all or some of the channel state information (fading amplitude, phase, and delay). In addition, a separate receiver chain is needed for each diversity branch which increases its complexity. In opposition to MRC and EGC, SC receiver is much simpler for practical realization because it processes only one of the diversity branches. In general, branch with the highest signal-to-noise ratio (SNR) (or equivalently, with the strongest signal assuming equal noise power among the antennas) is connected to the output. Efficient cellular system designs are interference-limited [2], i.e. the level of the thermal noise is sufficiently low as compared to the level of CCI, so the thermal noise effect may be ignored. In that case, three different decision algorithms can be applied: the desired signal power algorithm, the total signal power algorithm and signal-to-interference ratio (SIR) algorithm [3]. We choose to investigate desired signal power algorithm for an interference-limited SC system since it has identical performance as the total signal power algorithm and it is easier to model [4]. Also, it was shown that SIR algorithm provides the best performance for interference-limited environment systems in the sense of outage probability and average fade duration (AFD), but it almost provides the worst performance for the average level crossing rate (LCR). In desired signal power algorithm, SC receiver selects the branch with the largest instantaneous desired signal power.

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In the last years, there has been continuing interest in modeling various propagation channels with the Nakagami-*m* model, which describes multipath scattering with relatively large delay-time spreads, with different clusters of reflected waves [5]. It provides good fits to collected data in indoor and outdoor mobile-radio environments and is used in many wireless communications applications [6]-[9].

Motivated by the previous observations, in this paper, *L*-branch SC diversity receiver operating over Nakagami-*m* fading environment in the presence of CCI is modeled and simulated using program package Matlab. We use Nakagami-*m* fading simulator incorporating Pop's architecture with Zhang decomposition algorithm [10]. In other words, a random phase into low-frequency oscillators for gaining the wide-sense stationary property is inserted, while decomposing a real number of the fading figure, *m*, into two parts, an integer and a fraction to accomplish our design [11]. The average LCR of considered system is simulated to reflect the correlation properties of fading channels and provide a dynamic representation of the system outage performance. Furthermore, simulation results are compared with previously published numerical results in papers [4], [12].

II. NUMERICAL RESULTS

Regardless of the branch of science or engineering, theoreticians have always been enamored with the notation of expressing their results in the form of closed-form expressions [3]. Therefore, in open technical literature, performance measures of wireless systems – outage probability, average bit error probability, channel capacity, amount of fading, AFD and average LCR - were obtained in closed-forms [.

The average LCR of the envelope ratio of desired signal signal and CCI, μ, at threshold μ_{th} is defined as the rate at which a fading process crosses level μ_{th} in a positive (or negative) going direction and is mathematically defined by the Rice's formula [17]

$$N_\mu(\mu_{th}) = \int_0^\infty \dot{\mu}\, p_{\mu\dot{\mu}}(\mu_{th},\dot{\mu})\, d\dot{\mu}, \qquad (1)$$

where $\dot{\mu}$ denotes the time derivative of μ and $p_{\mu\dot{\mu}}(\mu,\dot{\mu})$ is the joint PDF of random variables $\mu(t)$ and $\dot{\mu}(t)$ in an arbitrary moment t.

Expressions for the average LCR of dual and triple SC diversity system applying desired signal power decision algorithm over Nakagami-m fading channels in the presence of CCI are presented in [4], [12] as

$$\begin{aligned} N_\mu(\mu_{th}) &= \frac{2\sqrt{2\pi}\, f_m m_I^{\,m_I-0.5} S^{m_I-0.5}}{\Gamma(m_I)\, m^{m_I} \mu_{th}^{\,2m_I}\Gamma(m)} \\ &\times\sqrt{Sm_I + m\mu_{th}^{\,2}} \left\{ \frac{\Gamma(m+m_I-0.5)}{\left(1+\dfrac{Sm_I}{m\mu_{th}^{\,2}}\right)^{m+m_I-0.5}} \right. \\ &-2\left(\frac{m\mu_{th}^{\,2}}{\Omega}\right)^{m+m_I-0.5} \int_0^\infty y^{2m+2m_I-2} \exp\left(-\left(\frac{m\mu_{th}^{\,2}}{\Omega}+\frac{m_I}{\Omega_I}\right)\right) \\ &\left.\times Q_m\left(\sqrt{\frac{2m\rho\mu_{th}^{\,2}}{\Omega(1-\rho)}}\, y, \sqrt{\frac{2m\rho\mu_{th}^{\,2}}{\Omega(1-\rho)}}\, y\right) dy \right\}, \end{aligned} \qquad (2)$$

and

$$\begin{aligned} N_\mu(\mu_{th}) &= \frac{\sqrt{2\pi}\, f_m \mu_{th}^{\,2m-1} m_I^{\,m_I-0.5} m^{m-0.5} S^{m_I-0.5}}{\Gamma(m_I)} \\ &\times\sqrt{Sm_I + m\mu_{th}^{\,2}} \sum_{i,j=0}^{\infty} \theta^j \alpha \left[\frac{2\Gamma(i+j+m)}{\Gamma(j+m)(1+\rho)^{i+j+m}} \right. \\ &\times\left(\frac{\Gamma(j+m+m_I-0.5)}{\alpha_1^{\,j+m+m_I-0.5}} - \sum_{k=0}^{i+m-1} \frac{\Gamma(j+m+m_I+k-0.5)\theta^k}{k!\,\alpha_2^{\,j+m+m_I+k-0.5}} \right. \\ &- \sum_{l=0}^{j+i+m-1} \frac{\Gamma(j+m+m_I+l-0.5)\theta^l(1+\rho)^l}{l!\,\alpha_3^{\,j+m+m_I+l-0.5}} \\ &\left. + \sum_{k=0}^{i+m-1}\sum_{l=0}^{j+i+m-1} \frac{\Gamma(j+m+m_I+k+l-0.5)\theta^{k+l}(1+\rho)^l}{k!\,l!\,\alpha_4^{\,j+m+m_I+k+l-0.5}} \right) \\ &+\theta^i \left(\frac{\Gamma(i+j+m+m_I-0.5)}{\alpha_5^{\,i+j+m+m_I-0.5}} - \sum_{l=0}^{j+m-1} \frac{\Gamma(i+j+m+m_I+l-0.5)\theta^l}{l!\,\alpha_3^{\,i+j+m+m_I+l-0.5}} \right. \\ &- \sum_{k=0}^{i+m-1} \frac{\Gamma(i+j+m+m_I+k-0.5)\theta^k}{k!\,\alpha_3^{\,i+j+m+m_I+k-0.5}} \\ &\left.\left. + \sum_{k=0}^{i+m-1}\sum_{l=0}^{j+m-1} \frac{\Gamma(i+j+m+m_I+k+l-0.5)\theta^{k+l}}{k!\,l!\,\alpha_4^{\,i+j+m+m_I+k+l-0.5}} \right) \right], \end{aligned} \qquad (3)$$

respectively, where f_m is Doppler shift frequency, ρ is the correlation coefficient, m and m_I are Nakagami parameters describing fading severity of desired signal and CCI, respectively, $Q_m(a,b)$ is the generalized Marcum Q-function, average SIR is $S=\Omega/\Omega_I$ and $\theta = m\mu_{th}^{\,2}/(1-\rho)$, $\chi = m_I S$, $\alpha = \rho^{i+j}/(i!\,j!\,\Gamma(m))$, $\alpha_1 = \chi+\theta$, $\alpha_2 = \chi + 2\theta$, $\alpha_3 = \chi + (2+\rho)\theta$, $\alpha_4 = \chi+(3+\rho)\theta$, $\alpha_5 = \chi+(1+\rho)\theta$.

III. Simulation results

The architecture of sum-of-sinusoids-based Nakagami-m simulator is depicted in Fig. 1 [11].

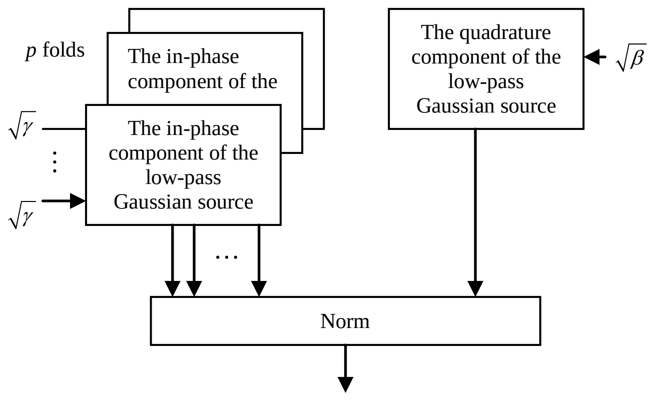

Fig. 1. The block diagram of sum-of-sinusoids-based Nakagami-m simulator

The corresponding composite signal is

$$g(t) = \sqrt{\gamma \sum_{k=1}^{p} g_{I,k}{}^{2}(t) + \beta g_{Q}{}^{2}(t)}\ , \tag{4}$$

where

$$g_I(t) = 2\sqrt{\frac{2}{N}} \times \left[\sum_{n=1}^{M} \cos\Phi_n \cos(\omega_n t + \Psi_n) + \sqrt{2}\cos\Phi_n \cos(\omega_N t + \Psi_N) \right], \tag{5}$$

$$g_Q(t) = 2\sqrt{\frac{2}{N}} \times \left[\sum_{n=1}^{M} \sin\Phi_n \cos(\omega_n t + \Psi_n) + \sqrt{2}\sin\Phi_n \cos(\omega_N t + \Psi_N) \right], \tag{6}$$

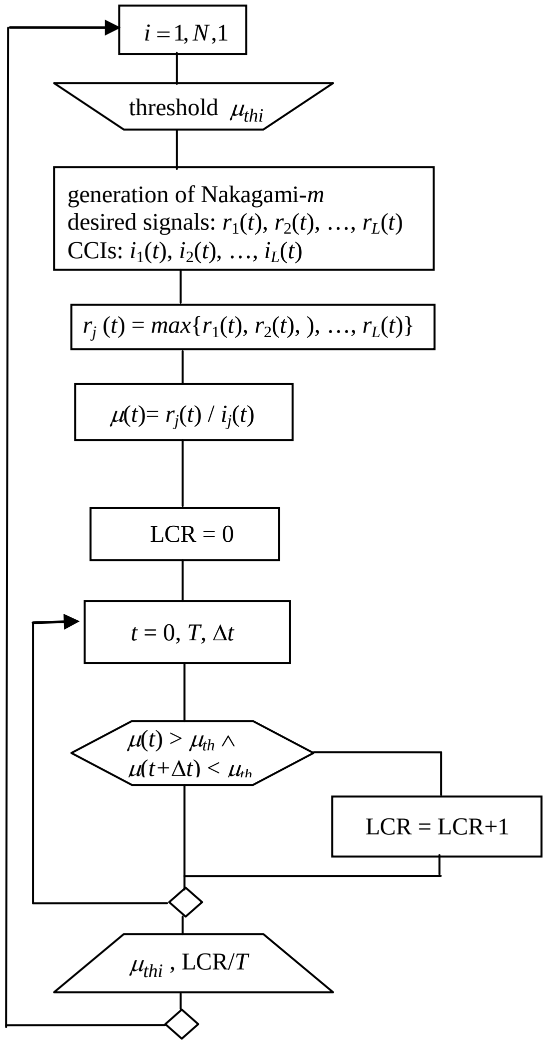

Fig. 2. The algorithm for simulation of average LCR of considered L-branch SC receiver

$$\gamma = \frac{2pm \pm \sqrt{2pm(1+p-2m)}}{p(1+p)} \tag{7}$$

and

$$\beta = 2m - \gamma p \tag{8}$$

With $p = [2m]$, $N = 4M+2$, $\omega_n = 2\pi f_m \cos(2\pi n / N)$, $\Phi_n = n\pi / M$, $\Phi_N = 0$ and ψ_j is random phase uniformly distributed in the range $(-\pi, \pi]$.

Having in mind applied decision algorithm in L-branch SC receiver, the Fig. 2 describes average LCR simulation process of system operating in Nakagami-m environment in the presence of CCI.

Program package Matlab is used to model considered problem. Simulation and numerical results for uncorrelated ($\rho \to 0$) dual and triple SC diversity system in environments under different fading severity are presented in Figs. 3 and 4.

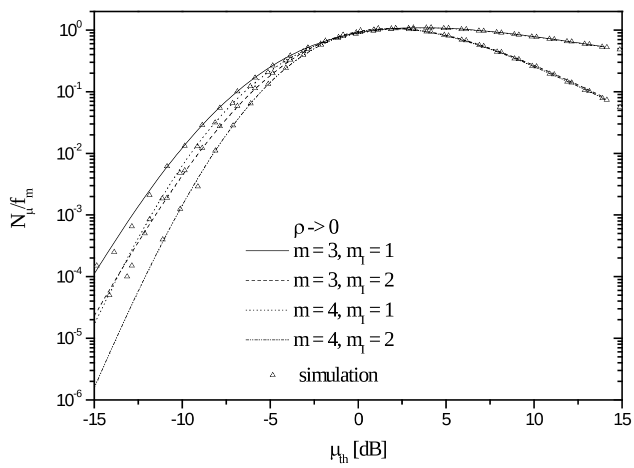

Fig. 3. Average LCR of dual SC diversity system

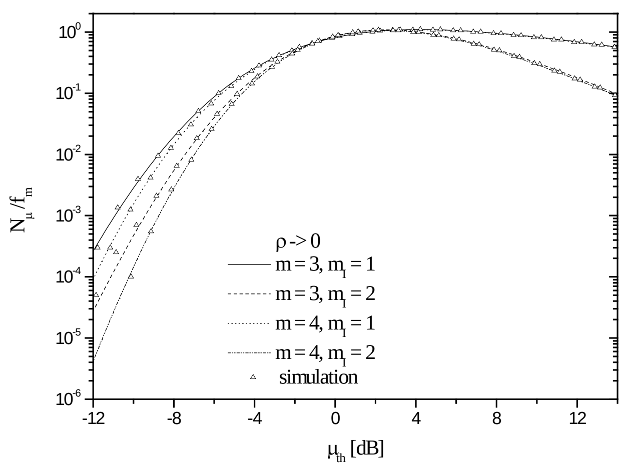

Fig. 4. Average LCR of triple SC diversity system

The great agreement between numerical and simulation results is evident regardless of number of diversity branches or fading severity.

For the reason of greater precision, number of choosen oscillators is M = 500. In all simulations maximum Doppler frequency is f_m = 100 Hz causing selected Δt = 10 μs.

IV. CONCLUSION

This work is result of intention to verify previously published theoretical results. Important and widely accepted performance indicator, LCR, is choosen to be simulated. SC diversity system with two and three uncorrelated branches in Nakagami-*m* fading environment in the presence of CCI is modeled. Simulation results obtained using program package Matlab show great agreement with earlier published numerical results calculated using program package Mathematica.

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