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Channel capacity and digital modulation schemes in correlated Weibull fading channels with non-identical statistics

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Abstract: The novel closed–form expressions for the average channel capacity of dual selection diversity is presented, as well as, the bit-error rate (BER) of several coherent and noncoherent digital modulation schemes in the correlated Weibull fading channels with nonidentical statistics. The results are expressed in terms of Meijer's G-function, which can be easily evaluated numerically. The simulation results are presented to validate the proposed theoretical analysis and to examine the effects of the fading severity on the concerned quantities.

Keywords: Average channel capacity, Weibull fading channels, Bit-error rate, Digital modulation, Nonidentical statistics.

1. Introduction

With the ever increasing demand for personal communication services (PCS) to anyplace, at anytime, wireless systems are required to operate in increasingly hostile environments, with less power consumption, and more interferences. Multipath fading and shadowing are two common destructive effects in the hostile environment, which severely degrade the performance of wireless communication systems. Many statistical distributions are available in the literature to model multipath and shadow fading in such systems[1]. The performance analysis of digital communication diversity receivers with selection combining (SC), has been extensively studied for several well-known fading channel models[2]. Very recently, the topic of communications over Weibull fading channels has begun to receive renewed interest, because of the fact that it is a flexible model providing a very good fit for experimental fading channel measurements for both indoor[3] and outdoor environments[4]. The performance of the dual-branch SC receiver over the Weibull fading channel with identical statistics has been studied, for example, the average channel capacity[5−10] and the average symbol error probability for several coherent, noncoherent, binary and multilevel modulations schemes[11−12]. However, to the best of the authors' knowledge, the average channel capacity and average bit error rate (ABER) of SC receivers with coherent frequency-shift keying (FSK) or noncoherent M-ary frequency shift keying (NMFSK) digital modulation schemes in a Weibull fading channel, have not been investigated with nonidentical statistics yet.

In this article, the average capacity and average BER of dual selection diversity operating with CFSK or NMFSK digital modulation schemes, over nonidentical Statistics Weibull fading channels are presented. The theoretical analysis is outlined and the effects of various system parameters are given. The proposed theoretical analysis is then validated by means of computer simulation.

2. Average channel capacity

The transmission of a signal with bandwidth BW over a fading indoor channel is considered here. The capacity can be considered as a random variable. Suppose that the probability density function (PDF) of the out-

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put signal-to-noise ratio (SNR, denoted as γ) can be expressed as $P_\gamma(\gamma)$. Then the average channel capacity over the PDF, in Shannon's sense[13], is given by

$$\bar{C} \cong BW \int_0^\infty \log_2(1+\gamma)P_\gamma(\gamma)\mathrm{d}\gamma \tag{1}$$

For a dual selection diversity system in correlated Weibull fading channels with nonidentical statistics, $P_r(\gamma)$ can be expressed as

$$\begin{aligned} P_\gamma(\gamma) = &\left\{ \frac{1}{a\bar{\gamma}_1}\left(\frac{\gamma}{a\bar{\gamma}_1}\right)^{(\frac{\beta}{2})-1} \exp\left[-\left(\frac{\gamma}{a\bar{\gamma}_1}\right)^{\frac{\beta}{2}}\right] + \right. \\ &\frac{1}{a\bar{\gamma}_2}\left(\frac{\gamma}{a\bar{\gamma}_2}\right)^{(\beta/2)-1} \exp\left[-\left(\frac{\gamma}{a\bar{\gamma}_2}\right)^{\beta/2}\right] - \\ &xD\gamma^{(\frac{\beta}{2})-1}\exp(-D\gamma^{\frac{\beta}{2}}) \end{aligned} \tag{2}$$

Where β is the fading parameter ($\beta \geqslant 0$), $\bar{\gamma}_1$ and $\bar{\gamma}_2$ are the corresponding average SNRs per symbol for each diversity branch, respectively. In (2), $a = 1/\Gamma(d_2)$, where Γ is the Gamma function. As β increases, the severity of the fading decreases. It is convenient to define the function $d_\tau = 1 + \tau/\beta$. In general, τ is a nonnegative real variable. Setting $D = a^{-(\frac{\beta}{2})-1}[\bar{\gamma}_1^{-(\frac{\beta}{2\delta})} + \bar{\gamma}_1^{-(\frac{\beta}{2\delta})}]^\delta$, the corresponding correlation coefficient ρ is given by

$$\rho = \frac{\Gamma^2(d_\delta)\Gamma(d_2) - \Gamma^2(d_1)\Gamma(d_{2\delta})}{\Gamma(d_{2\delta})[\Gamma(d_2) - \Gamma^2(d_1)]} \tag{3}$$

where the dependence factor $\delta (0 < \delta \leqslant 1)$ is directly related to the correlation coefficient ρ. Using the Meijer's G-function[14−15], the integral in (1) can be evaluated in a closed-form, given by

$$\begin{aligned} \bar{C} = &\frac{BW\beta}{2\ln 2}\frac{\sqrt{k}l^{-1}}{2\pi^{k+2l-3/2}} \times \left\{ (a\bar{\gamma}_1)^{-\frac{\beta}{2}} G^{k+2l,l}_{2l,k+2l} \cdot \right. \\ &\left[\frac{(a\bar{\gamma}_1)^{-\frac{\beta k}{2}}}{k^k} \middle| \begin{matrix} I(l,-\frac{\beta}{2}), I(l, 1-\frac{\beta}{2}) \\ I(k,0), I(l,-\frac{\beta}{2}), I(l,-\frac{\beta}{2}) \end{matrix} \right] + \\ &(a\bar{\gamma}_2)^{-\frac{\beta}{2}} G^{k+2l,l}_{2l,k+2l} \cdot \\ &\left[\frac{(a\bar{\gamma}_2)^{-\frac{\beta k}{2}}}{k^k} \middle| \begin{matrix} I(l,-\frac{\beta}{2}), I(l, 1-\frac{\beta}{2}) \\ I(k,0), I(l,-\frac{\beta}{2}), I(l,-\frac{\beta}{2}) \end{matrix} \right] - \\ &DG^{k+2l,l}_{2l,k+2l} \left[\frac{D^{-k}}{k^k} \middle| \begin{matrix} I(l,-\frac{\beta}{2}), I(l, 1-\frac{\beta}{2}) \\ I(k,0), I(l,-\frac{\beta}{2}), I(l,-\frac{\beta}{2}) \end{matrix} \right] \end{aligned} \tag{4}$$

where $I(n,\xi) \cong \xi/n, (\xi+1)/n, \cdots, (\xi+n-1)/n$, with ξ as an arbitrary real value and n as a positive integer. Moreover, $l/k = \beta/2$ where k and l are positive integers, depending on the value of β. A set of k and l for minimum values of β can be properly chosen.

3. Average bit-error rate

3.1 CFSK digital modulation schemes

The conditional BER in an AWGN channel can be written in explicit form as[11]

$$P_e = \frac{\Gamma(b, a\gamma)}{2\Gamma(b)} \tag{5}$$

where $a = b = 1/2$ for CFSK, $\Gamma(:,:)$ is the complementary incomplete gamma function in a flat-fading environment. Thus, the average bit-error probability is given by

$$\bar{P}_e = \int_0^\infty P_e(\gamma)P_\gamma(\gamma)\mathrm{d}\gamma \tag{6}$$

Substituting (2) and (3) in (6), the integral in (6) can be written as

$$\begin{aligned} \bar{P}_{e\mathrm{CFSK}} = &\frac{\beta}{4}\left[(a\bar{\gamma}_1)^{-\frac{\beta}{2}} \int_0^\infty \gamma^{(\frac{\beta}{2})-1}\mathrm{e}^{-\frac{\gamma}{2}}\mathrm{e}^{-(\frac{\gamma}{a\bar{\gamma}_1})^{\frac{\beta}{2}}}\mathrm{d}\gamma + \right. \\ &(a\bar{\gamma}_2)^{-\frac{\beta}{2}} \int_0^\infty \gamma^{(\frac{\beta}{2})-1}\mathrm{e}^{-\frac{\gamma}{2}}\mathrm{e}^{-(\frac{\gamma}{a\bar{\gamma}_2})^{\frac{\beta}{2}}}\mathrm{d}\gamma - \\ &\left. D\int_0^\infty \mathrm{e}^{-\frac{\gamma}{2}}\gamma^{(\frac{\beta}{2})-1}\mathrm{e}^{-D\gamma^{\frac{\beta}{2}}}\mathrm{d}\gamma \right] \end{aligned} \tag{7}$$

The integral in (7) can be evaluated in a closed-form as follows. Using Meijer's G-function, (7) becomes

$$\begin{aligned} \bar{P}_{e\mathrm{CFSK}} = &\frac{\beta}{4}\frac{(\frac{k}{l})^{\frac{1}{2}} l^{\frac{\beta}{2}}}{(2\pi)^{\frac{k+l-2}{2}}} \times \left\{ (a\bar{\gamma}_1)^{-\frac{\beta}{2}} G^{k,l}_{l,k} \cdot \right. \\ &\left[\frac{(a\bar{\gamma}_1)^{-\frac{\beta k}{2}} l^l}{(2k)^k} \middle| \begin{matrix} \{1-(\frac{\beta}{2})+\frac{n}{l}\}_{n=0,1,\cdots,l-1} \\ \{\frac{m}{k}\}_{m=0,1,\cdots,k-1} \end{matrix} \right] + \\ &(a\bar{\gamma}_2)^{-\frac{\beta}{2}} G^{k,l}_{l,k} \cdot \\ &\left[\frac{(a\bar{\gamma}_2)^{\frac{\beta k}{2}} l^l}{(2k)^k} \middle| \begin{matrix} \{1-(\frac{\beta}{2})+\frac{n}{l}\}_{n=0,1,\cdots,l-1} \\ \{\frac{m}{k}\}_{m=0,1,\cdots,k-1} \end{matrix} \right] - \\ &\left. DG^{k,l}_{l,k} \left[\frac{D^k l^l}{(2k)^k} \middle| \begin{matrix} \{1-(\frac{\beta}{2})+\frac{n}{l}\}_{n=0,1,\cdots,l-1} \\ \{\frac{m}{k}\}_{m=0,1,\cdots,k-1} \end{matrix} \right] \right\} \end{aligned} \tag{8}$$

3.2 Non-coherent MFSK digital modulation schemes

Similarly, for noncoherent MFSK, the conditional BER in an AWGN channel is given by[16]

$$P_e \approx \frac{M-1}{2}\mathrm{e}^{-\frac{\gamma}{2}} \tag{9}$$