Computation of Extended Suzuki Mobile Fading Channel (Type II) Parameters

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Abstract: Multipath fading occurs in any environment where there is multipath propagation and there is some movement of elements within the radio communications system. This may include the radio transmitter or receiver position, or in the elements that give rise to the reflections. The multipath fading can often be relatively deep, i.e. the signals fade completely away, whereas at other times the fading may not cause the signal to fall below a useful strength. In this paper we discuss a model for extended Suzuki process (type II) and an appropriate deterministic model, and we present and analyze simulation results based on these proposed models.

Index Terms: Fading channels, mobile radio channels, wireless communications, extended Suzuki processes.
II. Modeling And Analysis Of The Short-Term Fading

The stochastic reference model for extended Suzuki processes of Type II is shown in Fig. 1, where the short-term fading is modeled by the process

\[ \xi(t) = |\mu(t)| = |m(t) + \mu(t)| \quad (4) \]

where,

\[ \mu(t) = \mu_1(t) + j\mu_2(t) \quad (5) \]

represents the sum of all scattered non-line-of-sight components of the received un-modulated carrier signal over the mobile fading channel, and

\[ m(t) = m_1(t) + jm_2(t) = \rho e^{i(2\pi f_o t + \theta)} \quad (6) \]

is the line-of-sight signal component, where \( \rho \), \( f_o \), and \( \theta \) denote the amplitude, the Doppler frequency, and the phase of the line-of-sight component, respectively.

![Stochastic reference model for extended Suzuki processes of Type II](image)

As a result, the stochastic process \( \xi(t) \) which will be called the extended Rice process, can be given as

\[ \xi(t) = \sqrt{(|\mu_1(t)| + m_1(t) + m_2(t) - \mu_2(t))} \quad (8) \]

The Doppler power spectral density \( S_{v_o v_o}(f) \) of the process \( v_o(t) \) is described by

\[ S_{v_o v_o}(f) = \begin{cases} \frac{\sigma_v^2}{\sqrt{1 - |f|^2/f_{max}^2}}, & |f| \leq \kappa_0 f_{max} \\ 0, & |f| > \kappa_0 f_{max} \end{cases} \quad (9) \]

where \( f_{max} \) denotes the maximum Doppler frequency, and the variable \( 0 < \kappa_0 \leq 1 \) gives a simple and effective method to reduce the Doppler spread of \( S_{v_o v_o}(f) \), thus making the Rice process more realistic.

From Fig. 1, the following relations hold for the underlying processes:

\[ \mu_1(t) = v_0(t) \quad (10) \]

\[ \mu_2(t) = \cos\theta_0 v_0(t) + \sin\theta_0 \bar{v}_0(t) \quad (11) \]

where \(-\pi \leq \theta_0 < \pi\) and \( \bar{v}_0(t) \) is the Hilbert transform of \( v_0(t) \) for \( i = 1, 2 \).

Here, the spectral shaping of \( v_0(t) \) is based on filtering of white Gaussian noise by using an ideal filter whose transfer function is given by \( H_o(f) = \sqrt{S_{v_o v_o}(f)} \). The autocorrelation functions \( R_{\mu_1 \mu_1}(\tau) \) and \( R_{\mu_2 \mu_2}(\tau) \) as well as the cross-correlation functions \( R_{\mu_1 \mu_2}(\tau) \) and \( R_{\mu_1 \mu_2}(\tau) \) can be expressed in terms of the autocorrelation function of the process \( \hat{v}_0(t) \) of the processes \( \hat{v}_0(t) \) and \( v_0(t) \) as follows:

\[ R_{\mu_1 \mu_1}(\tau) = R_{\mu_2 \mu_2}(\tau) = R_{v_o v_o}(\tau) \quad (12) \]

**DOI**: 10.9790/0050-0312328

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\[
R_{\mu_1\mu_1}(\tau) = \cos \theta_0 \cdot R_{v_o,v_o}(\tau) - \sin \theta_0 \cdot R_{v_o,v_o}(\tau)
\]
\[
R_{\mu_2\mu_2}(\tau) = \cos \theta_0 \cdot R_{v_o,v_o}(\tau) + \sin \theta_0 \cdot R_{v_o,v_o}(\tau)
\]

By using these equations as well as the relation
\[
R_{\mu \mu}(\tau) = R_{\mu_1\mu_1}(\tau) + R_{\mu_2\mu_2}(\tau) + j[R_{\mu_1\mu_2}(\tau) - R_{\mu_2\mu_1}(\tau)]
\]

we get
\[
R_{\mu \mu}(\tau) = 2R_{v_o,v_o}(\tau) - j2\sin \theta_0 \cdot R_{v_o,v_o}(\tau)
\]

After Fourier transforming \(R_{\mu \mu}(\tau)\), the power spectral density can be given as
\[
S_{\mu \mu}(f) = 2S_{v_o,v_o}(f) - j2\sin \theta_0 \cdot S_{v_o,v_o}(f)
\]

which can be expressed in terms of \(S_{v_o,v_o}(f)\) as
\[
S_{\mu \mu}(f) = 2[1 + sgn(f) \cdot \sin \theta_0] \cdot S_{v_o,v_o}(f)
\]

### III. Modeling And Analysis Of The Long-Term Fading

Measurements have shown that in many wireless communication systems the statistical behavior of long-term fading is quite similar to a lognormal process [2]. With such a process, the slow fluctuation of the local mean value \(\hat{\lambda}(t)\) of the received signal, which is determined by shadowing effects, is given by
\[
\hat{\lambda}(t) = \exp{\sigma_3 v_3(t) + \mu_3}
\]

where \(v_3(t)\) is a real-valued Gaussian random process with mean of zero and variance of unit. The model parameters \(\mu_3\) and \(\sigma_3\) can be used in connection with the parameters of the extended Rice process \((\sigma_r^2, f_{\max}, \alpha, \theta_0, \rho, \theta_p)\) to fit the model behaviortothestatisticsofreal-worldchannels. We assume that the stochastic process \(v_3(t)\) is statistically independent of the process \(v_0(t)\). \(S_{v_3,v_3}(f)\) is assumed to have the form of the Gaussian power spectral density [2,4,5]:
\[
S_{v_3,v_3}(f) = \frac{1}{\sqrt{2\pi\sigma_r^2}} e^{-\frac{f^2}{2\sigma_r^2}}
\]

the 3-dB-cut-off frequency \(f_c = \sigma_r^2 2ln2\) is in general much smaller than the maximum Doppler frequency \(f_{\max}\). The autocorrelation function of the process \(v_3(t)\) can be expressed as
\[
R_{v_3,v_3}(\tau) = e^{-2(\sigma_r^2\tau)^2}
\]

which corresponds to the inverse Fourier transform of \(S_{v_3,v_3}(f)\). The autocorrelation function \(R_{\mu \mu}(\tau)\) of the lognormal process can be expressed in terms of \(R_{v_3,v_3}(\tau)\) as
\[
R_{\mu \mu}(\tau) = e^{2m_3 + \sigma_3^2[1 + R_{v_3,v_3}(\tau)]}
\]

The power spectral density \(S_{\mu \mu}(f)\) can now be expressed in terms of the power spectral density \(S_{v_3,v_3}(f)\) as follows
\[
S_{\mu \mu}(f) = e^{2m_3 + \sigma_3^2} \left[\delta(f) + \sum_{n=1}^{\infty} \frac{\sigma_r^2}{n!} \frac{S_{v_3,v_3}(f/n)}{n}\right]
\]

where \(\delta(f)\) is the Dirac-Delta function.

### IV. Deterministic Simulation Model For The Extended Suzuki Process Of Type II

Stochastic multipath propagation models for indoor and outdoor mobile radio channels are in general derived by employing colored Gaussian noise processes. Efficient design and realization techniques of such processes are therefore of particular importance in the area of mobile radio channel modeling [5]. Figure 2 shows the deterministic simulation model for extended Suzuki process of Type II that approximates the behavior of the stochastic reference model shown in Fig. 1. Using Eq.(10) and Eq.(11), we get
\[
\bar{\mu}_1(t) = \sum_{n=1}^{N_1} c_{1,n} \cos(2\pi f_1 n t + \theta_1 n)
\]
\[
\bar{\mu}_2(t) = \sum_{n=1}^{N_1} c_{1,n} \cos(2\pi f_1 n t + \theta_1 n - \theta_0)
\]

From these two equations, it can be noted that the Doppler phases \(\theta_{2,n}\) of the second deterministic process \(\bar{\mu}_2(t)\) depend on the Doppler phases \(\theta_{1,n}\) of the first deterministic process \(\bar{\mu}_1(t)\), because \(\theta_{2,n} = \theta_{1,n} - \theta_0\). The complex-valued deterministic process \(\bar{\mu}(t) = \bar{\mu}_1(t) + \bar{\mu}_2(t)\) can be expressed as
\[
\bar{\mu}(t) = \sum_{n=1}^{N_1} c_{1,n} e^{j(2\pi f_1 n t + \theta_{1,n})}
\]
The autocorrelation functions of the processes $\tilde{\mu}_1(t)$ and $\tilde{\mu}_2(t)$ can be given as:

$$R_{\tilde{\mu}_1\tilde{\mu}_1}(\tau) = R_{\tilde{\mu}_2\tilde{\mu}_2}(\tau) = c_{1,1}^2, n_2 N_1 n = 1 \cos(2\pi f_1 n \tau)$$  (29)

And the cross-correlation functions are:

$$R_{\tilde{\mu}_1\tilde{\mu}_2}(\tau) = R_{\tilde{\mu}_2\tilde{\mu}_1}(\tau) = c_{1,1}^2, n_2 N_1 n = 1 \cos(2\pi f_1 n \tau - \theta_0)$$  (30)

Using the Method of Equal Distances [2],[5] to calculate the Doppler coefficients $c_{1,n}$ and $f_{1,n}$, we get

$$c_{1,n} = \frac{2\sigma_0}{\sqrt{2}} \arcsin\left(\frac{n}{N_1}\right) - \arcsin\left(\frac{n-1}{N_1}\right)^{1/2}$$  (31)

And the Doppler frequencies

$$f_{1,n} = \frac{f_{\text{max}}}{2N_1} (2n - 1)$$  (32)

where

$$N_1' = \frac{N_1}{2\arcsin(\rho_0)}$$  (33)

is an auxiliary variable that depends on the frequency ratio $\kappa_0 = f_{\text{max}} / f_{\text{min}}$. The Doppler phases $\theta_{1,n}$ are assumed to be realizations of a random variable uniformly distributed within the interval $(0, 2\pi)$. The computation of the discrete Doppler coefficients $c_{3,n}$ of the deterministic Gaussian process $\tilde{\nu}_3(t)$, whose power spectral density is Gaussian shaped, are given by the solution to

$$c_{3,n} = \sigma_0 \sqrt{2} [\text{erf}\left(\frac{nN_1 \sqrt{\ln(2\pi)} N_3}{N_3}ight) - \text{erf}\left(\frac{(n-1)N_1 \sqrt{\ln(2\pi)} N_3}{N_3}\right)]^{1/2}$$  (34)

where $\text{erf}(\cdot)$ is the error function. The Doppler frequencies $f_{3,n}$ can be computed as

$$f_{3,n} = \frac{\sqrt{\kappa_0 f_{\text{max}}}}{N_3} (2n - 1)$$  (35)

V. Simulation Results

Figure 3 shows the power spectral density (as determined by the method of equal distances) as well as the autocorrelation function of $\nu_1(t)$, for $i = 1, 2$, where the number of harmonic functions $N_i$ is considered as 19 (ideally $\infty$), and the maximum Doppler frequency $f_{\text{max}}$ is 85Hz. The difference between the autocorrelation function of the reference model and the simulation model decreases by increasing the number of harmonic functions ($N_i$). The power spectral density of $\nu_3(t)$ shown in Fig. 4, resembles the Gaussian power spectral density given by eq. 20. Here again the difference between the autocorrelation function of the reference model and the simulation model decreases by increasing the number of harmonic functions $N_3$. The cut-off
frequency $f_c$ is selected in such a way that the mean power of the Gaussian power spectral density obtained makes up at least 99.99% of its total mean power. This demand is fulfilled with $f_c = \sqrt{\ln 2} f_{\text{max}}$ [6].

The parameters $\sigma_0, f_{\text{max}}/f_c, \kappa_0, \theta_0, \rho, \sigma_3, m_3$ were experimentally optimized in [2] for heavy and light shadowing, the optimized values are shown in Fig.5. Using these values of the parameters and assumed values for $N_1, N_3$, and $f_{\text{max}}$ in simulating the extended Suzuki process of type II, we get Fig. 6 for heavy shadowing regions and Fig. 7 for light shadowing regions. From these two figures, it can be seen that the average signal level for heavily shadowed line-of-sight component is smaller than that for lightly shadowed line-of-sight component. Also, the deep fades for heavy shadowing regions are much larger than that for light shadowing regions. These results are expected because as the strength of the line-of-sight component increases, it dominates the received signal, hence the effect of fading becomes less significant [6].

![Figure 3: Power spectral density $S_{\mu\mu i}(f)$ and autocorrelation function $R_{\mu\mu i}(\tau)$ for $i=1,2$, with $N_i=19, f_{\text{max}}=85\text{Hz}, \sigma^2=1$.](image1)

![Figure 4: Power spectral density $S_{\nu\nu 3}(f)$ and autocorrelation function $R_{\nu\nu 3}(\tau)$ with $N_3=19, \sigma^2=1$, and $f_{\text{max}}=85\text{Hz}$.](image2)

![Figure 5: The optimized parameters of the reference channel model for areas with heavy and light shadowing.](image3)

<table>
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<th>Shadowing</th>
<th>$\sigma_0$</th>
<th>$\kappa_0$</th>
<th>$\theta_0$</th>
<th>$\rho$</th>
<th>$\sigma_3$</th>
<th>$m_3$</th>
<th>$f_c/f_c$</th>
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<td>127°</td>
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<td>0.2061</td>
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</table>
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VI. Conclusions

In this paper, we discussed stochastic and deterministic (simulation) models for the extended Suzuki process of type II. The exact Doppler spread method was used to compute the primary parameters of the simulation model (Doppler coefficients and discrete Doppler frequencies), where finite numbers of harmonics were used to simulate the short term and long term fading components of this model. As a result, it was found that the deep fades for heavy shadowing regions are much larger than that for light shadowing regions.

References