COMPLEX SIMULATION MODEL OF MOBILE FADING CHANNEL

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Summary In the mobile communication environment the mobile channel is the main limiting obstacle to reach the best performance of wireless system. Modeling of the radio channel consists of two basic fading mechanisms - Long-term fading and Short-term fading. The contribution deals with simulation of complex mobile radio channel, which is the channel with all fading components. Simulation model is based on Clarke-Gans theoretical model for fading channel and is developed in MATLAB environment. Simulation results have shown very good coincidence with theory. This model was developed for hybrid adaptation 3G uplink simulator (described in this issue) during the research project VEGA - 1/0140/03.

1. INTRODUCTION

The environment of mobile communication networks is characterized by different morphology, e.g. the open mountaineering or flat area, suburbs with low buildings, town center with high-rise administration buildings [4]. Two basic types of fading influence the signal transferred through mobile channel:

1. Long-term fading – induced by two mechanisms: Path-loss and shadow fading.
2. Short-term fading – induced also by two mechanisms: Multipath propagation and Doppler spread.

These particular fadings are illustrated in Fig.1.

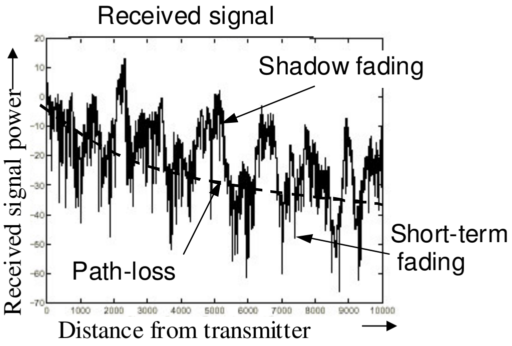

Fig.1. Long-term and short-term fading.

Let's define the received signal as

$$y(t) = L \cdot x(t - \tau), \qquad (1)$$

where τ is the mean multipath delay, $x(t)$ is the transmitted waveform, L is the general loss on the transmitted path and its value depends on three influences:

- ❑ Distance between transmitter and receiver – path loss L_{PL},
- ❑ Shadowing between transmitter and receiver – shadowing loss L_{SL},
- ❑ Short-term signal fluctuations – short-term fading loss L_{STL}.

So, L can be expressed as

$$L = L_{PL}\, L_{SL}\, L_{STL}\, e^{j\Phi}, \qquad (2)$$

where Φ is the signal phase.

2. COMPLEX SIMULATION MODEL

For purposes of mobile network simulations we have realized the complex simulation model of mobile channel in MATLAB environment. Our complex simulation model consists of three parts – long-term signal variations (path loss and shadow loss) and short-term fading (e.g. Rayleigh fading).
The long-term effects are modeled by multiplying blocks in the fig.7. We have used two ETSI path loss models [3]:

- ❑ *Path Loss Model for Outdoor to Indoor and Pedestrian Test Environment*, where the path loss L_{PL} is expressed by

$$L_{PL} = 40\log_{10}(R) + 30\log_{10}(f) + 49 \quad [\mathrm{dB}], \qquad (3)$$

where R is the base station – mobile station separation (km), f is the carrier frequency for UMTS application (2000 MHz). The model is valid for non-line-of-sight (NLOS) conditions and describes worse case propagation.
Log-normal shadow fading standard deviation of 10 dB can be expected. This model we have used only for pedestrian environment.

- ❑ *Path Loss Model for Vehicular Test Environment* is applicable for the test scenarios in urban and suburban areas outside the high rise buildings where these are of nearly uniform height.

$$\begin{aligned} L_{PL} = {} & 40(1 - 4\cdot 10^{-3}\Delta h_b)\log(R) - 18\log(\Delta h_b) + \\ & + 21\log(f) + 80 \quad [\mathrm{dB}] \end{aligned}, \qquad (4)$$

where R is the base station – mobile station separation (km), f is the same as above, Δh_b is the base station antenna height, measured from the average rooftop level. For simplicity we have fixed base station antenna height at 15 m and the formula becomes:

$$L_{PL} = 128{,}1 + 37{,}6\log(R) \quad [\mathrm{dB}]. \qquad (5)$$

Log-normal shadow fading with 10dB standard deviation is assumed in both urban and suburban areas.

The short-term effect is modeled by channel impulse response model based on a tapped-delay line model. The number of taps, the time delay relative to the first tap, the average power relative to the strongest tap, and the Doppler spectrum of each tap characterize the model. Because the measurements in outdoor environment showed that rms delay spread σ can vary over an order of magnitude [3] and this delay spread variability cannot be captured using a single tapped delay line, up to two multipath channels are defined for each test environment. Channel A is the low delay spread case that occurs frequently, channel B is the median delay spread case that also occurs frequently.

Tab.1 Pedestrian Test Environment Parameters.

Tap	Channel A		Channel B	
	Relative Delay (ns)	Average Power (dB)	Relative Delay (ns)	Average Power (dB)
1	0	0	0	0
2	110	-9.7	200	-0.9
3	190	-19.2	800	-4.9
4	410	-22.8	1200	-8
5	-	-	2300	-7.8
6	-	-	3700	-23.9

Tab.2 Vehicular Test Environment Parameters (High antenna).

Tap	Channel A		Channel B	
	Relative Delay (ns)	Average Power (dB)	Relative Delay (ns)	Average Power (dB)
1	0	0	0	-2.5
2	310	-1	300	0
3	710	-9	8900	-12.8
4	1090	-10	12900	-10
5	1730	-15	17100	-25.2
6	2510	-20	20000	-16

For simulation of short-term fading we assume the model developed by Clarke [1] which is based on fixed transmitter with vertically polarized antenna and mobile receiver with field comprised of N plane waves with arbitrary carrier phases, arbitrary azimuthal angles of arrival and each having equal average amplitude. Every wave received by the mobile undergoes a Doppler shift due to the motion of the receiver and arrives at the receiver at the same time. That is, no excess delay due to multipath is assumed for any of waves (flat fading).

Doppler shift for n-th wave arriving at an angle α_n is given by

$$f_n = \frac{v}{\lambda}\cos\alpha_n\,, \tag{6}$$

where v is the velocity of mobile and λ is the wavelength of the incident wave.

The vertically polarized waves arriving at the mobile have E and H field components. The E field can be expressed in an in-phase and quadrature form

$$E = T_c(t)\cos(2\pi f_c t) - T_s(t)\sin(2\pi f_c t)\,, \tag{7}$$

where

$$T_c(t) = E_0 \sum_{n=1}^{N} C_n \cos(2\pi f_n t + \Phi_n) \tag{8}$$

and

$$T_s(t) = E_0 \sum_{n=1}^{N} C_n \sin(2\pi f_n t + \Phi_n)\,. \tag{9}$$

Both $T_c(t)$ and $T_s(t)$ are Gaussian random processes which are denoted as T_c and T_s, respectively. These are uncorrelated zero-mean Gaussian random variables with an equal variance

$$\overline{T_c^2} = \overline{T_s^2} = \overline{|E_z|^2} = E_0^2/2\,, \tag{10}$$

where the overbar denotes the ensemble average.

The envelope of the received E-field, $E_z(t)$, is given by

$$|E_z(t)| = \sqrt{T_c^2(t) + T_s^2(t)} = r(t)\,. \tag{11}$$

Since T_c and T_s are Gaussian random variables it can be shown that the random received signal envelope r has a Rayleigh distribution given by

$$p(r) = \begin{cases} \dfrac{r}{\sigma^2}\exp\left(-\dfrac{r^2}{2\sigma^2}\right) & 0 \le r \le \infty \\ 0 & r < 0 \end{cases}\,. \tag{12}$$

Gans developed a spectrum analysis for Clarke's model. The received power from angle $d\alpha$ (in the case of isotropic antenna) is denoted $p(\alpha)d\alpha$ and the antenna gain (from that angle) $G(\alpha)$. Than the total received power (because of the great number of traveling paths, $N \to \infty$) is given by

$$P_r = \int_0^{2\pi} G(\alpha)\,p(\alpha)\,d\alpha\,. \tag{13}$$

From Gans's analysis implies that the spectrum is centered on the carrier frequency f_c and is zero outside limits of $f_c \pm f_m$, where f_m is the maximum Doppler shift. Each of the arriving waves has its own carrier frequency, which is slightly offset from the center frequency.

The resultant value of the received signal power spectral density can be expressed by

$$S(f)=\frac{2G(\alpha)\,p(\alpha)}{f_m\sqrt{1-\left(\dfrac{f-f_c}{f_m}\right)^2}}\,. \qquad (14)$$

For the case of a vertical λ/4 antenna and a uniform distribution $p(\alpha) = 1/(2\pi)$ over 0 to 2π, the output spectrum is given by

$$S_{E_z}(f)=\frac{1{,}5}{\pi f_m\sqrt{1-\left(\dfrac{f-f_c}{f_m}\right)^2}}\,. \qquad (15)$$

In equation (15) the power spectral density at $f = f_c \pm f_m$ is infinite, i.e., Doppler components arriving at exactly 0° and 180° have an infinite power spectral density.

Fig.2 shows the power spectral density (Doppler spectrum) of the resulting RF signal for the value f_m = 100 Hz (MATLAB simulation).

3. SIMULATION OF CLARKE-GANS MODEL

Simulation method uses the concept of in-phase and quadrature modulation paths to produce a simulated signal with needed spectral and temporal characteristics. Two independent Gaussian low pass noise sources are used to produce two modulation paths. Summing two independent Gaussian random variables, which are orthogonal, forms each Gaussian source.

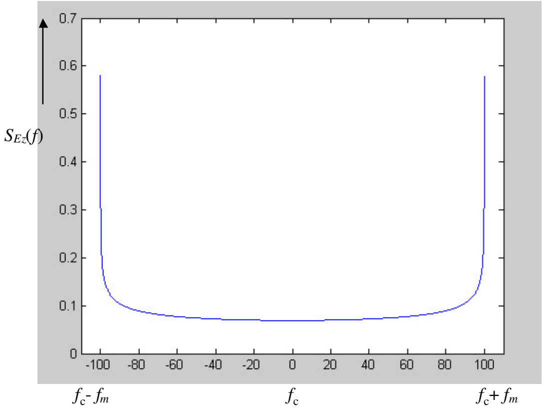

Fig.2. Doppler spectrum for f_m *= 100 Hz.*

With the spectral filter defined by (15) to shape the random signals in the frequency domain, we can produce the accurate time domain waveforms of Doppler fading by using an IFFT (Inverse Fast Fourier Transform).

Smith's algorithm [2] is to be used to realize this simulation:

1. Specify the number of spectral points N for Doppler filter representation $\sqrt{S_{E_z}(f)}$ and the maximum Doppler frequency shift f_m.
2. Compute the frequency spacing between adjacent spectral lines $\Delta f = 2\, f_m/(N\text{-}1)$. This defines the duration of fading $T = 1/\Delta f$.
3. Generate complex Gaussian random variables for each of the $N/2$ positive frequency components of the noise source.
4. Construct the negative frequency components of the noise source by conjugating positive frequency values and assigning these at negative frequency values.
5. Multiply the in-phase and quadrature noise sources by fading spectrum $\sqrt{S_{E_z}(f)}$.
6. Perform an IFFT on the resulting frequency domain signal and compute the sum of the squares of each signal.

Take the square root of the sum to obtain N point time series of a simulated Rayleigh fading signal.

Several Rayleigh fading simulators with variable gains and time delays are used to produce frequency selective fading.

In our simulation of mobile fading channel we have used modified Smith's algorithm for short-term fading simulation (one branch):

1. We have specified the number of spectral points to N=16.
2. In each branch it is used the Gaussian noise generator with low frequency to obtain random signal amplitudes (in time domain).
3. The following FFT block transforms signal to frequency domain so we get demanded spectral lines with the random amplitude in positive and negative frequencies.
4. The modified Doppler filter is than applied (at edge points the value of infinitive is replaced by value of 1).
5. The next points are exactly the same as in Smith's algorithm, i.e. IFFT and computation of an absolute value from both branches.

The Rayleigh fading simulator for one branch of multipath fading channel is in Fig.3.

Several Rayleigh fading simulators have been used in conjunction with variable gains and time delays (Tables 1, 2) to produce frequency selective fading effects. This is shown in Fig.7.

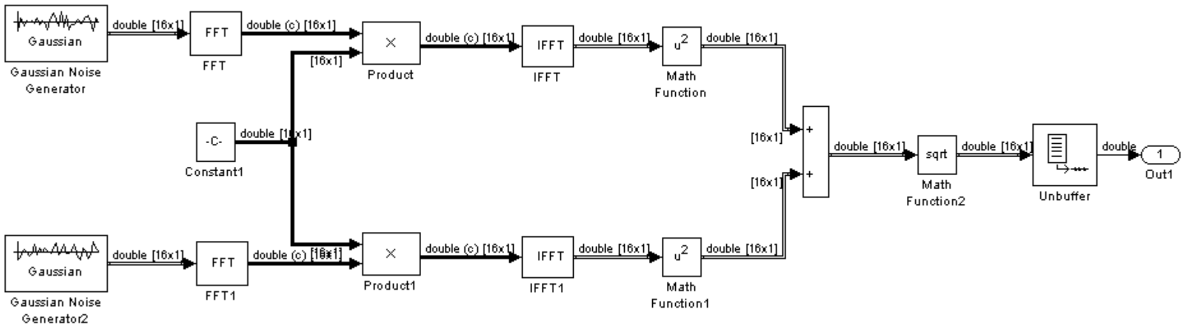

Fig.3. Rayleigh fading simulator for one branch of multipath fading channel.

4. SIMULATION RESULTS

Our simulation results are shown in fig.4 – 6.
We have presented here only B channels, because of their more damaging effect on transmitted signal. Channels have been modeled with the same initial seed of parameters. To compare these waveforms we have prolonged simulation to 2 sec. From both fig. 6 and 7 short – term fading and shadowing fading are visible, and the great scattering property of the vehicular channel is obvious.

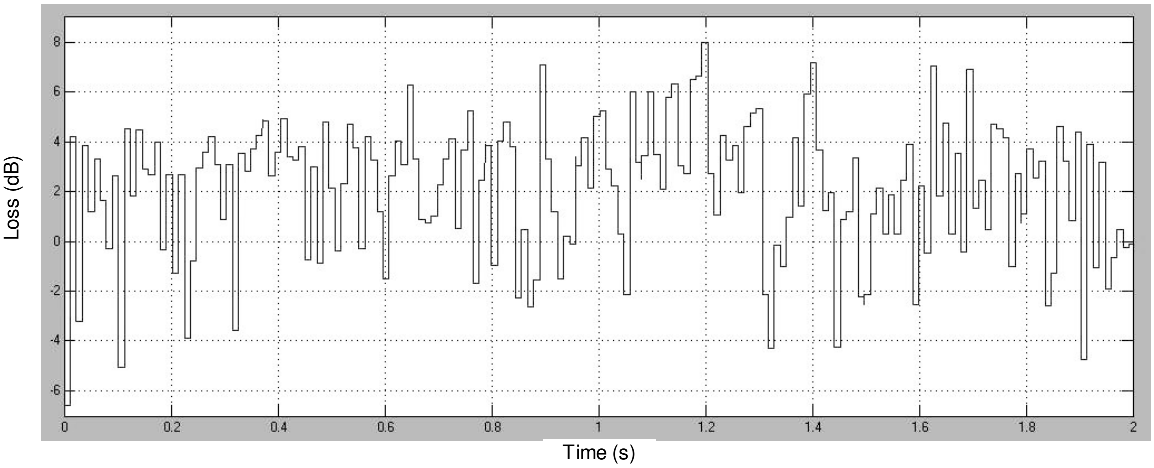

Fig.4. Short – term fading for Pedestrian – B channel

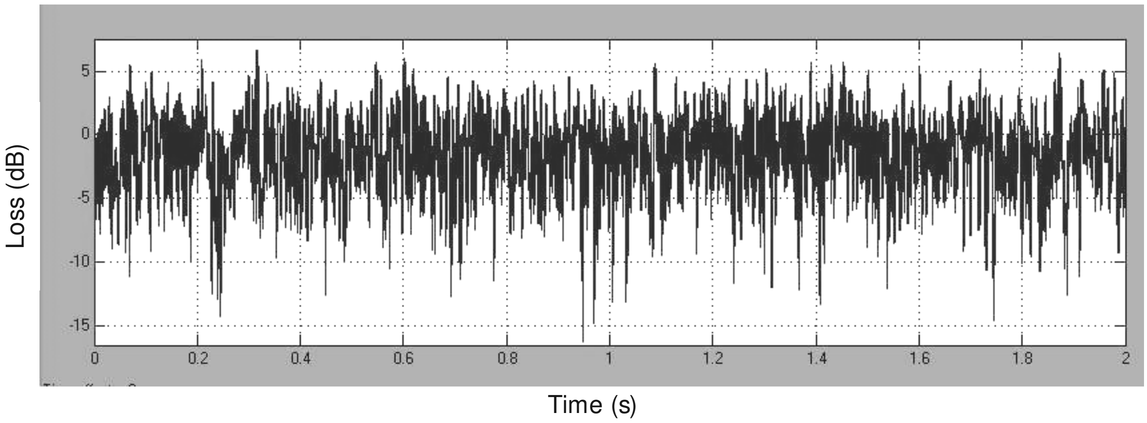

Fig.5. Short – term fading for Vehicular – B channel

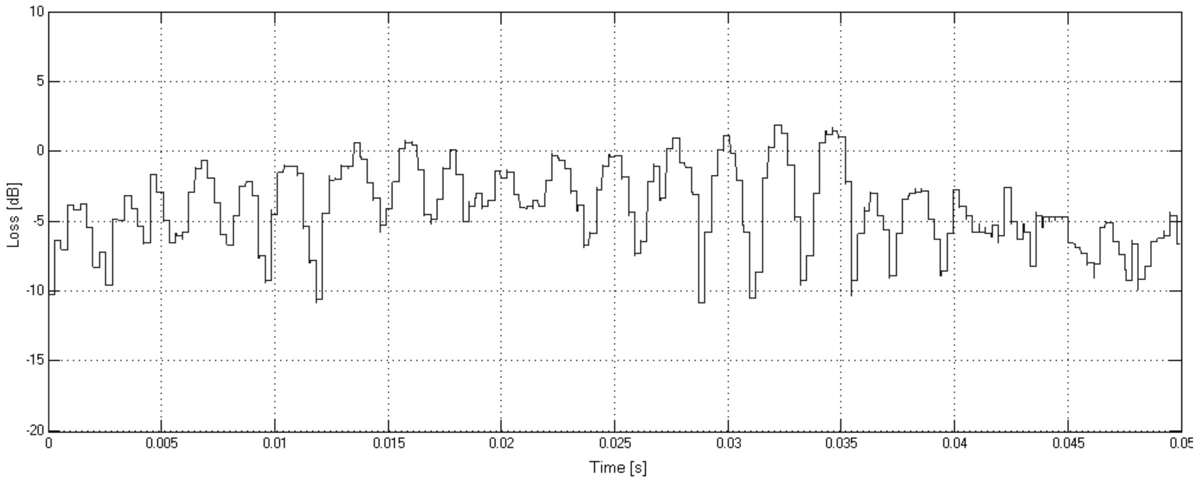

Fig.6. Short–term fading for Vehicular–B channel (segment of 50ms)

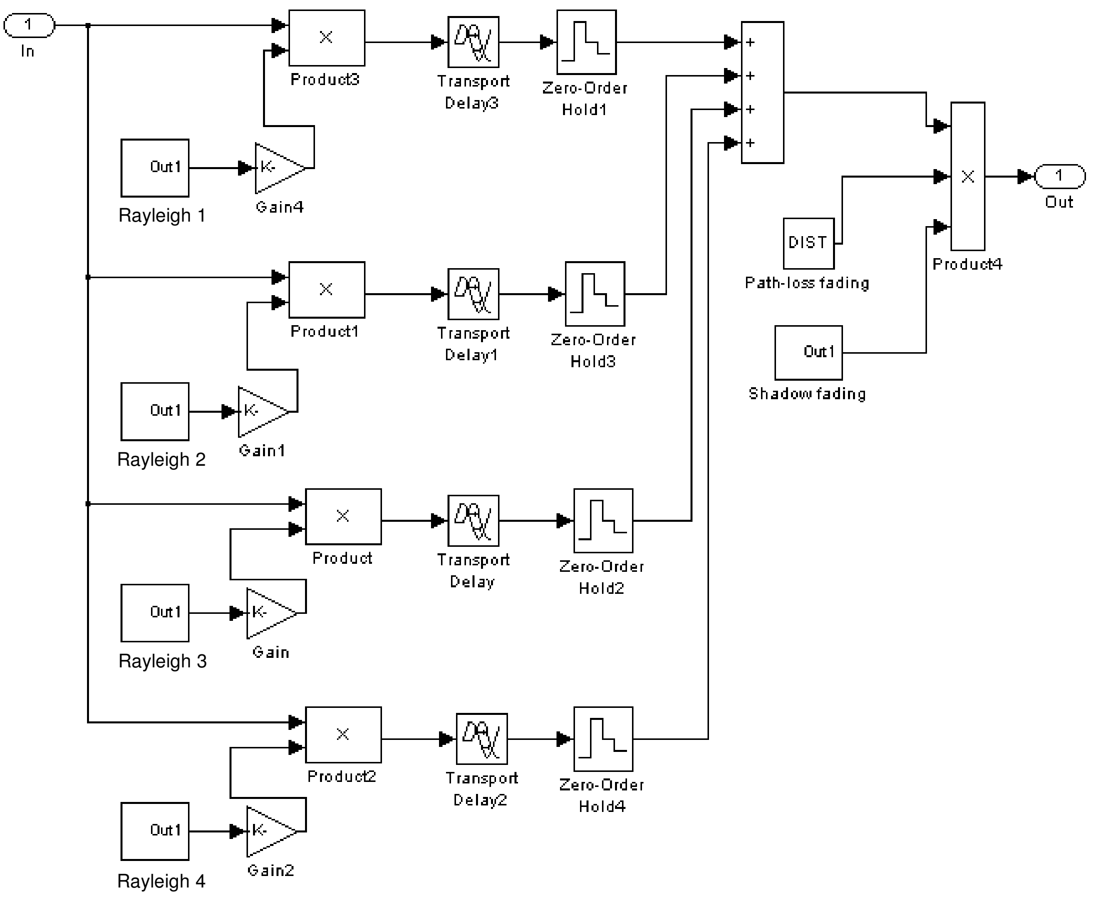

Fig. 7. Rayleigh fading simulator for four branches of multipath fading channel.

5. CONCLUSION

Complex fading channel for two environments (pedestrian and vehicular) has been modeled. Model consists in three main fading mechanisms, i.e. long-term fading, induced by two mechanisms: path-loss fading and shadow fading and short-term fading, induced also by two mechanisms: multipath propagation and Doppler spread. As theoretical model for short-term fading we have chosen the Clarke-Gans model prepared for computer simulation by Smith. Our complex fading model makes possible to simulate all three fading mechanisms in one MATLAB m-file. Simulation has shown very good coincidence with the theoretical model.

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