Wireless Channel Simulator

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1 Introduction

Our Wireless Channel Simulator is a set of MATLAB functions for simulating realistic wireless links. In the wireless communication literature [1–3], it is well established that the received signal strength between two nodes can be modeled with three major dynamics: *Multipath fading (or small-scale fading)*, *Shadowing (or shadow fading)* and *Path loss*. Fig. 1 shows the received signal strength along a route. The three main dynamics of the received signal strength are marked on the figure. Path loss is the slowest dynamic which is associated with the signal attenuation due to the distance-dependent power fall-off. Depending on the environment, blocking objects may result in a faster variation of the received signal strength, referred to as shadowing. Finally, multiple replicas of the transmitted signal can arrive at the receiver due to the reflection from the surrounding objects, resulting in an even faster variation in the received signal strength called multipath fading.

1.1 Wireless Channel Modeling

Given a set of input parameters (described below) the channel simulator generates a realistic channel that is statistically based on those three dynamics. The simulator uses the probabilistic channel modeling framework which characterizes the distribution of a sample of the channel as well as its spatial correlation. Let $\Upsilon(q)$ denote the received signal strength in the transmission from a fixed base station (remote station or transmitter) at $q_b \in \mathbb{R}^2$ to a mobile node at $q \in \mathbb{R}^2$. We can characterize $\Upsilon(q)$ by a 2D non-stationary random field with the following form [3]:

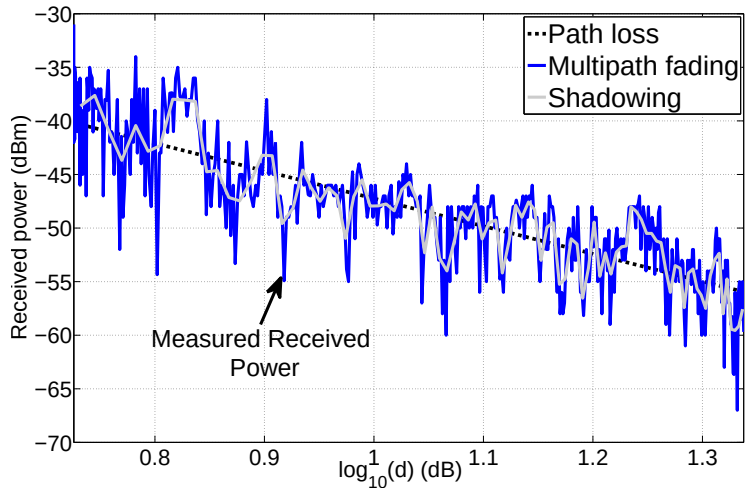

Figure 1: Underlying dynamics of the received signal strength along a route [4]. d is the distance to the transmitter.

$$\Upsilon(q) = \Upsilon_{\mathrm{PL}}(q)\Upsilon_{\mathrm{SH}}(q)\Upsilon_{\mathrm{MP}}(q), \tag{1}$$

where $\Upsilon_{\mathrm{MP}}(q)$ and $\Upsilon_{\mathrm{SH}}(q)$ are random variables representing the multipath fading and shadowing components respectively and $\Upsilon_{\mathrm{PL}}(q) = \frac{K_{\mathrm{PL}}}{\|q-q_b\|^{n_{\mathrm{PL}}}}$ is the distance-dependent path loss, where n_{PL} is the path loss exponent and K_{PL} is a constant parameter [3]. Let $\Upsilon_{\mathrm{dB}}(q) = 10\log_{10}\big(\Upsilon(q)\big)$ represent the received signal strength in dB. We have

$$\Upsilon_{\mathrm{dB}}(q) = 10\log_{10}\big(K_{\mathrm{PL}}\big) + \overline{\Upsilon}_{\mathrm{MP,\,dB}} - 10n_{\mathrm{PL}}\log_{10}\big(\|q-q_b\|\big) + \xi(q) + \omega(q), \tag{2}$$

where $\overline{\Upsilon}_{\mathrm{MP,\,dB}} = 10\,\mathbb{E}\Big\{\log_{10}\big(\Upsilon_{\mathrm{MP}}(q)\big)\Big\}$ is the average of the multipath fading in dB, $\xi(q) = 10\log_{10}\big(\Upsilon_{\mathrm{SH}}(q)\big)$ is a zero-mean random variable representing the shadowing effect in dB and $\omega(q) = 10\log_{10}\big(\Upsilon_{\mathrm{MP}}(q)\big) - \overline{\Upsilon}_{\mathrm{MP,\,dB}}$ is a zero-mean random variable, independent of $\xi(q)$, which denotes the impact of multipath fading in dB after removing its average.

In the communication literature, the distributions of $\Upsilon_{\mathrm{MP}}(q)$ and $\Upsilon_{\mathrm{SH}}(q)$ (or equivalently the distributions of $\omega(q)$ and $\xi(q)$) are established based on empirical data. In the simulator, we assumed $\Upsilon_{\mathrm{MP}}(q)$ to be Rician distributed with the following pdf [3]:

$$f_{\Upsilon_{\mathrm{MP}}}(x) = (1+K_{\mathrm{ric}})e^{-K_{\mathrm{ric}}-(1+K_{\mathrm{ric}})x}I_0\Big(2\sqrt{xK_{\mathrm{ric}}(K_{\mathrm{ric}}+1)}\Big), \tag{3}$$

where $I_0(.)$ is the modified 0th order Bessel function and K_{ric} is the Rician K-factor. Note that $K_{\text{ric}} = 0$ results in an exponential distribution, which has a considerable amount of channel variations, while $K_{\text{ric}} = \infty$ results in no fading, i.e. we will have a channel with only path-loss and shadowing. The distribution of the zero-mean multipath component, $\omega(q)$, can then be calculated based on the pdf of $\Upsilon_{\text{MP}}(q)$ as follows: $f_\omega(x) = \frac{\ln(10)}{10} 10^{(x+\overline{\Upsilon}_{\text{MP, dB}})/10} f_{\Upsilon_{\text{MP}}}\big(10^{(x+\overline{\Upsilon}_{\text{MP, dB}})/10}\big)$.

As for the shadowing variable, log-normal has been shown to be a good match for the distribution of $\Upsilon_{\text{SH}}(q)$. Then we have the following zero-mean Gaussian pdf for the distribution of $\xi(q)$:

$$f_\xi(x) = \frac{1}{\sqrt{2\pi\alpha}}\, e^{-x^2/2\alpha}, \tag{4}$$

where α is the variance of the shadow fading variations around path-loss.

Characterizing the spatial correlations of $\xi(q)$ and $\omega(q)$ is also considerably important for our model-based channel prediction framework. As for the spatial correlation of multipath fading, there is no single model that can be a good match for different environments. For generating correlated small scale fading, we assume the environment is rich in scatterers and the antenna has a uniform angle of arrival, in which case the correlation of multipath is given by the Jakes model [3, 5]. The autocorrelation function can be characterized by $A(\tau) = P_r J_0(2\pi f_D \tau)$, where $J_0(.)$ is the Bessel function of the 0th order, f_D is the Doppler shift, τ is the time difference and P_r is the total received power. Via a change of variable, $A(d) = P_r J_0(2\pi d/\lambda)$, where d is the distance and λ is the carrier wavelength. The autocorrelation is 0 when $d = 0.4\lambda$ (0.4λ is the decorrelation distance). Note that the user is also able to generate uncorrelated multipath fading by simply changing one of the input parameters as described later.

The spatial correlation of shadowing is more important as it stays correlated over larger distances. In the communication literature, this correlation is typically modeled with an exponential function:

$$\mathbb{E}\Big\{\xi(q_1)\xi(q_2)\Big\} = \rho\big(\|q_1 - q_2\|\big) = \alpha\, e^{-\|q_1-q_2\|/\beta}, \quad q_1, q_2 \in \mathbb{R}^2, \tag{5}$$

where the decorrelation distance, β, controls how correlated the channel is spatially.

2 How To Use The Channel Simulator

The main function that needs to be called is `channel_simulator.m` that takes all the required parameters as its inputs and generates the channel:

```
[gamma_TOT_dB, gamma_PL_SH_dB, gamma_PL_dB, gamma_SH_dB,...
gamma_MP_LIN, g_x, g_y] = channel_simulator(region, ...
    q_b, K_PL, n_PL, alpha, beta, N_sin, PSD_at_f_c, lambda,...
    K_ric, res, corr_mp);
```

with the following list of inputs and outputs:

- inputs
  - `region` : A vector containing the boundary of the target rectangular region: `region = [x_min, x_max, y_min, y_max]` in meters
  - `q_b` : Position of the base station (remote station or transmitter) in $\mathbb{R}^2$ in meters
  - `K_PL`, `n_PL` : Path-loss parameters K_{PL} and n_{PL} as described before
  - `alpha` : Power of the shadowing α (dB)
  - `beta` : Decorrelation distance β in meters
  - `N_sin` : Number of sinusoids to use when generating the shadowing components based on the method proposed in [6]
  - `PSD_at_f_c` : The amplitude difference (in dB) between PSD of shadowing at cutoff frequency and at frequency 0, which is used to find the cutoff frequency. The cutoff frequency is used to approximate the desired shadowing PSD, which has a "low pass" shape (see Eq. 24 of [2] for the mathematical expression of the PSD of shadowing). The portion of the PSD beyond the cutoff frequency will be ignored in the approximation. See Section 6 of [2] for more details.
  - `lambda` : The wavelength λ of transmission in meters
  - `K_ric` : Rician K factor (K_{ric})
  - `res` : The resolution of the grid (samples/meter)
  - `corr_mp` : A flag that determines if the multipath component is correlated. `corr_mp = 1` for correlated and `corr_mp = 0` for uncorrelated multipath
- outputs
  - `gamma_TOT_dB` : Channel (path loss + shadowing + multipath) (dB)

- `gamma_PL_SH_dB` : Path loss + shadowing (dB)
- `gamma_PL_dB` : Path-loss only (dB)
- `gamma_SH_dB` : Shadowing only (dB)
- `gamma_MP_LIN` : Multipath (in linear domain)
- `g_x, g_y` : The 2D grid corresponding to the given rectangular region

3 Where To Start

There are three demo scripts that can be used as a starting point:

- `test_channel.m` : This script shows how to specify the input parameters and call the `channel_simulator` function. A sample channel is generated by running this script.
- `test_corr_multipath.m` : In this script, the ACF (Autocorrelation function) of the inphase and quadrature components of the multipath fading are calculated and compared with the desired (theoretical) ones.
- `test_corr_shadow.m` : In this script, the ACF of shadowing component is calculated and compared with the desired (theoretical) ones. Two methods are used for calculating the ACF of the resulting shadowing signal. One method (the faster one) uses the `xcorr2` function of MATLAB to calculate the 2D ACF of the signal and considers the values along both x and y axis. The second method (the slower but more accurate one) uses a Monte Carlo method to calculate the ACF. In the Monte Carlo method, a set of random samples are chosen and the value of the ACF at distance d is calculated by considering all the points that are on the circle (with radius d) around each random sample.

References

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