# Brief Tutorial on the Statistical Top-Down PLC Channel Generator

Andrea M. Tonello
Università di Udine - Via delle Scienze 208 - 33100 Udine - Italy
web: www.diegm.uniud.it/tonello - email: tonello@uniud.it
December 2010

## Abstract

We report a brief tutorial for the use of the top-down power line communications channel generators (release 1.0 and release 2.0) that are available in the web site: www.diegm.uniud.it/tonello. The generators follow the models in [1] and in [2].

## Top-Down PLC Channel Generator

The top-down power line communications (PLC) channel generator herein described is based on the frequency domain multipath propagation model which is a well accepted model for transmission lines with discontinuities and unmatched loads. In detail, the PLC channel frequency response (analytical signal) is synthesized as follows

$$H^{+}(f) = A \sum_{p=1}^{N_p} g_p(f) e^{-j\frac{2\pi d_p}{\nu} f} e^{-(a_0 + a_1 f^K) d_p}, \quad 0 \leq B_1 \leq f \leq B_2, \tag{1}$$

where the number of paths $N_p$, the path gains $g_p$, and the path lengths $d_p$ are random variables. Further details on the distribution of the random variables and on the constant parameters obtained by fitting measurement data can be found in [1] and in the deliverable of the EU OMEGA project [3]. In the following, we assume the frequency dependent path gains model proposed in [2], i.e.,

$$g_p(f) = A_0 g_p + A_1 h_p f^{K_2}, \tag{2}$$

and we model the number of components $N_p$ as the arrivals of a Poisson process with intensity $\Lambda$ path/m, the path gains $g_p$ and $h_p$ as two independent uniformly distributed random variables in $[-1, 1]$, and the other parameters as constants.

By properly selecting the values of all the parameters and variables, the model is able to fit a set of measured data. In particular, we consider the results of a large measurement campaign reported in [3] and [4] according to which it has been verified that the channels can be partitioned in classes according to their average path loss profile. Each channel class is characterized by its own statistic in terms of path loss, delay spread, average channel gain, coherence bandwidth and so on. Furthermore, this classification yields several levels of achievable average channel capacity since there is a one-to-one correspondence between average path loss and average capacity under the assumption of having a certain background noise, e.g., colored Gaussian noise.

To obtain the set of parameters for each class, we have performed a fitting procedure where we minimize the mean squared error between a target average path loss and the average path loss of the channels obtained with the generator. In turn, the target path loss has been obtained from the analysis of the measured data [3], [4], and it is reported in Figure 1. We further constraint the minimization in such a way that the expected value of the delay spread approaches the one of the measured channels. We focus on channel classes 1, 5, and 9 of [3] in the 1 – 100 MHz frequency band. In Table 1, we report the parameters obtained with the fitting process and used in [2]. In Figure 1, we compare the target path loss obtained from experimental data (Target), to the simulated one (Fit) (a channel realization is also shown) which proves the fitting accuracy of the generator with the experimental data.

Table 1: Channel model parameters for classes 1, 5 and 9, [2].

| Parameter [unit] | Class 1 | Class 5 | Class 9 |
|---|---|---|---|
| $L_{max}$ $[m]$ | 580 | 280 | 130 |
| $\Lambda$ $[path/m]$ | 0.2 | 0.2 | 0.2 |
| $\nu$ $[m/s]$ | 2e8 | 2e8 | 2e8 |
| $\gamma_0$ $[m^{-1}]$ | -0.0064 | -0.0179 | -0.0281 |
| $\gamma_1$ $[s \cdot m^{-1}]$ | 9.9240e-27 | 1.9962e-5 | 2.4875e-20 |
| $K$ | 2.9843 | 0.3654 | 2.2005 |
| $K_2$ | 0.4039 | - | 0.3415 |
| $A_0$ | 2.1763e-5 | 0.0016 | 0.0108 |
| $A_1$ $[s^{-1}]$ | 2.6116e-8 | 0 | 1.62e-5 |

# Statistical Results

In this section, we provide the statistics of the delay spread of each channel class. The delay spread is defined as

$$\tau_{RMS} = \sqrt{\int_0^{+\infty} \left(a - m_\tau\right)^2 P(a) \mathrm{d}a} \quad (s)\,, \tag{3}$$

where

$$P(a) = \frac{|h(a)|^2}{\int_0^{+\infty} |h(b)|^2 \mathrm{d}b} \tag{4}$$

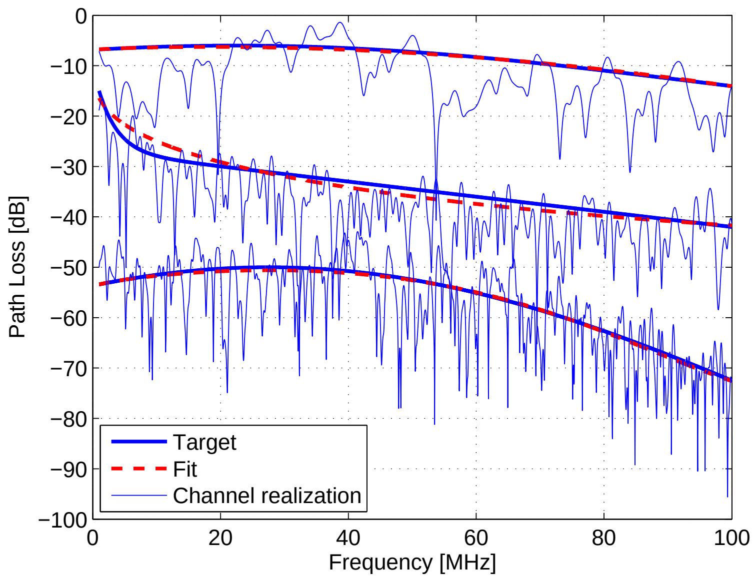



Figure 1: Frequency response models, fitted models and channel realizations for class 1 (bottom), 5 (middle) and 9 (top).

is the power delay profile, $h(\tau)$ is the real channel impulse response derived from the hermitian frequency response $H(f)$, and $m_\tau$ is the mean delay.

We further refer to $\tau_{norm}$ as the normalized logarithmic delay spread, i.e.,

$$\tau_{norm} = \log\left(\frac{\tau_{RMS}}{10^{-6}}\right) . \tag{5}$$

We also study the average channel gain (ACG) and the average logarithmic channel gain (ALCG). The two quantities are defined as follows

$$ACG = 10\log_{10}\left(\frac{1}{B_2 - B_1}\int_{B_1}^{B_2} |H(f)|^2\, df\right) \quad (dB), \tag{6}$$

$$ALCG = \frac{1}{B_2 - B_1}\int_{B_1}^{B_2} 20\log_{10}|H(f)|\, df \quad (dB). \tag{7}$$

In Figure 2, 3 and 4 we show the quantile-quantile plot of the ACG, ALCG and the normalized logarithmic delay spread, respectively. For each channel class we compare the quantiles of the three metrics to the quantiles of the standard normal distribution. We also report the mean values of the metrics. The mean of the delay spread $\tau_{RMS}$ is also shown. In all the cases we have found that the samples lie on the robust linear fit line. Thus, the ACG, ALCG and the normalized logarithmic delay spread are normally distributed with good approximation. Furthermore, it follows that the delay spread is log-normally distributed. All these results are in good agreement with those obtained from the analysis of measured data.

Finally, in Figure 5, we show the delay spread versus the average channel gain of all the channel realizations. The robust regression fit is also shown. In particular, we have found that the slope of the robust regression fit is -0.069 $\mu s/dB$, i.e., in good agreement with the experimental results. We point out that the average channel gain and the average delay spread are negatively correlated. That is, the higher the channel attenuation, the higher the delay spread is. This can be explained by the fact that attenuation in PLC channels is due to multipath propagation.

## Guidelines for the Use of the Generator

Two releases of the generator are available online. Release 1.0 is a simplified generator capable of generating channels according to the model in [1], while Release 2.0 is capable of generating channels according to the model [2].

### Release 1.0

The release 1.0 is based on a simplified expression of (1), where the frequency dependence of the path gains is neglected. The Matlab code is open-source and it is available online at

http://www.diegm.uniud.it/tonello/SOFTWARE/GEN_PLC_CHAN.m

The function accepts as inputs

- `B2` : the stop frequency in Hertz. The start frequency `B1` is set to 0;
- `a0 a1` : the attenuation parameters of the last exponential in (1). The parameter `k` is set to 1;
- `lambda` : the intensity of the Poisson process that specifies the number of mismatches. It is expressed in $1/m$;
- `Lmax` : the maximum path length in $m$;
- `CHANNEL_DURATION` : channel duration in seconds with maximal value of $10\,\mu s$. The returned channel impulse response (CIR) is truncated by finding the highest energy window of duration `CHANNEL_DURATION`.

and it returns as outputs

- `g_ch` : the complex CIR $g_{ch}(nT_c)$ with a sampling period equal to $T_c = 1/(2 * B_2)$. The channel is normalized such that the frequency response in $dB$ at zero frequency is zero;

- `C0` : a guard parameter. If `C0` is true, the generated impulse response is not valid. Conversely, if `C0` is false, the CIR is valid.

More details about the model can be found in [1], [3]. Essentially, this generator provides channels with average path loss profile similar to those of Classes 2-5 of [3]. The gain factor $A$ shall be adjusted to scale the attenuation to the desired level.

### Release 2.0

The release 2.0 allows for the generation of channels according to the model in [2] for class 1, 5 and 9 of [3] that has been also described here. The class statistics are reported in the previous section. The function generates channel transfer functions between 1 MHz and 100 MHz with a frequency resolution of 24.414 kHz. Differently from release 1.0, the release 2.0 offers an input interface through which the user defines the channel type and the number of channel realizations. In detail,

- Channel type [1, 5, 9]: it specifies the class of the generated channels, i.e., 1, 5 and 9.

- Number of channel realizations (default: 1): it specifies the number of generated channels.

The output is the structure `Data.mat` within the folder `Data` in the working directory. The structure contains the frequency response matrix `H` and the vector of frequency points `f`. If $N$ denotes the number of channel realization and $M$ the number of frequency points, then H is a $M \times N$ matrix. The function plots the path loss in magnitude and phase of the generated channels. When more than one channel realization is generated, the average path loss profile is also shown. The Matlab pseudo code is available online at

http://www.diegm.uniud.it/tonello/SOFTWARE/GEN_PLC_CHAN_REL_2.p

## Acknowledgement

The author wishes to acknowledge the help of B. Béjar, F. Versolatto, and L. Di Bert for the preparation of these notes.

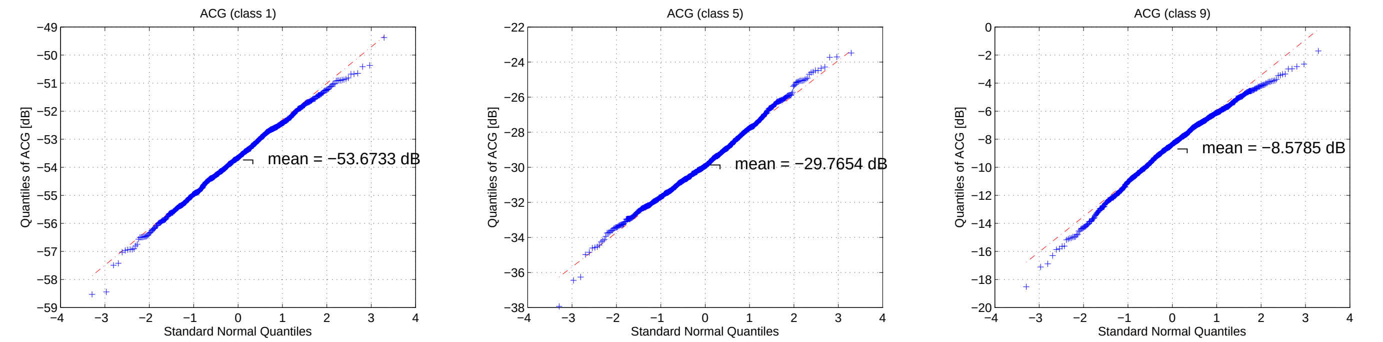
## References

[1] A. M. Tonello, "Wideband Impulse Modulation and Receiver Algorithms for Multiuser Power Line communications," EURASIP Journal on Advances in Signal Processing, vol. 2007, pp.1-14.

[2] A. M. Tonello, S. D'Alessandro, L. Lampe , "Cyclic Prefix Design and Allocation in Bit-Loaded OFDM over Power Line Communication Channels," IEEE Trans. on Commun., vol. 58, no. 11, pp. 3265-3276, November 2010.

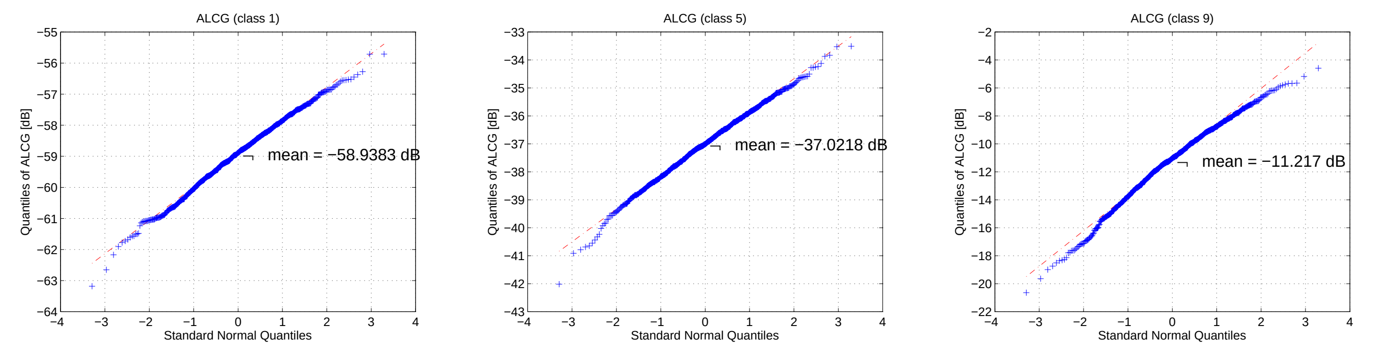
[3] Seventh Framework Programme : Theme 3 ICT-213311 OMEGA, Deliverable D3.2, "PLC Channel Characterization and Modelling," Dec. 2008. http://www.ict-omega.eu/fileadmin/documents/deliverables/Omega_D3.2_v1.1.pdf

[4] M. Tlich, A. Zeddam, F. Moulin, F. Gauthier, "Indoor Power-Line Communications Channel Characterization Up to 100 MHz - Part I: One-Parameter Deterministic Model," IEEE Trans. on Power Del., vol. 23, no. 3, pp. 1392 - 1401, July 2008.



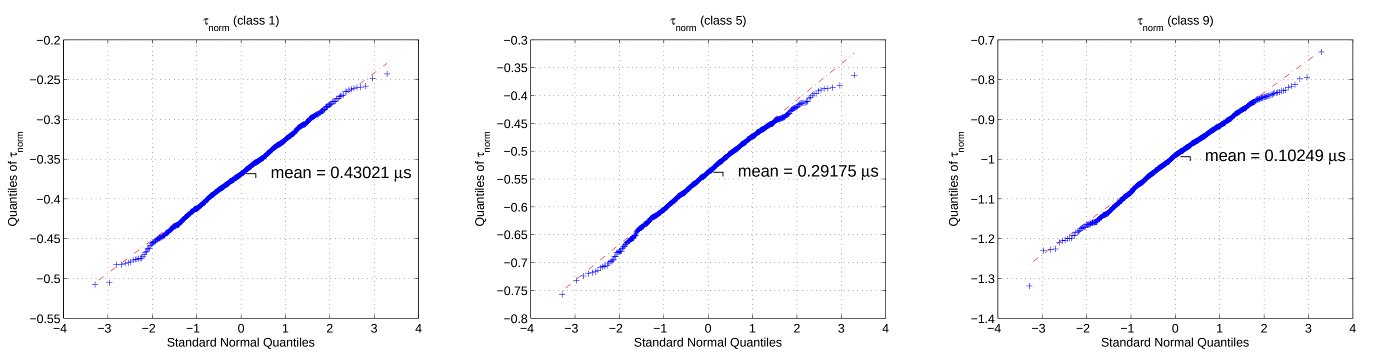

(a) Class 1. (b) Class 5. (c) Class 9.

Figure 2: QQ plot of the average channel gain (ACG).




(a) Class 1. (b) Class 5. (c) Class 9.

Figure 3: QQ plot of the average logarithmic channel gain (ALCG).




(a) Class 1. (b) Class 5. (c) Class 9.

Figure 4: QQ plot of the normalized logarithmic delay spread ($\tau_{norm}$).

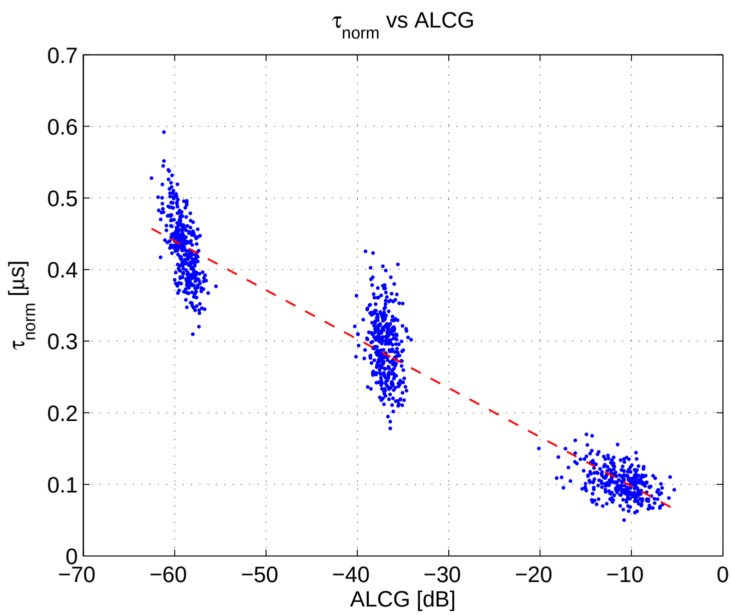



Figure 5: Scatter plot of the delay spread versus the average logarithmic channel gain (ALCG).