# Modelling of Statistical Fading Parameters in Maritime Container Terminal Environments

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## Abstract

In this paper a detailed analysis of slow and fast fading effects in container terminal environments is presented, fading distribution parameters are evaluated and an analytical model is proposed. The model is composed of a set of analytical equations allowing to evaluate fading statistical distribution parameters for different system and environments conditions. Globally, it is observed that for slow fading a good fitting is obtained with the Lognormal distribution. Values of $\overline{\mu_L}$ and $\overline{\sigma_L}$ ranges from -1.95 to -1.18 dB and 2.45 to 3.22 dB, respectively. Fast fading effects are well modelled by Rayleigh, Rice or Nakagami distributions with the later one being the more appropriate. The best fit was obtained with the Nakagami distribution with shape and scale parameters, $\overline{\mu_N}$ and $\overline{\Omega_N}$, ranging from 0.79 to 1.23 and 2.52 to 3.58, respectively.

*Keywords* — fading, shadowing, maritime container terminal, statistical distribution fitting.

## 1 Introduction

Radio channel characterization is a very important part of the wireless systems design process and it has crucial influence on the system reliability. There are many channel models for the most common outdoor and indoor environments, but industrial environments, especially outdoor ones, are still insufficiently investigated.

So far, there are several channel models for industrial environments but in vast majority for indoor scenarios like steel and paper mills [1], chemical pulp factory and cable production hall [2], car parks [3] and airports [4], among others. Due to the lack of channel models for outdoor industrial environments the well-known propagation models for urban areas may be used after statistical tuning [5]. However, the accuracy of adjusted models is not satisfactory and there is a need to develop new channel models for untypical environments like maritime container terminal ones where radio wave propagation takes place in the presence of metallic and corrugated walls formed by stacked cargo containers whose heights are different and time varying. Additionally, diffraction and reflections caused by numerous trucks and cranes moving in the quay have a strong influence in wave propagation.

There are some undertaken investigations on radio wave propagation in the environment under consideration. In [6] the path loss modelling for three frequencies (433, 868, and 2 400 MHz) in the environment of stacked shipping containers has been presented. The path loss model for wider frequency range (0.5 to 4 GHz) has been presented in [7]. A most complex approach has been presented in [8], where the empirical propagation model for mobile radio links in a container terminal environment has been described. This model ensures an accurate path loss estimation, nevertheless, no information about fading characteristics in the investigated environment, including slow and fast fading effects are addressed.

In this paper, slow and fast fading characteristics are evaluated from fitting Lognormal, Rayleigh, Rice and Nakagami distributions to measurement results. Distributions parameters for different frequencies, Base Station (BS) antenna height and container terminal areas are evaluated and an analytical model for these parameters is proposed.

This paper is organized as follows. The scenario description and measurement setup is described in Section 2. A detailed analysis of slow and fast fading fitting results is presented in Section 3. The proposed analytical model is described in Section 4. Conclusions are drawn in Section 5.

## 2 Measurement scenario

The scenario being considered in this paper is the Deepwater Container Terminal (DCT) in Gdańsk, Poland. This terminal is located on an artificial peninsula surrounded by the sea on three sides and it has been widely described in [8].

### 2.1 Scenario description

A view of the Gdańsk DCT is presented in Figure 1.

**Figure 1.** Panoramic view of the Gdańsk DCT.

The area is about 20 ha with a length of 650 m and width of 310 m. Containers are stored on 32 containers storage fields, spaced in 8 rows, 4 fields for each row. Each containers storage field is 139 m long and 20 m wide. The width of the main routes in between these fields is 10 m, and the width of perpendicular routes is 19 m. On each storage field, it is possible to place 154 stacks of 20-ft containers. At most, five containers may be placed in one stack, and standard 20-ft container is about 6.1 m long, 2.5 m wide and 2.6 m high.

The container terminal area classification proposed in [8] has been taken into account. In this scenario, the BS is mounted on a crane which moves along the DCT. Therefore, there are three areas of the DCT, where different propagation mechanisms have a crucial influence on the path loss [8]. The LoS Area is defined for the propagation path lengths shorter than the distance between transmitting antenna and the first row of storage fields. The Containers Area starts with the first row of storage fields and ends with the last one. The Off-T Area is beyond the last (8$^{\text{th}}$) row of storage fields.

The measurement campaign spanned over several days and, in consequence, scenario characteristics had significantly changed during the whole measurement campaign. For the different campaigns the weighted average off all container stacks, $\bar{h}_T$, was evaluated as,

$$\bar{h}_{T[\mathrm{m}]} = \frac{\sum_{i=1}^{8} h_{c,i[m]} \cdot S_i}{\sum_{i=1}^{8} S_i} \quad (1)$$

and the weighted standard deviation, $\sigma_{h_T}$, as

$$\sigma_{h_{T}[\mathrm{m}]} = \sqrt{\frac{\sum_{i=1}^{8} \sigma_{c,i[\mathrm{m}]}^{2} \cdot S_i}{\sum_{i=1}^{8} S_i}} \quad (2)$$

where $h_{c,\mathrm{i}}$ and $\sigma_{h_{c,i}}$ correspond to the average height and standard deviation of the height of container stacks for the $i^{\text{th}}$ row. $S_i$ is defined as the ratio of surface occupied by containers to the whole surface available for storage in the $i^{\text{th}}$ row.

## 2.2 Measurement setup

A detailed description of the measurements equipment and procedures may be found in [8]. The transmitted signal was a Binary Phase Shift Keying (BPSK) modulated signal with a bandwidth of 6 kHz and the following different center frequencies: 0.5, 1.0, 2.0, and 4.0 GHz. The BS was installed on the ship-to-shore gantry crane and the BS antenna heights, $h_{BS}$, being considered are 12, 24, and 36 m.

The mobile receiving section, the MT, is placed on the hand cart and during measurements it was moving along the routes between containers storage fields. Measurement points were spaced every 0.8 of wavelength, which is in accordance with [9]. The MT antenna is being positioned at 2 m height.

# 3 Fading Analysis

An analysis of measured slow and fast fading effects is presented in this section and statistical distribution parameters are evaluated for different values of $f$, $h_{BS}$ and DCT areas being considered.

A Lognormal distribution with mean value, $\mu_L$, and standard deviation, $\sigma_L$, is used to characterize the slow fading effects. For modelling fast fading effects, the following distributions are used: Rayleigh, with scale parameter $\sigma_{Ra}$; Rice, with parameters $\upsilon_{Ri}$ and $\sigma_{Ri}$ corresponding to the magnitude of the LoS and the nLoS components, respectively; and Nakagami, with shape parameter $\mu_N$ and scale parameter $\Omega_N$.

## 3.1 Data Analysis

In order to evaluate slow and fast fading statistics and derive the corresponding distribution parameters, distance independent attenuation values, $L_{i\_norm}$, were evaluated.

The slow fading, $L_{slow}$, is then calculated by averaging $L_{i\_norm}$ over a window of 20λ [10]. Fast fading values, $L_{fast}$, are evaluated as the difference between $L_{i\_norm}$ and $L_{slow}$. Statistical parameters for the different distributions being considered were evaluated from fitting of measured data and correlation and chi-squares tests were made for assessing the fitting accuracy. Chi-square tests were performed for a significance level of 5%. It must be stressed that due to the sensitivity of the chi-square test to the total number of samples, and in order to ensure that it will not influence the results, a constant number of samples was considered for each of the measurement scenarios being considered [11]. Hence, 100 random samples were extracted from the complete data set being considered in each measurement scenario. This procedure was repeated 50 times and it is considered that the test passes if more than 50% of the cases pass.

## 3.2 Slow fading

Average values and standard deviation of Lognormal distribution parameters are presented in Table 1. For each value of $f$ and $h_{BS}$, $\mu_L$ and $\sigma_L$ Lognormal parameters were evaluated and correlation and chi-square tests were performed for assessing accuracy.

**Table 1**. Slow fading, average Lognormal fitting values.

| **Par.** [dB] | $f$ [GHz] | | | | $h_{BS}$ [m] | | | **Area** | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **0.5** | **1** | **2** | **4** | **12** | **24** | **36** | **LoS** | **Cont** | **Off-T** |
| $\overline{\mu_L}$ | -1.67 | -1.43 | -1.41 | -1.50 | -1.84 | -1.40 | -1.27 | -1.18 | -1.95 | -1.38 |
| $\sigma_{\mu L}$ | 0.79 | 0.59 | 0.64 | 0.62 | 0.53 | 0.63 | 0.68 | 0.76 | 0.38 | 0.50 |
| $\overline{\sigma_L}$ | 2.75 | 2.62 | 3.20 | 3.09 | 2.58 | 3.14 | 3.02 | 3.22 | 2.45 | 3.07 |
| $\sigma_{\sigma L}$ | 0.62 | 0.86 | 0.95 | 0.60 | 0.70 | 0.78 | 0.78 | 0.69 | 0.41 | 0.95 |

It is observed that the average mean value, $\overline{\mu_L}$, is comparable for all cases, similarly as the average standard deviation, $\overline{\sigma_L}$, which means that the model for slow fading has a similar form for all investigated cases.

Average, $\bar{\rho}$ and standard deviation correlation values obtained for the given values of $f$ and $h_{BS}$ in the different DCT areas under study are presented in Table 2. As one can observe average correlation values are between 83.28 and 96.57% with a maximum standard deviation of 14.92%. The standard deviation is between 3.58 and 14.92%, with smaller values being obtained for higher frequencies. This is not surprising since higher the frequency the higher is the wavelength and, hence, the larger the number of samples obtained for the fitting process.

**Table 2.** Slow fading, Average correlation values.

| **Par.** [%] | ***f*** [GHz] | | | | $\boldsymbol{h_{BS}}$ [m] | | | **Area** | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0.5 | 1 | 2 | 4 | 12 | 24 | 36 | LoS | Cont | Off-T |
| $\bar{\rho}$ | 83.28 | 88.89 | 96.57 | 96.85 | 89.74 | 91.39 | 93.07 | 90.32 | 92.33 | 91.55 |
| $\sigma_\rho$ | 14.92 | 10.98 | 3.58 | 4.80 | 14.93 | 10.86 | 5.83 | 11.93 | 11.47 | 10.23 |

Average correlation values obtained for different DCT areas are quite similar being between 90.32 and 92.33%. Also, there is no significant difference regarding $h_{BS}$, the average correlation values being between 89.74 and 93.07%.

Regarding the chi-square test, it is observed that the average percentage of success is 83.33%.

## 3.3 Fast fading

Average and standard deviation values of fading distribution parameters in the different DCT areas are presented in Table 3. Correlation values obtained for the given values of $f$ and $h_{BS}$ in different DCT areas are presented in Table 4. Globally, a good fitting is obtained for the different distributions being considered, the better one being obtained with the Nakagami distribution.

From the results, one observes that average correlation values are between 92.4 and 94.72%, 92.56 and 96.22%, and 95.65 and 97.72% for Rayleigh, Rice and Nakagami distributions respectively. Moreover, these values are practically independent of $f$, $h_{BS}$ and the DCT area, nevertheless, for Rayleigh and Rice distributions a slightly better fitting accuracy is observed for higher values of $f$ and $h_{BS}$ in the Off-T Area. For the Nakagami case better results are obtained also for higher values of $f$ and $h_{BS}$ in the Containers Area.

The percentage of successful chi-square tests are between 88.89% for the Rayleigh and Rice distributions and 97.22% for the Nakagami one.

Globally, it is observed that fast fading effects are well modelled by Rayleigh, Rice or Nakagami distributions with the later one being the more appropriate.

**Table 3.** Fast fading, average fitting values.

| **Dist.** | **Par.** | ***f*** [GHz] | | | | $\boldsymbol{h_{BS}}$ [m] | | | **Area** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.5 | 1 | 2 | 4 | 12 | 24 | 36 | LoS | Cont | Off-T |
| **Rice** | $\overline{\upsilon_{Ri}}$ | 0.34 | 0.23 | 0.57 | 0.38 | 0.26 | 0.35 | 0.53 | 0.46 | 0.07 | 0.61 |
| | $\sigma_s$ | 0.43 | 0.33 | 0.48 | 0.47 | 0.35 | 0.43 | 0.49 | 0.43 | 0.01 | 0.48 |
| | $\overline{\sigma_{Ri}}$ | 1.12 | 1.14 | 0.98 | 1.06 | 1.22 | 1.05 | 0.96 | 1.01 | 1.33 | 0.88 |
| | $\sigma_{\sigma_{Ri}}$ | 0.34 | 0.20 | 0.36 | 0.31 | 0.24 | 0.30 | 0.32 | 0.31 | 0.08 | 0.26 |
| **Rayleigh** | $\overline{\upsilon_{Ra}}$ | 1.21 | 1.18 | 1.14 | 1.16 | 1.27 | 1.14 | 1.11 | 1.13 | 1.34 | 1.06 |
| | $\sigma_{\upsilon_{Ra}}$ | 0.21 | 0.13 | 0.21 | 0.17 | 0.17 | 0.18 | 0.17 | 0.20 | 0.08 | 0.10 |
| **Nakagami** | $\overline{\mu_N}$ | 1.02 | 0.98 | 1.13 | 1.06 | 0.89 | 1.09 | 1.16 | 1.12 | 0.79 | 1.23 |
| | $\sigma_{\mu_N}$ | 0.34 | 0.18 | 0.37 | 0.32 | 0.19 | 0.31 | 0.34 | 0.29 | 0.07 | 0.28 |
| | $\overline{\Omega_N}$ | 2.99 | 2.83 | 2.69 | 2.76 | 3.27 | 2.67 | 2.52 | 2.62 | 3.58 | 2.26 |
| | $\sigma_{\Omega_N}$ | 1.02 | 0.62 | 1.05 | 0.83 | 0.88 | 0.83 | 0.76 | 1.02 | 0.42 | 0.41 |

**Table 4.** Fast fading, Distributions correlation.

| **Dist.** | **Par.** [%] | ***f*** [GHz] | | | | $\boldsymbol{h_{BS}}$ [m] | | | **Area** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.5 | 1 | 2 | 4 | 12 | 24 | 36 | LoS | Cont | Off-T |
| **Rice** | $\bar{\rho}$ | 93.59 | 94.23 | 94.21 | 95.44 | 93.82 | 94.10 | 95.18 | 93.13 | 93.75 | 96.22 |
| | $\sigma_\rho$ | 3.45 | 4.71 | 5.33 | 3.52 | 5.21 | 4.56 | 2.64 | 5.99 | 3.39 | 1.67 |
| **Rayleigh** | $\bar{\rho}$ | 92.83 | 94.11 | 93.14 | 94.46 | 93.83 | 93.39 | 93.67 | 92.42 | 93.76 | 94.72 |
| | $\sigma_\rho$ | 3.41 | 4.69 | 5.69 | 4.44 | 5.21 | 4.85 | 3.61 | 5.93 | 3.39 | 3.77 |
| **Nakagami** | $\bar{\rho}$ | 96.79 | 95.79 | 96.97 | 97.56 | 96.96 | 96.27 | 97.10 | 95.65 | 97.72 | 96.97 |
| | $\sigma_\rho$ | 1.09 | 4.65 | 2.03 | 1.19 | 1.67 | 4.05 | 1.51 | 4.08 | 0.86 | 1.45 |

# 4 Fading Model

Since the analysis of the propagation conditions on the DCT, in different areas, settles a set of relevant factors affecting the fading statistics, namely, $f$, $h_{BS}$, $\bar{h}_T$ and $\sigma_{h_T}$, an analytical model is proposed for modelling fading effects. The proposed model is obtained from fitting measurement data in the DCT area being described by a set of analytical equations allowing to evaluate fading statistical distribution parameters for different system and environments conditions. The coefficients of the proposed model were evaluated from a multivariate linear regression of the fitted distributions parameters, to the results from measurements, using the least squares method.

For slow fading the proposed analytical model for the average, $\mu_L$, and standard deviation of the Lognormal distribution is given by:

$$\mu_{L[\text{dB}]} = a_{\mu_L} + b_{\mu_L} \cdot \log\left(f_{[\text{GHz}]}\right) + c_{\mu_L} \cdot \log\left(h_{BS[\text{m}]}\right) + d_{\mu_L} \cdot \log\left(\bar{h}_{T[\text{m}]}\right) \tag{3}$$

$$\sigma_{L[\text{dB}]} = a_{\sigma_L} + b_{\sigma_L} \cdot \log\left(f_{[\text{GHz}]}\right) + c_{\sigma_L} \cdot \log\left(h_{BS[\text{m}]}\right) + d_{\sigma_L} \cdot \log\left(\sigma_{h_{T[\text{m}]}}\right) \tag{4}$$

The coefficients of the proposed analytical model for slow fading (Lognormal distribution) are presented in Table 5.

**Table 5.** Model coefficients for slow fading.

| Area | $a_{\mu_L}$ | $b_{\mu_L}$ | $c_{\mu_L}$ | $d_{\mu_L}$ | $a_{\sigma_L}$ | $b_{\sigma_L}$ | $c_{\sigma_L}$ | $d_{\sigma_L}$ |
|---|---|---|---|---|---|---|---|---|
| LoS | -4.20 | 0.66 | 2.34 | -0.59 | 1.18 | 0.78 | 0.57 | 2.41 |
| Cont | -1.13 | 0.30 | 0.09 | -2.80 | 2.28 | 0.20 | 0.30 | -0.55 |
| Off-T | -2.94 | -0.20 | 1.50 | -1.19 | -2.30 | 0.13 | 1.06 | 8.14 |

For fast fading, the proposed analytical model for the Nakagami distribution (the one that best fits measurement results), with shape parameter $\mu_N$ and scale parameter $\Omega_N$ is given by:

$$\mu_N = a_{\mu_N} + b_{\mu_N} \cdot f_{[\mathrm{GHz}]} + c_{\mu_N} \cdot h_{BS[\mathrm{m}]} + d_{\mu_N} \cdot \bar{h}_{T[\mathrm{m}]} \quad (5)$$

$$\Omega_N = a_{\Omega_N} + b_{\Omega_N} \cdot f_{[\mathrm{GHz}]} + c_{\Omega_N} \cdot h_{BS[\mathrm{m}]} + d_{\Omega_N} \cdot \bar{h}_{T[\mathrm{m}]} \quad (6)$$

The coefficients of the proposed analytical model for the Nakagami distribution are presented in Table 6.

**Table 6.** Model coefficients for fast fading.

| Area | $a_{\mu_N}$ | $b_{\mu_N}$ | $c_{\mu_N}$ | $d_{\mu_N}$ | $a_{\Omega_N}$ | $b_{\Omega_N}$ | $c_{\Omega_N}$ | $d_{\Omega_N}$ |
|---|---|---|---|---|---|---|---|---|
| LoS | 1.05 | -0.01 | 0.02 | -0.22 | 2.61 | -0.10 | -0.08 | 0.94 |
| Cont | 0.70 | -0.01 | 0.00 | 0.04 | 4.17 | 0.02 | 0.00 | -0.23 |
| Off-T | 0.99 | 0.10 | 0.01 | -0.11 | 2.63 | -0.15 | -0.02 | 0.17 |

The validity domain of the proposed models is shown in Table 7.

**Table 7.** Analytical model validity domain.

| Parameter | Range |
|---|---|
| Frequency | $0.5 \leq f_{[\mathrm{GHz}]} \leq 4.0$ |
| BS Antenna height | $12 \leq h_{BS[\mathrm{m}]} \leq 36$ |
| Average height of container stacks | $1.58 \leq \bar{h}_{T[\mathrm{m}]} \leq 2.68$ |
| MT antenna height | 2 m |

# 5 Conclusions

In this paper, a detailed analysis of slow and fast fading effects in container terminals environments is presented, fading distribution parameters are evaluated and an analytical model is proposed.

For slow fading, a good fitting is obtained with the Lognormal distribution with the better one being obtained for the containers and Off-T areas. In general, values of $\overline{\mu_L}$ ranges from -1.95 to -1.18 dB, and $\overline{\sigma_L}$ values are from 2.45 to 3.22 dB. For fast fading the best fit was obtained with the Nakagami distribution with $\overline{\mu_N}$ ranging from 0.79 to 1.23, and $\overline{\Omega_N}$ from 2.52 to 3.58.

Taking into account the range of frequencies being considered (0.5 to 4.0 GHz), the proposed analytical model is broad enough to be used for coverage planning purposes in wireless and mobile networks such as 802.11b/g/n, GSM, UMTS and LTE networks, while providing a simple but accurate framework for the statistical fading characterization in container terminals such as the DCT.

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