# Analysis of Signal Attenuation in UHF Band

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***Abstract.*** *This paper deals with signal attenuation in ultra-high-frequency bands caused by rain. We focus mainly on the effect of the rain on the radio waves propagation in the frequency band 2.1 GHz. Two exact approaches for investigating this dependency are used. In the first approach, we use the fitting probability density function for determination Rician distribution K-factor. In the second approach, we want to find more concrete rain-rate dependency with using linear regression. The results achieved in our long-term investigation clearly indicate that the strong impact of rain itself is a minor. So-called secondary rain impacts such as scattering of reflections from wet surfaces cause the main attenuation contribution.*

## Keywords

***Attenuation, linear regression, rain, UHF.***

## 1. Introduction

The received signal strength of User Equipment (UE) is affected by many aspects, such as the distance between UE and NodeB, the terrain shape of the radio propagation environments or the multipath fading. The multipath fading is the propagation phenomenon that results in radio signals reaching the receiving antenna by two or more paths. Causes of multipath include the tropospheric reflection and refraction, and the reflection from obstacles such as water bodies, terrestrial objects, mountains and buildings. The result of the multipath fading is the instant fluctuation of the received signal level [1].

Meteorological factors such as rain or snow and other forms of precipitation may have a significant impact on the transmission of radio frequency signals through the air environment. Despite, if a Rayleigh channel exists, the signal may still reach the receiver via reflections, diffraction or bending from objects in proximity to the receiver [2], [3].

The reference [4] investigates the effect of rain on the received signal strength of mobile broadband communications in Mubi, Adamawa State over seven months during the wet (rainy) season. The effects of rainfall rates on the propagation along a Line-of-Sight (LOS) channel for wireless access paths were investigated in [5]. They determined that higher rainfall rates lead to higher distortion of signals and, therefore, more paths of propagation. The paper [6] concerns the use of attenuation measurements over microwave link networks to provide time continuous rainfall distribution estimates. A prediction method for attenuation of radio links due to both rain and wet snow is presented in [7]. The method estimates an extra margin for the design of radio links in areas with wet snow precipitation. The paper [8] investigates the effects of trees on the fixed wireless access operating at the frequency 5.8 GHz. As expected, the LOS-link is not affected even during heavy rain condition, however, the presence of trees in the vicinity of the transmission path can cause relevant signal deterioration in the case of Non-Line-of-Sight (N-LOS) link, where the fading of the received signal varies from 2 to 16 dB as the strength of wind and rain increases.

In the worst case, communication systems may suffer from the signal loss caused by the effects of rain or more by the secondary effects (such as a signal scattering) on a radio link. Therefore, the investigation of such the loss can be interested and scientifically contributed in [9], [10]. The all performed research follow [2] that introduces a specific attenuation model for the rain on the frequencies band between 1 to 100 GHz. Our re-

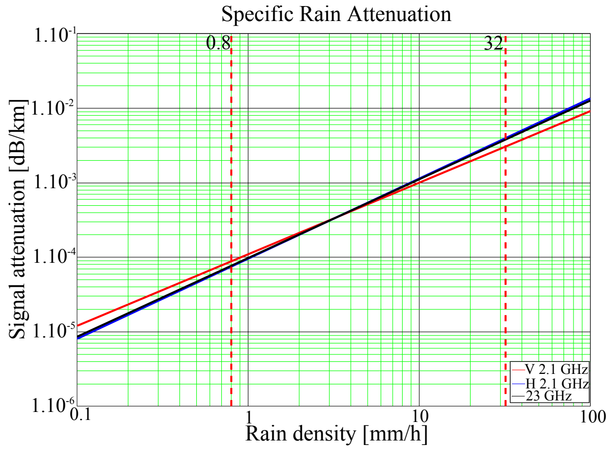


**Fig. 1:** Graph of the signal attenuation at 2.1 GHz depending on rain density.

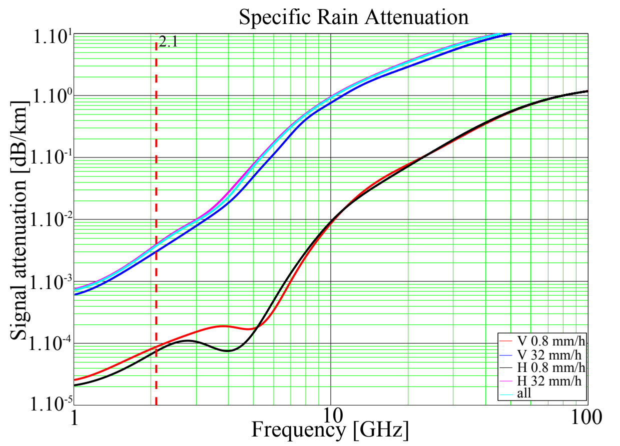


**Fig. 2:** Graph of the signal attenuation at 0.8 (annual average density) and 32 mm·h$^{-1}$ (relative rain rate for 0.01 %).

search examines the impact of rain on the Universal Telecommunication System (UMTS) at 2.1 GHz.

## 2. Method and Procedure

### 2.1. Theory

The ITU-R Rain Attenuation Prediction Method [2] specifies a signal attenuation in rain. The attenuation (dB·km$^{-1}$), is given as a function of rain-rate (mm·h$^{-1}$), signal frequency and polarization. Our investigation is focused only to a spatially homogeneous rain as the UE and the NodeB are in short range area. The time variability of rain occurrence in the current ITU model is given by one of two fixed cumulative distributions, relative to the rain rate exceeded for 0.01 % of an average year. The rain rate is mapped globally in [11]. Consequently, the ITU model defines for the Czech Republic the rain attenuation (dB) exceeded for 0.01 % time 32 mm·h$^{-1}$ (52 min·year$^{-1}$). The trend of the power-law function describes Eq. (1) [2].

$$\gamma(f) = k(f)R^{\alpha(f)}, \qquad (1)$$

where $k$ and $\alpha$ are tabulated coefficients (specific for horizontal and vertical polarization) [2]. Figure 1 gives an example of the signal attenuation at 2.1 GHz depending on rain density. The value 0.8 mm·h$^{-1}$ responds to the annual average rain density in the focused area. The frequency dependence of the signal attenuation is shown on Fig. 2.

### 2.2. Data Acquisition

We acquire the network parameters since April 2011 so over 4 years. The data, which are analyzed consist of two subsets. The first subset is related to the identifiers associated with the UMTS technology while the second subset is related to the identifiers associated with weather. Since we focus on affecting the receive power level by meteorological parameters, we use Received Signal Code Power (RSCP) in UMTS respectively. RSCP is the received power on one code measured on the Primary Common Pilot Channel (CPICH). All identifiers are acquired by Telit GE863 modem and stored on a Raspberry PI board at periodic intervals within 10 seconds period. The data related to weather are acquired by Davis VantagePro2 meteorological stations located in same locations as modems. In our assumptions, we focus only on rainfall meteorological parameter since the snowfall is until now short-term monitored by laser precipitation monitor. Further, we post-process the acquired data, which we introduced in [12] and we obtained more than 250.000 of samples for subsequent analysis.

### 2.3. Estimation of Rician K-Factor

The Rician PDF describes the fading of nonspecular power in the presence of a dominant, the nonfluctuating multipath component [1], [13]. The analytical expression for the Rician distribution results from the integration of Eq. (2) under the condition $N = 1$ and nonzero $P_{dif}$. After applying a well-understood definite integral relationship, the resulting PDF is:

$$f_R(\rho) = \frac{2\rho}{P_{dif}} \exp\left(\frac{-\rho^2 - V_1^2}{P_{dif}}\right) I_0\left(\frac{2\rho V_1}{P_{dif}}\right), \; \rho \geq 0, \qquad (2)$$

where $I_0()$ is a zero-order modified Bessel function.

Figure 3 and Fig. 4 show two histograms of relative power level for the investigated NodeBs with Primary Scrambling Code (PSC) 273 and 444. In the first subgroup was selected that ones, where rainfall was nonzero, and a PDF was applied. The second group contains only levels with zero rainfall. Both subgroups use

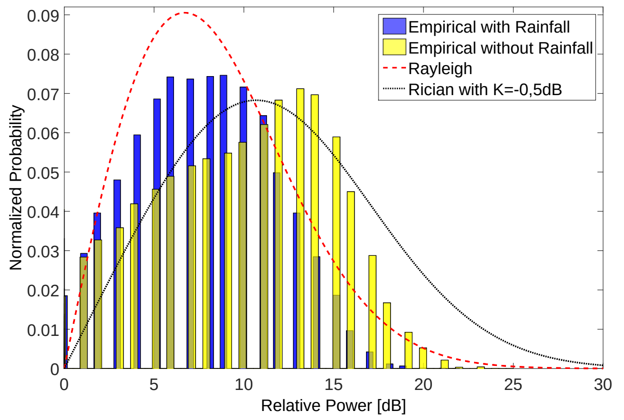


**Fig. 3:** Fitting the probability density functions to the empirical data for NodeB with PSC 273.

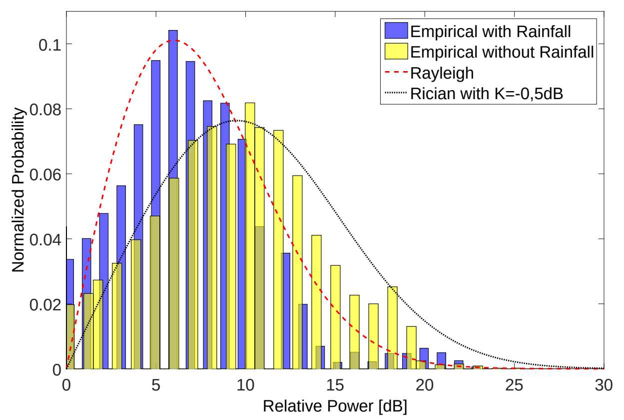


**Fig. 4:** Fitting the probability density functions to the empirical data for NodeB with PSC 444.

the collection of RSCP, which we continuously acquired over 4 years.

The empirical histograms were poorly compared to the *Rayleigh* and *Rician* distribution. The Rician plot is labeled using a $K$-factor, which is the ratio of the power of the dominant multipath component to the power of the remaining nonspecular multipath. From the previous discussion, it can be seen that $K$ is a measure of the severity of fading. Both histograms have a good fit into Rayleigh or Rician distribution respectively.

The comparison proved lower receive levels that indicate the fact that the rainfall has a secondary effect in the form of increased scatter of the signal and, therefore, correspond to the Rayleigh distribution. Rain produces wet surfaces of objects (roofs of buildings, foliage, etc.) while some energy is re-radiated in random directions and causes loss of signal. Increased conductivity of such objects also makes reflections, which should amplify the signal but this fact we did not prove by our empirical experiments. On the other hand, empirical data without rainfall shows that the significant components of the signal correspond to the Rician distribution with $K = -0.5$ dB for both NodeBs. Initial observations suggest that there may be both LOS and NLOS component with the equal amplitudes.

## 2.4. Linear Regression

For modeling the dependency of Receive Level on rain rate, the approach of linear regression (LR) was chosen. Regression analysis is a technique for modeling the relationship between a dependent variable and a number of independent explanatory variables [14], [15]. In the case of the linear regression, the relationship between variables is expected to be linear. Using an ordinary least squares (OLS) method, a line representing a relationship between dependent and explanatory variables is estimated. In the case there is only one explanatory variable in an LR model, we call the method simple linear regression (SLR), [16]. SLR model can be described as follows:

$$Y = \beta_0 + \beta_1 \cdot X + \varepsilon, \tag{3}$$

where $Y$ is a dependent variable, $\beta_0, \beta_1$ are regression coefficients, $X$ is an explanatory variable and $\varepsilon$ is error term.

The regression coefficient $\beta_0$ represents a deviation of the regression model line from the center and the $\beta_1$ represents the nature of dependency of the dependent variable on the explanatory variable. Both of these coefficients are therefore the main focus of statistical estimation by the OLS method. The significance of regression coefficients in the model is verified by a $t$-test, which is used to conduct hypothesis tests on the obtained regression coefficients.

The coefficient of determination ($R^2$) can assess the quality of the resulting regression model. It is computed as a regression sum of squares divided by the total sum of squares. This coefficient represents a measure of the amount of variability in the data accounted by the regression model. In SLR, higher the value of the $R^2$, the better fitting model was found.

The linear regression models utilizing OLS method make a number of assumptions about the explanatory variables, which are verified by residual analysis [17]. Residuals should follow a normal distribution, they have a constant variance and should not form a pattern when plotted in a time sequence. The violation of these assumptions then shows that the relationship between variables is not linear. Thus, different regression approach should be applied.

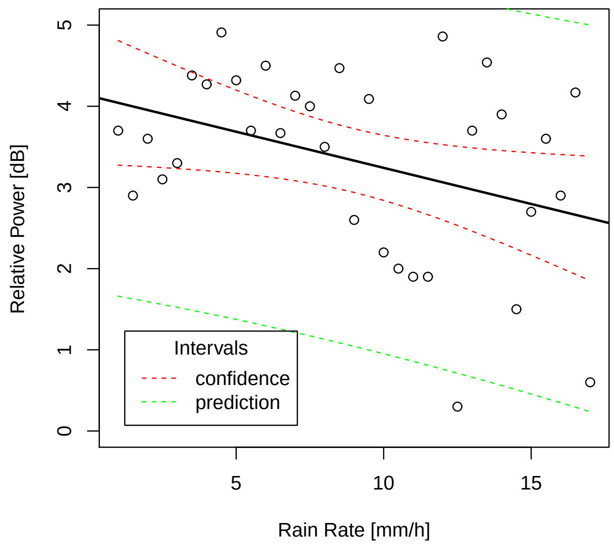


**Fig. 5:** Regression for the receive level and the rain rate of PSC 273.

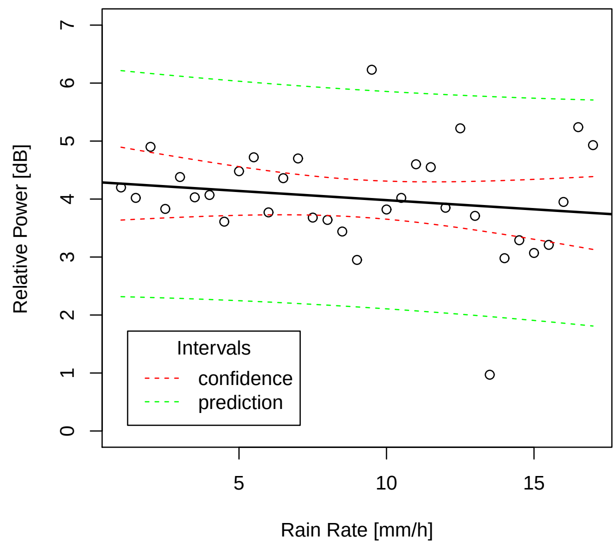


**Fig. 6:** Regression for the receive level and the rain rate of PSC 444.

## 3. Results and Discussion

As a first step in the preparation for regression analysis of a Receive Level (Received Signal Code Power) dependency on a rain rate, the rain rate values were organized into several intervals. For each interval, the mean of Receive Level values was computed, thus reducing the influence of any outliers and increasing regression model lucidity. However, in the case of the higher rain rates, Receive Level values were very scarce. Therefore, the maximum rain rates were limited by 95 % rain rate lower quantile.

**Tab. 1:** Regression model coefficients for selected NodeBs.

| **PSC** | $\beta_0$ | $\beta_1$ | $R^2$ |
|---|---|---|---|
| 273 | −99.869 | −0.089 | 0.107 |
| 444 | −89.702 | −0.032 | −0.003 |

For further analysis, we selected already mentioned NodeBs with PSC 273 and PSC 444. For both PSC, we created a simple linear regression model, and we obtained the regression coefficients. By the use of $t$-tests and residual analysis, we verified models while we determined the accuracy of the models by the value of $R^2$. Resulting regression coefficients and $R^2$ index are shown in Tab. 1.

While both models show a slight decrease of Receive Level for raising rain rate, the accuracy of these models is very low. $R^2$ for more accurate model based on the data from the PSC 273 slightly exceeds 10 % (adjusted $R^2$ index was used as it provides better assessment of model accuracy, negative values represent extremely low model accuracy). Therefore, these models are not suitable for forming a basis for Receive Level prediction for differing rain rates. In Fig. 5 and Fig. 6 Receive Level means layout for each rain rate interval, the regression line and both confidence and prediction intervals are shown.

While there was an expectation that Receive Level should decrease with increasing rain rate, both models show the Receive Level means that are heavily influenced by outliers (best seen in Fig. 5). As none of these data can be considered an observational error, it cannot be removed and thus it strongly contributes to the low model accuracy. However, we have to note that our assumption in not entirely wrong as the models show a decreasing trend for all observed NodeBs.

## 4. Conclusion

We revised the regression analysis model for calculation of attenuation on the receive level due to rainfall. The analysis was performed using 2.1 GHz channel and indicates that the rain drops did not impose any significant attenuation on the signal level in such channel. Our interim assumptions are not entirely wrong as the models show a decreasing trend. However, the rain drops itself produce wet surfaces with increased conductivity and consequently the increased scattering and loss of signal. Fitted PDF proved this loss to the empirical data where we determined K-factor of −0.5 dB.

In the further research, we focus on monitoring of radio links parameters at the tens of GHz frequencies, which have a conclusive correlation weather with the signal level. The attention is going to be also focused on the weather impact on a different type of modulations.

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