Paper

Rain precipitation in terrestrial and satellite radio links

Jan Bogucki and Ewa Wielowieyska

Abstract—This paper covers unavailability of terrestrial and satellite line-of-sight radio links due to rain. To evaluate the rain effects over communication system, it is essential to know the temporal and spatial evolution of rainfall rate. Long-term 1-min average rain-rate characteristics necessary for the design of microwave radio links are determined for central Poland. 1-min rain rate distributions are presented. It also describes comparison results of predicted attenuation obtained from ITU-R formula and empirical data at frequency bands 11 GHz and 18 GHz and satellite 12 GHz. The National Institute of Telecommunications stores 11-year long rain intensity characteristics (1985–1996), based on data derived on 15.4 km long experimental path. In this paper chosen experimental data are presented.

Keywords—satellite and line-of-sight radio links, propagation, rain fading.

1. Introduction

The quality of microwave signal transmission above 8 GHz is dependent on precipitation [1, 2]. The most significant contribution to atmospheric attenuation is due to the rain [3]. Nowadays numerous prediction models for rain attenuation exist. Generally, these prediction methods employ two stages of modeling. The first stage involves the prediction of rain fall rate probability distribution. The second stage relates the path attenuation with the specific attenuation, which is expressed in terms of the rain fall rate and path length.

Fading due to rain is the dominating degradation factor on radio-relays at the frequencies above 20 GHz and is essentially comparable to fading due to the layering of the atmosphere in the frequency range from 8 GHz to 20 GHz.

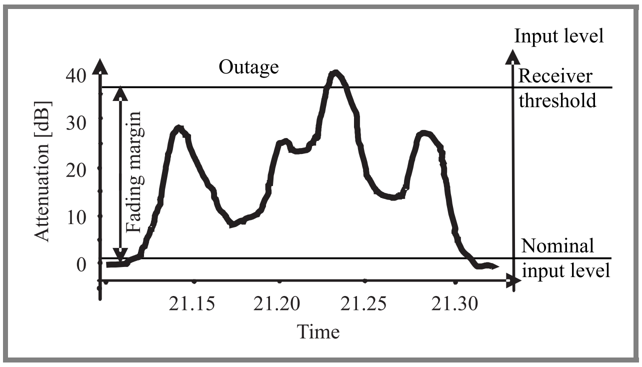

Fig. 1. An example of rain attenuation of 18.6 GHz terrestrial path.

The received signal varies with time and the system performance is determined by the probability for the signal to drop below the radio threshold level (Fig. 1).

It is very important to estimate degradation of radio-relays. Rain fall in the space separating the transmitter and receiver may sometimes cause detrimental effects to the received signal.

This type of fading has been well characterized by yearly measurements resulting in system design methods that limit outages within international standard limits [4]. For this reason it is necessary to develop an experimental network which provides the adequate data to study, prevent and compensate for rain fade. In this paper an experimental rain fall characteristics are presented.

2. Rain fading

2.1. Rain predictions

There are many methods which permit to estimate rain attenuation on radio link paths. The most popular are the ITU-R models [5, 6, 7]. At the National Institute of Telecommunications (NIT) TrasaZ and TraSat computer programs which implement these models have been worked out. They are radio frequency propagation computer programs for transmission path between RF transmitter and receiver. The TrasaZ program calculates fades expected from rain and multipath, attenuation by atmospheric gases, interference, diversity, Fresnel zone as well as determines antenna heights, reduction of cross-polar discrimination and power budget. Earth curvature for standard or sub-standard atmosphere is taken into account. The program frequency range is from 1 GHz to 60 GHz. The TraSat program calculates fades expected from rain, attenuation by atmospheric gases, and power budget of the satellite link for different angles of elevation and geographic location [8].

In the ITU-R model, input data to compute attenuation due to rain are: rain rate $R_{0.01}$ exceeded by 0.01% of the time, effective path length and geographic location [9] and also 0° isotherm height for the satellite path.

2.2. Measurement system

Taking into consideration the nature and the necessity of research on propagation effects occurring in radio links, detailed instructions and requirements, which should be met to prepare a self-operating measuring site, have been described in [9].

The radio links have been developed to test propagation at frequencies 11.5 GHz and 18.6 GHz terrestrial and 12.5 GHz satellite links. Along the path 5 rain gauges were situated (*s1*, …, *s5*) – see Fig. 2. Terrestrial and satellite receivers were situated at the NIT.

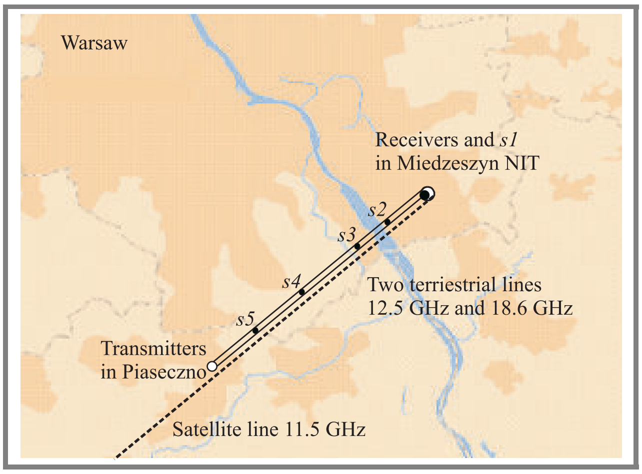

Fig. 2. Map of situated experimental links.

This paper describes the example test results of wave attenuation in above mentioned radio links. National Institute of Telecommunications carried out research on all phenomena causing fading on line-of-sight radio links and then selected only rain fading.

Rain rates and rain attenuation in mentioned radio links were measured in NIT in Miedzeszyn, near Warsaw and statistic distributions were carried out [10].

2.3. Rain measurements

Rainfall is measured in millimeters and the rain intensity in millimeters per hour. An important parameter is the integration time. Typical values of the integration time are 1 min, 5 min, 10 min and 1 hour. An integration time of 1 min should be used for rain intensity in link calculations.

Two types of rain gauges are used in the propagation experiments: capacitor gauges and typing bucket gauges. They have different dynamic ranges, integration time and calibration problems. In our measurement system typing bucket gauges were applied. Their parameters are:

- 1 tip/min corresponded to rain rate of 2.8 mm/h.
- Rain rates from this value down to 0.28 mm/h were calculated by programme application, which averaged single tips in the gaps shorter than 10 min. Longer gaps were considered as the breaks between the rain events.
- Rain intensity was measured in mm/h with values for integration of 1 min.

3. Measurement results and prediction

3.1. Data processing

Received signal samples were used for calculation of monthly and annual fading distributions as well as distributions for worst months. In this last case the formula for selected fading level A [dB] was applied:

$$p_{nm} = \max(p_1, p_2, \ldots, p_{12}),$$

where: $p_1, p_2, \ldots, p_{12}$ – percentage of A [dB] level exceedances in successive months of the year.

Software package was written to analyze propagation data.

3.2. Some rain statistical characteristics

The rain data are important because the percentage of time for which given value of rain attenuation is exceeded can be calculated from the rainfall rate $R_{0.01}$. The $R_{0.01}$ is the rain rate expressed in mm/h exceeded at the considered location by 0.01% of an average year.

Attenuation produced by rain can be caused by rain anywhere along the path where the air temperature is warm enough to maintain liquid raindrops. Rain can occur over the rain gauge but not cover the rest of the path or, conversely, be over most of the path but not over the rain gauge.

Figure 3a presents the results of minute-by-minute comparison of attenuation and rain-rate measurements. Along the path 5 rain gauges were situated as shown in Fig. 3a where rain rates in successive minutes at the five sites during a severe storm are presented. The path attenuation at 18.6 GHz and 11.5 GHz on the line-of-sight radio links and 12.5 GHz satellite path are also shown. In this example the line of columns passed the path at different times.

Figure 3b shows the area to time distribution of rainfall intensity along the path of this rainfall storm. The duration of storm lasted about 18 minutes.

Figures 4 and 5 present the empirical rain rate characteristics. Annual and averaged rain rate distributions for the period of five years are presented in Fig. 4. For the small rain rates, below 10 mm/h, results are the same in each year. Rain rates distributions for high rain rates changed markedly. For example at 0.001% the rain rate threshold increased from 43 in second year up to 106 mm/h in third year.

The stabilization of distributions cumulated in periods of one, two, three, four and five years is presented in Fig. 5.

3.3. Prediction and empirical data at the 12.5 GHz satellite link

The measurements of 12.5 GHz beacon signal from Lucz 1 were conducted and simultaneously of 1-minute average rain rate under the Earth-Lucz path. The projection of the satellite link on the Earth agrees with the terrestrial path. Received antenna elevation angle was 22° and azimuth 224.3°.

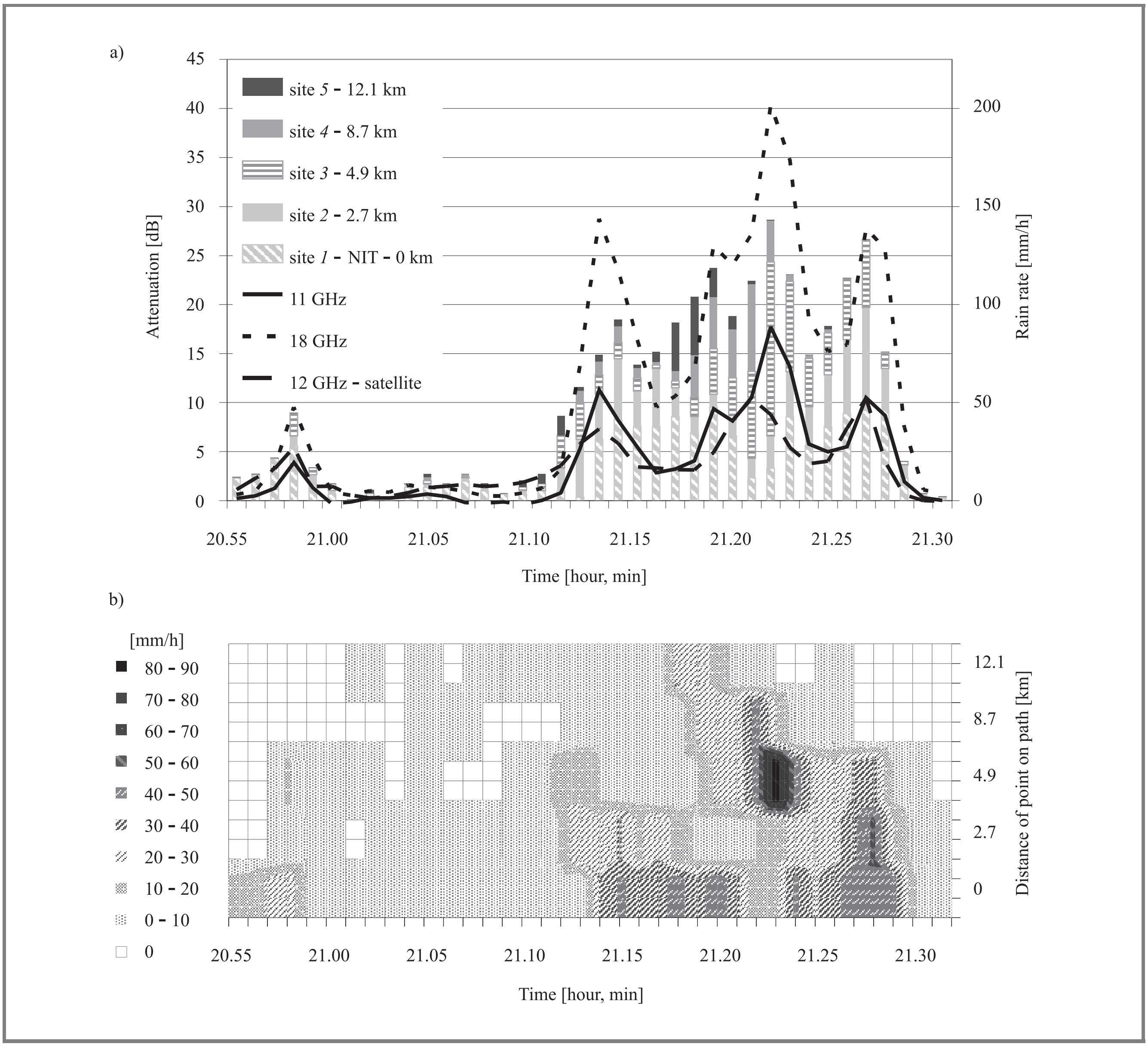

Fig. 3. An example of the storm along 15.4 km path: (a) point rain-rates along the path and path attenuation at 18.6 GHz, 11.5 GHz terrestrials and 12.5 GHz satellite; (b) spatial-temporal distribution of rainfall intensity along the path.

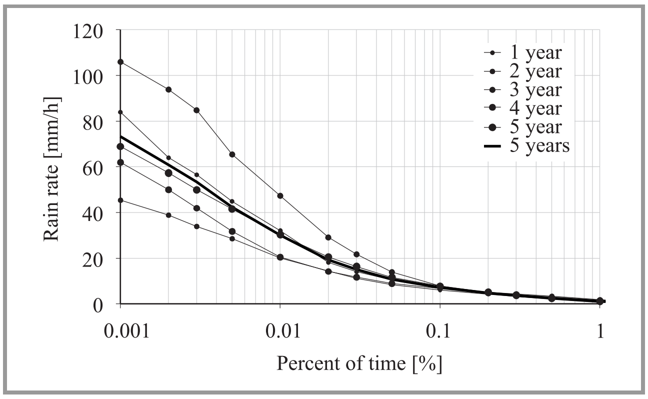

Fig. 4. Annual and averaged rain rate distributions for period of five years.

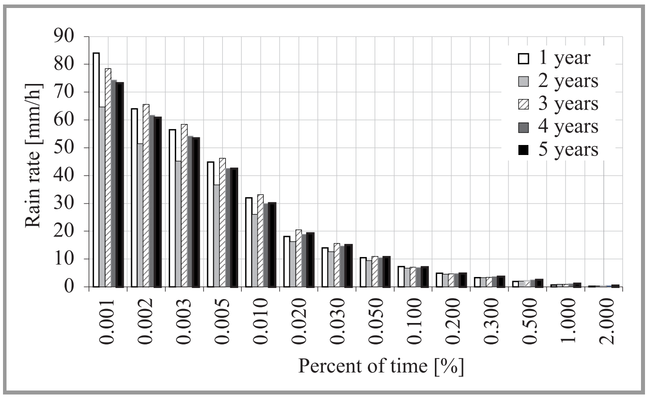

Fig. 5. Cumulated distributions of rain rate in consecutive years.

Having in mind unstable position of satellite and the lack of antenna tracking facility, the signal samples were processed in a special way in order to obtain zero level during the event. 1 minute average values of samples in several minutes before the event and several minutes after the event were calculated. Straight line, which connected both average levels, was taken as zero level for the event.

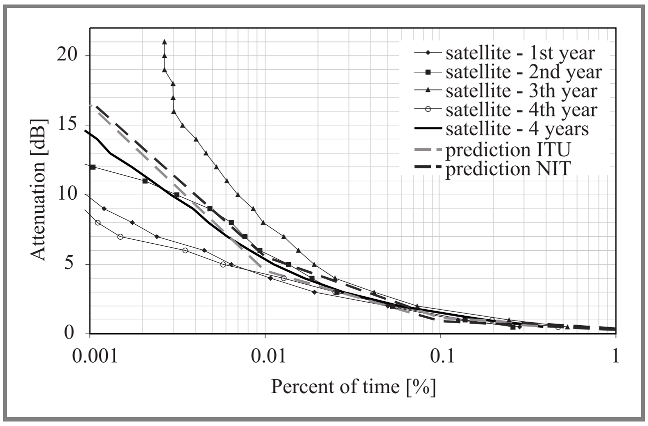

Fig. 6. Measured and calculated distributions of attenuation at 12.5 GHz satellite path.

Annual distributions of attenuation due to rain are presented in Fig. 6. During one storm with very intense rainfall the signal exceeded 20 dB level in this case during 10 minutes. The empirical annual attenuation distribution was compared with predicted distribution, based on model of ITU-R [6].

In this prediction model the input data to calculate attenuation due to rain are:

- data in world database recommended by ITU-R (prediction ITU Fig. 6);
- 0° isotherm height recommended by the Institute of Meteorology and Water Management (IMGW) in Warsaw and rain intensities measured by NIT in Warsaw (prediction NIT Fig. 6).

The biggest difference between empirical average of 4 years and prediction distributions is at 0.001% and is less than 2.4 dB for both prediction distributions. For bigger percentage, it was found out that prediction NIT model at 12.5 GHz satellite links is better than prediction ITU model. The absolute value of the biggest difference from empirical distribution for ITU distribution is 1 dB and for NIT distribution is 0.5 dB.

3.4. Prediction and empirical data at frequencies 11.5 GHz and 18.6 GHz terrestrial links

The terrestrial path of 15.4 km length operated continuously at frequencies of 11.5 GHz and 18.6 GHz [11]. The attenuations due to rain have been selected from other events. Figure 7 presents the rain attenuation statistics, show the percentages of the year that attenuation level *A* [dB] has been exceeded in case of rain on those two paths. Statistics do not include the events with melting snow. The annual attenuation distributions in five year period at 11.5 GHz and 18.6 GHz are presented in Fig. 7.

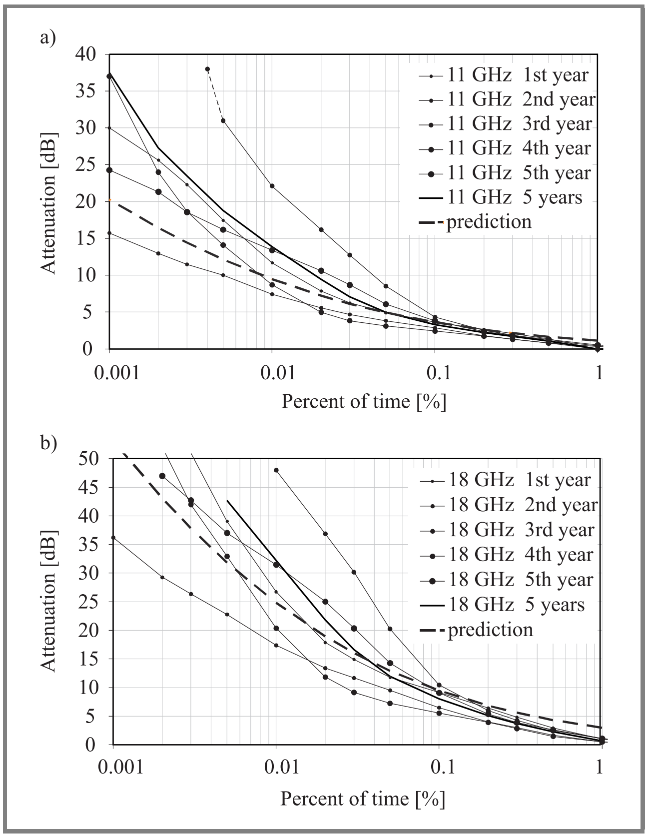

Fig. 7. Measured and calculated distributions of attenuation at (a) 11.5 GHz and (b) 18.6 GHz.

Mathematical description of 11.5 GHz paths corresponds to experimental data of attenuation caused by rain for percents greater than 0.03% time; the difference is below 1 dB (Fig. 7a). But measurement results done in the third year of measurement differ a lot.

Mathematical description of 18.6 GHz paths corresponds to experimental data of attenuation caused by rain for percentage greater then 0.03%; maximum difference measured is 2.3 dB. The maximum difference is 10.8 dB for 0.005% time (Fig. 7b).

4. Conclusion

Microwave radio links can be properly and precisely engineered to overcome potentially detrimental propagation effects. One of the characteristics that must be taken into consideration is rain attenuation. Some power margin has to be incorporated into the network design to allow for the amount of power reduction of received carriers due to rain. Prediction model does not entirely correspond to measurement results because only statistical relationship between rain rate and attenuation is possible.

The data calculated using the ITU-R model differ from experimental data for 11.5 GHz band for small percentage.

It was found out that predicted attenuations at 11.5 GHz radio links are less than measured. And for 18.6 GHz band attenuation measured for small percentage is larger than predicted. ITU-R model corresponds to measurement results in 12.5 GHz satellite link.

The results of rain measurements done in the third year differ a lot – 32 mm/h greater than average value for 0.001%. According to research done at NIT in Warsaw the measured rain intensities are larger than data in world database recommended by ITU-R.

Knowledge of the fading statistics is extremely important for the design of wireless systems. For microwave radio link design it is best to get local cumulative rainfall data. Unfortunately, for many places, there are no data on rain intensities averaged in 1 minute, and we are forced to use global values according to the climatic zone of the link.

If reception frequently cuts in and out of during light rainstorm, this is a good indication that the system has not been peaked to maximum performance. Most of existing rain attenuation prediction models do not appear to perform well in high rainfall regions. Further work should be devoted to parameterize the effects of rain path attenuation in order to provide a quantitative estimation useful for communication system design.

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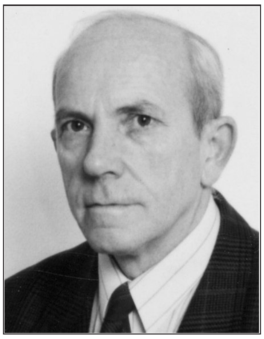

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