Rain Attenuation on Terrestrial Wireless Links in the mm Frequency Bands

Vaclav Kvicera and Martin Grabner
Czech Metrology Institute
Czech Republic

1. Introduction

Millimetre wave terrestrial wireless communication systems are becoming an increasingly important part of the telecommunication infrastructure. They offer a higher transmission capacity thanks to a higher available bandwidth when compared to systems operating in lower frequency bands. Moreover, the frequency spectrum is heavily occupied at lower frequencies by a great number of competing services. Therefore the radio communication systems operating at frequencies higher than 30 GHz will be utilized more frequently in the future.

The performance of all radio systems in general is related to the propagation of electromagnetic waves between the transmitter and receiver. The propagation of millimetre electromagnetic waves through the medium of the lower troposphere is influenced by weather conditions. Rain attenuation belongs among the most important adverse propagation effects impairing the performance of fixed terrestrial wireless systems operating in millimetre wave frequency bands. The study of the rain attenuation phenomenon is therefore indispensable for their efficient planning and utilization.

Rain attenuation characteristics on millimetre wave radio systems are the subject of current experimental research (ITU-R, 2008). In this chapter, the availability objectives for fixed wireless links are briefly discussed, rain attenuation characteristics are defined and the geographical dependence of rain attenuation is demonstrated. Then the specific results obtained from rain attenuation measurements in several mm wave bands are presented. Frequency, polarisation and path length scaling of rain attenuation statistics in mm wave bands are analysed.

2. Availability Objectives for Fixed Wireless Links

Terrestrial fixed wireless links form a part of the global telecommunication network. In order to achieve the reasonable availability and stability of network connections, the basic performance criteria defined for these links has to be required. The availability performance of a particular fixed wireless link is defined roughly as the fraction of time in which data transmission through the link is fully operating. The availability of the link can be limited by both a device malfunction and by propagation effects. Rain attenuation is generally

considered to be the most important effect impairing the millimetre wave links. When the received signal is attenuated due to the scattering and absorption of electromagnetic waves on the rain drops and the attenuation value exceeds the link power margin (also called the fade margin), the link transmission is interrupted. It follows that the availability performance of the particular mm wave link depends on the rain attenuation statistics and the power margin of the link.

2.1 Overview of ITU recommendations on the availability of fixed wireless links

The International Telecommunication Union, Radiocommunication Sector (ITU-R) recommends the quality and availability objectives applicable for fixed wireless links within a telecommunication network (Rec. ITU-R F.1703, 2008). These objectives should be met on the links used in a 27 500 km hypothetical reference path (HRP). An HRP is a model of the path between the two end terminals of the network. The HRP is divided into 2 parts - international and national portions with different quality/availability criteria. The national portion is further subdivided into long haul, short haul and access portions, again with different quality/availability objectives. The most stringent criteria are applicable for links used in the international portion of the HRP, the least stringent criteria are applicable in the access portion of the HRP. The availability performance objectives defined by ITU-R (Rec. ITU-R F.1703, 2008) are expressed by means of two parameters - the availability ratio AR and the mean time between outages Mo.

The availability ratio AR is the proportion of time that a path is in an available state during an observation period. The AR is calculated by dividing the total available time during the observation period by the duration of the observation period – usually one year. In order to distinguish available and unavailable time, the following rules are applied. A period of unavailable time begins at the outset of 10 consecutive Severely Errored Second (SES) events. These 10 seconds are considered to be part of the unavailable time. A new period of available time begins at the onset of 10 consecutive non-SES events. These 10 seconds are considered to be part of the available time. A Severely Errored Second (SES) is a one-second period which contains ≥30% Errored Blocks or at least one defect. An Errored Block (EB) is a block of bits in which one or more bits are in error. Examples of defects are loss of signal, alarm indication signal, loss of frame alignment (Rec. ITU-T G.826, 2002).

Without going further into the details described in (Rec. ITU-R F.1703, 2008), two examples will be provided of availability objectives calculated for a 30 km long link that can be formed by several radio hops connected in series. For such a link that is part of the *international* section, the AR should reach at least 99.985% (an unavailability of 78 min/year, i.e. 0.015%). For a link that is part the *access* section, the AR should equal or exceed 99.95% (an unavailability of 263 min/year, i.e. 0.05%). The further subdivision of availability objectives into the individual radio hops of the link is not specified and is under the network operator's responsibility. A conservative assumption that unavailability events on different radio hops are not correlated is often adopted. Then the unavailability time of the whole link is the sum of the unavailable times of its individual radio hops. It follows that more stringent AR values than those presented in the above example should be required on these hops.

The mean time between outages Mo and its reciprocal value – the outage intensity OI are parameters expressing a relatively new concept within ITU-R availability recommendations. They define how many unavailability events are tolerable on the link during the one-year

period. The idea is that a great number of short outages on the link are not desirable despite the fact that *AR* of the link meets the required objectives. Unfortunately, there is not enough knowledge at the moment that would provide an estimation of these parameters on a worldwide basis. The practical usefulness of these parameters still remains to be seen.

One should note that historically, ITU-T and ITU-R quality/availability objectives were developed under the assumption of a single protected connection between two end terminals that is established within a public switched telephone network (PSTN). This assumption is not valid in IP packet based networks however. Link operators may therefore require their own quality/availability objectives for links used in such networks. In practice, it seems that the similar or the same objectives as in ITU-R are often used because of lack of more relevant knowledge.

2.2 Fixed wireless link power budget

Once the availability objectives are specified for the designed radio path, the link parameters have to be considered in order to meet these objectives. Propagation related bit errors that occur on millimetre wave links are caused dominantly by poor detection when the received signal power falls under the receiver threshold due to the attenuation of incoming electromagnetic waves. This is why the link power budget has to be determined above all. The nominal power available at the input of the receiver can be obtained from the following formula:

$$P_r = P_t - L_t + G_t - FSL + G_r - L_r \tag{1}$$

where P_t (dBm) is the power at the output of the transmitter, P_r (dBm) is the power at the input of the receiver, G_t and G_r (dB) are transmitting and receiving antenna gains, L_t and L_r (dB) are additional losses (branching, feeder,…) in the transmitter and receiver and *FSL* (dB) is the free space loss which is dependent on the path length d (m) and wavelength λ (m):

$$FSL = 20 \log(4\pi d/\lambda). \tag{2}$$

Normally, the nominal received power P_r is much higher than the receiver threshold P_{rth} (dBm) which is an important parameter of the receiver that depends on the modulation format and on the receiver noise figure. P_{rth} is usually defined as the power at the input of the receiver that will result in a certain threshold value of bit error ratio BER, typically 10^{-6} or 10^{-3}. It follows that the fade margin F (dB):

$$F = P_r - P_{rth} \tag{3}$$

determines the maximum attenuation of the received signal that maintains a BER lower than this threshold. Given the required maximum of unavailability time percentage p (%) according to the objectives described in the previous section, rain attenuation A_p (dB) exceeded p % of time is derived from rain attenuation statistics. In order to meet the availability performance objectives, link parameters (antenna gain, link length …) have to be adjusted so that the following condition for the fade margin is satisfied:

$$F \geq A_p. \tag{4}$$

3. Rain Attenuation

Rain that occurred along the terrestrial path causes the rain attenuation as a result of the absorption and scattering of electromagnetic waves by rain particles. The rain attenuation depends on the frequency and polarisation, the temperature, on the size distribution of raindrops, and on their fall velocity. In the mm frequency bands, i.e. for frequencies above 10 GHz, the reason of the rain attenuation is both the absorption and scattering of electromagnetic waves by rain particles. The frequency dependence of the specific rain attenuation can be obtained from (Rec. ITU-R P.838, 2008).

3.1 Rain characteristics

Rainfall intensity along the terrestrial path is inhomogeneous in space and time. The raindrops have a non-spherical shape and therefore the attenuation of the horizontally polarized waves is greater than the attenuation of the vertically polarized waves. Rainfall intensity can be measured by different types of rain gauges located at the surface of the Earth. The cumulative distributions (CDs) of the average 1-minute rain intensities are needed for the calculations of the CDs of attenuation due to rain by different methods.

3.2 Rain attenuation models

Various methods were developed for calculations of CDs of attenuation due to rain from rain intensity measurements (COST 235, 1996; ITU-R, 2008). The ITU-R recommendation (Rec. ITU-R P. 530-12, 2008)) uses an effective path length to consider the time-space variability of rain intensity along the terrestrial path. Rain attenuation exceeded at 0.01% of the time of year is calculated from the average 1-minute rain intensity exceeded at the same time percentage. The obtained value is scaled by the empirical formula to other percentages of time between 1% and 0.001%.

3.3 Monthly and yearly statistics

The obtained CDs of both the rain intensities and the rain attenuation should be the "long-term average annual", i.e. the measurements should be taken for several years (at least 3 years) to take into account the effects of both the month-to-month and year-to-year variability of rain intensities. The obtained long-term CDs of attenuation due to rain for the average year can be used for the assessment of availability performance parameters of the mm terrestrial fixed wireless link (Rec. ITU-T G.827, 2003). The obtained long-term CDs of attenuation due to rain for the average annual worst month can be used for the assessment of error performance parameters of the mm terrestrial fixed wireless link (Rec. ITU-T G.828, 2000). The "worst month" concept is described in (Rec. ITU-R P.581-2, 2008).

4. Geographical Dependence of Rain Attenuation

Rain attenuation statistics depend on local climatic conditions. Typical values of rain intensity (and to some extent also drop size distributions) vary significantly worldwide. In this section, ITU-R methods and datasets are used to give an overview of the geographical dependence of the rain attenuation of millimetre waves.

4.1 ITU-R world map of rain intensity statistics

Rain intensity R (mm/hour) is the most important quantity determining rain attenuation. ITU-R provides a global dataset of rain intensity statistics derived from local measurements as well as from global satellite observations of liquid water precipitation in the atmosphere. Figure 1 shows a world map of rain intensity exceeded 0.01% of time (about 53 minutes in a year).
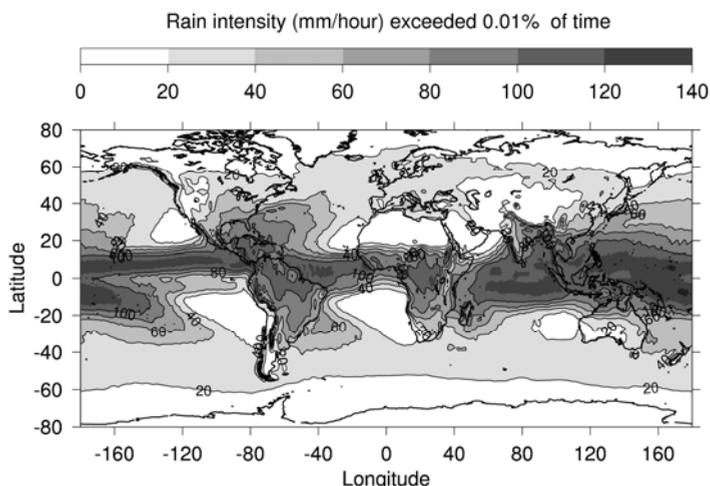

Fig. 1. Worldwide rain intensity 0.01% percentile distribution

The maximum value of the rain intensity 0.01% percentile reaches more than 130 mm/hour in tropical regions. In Europe, for example, the value is lower than 40 mm/hour over most of the continent. The observed peak values of rain intensity are even significantly higher.

4.2 ITU-R world map of rain attenuation statistics

Rain intensity increases with the concentration of raindrops within the propagation path. The higher number of scatterers – raindrops, the higher attenuation of the electromagnetic wave, thus rain attenuation generally increases with increasing rain intensity. The frequency dependence of specific attenuation for different rain intensities is depicted in Figure 2. The ITU-R model (Rec. ITU-R P.838-3, 2008) was used which is of the form:

$$\gamma = k R^a \tag{5}$$

where specific attenuation γ (dB/km) is related to rain intensity R (mm/hour) and frequency-dependent coefficients k and a. It is seen that in millimetre wave bands attenuation slightly increases with frequency up to about 100 GHz depending on rain intensity.
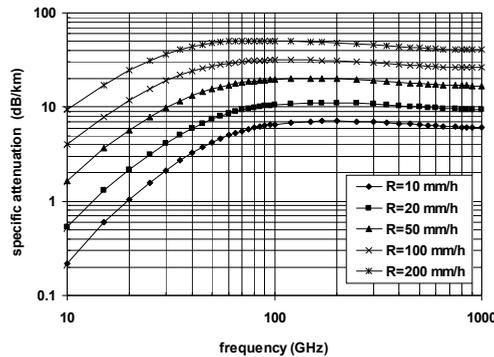
Fig. 2. Frequency dependence of specific rain attenuation for several values of rain intensity R (mm/hour)

ITU-R recommends the estimation procedure of rain attenuation statistics (Rec. ITU-R P.530-12, 2008) which has been validated against attenuation data obtained on the terrestrial links with operating frequencies of up to 40 GHz. The method makes certain that the estimated 0.01% percentile of specific rain attenuation $A_{0.01}$ is proportional to the value of specific attenuation γ calculated by equation (5) with $R=R_{0.01}(1)$ where $R_{0.01}$ is the 0.01% percentile of the average 1-minute rain intensity cumulative distribution observed in the planned link location. The coefficients in (5) are currently available for frequencies of up to 1000 GHz (Rec. ITU-R P.838-3, 2008) and therefore one can estimate $A_{0.01}$ in millimetre wave bands.

In Figure 3, a world map of estimated rain attenuation exceeded 0.01% of time on a 1 km long path with a frequency of 38 GHz is presented. It can be seen that in most of Europe, for example, $A_{0.01}$ exceeds the value of 5 dB/km. In Figures 4 and 5, world maps of estimated rain attenuation exceeded 0.01% of time on a 1 km long path with a frequency of 58 GHz and 93 GHz respectively are presented. At these frequencies, $A_{0.01}$ exceeds the value of 10 dB/km in most of Europe.
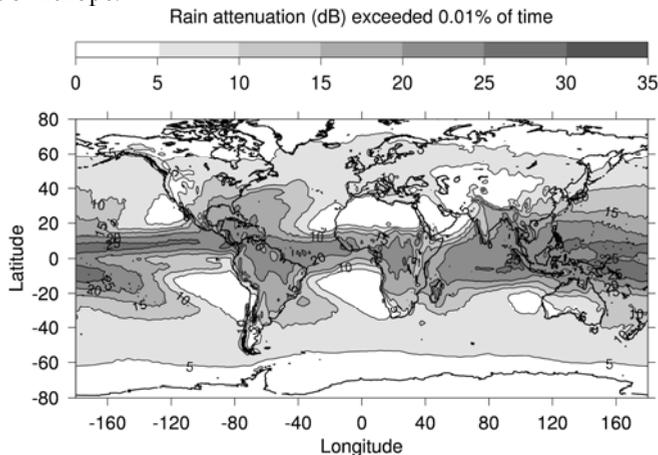

Fig. 3. Worldwide rain attenuation 0.01% percentile distribution, frequency 38 GHz, path length 1 km
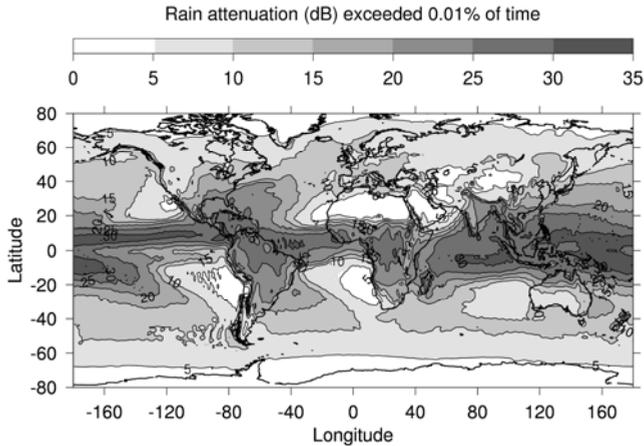
Fig. 4. Worldwide rain attenuation 0.01% percentile distribution, frequency 58 GHz, path length 1 km
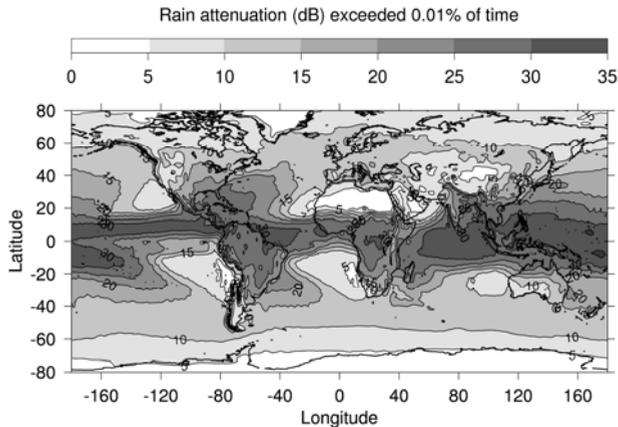

Fig. 5. Worldwide rain attenuation 0.01% percentile distribution, frequency 93 GHz, path length 1 km

4.3 Why local experimental measurements of rain attenuation statistics?

The global prediction methods of rain attenuation statistics provided by (ITU-R Rec. ITU-R P.530-12, 2008) are very useful when no sufficiently accurate local data is available especially for frequencies lower than 40 GHz. In millimetre wave bands for frequencies higher than 40 GHz, the ITU-R method still can serve well as a reliable approximation. However potential users should be aware of its inherent limited accuracy. The estimation method formulas were derived using a global fitting approach which tends to average out the errors over the world. The spatial resolution of the rain intensity dataset provided by ITU-R is 1.5 degrees in both the latitude and the longitude, which is not sufficient for the description of specific areas with extreme rain characteristics. This is a reason why it is also recommended by ITU-R to use locally-measured statistics of both rain intensities and rain attenuation whenever they are available.

5. Experimental Set-up

The used 38 GHz, 58 GHz, and 93 GHz radio systems, the meteorological measurements and the data processing are described in this section.

5.1 Terrestrial wireless systems used

Attenuation events caused by hydrometeors (rain, snow, hailstones, fog) at 38 GHz, 58 GHz and 93 GHz are measured at the Czech Metrology Institute on three parallel paths – marked as A, B, and C. On path A, a microwave system operating at 38 319.75 MHz with V polarization is used. The path length is about 9.3 km, the transmitted power is 16 dBm, and the recording margin is about 34 dB. Two microwave systems working at 58 GHz and 93 GHz are used on the parallel paths B and C with the same path length of 853m. A microwave system operating on frequency 57 650 MHz with V polarization transmitting power of 5 dBm is used on path B. The recording margin is about 24 dB thanks to the special parabolic off-set antennas used. The other microwave system is operating on path C at 93 370 MHz with V polarization. The transmitted power is 17 dBm; the recording margin is about 38 dB.

5.2 Meteorological measurements

The meteorological conditions are identified both by means of colour video-camera images of the space between the transmitter and the receiver sites and of the data obtained from a weather observation system located near the receiver site. The system is equipped with VAISALA sensors for measuring the temperature, humidity and air pressure, the wind velocity and direction, and a tipping-bucket rain gauge for the measurement of rainfall intensities. The VAISALA PWD11 device is used for the measurement of visibility. The observed meteorological conditions are continuously recorded.

The rain intensities are measured by the dynamically calibrated heated tipping-bucket rain gauge with a collector area of 500 cm^2, and the amount of rain per tip was 0.1 mm. The time of the tips was recorded with an uncertainty of 1 second. The rain gauge is situated near the receivers of the radio systems used.

5.3 Data processing

The records of received signal levels obtained on the aforementioned paths were processed statistically over a one year period from May 2007 to April 2008. The records of attenuation events were compared with the concurrent meteorological situations to identify the reason of the attenuation events. Strictly concurrent rain attenuation events occurred on three paths and only rain events were processed. The CDs of rain attenuation at 38 GHz on the 9.3 km path, 58 GHz and 93 GHz on the 853m path were obtained.

Rain intensities were processed over the same one-year period. The CD of average 1-minute rain intensities was obtained.

6. Experimental Results

The obtained monthly and annual statistics of both rain intensities and rain attenuation and the assessed availability performances of experimental links are presented in this section.

6.1 Monthly and annual statistics of rain intensities

The obtained CDs of the average 1-minute rain intensities $R(1)$ for the individual months and the whole year period are given in Fig. 6. The obtained average 1-minute rain intensity for 0.01% of the time of year $R_{0.01}(1)$ is 49.5 mm/h. This rain intensity should be used for the calculation of CDs of attenuation due to rain only according to the relevant ITU-R Recommendations (Rec. ITU-R P.530-12, 2008; Rec. ITU-R P.838-3, 2008).
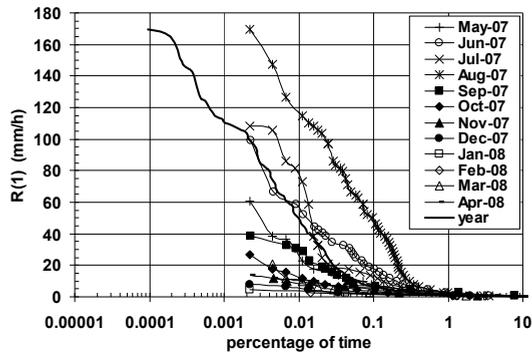

Fig. 6. Monthly and yearly CDs of rain intensities

This shows a great month-to-month variability of the rain intensity distribution. The highest measured average 1-minute rain intensity was about 170 mm/h which occurred in August 2007 which also forms the CD for the worst month in the region from 170 mm/h to 3 mm/h. The CD for the worst month for the rain intensities smaller than 3 mm/h forms the pertinent part of the CD for September.

6.2 Monthly and annual statistics of rain attenuation

The obtained monthly and yearly CDs of attenuation due to rain only at 38 319.75 MHz with V polarization on a path length of about 9.3 km are given in Fig. 7.
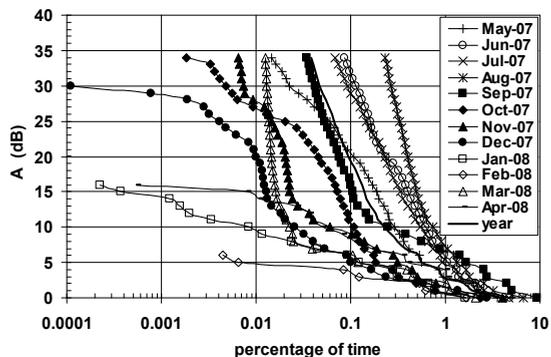

Fig. 7. Monthly and yearly CDs of attenuation due to rain at 38 GHz

A large month-to-month variability of the CDs of attenuation due to rain only caused by the large month-to-month variability of rain intensities can be observed. The CD of attenuation

due to rain only at the 38 GHz path for the worst month over the one-year period is formed for the attenuation between 34 dB and 6 dB by the pertinent part of the CD for August 2007 and for attenuation smaller than 6 dB by the pertinent part of the CD for September 2007. The obtained monthly and yearly CDs of attenuation due to rain only at 57 650 MHz with V polarization on a path length of 853 m are given in Fig. 8.
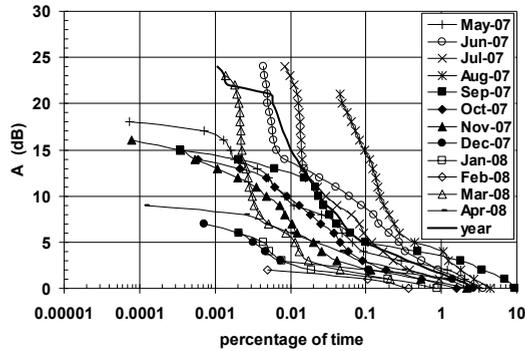

Fig. 8. Monthly and yearly CDs of attenuation due to rain at 58 GHz

The large month-to-month variability of the CDs of attenuation due to rain only caused by the large month-to-month variability of rain intensities can be observed once again. The CDs of attenuation due to rain only at the 58 GHz path for the worst month over the one-year period is formed for the attenuation between 24 dB and 21 dB by the pertinent part of the CD for July 2007, for the attenuation between 21 dB and 3 dB by the pertinent part of the CD for August 2007 and for the attenuation smaller than 3 dB by the pertinent part of the CD for September 2007.

The obtained monthly and yearly CDs of attenuation due to rain only at 93 370 MHz with V polarization on a path length of 853 m are given in Fig. 9.
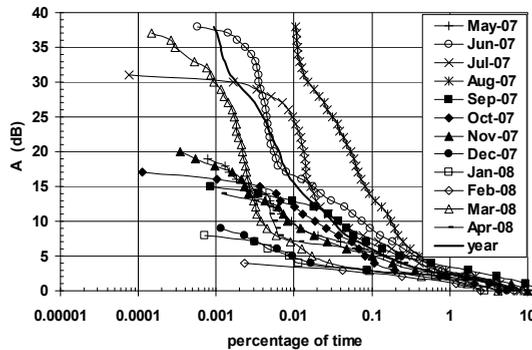

Fig. 9. Monthly and yearly CDs of attenuation due to rain at 93 GHz

The large month-to-month variability of CDs of attenuation due to rain only caused by the large month-to-month variability of rain intensities can also be observed. The CD of attenuation due to rain only at the 93 GHz path for the worst month over the one-year period is formed as for the attenuation between 38 dB and 4 dB by the pertinent part of the

CD for August 2007 and for the attenuation smaller than 4 dB by the pertinent part of the CD for September 2007.

The obtained CDs of attenuation due to rain only and the CDs of attenuation due to rain only calculated in accordance with the ITU-R Recommendation (ITU-R P.530-12, 2008) for the used frequencies and the used path lengths are shown in Fig. 10. The average 1-minute rain intensity for 0.01% of the time of year $R_{0.01}(1)$ = 49.5 mm/h obtained from Fig. 6 was used for the calculation.
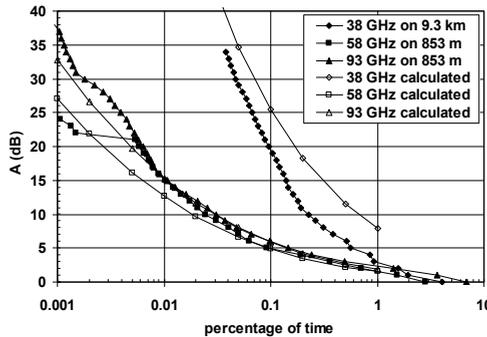

Fig. 10. Measured and calculated yearly CDs of attenuation due to rain only

The values of the measured attenuation due to rain only at 38 GHz are smaller than the calculated ones up to about 7 dB. These differences can be caused by the year-to-year variability of the rain attenuation distributions due to the year-to-year variability of the rain intensity distribution. The measured CDs due to rain only at 58 GHz and 93 GHz are very close to each other. The measured CD of attenuation due to rain only at 58 GHz is slightly over the calculated one in the region of 0.008% - 1% of the time of year. The measured CD of attenuation due to rain only at 93 GHz corresponds very well with the calculated one in the same region. For the percentages of the time of year smaller than 0.01% both CDs at 58 GHz and 93 GHz are very close to each other and are above the calculated CDs (up to about 3 dB for the CD at 93 GHz). The further inaccuracy can be caused by the fact that the ITU-R Recommendation (Rec. ITU-R P.530-12, 2008) is only considered to be valid for frequencies up to 40 GHz and path lengths up to 60 km while the lower path length limit is not mentioned.

6.3 Availability performances of experimental links

Availability performances of the three experimental links can be assessed from Fig. 10. The obtained availability performances for the three chosen fade margins of 10 dB, 15 dB, and 20 dB are given in Table 1.

Fade margin	38 GHz link	58 GHz link	93 GHz link
10 dB	99.7720%	99.9757%	99.9692%
15 dB	99.8610%	99.9897%	99.9900%
20 dB	99.9041%	99.9942%	99.9936%

Table 1. Availability performances

It can be seen that the availability performances of both experimental links at 58 GHz and 93 GHz are fully comparable to each other up to fade margins of 20 dB. Due to the fact that the 58 GHz system has a fade margin of about 24 dB only, it is not possible to compare the availability performances of both links for the fade margin greater than 20 dB. The lower availability performance of the 38 GHz link follows from the greater path length in comparison with the 58 GHz and 93 GHz links.

7. Scaling

The obtained CDs of attenuation due to rain only obtained on terrestrial paths with the different path lengths and at other frequencies and polarisations in the same climate conditions can be scaled to the required path lengths, frequencies and polarisations.

7.1 ITU-R scaling of rain attenuation

The frequency scaling and the polarisation scaling of long-term statistics of rain attenuation only are described in (Rec. ITU-R P.530-12, 2008), the path length scaling is not mentioned there.

7.2 Frequency and path length scaling of rain attenuation

A transformation method based on the ITU-R Recommendation (Rec. ITU-R P.530-12, 2008) can be applied to compare the results obtained. The simplified method was successfully used in (Tikk & Bito, 2003). The CD of rain attenuation obtained on the chosen reference path can be transformed to the other two paths for the frequencies used. The used frequency and path length scaling of 1-year statistics of rain attenuation is based on the following equation (Kvicera et al, 2009):

$$A_r = \frac{k_r \, L_r \, 0.12 \, p^{\,(0.546 + 0.043 \log_{10} p)}}{1 + L_r / d_0} \left[\frac{A \, (1 + L / d_0)}{k \, L \, 0.12 \, p^{\,(0.546 + 0.043 \log_{10} p)}} \right]^{\frac{a_r}{a}} \tag{6}$$

where A_r is the attenuation on the reference path, A is the attenuation on the certain path, k_r and a_r are coefficients dependent on frequency (Rec. ITU-R P.838-3, 2008) for the reference path, k and a are the same coefficients for the certain path, L_r is the reference path length, L is the path length of the certain path, d_0 is used for the calculation of the path reduction factor with $R_{0.01\%}$ = 49.5 mm/h, p is the percentage of time. Then the transformed CDs of rain attenuation on the reference path at 38 GHz, 58 GHz, and 93 GHz can be mutually compared and moreover they can be also compared with the calculated CD of rain attenuation in accordance with ITU-R Recommendation (Rec. ITU-R P.530-12, 2008).

7.2.1 Path A as the reference path

Let path A (9.3 km, 38 319.75 MHz) be considered as the reference path. The CDs of attenuation due to rain only obtained on paths B (853 m, 57 650 MHz) and C (853 m, 93 370 MHz) are scaled to reference path A in accordance with equation (6). For path A, the CD of attenuation due to rain only was calculated in accordance with the ITU-R Recommendation (Rec. ITU-R P.530-12, 2008). The average 1-minute rain intensity for 0.01% of time of year $R_{0.01}(1)$ = 49.5 mm/h obtained from Fig. 6 was used for the calculation.
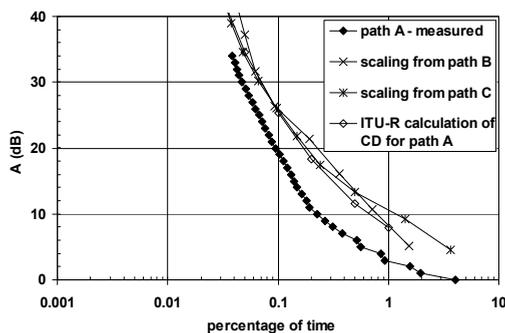The results obtained are given in Fig. 11.

Fig. 11. Measured, scaled and calculated CDs for reference path A

It can be observed from Fig. 11 that both the scaled distributions and calculated distributions are very tight to each other and are slightly over the measured distribution (up to about 10 dB). From the point of the percentages of time, the differences between the measured distribution and the scaled and calculated distributions are not significant for attenuation values greater than 10 dB (the ratio between the percentages of time for the measured distribution and the scaled ones is smaller than factor 2).

7.2.2 Path B as the reference path

Let path B (853 m, 57 650 MHz) be chosen as the reference path. The CDs of attenuation due to rain only obtained on paths A (9.3 km, 38 319.75 MHz) and C (853 m, 93 370 MHz) are scaled to reference path B in accordance with the equation (6). For path B, the CD of attenuation due to rain only was calculated in accordance with ITU-R Recommendation (Rec. ITU-R P.530-12, 2008). The average 1-minute rain intensity for 0.01% of time of year $R_{0.01}(1)$ = 49.5 mm/h obtained from Fig. 6 was used for the calculation.
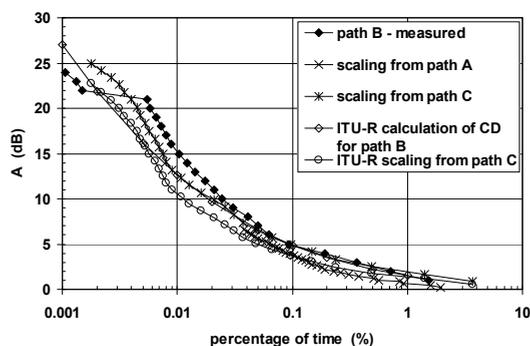
Fig. 12. Measured, scaled and calculated CDs for reference path B

In addition, the ITU-R scaling method (Rec. ITU-R P.530-12, 2008) was used for the conversion of the CD of attenuation due to rain only measured on path C to path B. The results obtained are given in Fig. 12.

The very good agreement between the scaled distributions and the measured one can be seen. The differences are smaller than 3 dB and the ratio between the percentages of time for the measured distribution and the scaled ones is smaller than 2. Both the scaled distributions from paths A and C are slightly under the measured distribution (up to about 2 dB and the ratio between the percentages of time for the measured distribution and the scaled ones is smaller than a factor of 2). The scaled distribution from path C agrees excellently with the measured distribution in the region of 0.05% - 4% of the time of year. For the percentages of time smaller than 0.05%, the scaled distribution from path C is slightly under the measured distribution and the scaled attenuation values are less than 3 dB under the measured ones. The ratio between the percentages of time for the measured and the scaled distribution is smaller than a factor of 2.

The CD due to rain only calculated in accordance with Recommendation ITU-R (Rec. ITU-R P.530-12, 2008) agrees very well with the measured distribution in the region of 0.05% - 1% of the time of year. For the percentages of time smaller than 0.05%, the calculated distribution is slightly under the measured distribution – up to about 5 dB for 0.005% of the time of year.

The CD calculated in accordance with the ITU-R scaling method (Rec. ITU-R P.530-12, 2008) lies under the measured distribution and the differences are about 5 dB for the percentages of time of year smaller than 0.01%. For the percentages of time of year greater than 0.01%, the differences are smaller.

7.2.3 Path C as the reference path

Let path C (853 m, 93 370 MHz) be considered to be the reference path. The CD of attenuation due to rain only obtained on paths A (9.3 km, 38 319.75 MHz) and B (853 m, 57 650 MHz) are scaled to reference path C in accordance with the equation (6). For path C, the CD of attenuation due to rain only was calculated in accordance with Recommendation ITU-R (Rec. ITU-R P.530-12, 2008). The average 1-minute rain intensity for 0.01% of the time of year $R_{0.01}(1)$ = 49.5 mm/h obtained from Fig. 6 was used for the calculation.
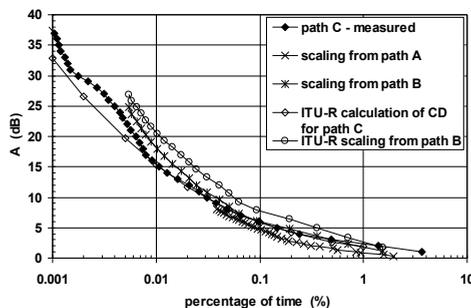

Fig. 13. Measured, scaled and calculated CDs for reference path C

The ITU-R scaling method (Rec. ITU-R P.530-12, 2008) was also used for the scaling of the CD of attenuation due to rain only measured on path C to path B. The results obtained are given in Fig. 13.

Similar results can be seen as for reference path B. There is very good agreement between the scaled distributions and the measured one. The differences are smaller than 3 dB and the ratio between the percentages of time for the measured and the scaled distribution is smaller than about a factor of 2. The scaled distribution from path A is slightly under the measured distribution and the scaled attenuation values are less than 2 dB under the measured ones. The ratio between the percentages of time for the measured and the scaled distribution is smaller than a factor of 2. For the percentages of time greater than 0.05%, the scaled attenuation values for path B agree excellently with the measured values. For the percentages of time smaller than 0.05%, the scaled distribution is slightly above the measured distribution. The scaled attenuation values are less than 3 dB above the measured ones and the ratio between the percentages of time for the measured and the scaled distribution is smaller than a factor of 2.

The CD due to rain only calculated in accordance with Recommendation ITU-R (Rec. ITU-R P.530-12, 2008) agrees excellently with the measured CD in the region of 0.01% - 1% of the time of year. For the percentages of time smaller than 0.01%, the calculated distribution is slightly under the measured distribution – up to about 3 dB for 0.003% of time of year.

The CD calculated in accordance with the ITU-R scaling method (Rec. ITU-R P.530-12, 2008) lies above the measured distribution and the differences are up to about 5 dB for the percentages of the time of year smaller than 0.01%. The differences are smaller for the percentages of the time of year greater than 0.01%.

7.2.4 Summary

Very good agreement is observed between the scaled and the calculated distributions for all three reference paths A, B, and C. Very good agreement of the scaled distributions, the calculated distributions and the measured distributions is seen for the reference paths B and C. The measured CD of attenuation due to rain only lies slightly under the scaled distributions and the calculated ones (up to about 10 dB) for the reference path A only. Nevertheless, the difference among the measured distribution and the scaled and calculated distributions is not significant for attenuation values greater than 10 dB from the point of the percentage of time due to the fact that the ratio between the percentages of time for the measured distribution and the scaled ones is smaller than a factor of 2. Scaled distributions from path A (i.e. for the reference path B and C) only lie slightly under the measured ones. Therefore it can be assumed that the method used can be used for the frequency and path length scaling for both the frequencies from 38 GHz to 93 GHz and the path lengths from 0.85 km to 9.3 km with the accuracy sufficient for the assessment of propagation conditions.

7.2.5 Scaling to other frequencies and path lengths

The described method of the frequency and path length scaling was successfully used for the assessment of CDs of attenuation due to rain only on the path between a High Altitude Platform (HAP) and an Earth base station operated on the 48 GHz band (Kvicera et al, 2009).

8. Conclusion

Terrestrial fixed wireless links form an important part of the global telecommunication network. Their availability performance and error performance are significantly influenced by weather conditions, especially by heavy rain events. An overview of the ITU

recommendations related to the availability performance and error performance objectives is given. The examples of both the link power budget and the system fade margin calculations which are needed to fulfil the required availability objectives are given. Characteristics of rain that are the most important impairment factor are described and rain attenuation models are mentioned. Monthly and yearly statistics of rain attenuation which are needed for the availability performance assessment are introduced. The ITU-R world map of both rain intensity statistics and rain attenuation statistics illustrating and confirming the geographical dependence of rain attenuation are given. The meaning and the necessity of the local experimental measurement of concurrent rain intensities and rain attenuation are both explained. Both the experimental set-up of the radio systems operating at 38 GHz, 58 GHz, and 93 GHz and the concurrent meteorological measurements in Prague, the Czech Republic as well as the data-processing procedures are described in detail. The obtained experimental results, i.e. monthly and annual statistics of both rain intensities and rain attenuation are given. The availability performances based on experimental results are assessed. Due to the fact that experimental results can only be obtained at several frequencies, both the ITU-R frequency scaling method and polarisation scaling method as well as the novel path length scaling method are demonstrated.

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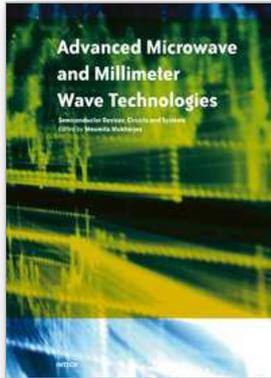
Advanced Microwave and Millimeter Wave Technologies
Semiconductor Devices Circuits and Systems
Edited by Moumita Mukherjee

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Vaclav Kvicera and Martin Grabner (2010). Rain Attenuation on Terrestrial Wireless Links in the mm Frequency Bands, Advanced Microwave and Millimeter Wave Technologies Semiconductor Devices Circuits and Systems, Moumita Mukherjee (Ed.), ISBN: 978-953-307-031-5, InTech, Available from: http://www.intechopen.com/books/advanced-microwave-and-millimeter-wave-technologies-semiconductor-devices-circuits-and-systems/rain-attenuation-on-terrestrial-wireless-links-in-the-mm-frequency-bands

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