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calculated by simulation the optimal coefficients for $p_0(\cdot)$ and $p_1(\cdot)$, found that $\alpha_0 = 0.7092$ and $(\alpha_0, \alpha_1) = (1.4184, -0.5030)$, respectively. Figs. 3 and 4 show, respectively, performance convergence of PP-LPIC with polynomial preconditioner of degree zero (0PP-LPIC) and one (1PP-LPIC) at different SNR. By comparison between Figs. 3 and 4, we find that the convergence speed of 1PP-LPIC is faster than 0PP-LPIC.

Conclusion: PP-LPIC can overcome the shortcoming of LPIC of divergence in the case of a large number of users, and accelerate the convergence of LPIC.

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Short-term prediction of rain attenuation using two samples

M.M.J.L. van de Kamp

An empirical short-term prediction model of rain attenuation on satellite links is presented. This model predicts the probability distribution of rain attenuation a short time after a known value. The probability distribution depends on two previous attenuation sample values. This model is useful for the design of adaptive fade control techniques, and for the generation of simulated attenuation data.

Introduction: Rain attenuation, caused by scattering and absorption by water droplets, is one of the most fundamental limitations to the performance of satellite communication links in the microwave region. In the Ka- and V-bands, some useful countermeasures are adaptive fade compensation systems, in which the transmitted signal is enhanced to compensate for fading due to rain on the propagation path.

For the development of adaptive fade countermeasure algorithms, a method has been researched for predicting the probability distribution of rain attenuation a short time after a measured value. This will enable adaptive fade countermeasure systems to anticipate the expected attenuation.

In an earlier study [1], it was found that a prediction dependent on only one previous rain attenuation sample led to a discrepancy in the predicted distribution function between theory and measurements. It was concluded that the attenuation distribution must be significantly dependent on two previous sample values. Other studies also indicated the usefulness of more than one sample in the dynamic prediction of rain attenuation [2]. The model in this Letter predicts the probability distribution of attenuation as dependent on two previous attenuation values.

Measurements: The study used results from the Olympus measurement experiment at Eindhoven University of Technology, Netherlands [3]. All Olympus beacon signals were received using a 5.5 m Cassegrain antenna, at an elevation angle of 26.78°. The signals were sampled at a frequency of 3 Hz, and averaged over every second. Over the period from January 1st 1991 to June 30th 1992, 104 rain events were selected. The signal level was averaged over each block of 10 s, in order to reduce scintillation effects. The resulting resampled data have been used for the analysis. The results for 20 GHz, at vertical polarisation, are shown in this Letter.

Fig. 1 Average attenuation m_A
 --- as function of A_0 for $A_{-1} = A_0$
 — as function of A_{-1} for $A_0 = 0, 0.5, 1, 1.5, \dots, 6$ dB
 ○ A_0

Short-term rain fade prediction model: To study the dependence of the distribution of attenuation on previous attenuation values, three-dimensional statistics were collected of attenuation of three consecutive samples, i.e. $A = A(t + \Delta t)$, $A_0 = A(t)$, and $A_{-1} = A(t - \Delta t)$, where $\Delta t = 10$ s. The bin size was 0.1 dB for A_0 and A_{-1} , and 0.01 dB for A .

In Fig. 1, the average m_A of attenuation A conditional for values of A_0 and A_{-1} is shown. In this Figure, the dashed line is for $A_0 = A_{-1}$, and each solid line is valid for one value of A_0 , indicated as '○', and as a function of A_{-1} (thus, at the circles: $A_0 = A_{-1}$). This graph shows that m_A is approximately equal to A_0 when $A_0 = A_{-1}$. For fixed values of A_0 , m_A decreases approximately linearly with A_{-1} . The behaviour is different only for very small values of A_0 , which is due to residual scintillation still present in the signal [4].

In Fig. 2, the standard deviation σ_A of attenuation conditional for values of A_0 and A_{-1} is shown. The dashed line shows that for $A_{-1} = A_0$ the standard deviation is approximately proportional to A_0 , except for the smallest values of A_0 , which is again due to residual scintillation [4]. The solid lines show that for small values of A_0 , the standard deviation increases with the difference of A_{-1} from A_0 . For small A_0 the result is mainly due to scintillation, but for $A_0 > 1$ dB the dependence of σ_A on the difference $A_0 - A_{-1}$ is almost entirely due to rain attenuation fluctuations.

Fig. 2 Standard deviation σ_A of attenuation
 --- as function of A_0 for $A_{-1} = A_0$
 — as function of A_{-1} for $A_0 = 0, 0.5, 1, 1.5, \dots, 6$ dB
 ○ A_0

The skewness and kurtosis of the distribution of A were also calculated for all values of A_0 and A_{-1} . It was found that the skewness fluctuated around 0 in all cases, which means that the distribution can be assumed symmetrical. The kurtosis resulted to be approximately 5 independently of A_0 and A_{-1} , meaning that the distribution is

more 'triangular' in shape than a Gaussian distribution, which has a kurtosis of 3.

Based on these observations from the measured data, an empirical short-term prediction model for the probability distribution $p(A)$ of attenuation was formulated [4]:

$$p(A) = \frac{1}{2\sigma_A} \operatorname{sech} \left\{ \frac{\pi(A - m_A)}{2\sigma_A} \right\} \quad (1)$$

$$m_A = A_0 + \alpha_2(A_0 - A_{-1}) \quad (2)$$

$$\sigma_A = A_0 \sqrt{\beta_2 \Delta t + \gamma_2 |A_0 - A_{-1}|} \quad (3)$$

The 'hyperbolic secant distribution' of (1) is symmetrical and has a kurtosis of 5. Its mean m_A and standard deviation σ_A , given by (2) and (3), depend on the two previous sample values A_0 and A_{-1} , and three parameters, α_2 , β_2 , and γ_2 . This 'two-sample model' is a generalisation of the 'one-sample model', which was tested earlier [1]. The one-sample model, which used only one previous sample A_0 and had only one parameter β_1 , is a special case of the two-sample model for $\alpha_2 = \gamma_2 = 0$ and $\beta_1 = \beta_2$.

Verification and parameter adjustment: The two-sample model was implemented in a data simulation program, which was tested by generating long-term simulated data, using many different combinations of the input parameters α_2 , β_2 and γ_2 . As outputs of this test, several dynamic characteristics of the simulated data were evaluated quantitatively: the autocorrelation of the fade slope (= time derivative of attenuation), and the standard deviation and kurtosis of the long-term distribution of the fade slope. All of these quantities appeared to depend on the values of the model parameters α_2 , β_2 and γ_2 . The same output quantities were also determined from the measured data from Eindhoven. By comparing these to those from the simulations, it was found that by adjusting the model parameters, the dynamic characteristics of the simulated data can be made to agree well with those of the measured data. The result of this comparison confirmed the validity of (1)–(3).

Also, the comparison enabled the determination of the parameters α_2 , β_2 and γ_2 more accurately than would be possible directly from Figs. 1 and 2. In particular, this comparison demonstrated the necessity of the inclusion of the two samples A_0 and A_{-1} , since the use of the 'one-sample model' (see before) would imply $\alpha_2 = \gamma_2 = 0$, which would not be in agreement with the measurements.

The simulated data were also compared in a similar way to measured data from the other beacon signals received in Eindhoven, and to data which had been measured in Gometz-la-Ville and La Folie Bessin, (France), Louvain-la-Neuve and Lessive (Belgium), Sparsholt (UK), and Spino d'Adda (Italy), at different frequencies in the Ku-, Ka- and V-band. The length of these databases varies from two months to six years. From these comparisons, the values of the parameters could be determined for each data set separately.

Table 1: Model parameter values found for different sites

Station	Data length	α_2	β_2 (s^{-1})	γ_2
Eindhoven	15 months	0.4	2.5×10^{-4}	0.37
Gometz	15 months	0.5	1.2×10^{-4}	0.38
La Folie	1 year	0.4	1.1×10^{-4}	0.45
Lessive	3 months	0.3	2.5×10^{-4}	0.37
Louvain	3 months	0.4	3.0×10^{-4}	0.31
Sparsholt	2 months	0.3	1.4×10^{-4}	0.50
Spino	6 years	0.2	0.9×10^{-4}	0.50

From this analysis it was found that the model parameters are not significantly dependent on frequency, in the frequency bands considered. For each different site, the values found from the analysis are summarised in Table 1. The results show only minor differences between the sites in France, UK, Belgium and the Netherlands. These differences are not likely to be indicative of climatic differences between the sites, because of the relatively small amount of data in some databases, which does not permit an accurate long-term analysis, and because of the short distance between Gometz and La Folie, and between Lessive and Louvain, allowing for no significant climatic differences. It can be concluded that by averaging these values, overall average values for the maritime climate of northwestern Europe are

found as

$$\begin{aligned} \alpha_2 &= 0.4 \\ \beta_2 &= 1.8 \times 10^{-4} s^{-1} \\ \gamma_2 &= 0.43 \end{aligned} \quad (4)$$

Only in Spino, it appears that α_2 and β_2 are lower, possibly due to the mediterranean climate in northern Italy.

For a more accurate determination of the values of the model parameters, depending on climatic differences, it will be necessary to analyse more long-term data from sites with significantly different climates.

Conclusions: A short-term prediction model of rain attenuation is formulated as the probability distribution of attenuation, dependent on two attenuation values measured shortly earlier. The parameter values of the model as found valid for western Europe are given.

This model can enable adaptive fade mitigation techniques to anticipate the expected attenuation. Also, the model can be used to develop data simulation procedures of rain attenuation, which are useful for testing fade countermeasure techniques.

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Ultrawideband measurements for wireless indoor communication systems at 37.2 GHz

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Results of an ultrawideband propagation study are described based on 1 ns impulse response measurements obtained by using a directive horn antenna as a base station in relatively narrow rooms. A brief description of the propagation measurement technique is followed by data analysis using time domain statistical processing. The results are discussed in terms of threshold levels and base station location.

Introduction: There is an increasing demand for high data rate wireless transmission for indoor radio networks and personal communication network systems. The millimetre wave frequency band is promising for supporting such applications since it offers wide bandwidths [1]. However, higher operating frequencies and higher data rates result in increased multipath problems, i.e. degradation of the transmission quality. In fact, in indoor environments energy may arrive from different directions and at different times, due to reflections and diffractions from surrounding objects, and these multipath propagation routes cause deep fades in the received signal and give rise to intersymbol interference due to symbol spreading. The design and planning of high-performance broadband systems requires detailed knowledge of the wave propagation channel and the most