Paper

Empirical Season's Fadings in Radio Communication at 6 GHz Band

Jan Bogucki and Ewa Wielowieyska

Abstract—This paper covers unavailability of line-of-sight radio links due to multipath propagation. Multipath fading in the atmosphere is not permanent phenomenon. The five year investigation results of the received radio signal fading in the radio links and their season empirical distributions are presented.

Keywords— line-of-sight radio links, multipath, propagation.

1. Introduction

The use of digital microwave radio-link systems is widely recognized as flexible, reliable and economical means of providing point-to-point communication [1], [2], [3]. These radio systems, when used with appropriate multiplex equipment, can carry from a few up to a large number of voice, video and data transmissions. They can also be arranged to carry additional wide-band for high-speed data, Internet, multimedia wireless or high-quality audio and high definition TV channels.

Comparative cost studies usually prove the radio microwave systems to be the most economical means for providing communication transmission where there are no existing cable lines to be expanded. For temporary facilities and other applications where installation time is severely limited the advantages of the radio technique are obvious.

Many fixed broadband wireless radio links are designed to be available essentially all the time. "Available" means that bit error rate (BER) or frame error rate (FER) is at or below given threshold level. Conversely, "outage" is the time when the link is not available; for example, BER/FER value is above the quality threshold level. In the fix-link, service availability of 99.99% for the worst month is usually a target that means an outage of only 53 minutes a year.

Nearly all radio systems are the subject to regulation by the government of the country, where the system is to be located. In general, each country allocates specific sub-bands of frequencies for specific services or users. Within Poland the Office of Electronic Communications (UKE) is the controlling authority for all the radio-communication systems except those operating in the frequency bands where simplified or no frequency coordination procedures are applied [4].

In Poland the 6 GHz band is meant for high-capacity long distance radio links. The radio signal of this frequency range is susceptible to some kinds of fading due to the changes in atmosphere.

One kind of fading essential in this band is multipath propagation fading [5].

This paper presents the problems of unavailability of line-of-sight radio links due to multipath propagation phenomena. In the National Institute of Telecommunications (NIT) the radio links have been used to investigate the propagation fading in the 6 GHz sub-band. The five year investigation results of the received radio signal fading in the radio links mentioned above and their season empirical distributions are presented below [6]–[9].

2. The Multipath Fading

The beam of microwave energy is not a single ray, but wavefront extending in considerable space along the center line. Since the refraction index for normal atmospheric conditions is lower at the top of wavefront and higher at the bottom, and since the wave velocity is inversely proportional to refraction index, the upper portion of wavefront will travel slightly faster, with result that the top of the wavefront is tiled. Since the direction of beam travel is always perpendicular to wavefront, the beam itself will be tilted downward. The degree of the tilt is actually very slight on percentage basis, but is sufficient to cause significant variation of the fading phenomena. It is normal propagation situation.

But sometimes at certain atmospheric situations there can be even "greater' than normal negative N gradient, or other in which N gradient becomes less negative and even positive. In the latter situation lower part of wavefront will travel faster, and the beam will be bent upward, reducing apparent clearance.

Most of time the vertical profile of these gradients in the lower atmosphere are essentially linear. These linear variations affect clearance and are also important, when the path is reflective, but they do not produce atmospheric multipath situations.

However, when gradients are nonlinear, it is possible for multiple paths, in addition to direct path, to exist within the atmosphere itself, independently of any reflecting surface on ground. These situations in atmosphere occur when stratified layers with different gradients lie on top of one another. Such conditions strongly depend on seasons of the year.

The incidence of multipath fading varies not only as function of path length and frequency, but also as function of climate and terrain conditions.

The treatment of multipath fading is based largely on experience.

3. The Index of Refraction for the Troposphere

The index of refraction for the troposphere air is very close to that of vacuum. Due to that, radio refractivity is used instead of index of refraction:

$$N = (n-1) \cdot 10^{-6}, \tag{1}$$

where: n – index of refraction, N – radio refractivity.

The N term would be zero in free space and value on order of 300 at the earth surface. An empirical formula for N is:

$$N = \frac{77.6}{T}\left(p + 4810\frac{e_H}{T}\right), \tag{2}$$

where: T – temperature [K], p – total air pressure [hPa], e_H – water vapour pressure [hPa].

Water vapour pressure corresponds to relative humidity of air:

$$e_H = H\,\frac{6.1121\exp\left(\frac{17.502\,t}{t+240.97}\right)}{100}, \tag{3}$$

where: H – relative humidity of air [%], t – temperature [°C].

Since p, e, and T all are functions of height, consequently N is also function of height. For normal atmosphere, standard – well mixed, the variation of $N(h)$ with height is:

$$\frac{\mathrm{d}N(h)}{\mathrm{d}h} = -40 \quad \left[\frac{1}{\mathrm{km}}\right], \tag{4}$$

$$N(h) = 315 \cdot \mathrm{e}^{-0.136h}, \tag{5}$$

where: h – height above earth surface [km].

Multipath propagation occurs when there is more than one ray reaching the receiver. It is the main cause of fading in 6 GHz band. Multipath can only happen when $\frac{\mathrm{d}N}{\mathrm{d}h}$ varies with height.

4. The Measurement System

There were six radio links at 6 GHz band with the length from 36.6 km to 69.8 km [6]. Sites of four radio links were located near Warsaw and two of the longest paths were situated farther north of Warsaw – see Fig. 1. Self-operating measuring position was set-up to cooperate with radio link receivers. The measurements were carried out during ordinary operation radio links. Received signals were sampled each 0.2 s during high attenuation and 5 min in the other time. The system measured only result of multipath, not the reason.

Layers of the atmosphere with different gradients of refractivity may cause detrimental effects to received signal. The radio wave rays, that normally would have been lost in the troposphere may be refracted towards receiving antenna, where they are added to wanted signal. The phase and amplitude relationships between multipath signals determine resulting input signal at receiver. The example of input level as a function of time during the fading event is shown in Fig. 2.

Fig. 1. The locations of experimental links.

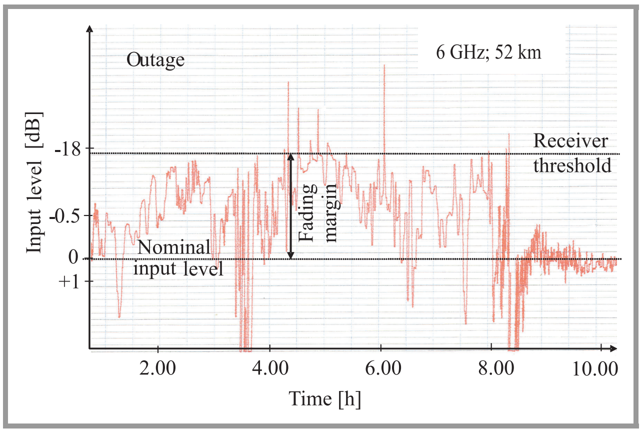

Fig. 2. An example of multipath fading of 6 GHz terrestrial path.

5. The Measurement Results

The occurrence of multipath mainly depends on weather conditions such as temperature, wind, humidity, air pressure, and these weather phenomena can be described only

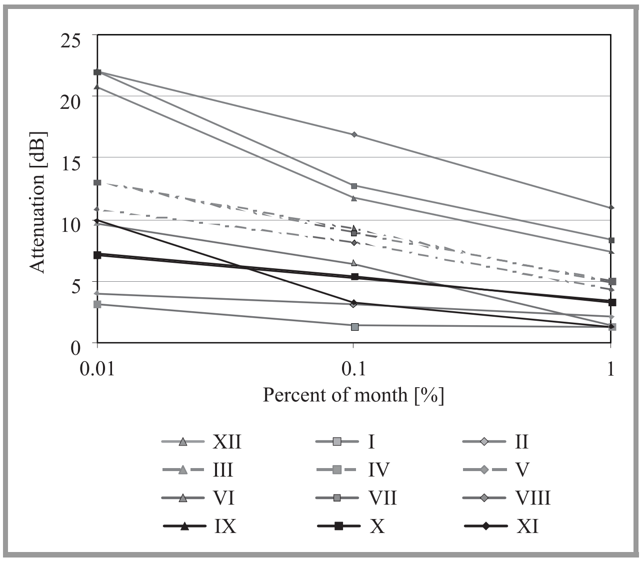

Fig. 3. The measured monthly 4th year distributions of attenuation at 6 GHz.

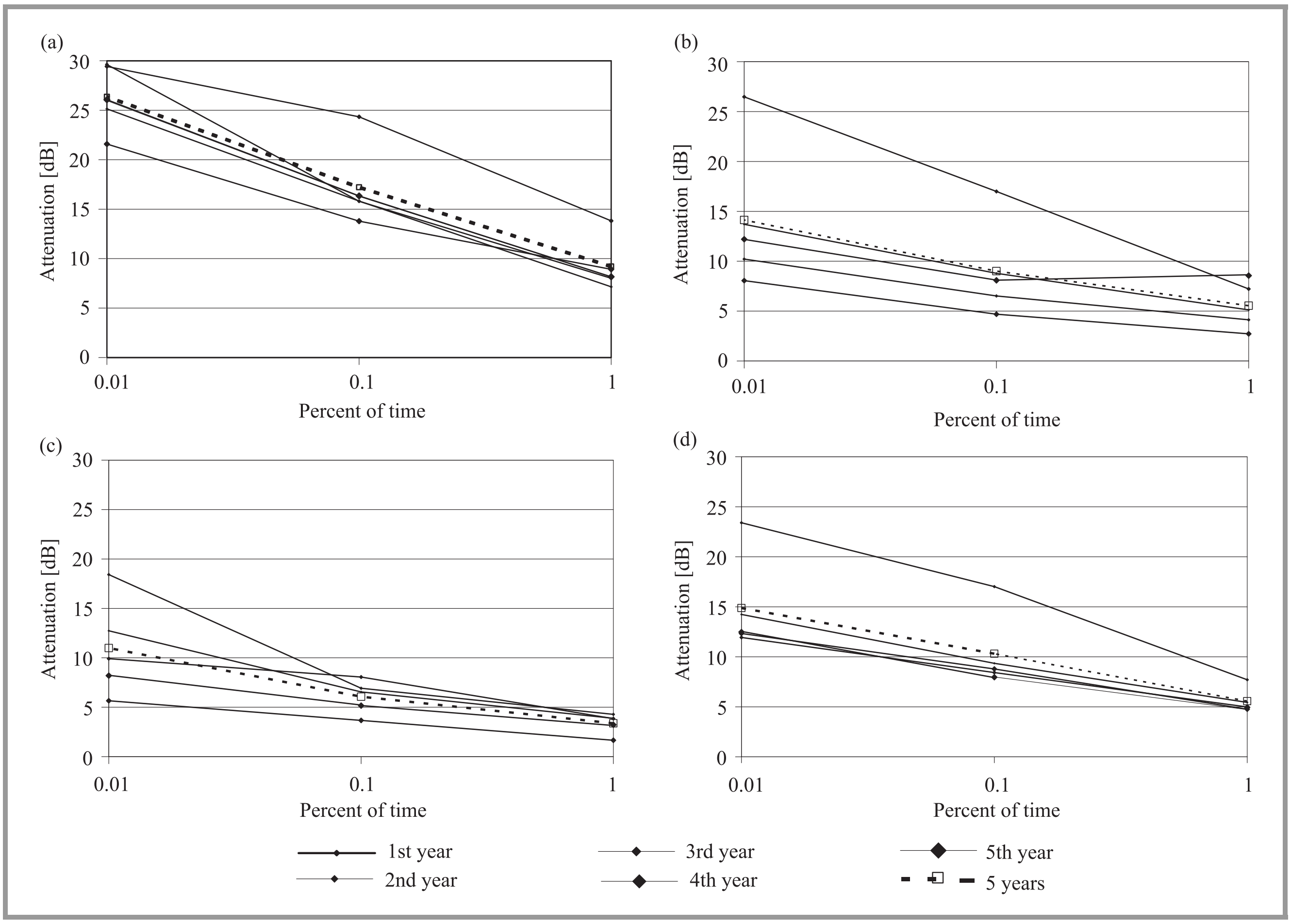

Fig. 4. The measured seasons distribution for: (a) summer (June, July, and August); (b) autumn (September, October, and November); (c) winter (December, January, and February); (d) spring (March, April, and May).

statistically. Therefore the changes of path loss, which are very important in the design of the radio-link system, can also be described only statistically.

The results of the measurement investigations allowed to determine among other things season's behavior of radio channel at 6 GHz band. In point-to-point link immersed in time varying propagation medium the received signal power varies with time even when transmitter power remains constant. Measuring the probability fades of particular magnitude occur with, will lead directly to the probability of outage and hence the link availability probability.

Received signal samples were used for computation of monthly and annual fading distributions as well as distributions for the worst months and then season's fading distributions were obtained. The important problem of "zero" level during multipath effects was solved assuming that monthly 50% level is "zero" level for multipath fading [10].

Monthly distributions of attenuation for each path are the basis for cross-sectional statistical analysis.

Figure 3 shows the distribution of attenuation for 12 months obtained from a one year measurements on the 41.3 km path.

It illustrates how attenuation varies with months. For example, attenuation reaches 22 dB in July and August, and only a few decibels in January and February, for 0.01% of time.

Changing of season's attenuation distributions will be shown on the basis of measurements results from radio link at 5885.04 GHz and 41.3 km path length.

Figure 4 shows season's distribution of attenuation due to multipath obtained from five years of measurements on the 41.3 km path.

The attenuation changes a lot during a year. Summer season average at 0.01% of time is 26 dB and only 14 dB for season's autumn average.

Our studies indicate that there were many differences between season's average attenuation obtained from 5 years and season's average attenuation in individual year. For example, maximum attenuation difference is 12 dB on autumn at 0.01%, 7 dB on summer at 0.1%, 7.4 dB on winter at 0.01% and 8.5 dB on spring at 0.01%. There are statistics, empirical results.

Figure 5 compares average season, annual and the worst month distributions obtained from 5 year measurements. It shows that average autumn season attenuation is similar to average spring season. Maximum attenuation difference is 0.8 dB at 0.01% and 0.65 dB at 0.1%.

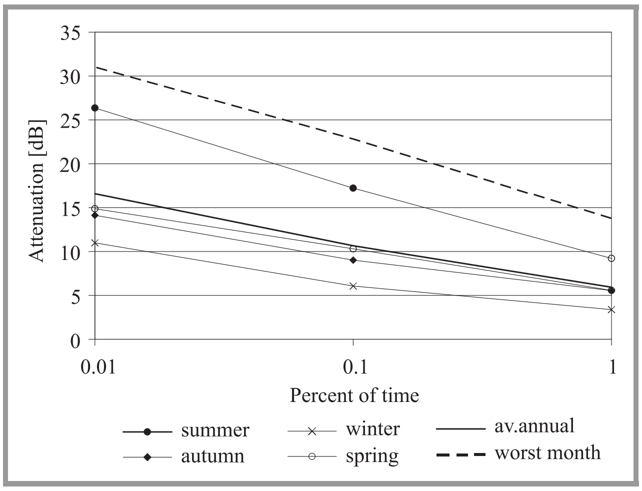

Fig. 5. The average season, annual and worth month distributions for 5 years.

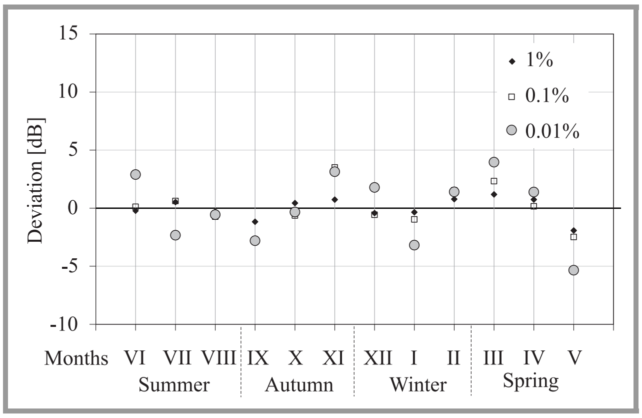

Fig. 6. The deviations of attenuation for average months in the year from appropriate average season for 1, 0.1, and 0.01%.

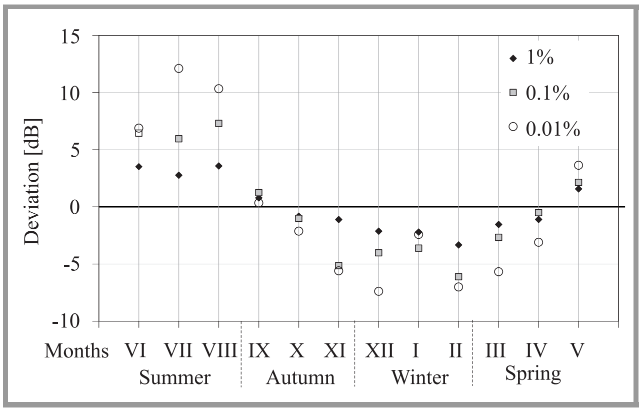

Fig. 7. The deviations of attenuation for average months in the year from average annual attenuation for 1, 0.1, 0.01%.

The order of calculation to obtain the input data for Fig. 6:

– 12 distributions of average month attenuation for the period of 5 years;

– 4 distributions of average season attenuation for the period of 5 years;

– the difference between average month attenuation and appropriate average season attenuation for 1, 0.1, 0.01%.

The result of these calculations seems not to be obvious. It can be explained that in summer average value is high, but there are less unpredicted events. The smallest deviations for 0.01% are for summer (maximum 2.9 dB), and are bigger in autumn (3.1 dB), in winter (–3.2 dB), and are the biggest in spring (–5.5 dB).
The data for Fig. 7 were obtained in an analogous way to these for Fig. 6; the average month distributions were compared with average annual distribution.
The comparison between Figs. 6 and 7 indicate that average season distributions were more accurate than average annual distribution, particularly in summer. The difference between average month and average annual attenuation is 12.1 dB in July while deviation of average month from average season's attenuation never exceeded ±5.5 dB.

6. Conclusion

The knowledge of fading statistics is extremely important for the design of wireless systems. Microwave radio links can be properly and precisely engineered to overcome potentially detrimental propagation effects. One of characteristics that must be taken into consideration is multipath attenuation.
The gathered empirical data at 6 GHz of seasonal statistical distributions broaden our knowledge about the signal changes with weather variations. This knowledge can improve our interpretation of the phenomena that appear in installed modern radio systems.

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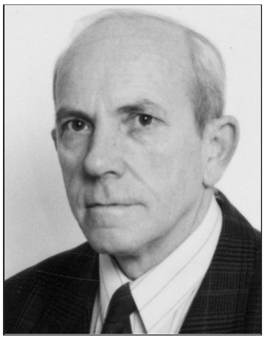

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