Cumulative Rain Attenuation Probability In Ukraine

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Abstract— **A 4-month cycle of meteoric observations in the mode of short integration time (averaging) of 5 minutes was carried out. Using the selected radiophysical model (MPM), data arrays were obtained on atmospheric attenuation in rain. On the basis of experimental data of the rain rate in Kharkov (which obtained by 5 min averaging interval) for the first time at Ukraine, evaluations of events and probabilities of communication outage due to manifestations of a critical level of precipitation (rain) were made justified from a microclimatic point of view. Estimates of meteorological situations characteristic of communication outages were determined for the warm period of the year and the worst months in terms of communication link availability at 28 GHz, 38 GHz, 60 GHz and 94 GHz.**

Keywords— rain rate, cumulative function, communication line, atmospheric attenuation, communication outage.

I. INTRODUCTION

The development of technologies in the field of mobile networks, the Internet and land-space communications has increased the demand for high-speed data transmission. Therefore, in the field of data transmission technology, a transition to higher frequencies up to 100 GHz is observed. The use of this relatively new for the widely used communication applications range, provides an increase in the volume and speed of information transmitted above 10 Gbit/s with acceptable availability factors in communication networks (10^{-3}–10^{-4}). However, for operating frequencies over 10 GHz, important problem is the absorption and scattering of millimeter radio waves (MMW) in the rain [1-2]. In this regard, the relevance of the study of the statistical parameters of the full vertical and linear ground-level attenuation of radio waves of MMW has increased dramatically in the world in recent years, in particular, due to the development of promising ultra-high-speed and information-capacious fifth-generation ground-based and tropospheric communications (5G). Obtaining these additional data is also necessary to refine the development of a local model for predicting rain attenuation.

The report describes the results of a study of rainfall intensity statistics in 2018 in Kharkov (Ukraine) for the most rainy months of the year, and also assessed the impact of these statistics on the tropospheric attenuation in surface communication lines from the point of view of communication outage in MMW.

II. PROBLEM STATEMENT

From the point of view of the problem under consideration, the climate in Kharkov is characterized by the fact that the annual amount of precipitation averages 517 mm, their peak falls on thunderstorm June and July (61 mm each), and precipitation in the city falls fairly evenly. As in the entire temperate zone, precipitation is greatest in the summer months, mainly due to the movement of the sun along the ecliptic, its high position above the horizon stimulates the evaporation of moisture and the formation of rain and thunderstorms. From July to August, the dry period lasts, during which moisture is mainly thunderstorm. It is in July at Kharkov there is the greatest amount of hot days, and the greatest amount of precipitation. At the same time, precipitations in July are usually rare, occurring several times, but then thunderstorms have heavy rainfall, and are characterized by enormous strength. This circumstance may be the most destructive factor that disrupts the performance of the designed communication lines.

The most important parameter that determines the reliability of the communication line is the link availability parameter (unavailability), which quantitatively characterizes the probability of communication failure. [3]. The values of the link availability/unavailability parameter can be calculated using the recommendations of the international telecommunications union. *ITU* [4-5], based on the following expressions, we can calculate the required signal power at the receiver input [6]:

$$P_r = P_t + G_t - L_{FS} - L_{rain} - L_{atm} + G_r \qquad (1)$$

where P_t – transmitter power in *dBm* ; G_t , G_r – transmitter and receiver antenna gain; L_{FS} – signal attenuation in the headspace; L_{rain} - signal attenuation in the rain; L_{atm} - signal attenuation due to atmospheric gases.

From the above expression, it follows that prediction of readiness values, in addition to specifying the set hardware parameters of the communication line (receiver sensitivity, transmitter radiated power, antenna gain, etc.), required data of cumulative distribution function of atmospheric attenuation for each considering region. At the same time, it is necessary to take into account that the attenuation caused by rain is the main cause of interruptions in the operation of

tropospheric and satellite communication systems using centimeter and millimeter wavelengths.

The cumulative attenuation distribution in the rain is fairly simple to determine if the statistical distribution of the rain rate p(R) is known (the probability p, the magnitude of the rain rate for which is greater than value R).. However, it is necessary to bear in mind the regional or microclimatic dependence of these distributions for the considered wavelengths. It is well known that with an increase in the operating frequency, the communication range rapidly decreases, the dependence of signal transmission on weather and microclimatic conditions characteristic of a particular region increases. Given the importance of obtaining the most accurate estimates of the prediction of the reliability of communication, *ITU* recommends to take into account the microclimatic features of the regions under consideration through the experimental accumulation of seasonal and annual statistics of atmospheric attenuation.

For the territory of Ukraine, such experimental data on the cumulative functions of the vertical and horizontal atmospheric attenuation are absent for MMW.

The initial data for the construction of cumulative distribution functions of the specific attenuation for centimeter and millimeter wavelengths can be obtained in two ways:

1. Experimentally, by collecting long-term statistics of continuous changes in the horizontal linear atmospheric attenuation at a point-to-point path [7-8], or by determining the total atmospheric attenuation on inclined paths by radiometric methods at individual frequencies [9-12]. Studies of long-term data have shown that, as a rule, a suitable period for practical use is 3–7 years. [13].

2. By formation of (on the basis of processing a large number of experimentally obtained data) phenomenological models of communication of the rain rate and specific attenuation of the signal, which depend on the frequency.

Despite the fact that the first approach is considered more preferable from the point of view of accuracy of assessments, its essential drawback is the relative complexity of preparing and implementing such a long program of continuous radio physical observations, which, as a rule, are limited to one or two points of a wide frequency range.

The advantages of the second approach, which is widely used in the world, include the presence of multi-year databases containing the intensity of precipitation in an extensive network of meteorological stations, along with the presence of radiophysical models that quite accurately describe the amount of specific attenuation for various rain intensities in different radio wave bands (usually from 5% around 10 GHz to 30% at frequencies around 1000 GHz). The disadvantages of this approach are also attributed to the fact that in the vast majority of such databases, the rain rate values are presented with an averaging time of 20 to 60 minutes. At the same time, one-minute periods of averaging the rain rate are considered the most suitable for calculating the attenuation on the track. This circumstance makes it necessary to recalculate T-minute data into 1 minute data, by using additional models, which also have microclimatic features, which can lead to additional errors. Therefore, a more accurate solution can be obtained using modern automated rain gauges with a 1-minute integration time for long-term accumulation of statistical information about the intensity of rain in the region under consideration.

III. HARDWARE-METHODOLOGICAL SUPPORT AND OBSERVATION CONDITIONS

The cumulative distribution function of the rainfall rate with an integration time of 1 minute can be obtained by converting the integral distribution functions for a longer integration time using the following relation:

$$R_1(P) = \alpha(T)R_T^{\beta(T)}(P) \qquad (2)$$

where $R_1(P)$ and $R_T(P)$ – rainfall intensities measured at integration times of 1 min. and T min., which are exceeded with equal probability ($P,\%$), α and β – regression coefficients. Coefficient values α and β are using to conversion from integration time for example, $T = 5$ min. in 1 min. in accordance with the recommendations ITU - R 837-5 equals 0.986 and 1.038 respectively.

However, it is necessary to bear in mind that this and other similar models have microclimatic features, which can lead to additional errors. For example, the above values of conversion factors were obtained on the basis of long-term measurements of local rainfall rate at 14 locations in Korea, China and Brazil, for other regions other coefficients may be required. [13].

Most of the previous studies on short-term rainfall for use in attenuation models provide data in the form of annual rainfall frequencies. However, annual statistics can be misleading, since in most places rain events with intensities higher than critical (when rain rate can cause communication outages) are concentrated only in certain months of the year. Low annual periodicity of communication outages due to rain may be unacceptably high in these months. Therefore, monthly or seasonal rain rate statistics are preferred.

In this work, we used critical rain velocities as a criterion for communication outage, which could cause a total attenuation of 15 dB [1] on a 1 km long path for the considered frequencies 28 GHz, 38 GHz, 60 GHz and 94 GHz. These promising frequencies for communication applications were chosen for radiophysical calculations from the following considerations. Frequencies 28 GHz, and 39 GHz – as approved for 5G by the Federal Communications Commission (FCC) by its decision 07/14/2016. Frequency 60 GHz, as used in the new standard of information transmission technology *IEEE 802.11ad* and being promising to provide covert communication based on small cells. Frequency 94 GHz – as having prospects of use for the subsequent development of 5G and more distant 6G communication formats.

Calculations of specific attenuation values in rains were performed using the MPM model, which provides for the frequency range below 100 GHz the error less than 5% [14].

Rain rate measurements were carried out continuously for 4 months in 2018 (June-September) using the automated wireless weather station TFA OPUS. This weather station provides autonomous receiving (via adjustable 1, 5, 10, 20 or more minutes) values of temperature, humidity and air pressure, wind speed \ direction, as well as rainfall measured in millimeters (with a minimum sampling of 0.2mm).

In this work, we used 5min averaging mode because of the limited amount of RAM, which allowed to accumulate data without a loss of information read from meteorological sensors in 1min mode for no more than 2 days. In the 1min averaging mode, several test records were made for rain events in order to compare their result with the result obtained in 5min. averaging mode and estimate the degree of difference.

Data transmission from weather station to PC and settings of measurement modes with PC were carried out using wireless communication between them.

IV. SIMULATION RESULTS

Fig. 1 shows the probabilities of exceeding the values of rain rate (which are plotted on the x-axis), which were obtained based on meteorological observations (with a 5-minute integration interval) during the 4th warm months of 2018.
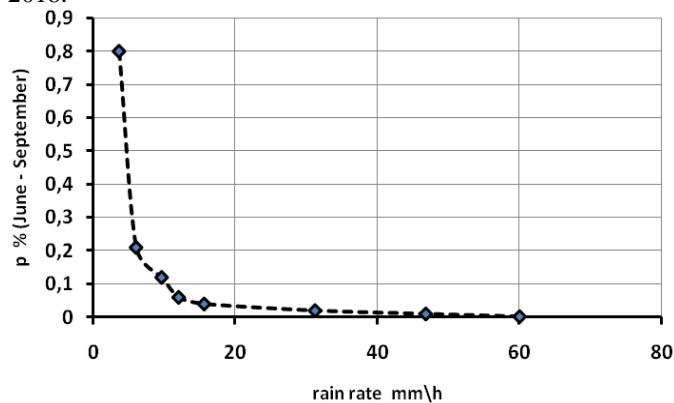

Fig. 1. The cumulative distribution of rain rate over the 4-month period 2018 (June-September) in Kharkiv, Ukraine.

The total precipitation time for the considered 4–month period of 2018 was 990 minutes – 240 minutes. in June, 415 min. in July, 35 min. in August and 300 min. in September.

Based on these meteorological data, were performed atmospheric attenuation calculations using the MPM model for the frequencies of 28 GHz, 37 GHz, 60 GHz and 94 GHz.

Fig. 2 shows the calculated dependences of the cumulative distribution of the atmospheric attenuation for the frequencies of 28 GHz, 37 GHz, 60 GHz and 94 GHz in July 2018, and in fig. 3 - for June.
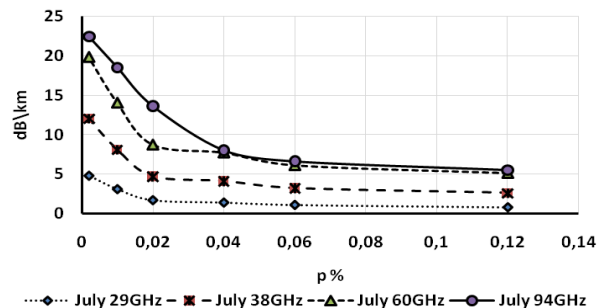

Fig. 2. The cumulative distribution of the atmospheric attenuation for the frequencies 28 GHz, 37 GHz, 60 GHz and 94 GHz (July)

For both August and September, for p = 0.01% attenuation is 1.4, 4.1, 7.7 and 8 dB / km for 28 GHz, 37 GHz, 60 GHz and 94 GHz respectively.

Fig. 4 shows the critical intensities of rain in the worst months for Kharkov. Fig. 4 contains some fragments of Fig. 2 and 3 and is given for convenience of analyzing quantitative and qualitative differences in the range of extreme attenuation values.
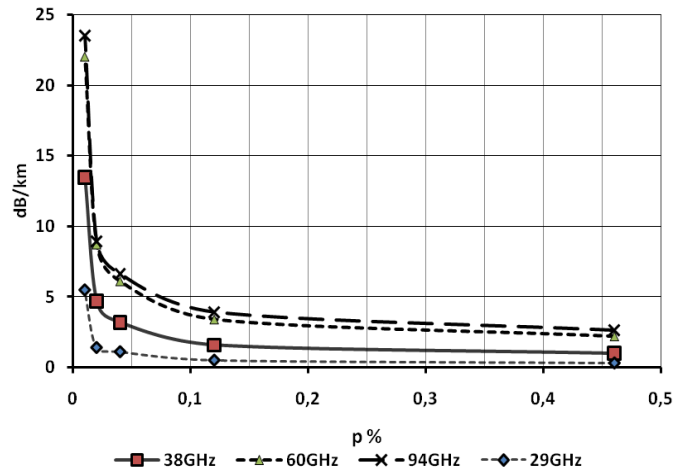

Fig. 3. Cumulative distribution of specific atmospheric attenuation for the frequencies of 28 GHz, 37 GHz, 60 GHz and 94 GHz (June)

The data obtained demonstrated that for p = 0.01% over a period of 4 warm months, the attenuation does not exceed 9 dB / km, i.e., at least for 2018, the connection can be considered reliable in all considered wavelengths. Accordingly, for the one-year observation period, even lower probabilities of extremely high specific attenuation values should be expected. However, if we consider communication problems in the worst months (June-July), then for each of them separately, the attenuation with probabilities of 0.01% (Fig. 4) at frequencies of 60 GHz and 94 GHz will exceed the communication violation threshold noted above (15 dB/km). The issues of the duration of precipitation events causing communication outages and their inter-annual variability deserve additional study for high-frequency tropospheric and satellite communication networks.
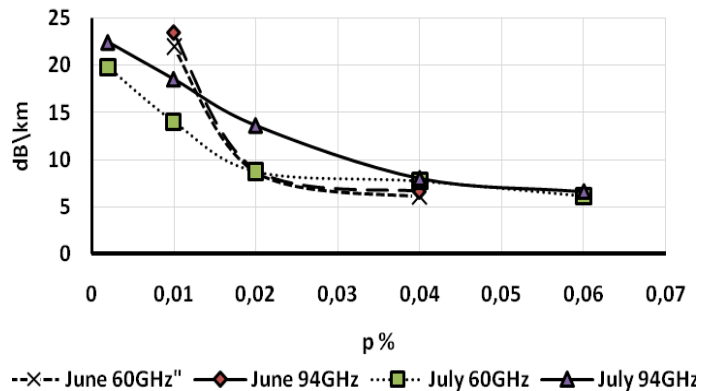

Fig. 4. The probabilities of exceeding the extreme values of specific attenuation in the atmosphere for June and July 2018 at frequencies of 38 GHz and 94 GHz.

In the process of this kind of research, the question also arises of how accurate the formulas for converting T-minute into 1-minute data on rain rate in the considered region of Ukraine [15]. Fig. 5 shows as a particular example the differences of the recovered atmospheric attenuation according to the recorded rain rate with 1-min averaging

time, as well as the simulated attenuation values for the case of recording the same event with 5-min averaging.
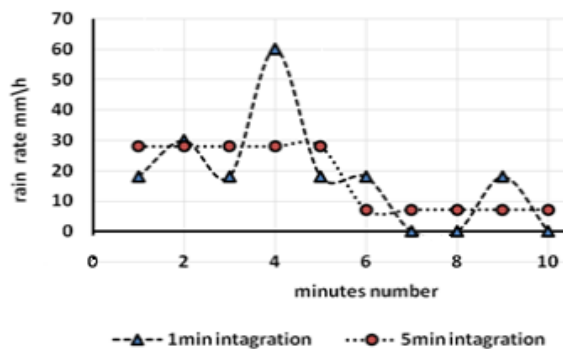

Fig. 5. Comparison of rain intensities measured over 10 minutes of observation for 1-min and 5-min integration intervals.

A control measurement with a 1-min integration time interval showed that during the considered 10-minute period, the communication outage could be for 2 minutes (2nd and 4th minutes) for all frequencies above 37 GHz (if the threshold is the critical intensity of rain, which causes outage on the communication line with a length of 1 km with a total attenuation on the track more than 15 dB). At the same time, if we measured the rain rate for the same event with a 5-min integration interval and then transferred the measured data using the ITU formulas to the 1-minute interval (Fig. 5), we could not predict any communication outage events.

The answer to the question of how often such situations arise in practice probably also requires further additional research, however, as well as questions about the set of statistical data shown in the figures for other years using a 1-minute averaging interval.

CONCLUSIONS

Data on rain rate obtained from a 5 min averaging interval for one of the most industrially and infrastructurally developed, as well as the most populated regions of Ukraine (Kharkov) are presented. On their basis, experimentally substantiated estimates of cases and probabilities of communication outages due to critical rain levels have been made. Estimates of meteorological situations that are characteristic of communication outages were determined for the worst month and for 4 months of the warm period of the year using the radiophysical MPM model. As a criterion for communication failure, a attenuation threshold of 15 dB was used on a 1 km horizontal path for all considered wavebands — 28 GHz, 38 GHz, 60 GHz, and 94 GHz. Obtained results indicate that it is possible to ensure reliable communication in the considered frequency bands during the non-warm-time periods of the year (from September to April).

Attention is drawn to the fact that the annual statistics, which include the winter months with a very low probability of interruptions, hide the real effect of rain attenuation on work during the warm period of the year. Designing EHF communications should also take into account conditions during the months when the probability and duration of outages are maximum.

The data presented may be useful to formulate a general strategy for minimizing the effect of signal attenuation in rain.

New data of rain rate, analyzed in the work, allow for the first time for Ukraine to give a reasonable quantitative estimate of the probability and duration of outages in the EHF communication due to weather conditions for the region under consideration. Obtained results can also provide a analogy to account rain effects of in other regions with similar climate precipitation.

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