Dependence of Area-Averaged Rain Rate on PMP System Coverage Planning

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Abstract

In this paper, area-averaged rain rate calculation using the ITU-R statistical model is discussed and its accuracy investigated. The influence of its proper determination on the coverage planning of PMP systems is revealed. Moreover, a model modification which better fits the local conditions prevailing in the Czech Republic is provided.

1. INTRODUCTION

The assessment of the precipitation phenomenon during coverage analysis of the millimeter wave band PMP (or MP-MP) systems presents a fundamental step in the system design process. The basic concept of area coverage is common throughout all frequency ranges. It is based on marketing and sales requirements as well as on technical design criteria. Marketing and sales define the locations of potential customers (coverage requirements), while the RF design criteria determine the number of sites needed in order to meet the system requirements (line-of-sight, coverage, capacity, reliability, BER, etc.). Since Line of Sight (LOS) coverage is always required for PMP systems, it can be evaluated separately.

The area coverage, however, is defined as an area where all system requirements are met. Therefore, the particular availability of service in a coverage area affected by rain is a high priority. The cell coverage distance will vary depending on the rainfall statistics for that particular area. Subsequently, preliminary assumptions of the area coverage by a base station in clear air conditions have to be revised by factoring in the rain attenuation (see Fig. 1).

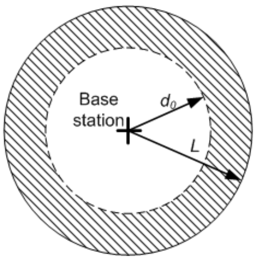


Fig. 1. Coverage of an area during clear sky conditions (radius L) and during rain (cut-off distance d_0)

It could be emphasized that there is significant difference between point-to-point and point-to-multipoint systems, specifically in the assignment of the rain attributes to coverage planning. In the case of a single link, the point rain rate statistics are considered, whereas in the PMP systems the system sensitivity on the spatial distribution of rainfall is utilized [1]. Therefore, rain rate statistics related to an area (area-averaged rain rates) are considered during the enumeration of coverage [2] [3]. Values of the area-averaged rain rate and its consequential statistics can be obtained by averaging all rain rates from a given circular area. Usually discrete data from a mesh of rain gauges or continuous radar rainfall scans are utilized to enumerate the area-averaged rain rate [3]. In this paper, the area-averaged rain rate calculation using the ITU-R statistical model is discussed and a model modification to better fit the local conditions of the Czech Republic is provided.

2. AREA-AVERAGED RAIN RATE

The utilization of the area-averaged rainfall rate obtained from radar observations in the United Kingdom is introduced in ITU-R P.1410 [3]. In particular, cumulative distribution functions of the area-averaged rain rate for radii of 2.5 and 5 km are listed here. Area-averaged rain rate values from [3] are mentioned in Tab. 1.

TABLE 1: POINT AND AREA-AVERAGED RAINFALL RATE OBTAINED FROM A TWO-YEAR RADAR DATA SET IN THE U K (ITU-R RAIN ZONE F/E) [3]

Percentage of time	Point rainfall rate, R (mm/hr)	Area-averaged R	
		Radius = 2.5 km	Radius = 5 km
0.001	65.6	36.0	33.0
0.003	46.2	29.0	23.4
0.01	29.9	19.4	17.1
0.03	18.1	16.3	12.6
0.1	9.8	9.5	8.5
0.3	5.0	4.9	4.8
1	2.0	2.1	2.1

However, in order to obtain a better estimate of the covered area under local conditions, the data valid for the Czech Republic has to be considered. Therefore, the annual meteoradar data (year 2004) from the area with a specific center situated approximately in the centre of Prague (from the rain database [4]) has been utilized for the analyses. To determine the area-averaged rain rates as accurately as possible, the meteoradar data were interpolated by a cubic spline. The average rain rate was then calculated from these two-dimensional 0.5 kilometer grid resolution rain-rate maps (inside circles with radii ranging from 1 to 5 kilometers).

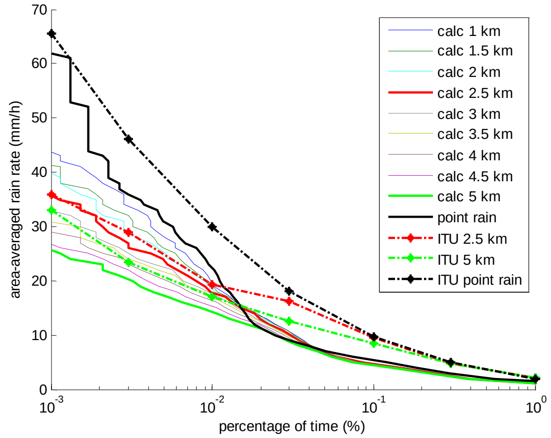


Fig. 2. Comparison of statistics of averaged rain rate obtained from meteoradar data and from [3]

Fig. 2 provides a comparison of the statistics relating to the area-averaged rain rate obtained from our meteoradar data and from ITU-R P.1410 [3]. Point rain rates are depicted as well. A statement valid for both types of data sets can be obtained from the figure - the larger the averaging area considered, the more reduced the values for area-averaged rain rate that can be obtained for a given non-availability of service. This is especially true for lower percentages of time. Since the averaged rain rates increase as the time percentage decreases, it can be concluded that higher rain rates are more likely to occur in smaller, localized areas for very short periods of time. One can see that the simulation results significantly differ from those predicted by the ITU-R model, especially for a 5 kilometer diameter (green lines). When comparing the second diameter mentioned in ITU, the values for 2.5 km (drawn in red) are almost identical for the smaller time percentages (from 10^{-3} up to 10^{-2} % of time), which are utilized during the planning of coverage for systems with higher availabilities required (from 99.999 to 99.99%), and completely different for the higher time percentages.

During the next stage, the spatial variability of the area-averaged rain rate was investigated. We wanted to find out whether the values of the area-averaged rain rate would be noticeably different in close proximity to the previous location. The statistics were computed for four new locations placed 10 kilometers northward, westward, eastward and southward from the first area. The deployment of centers of averaging in the analyzed area is depicted in Fig. 3. In these cases the outer circles demarcating the 5 km diameters are in tight juxtaposition.

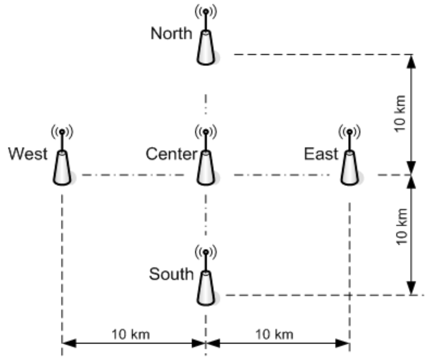
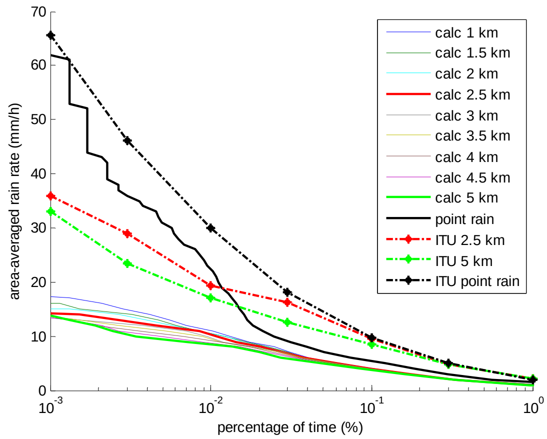


Fig. 3. Analyzed areas

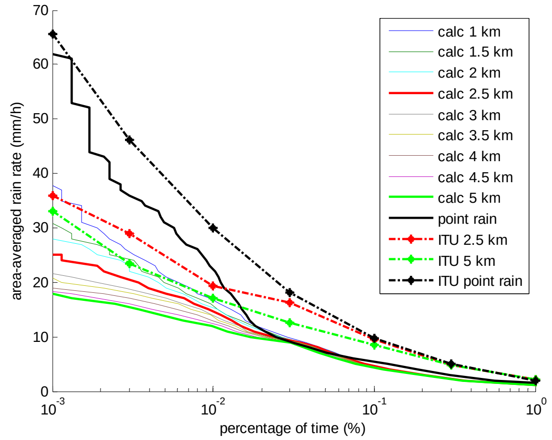
The distinguishable changes between area-averaged rain rates depending on placement can be seen when comparing our averaged rain rate statistics taken from these five locations (Fig. 2 and Fig. 4).

It was realized that the rain events tended to differ statistically (within a certain level of probability) in particular geographical regions [5], moreover, as could be seen, the averaged rain rates also vary depending on the position within such region. Whereas there are no visible differences between averaged rain rates that were observed in different locations in 0.2 - 1 % of time, the curves changes are distinguishable according to the position of the averaging centre at the shorter time periods (i.e. from 0.001 to 0.2 %). What is more, as can be clearly seen from either Fig. 2 or Fig. 4, the results from the simulation are different to the values given by ITU-R P.1410 [3].

The mean values of the area-averaged rain rates have been derived for particular radii utilizing all the simulation results (from each time step) from all locations. Note that the resulting curves are quite different from those obtained by only averaging statistics from Fig. 2 and Fig. 4 a),b),c),d). It should be highlighted that the averaging of rain rates for a particular time percentage from different locations can leads to a misrepresentation of the results.



a)



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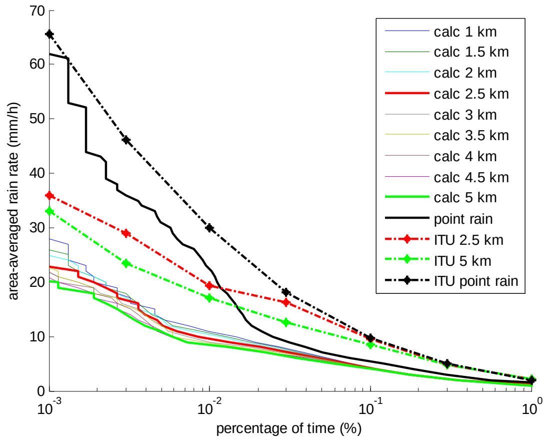
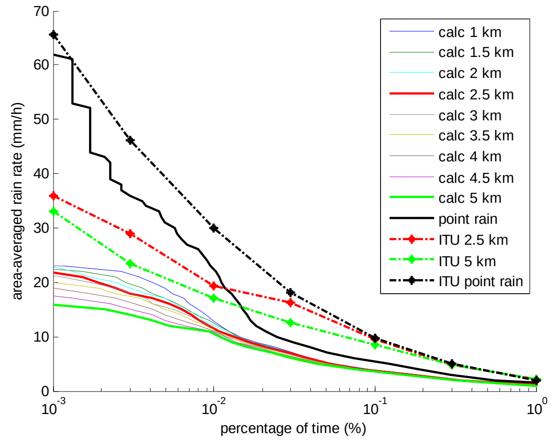


c)



d)

Fig. 4. Statistics of averaged rain rate from surrounding locations: a) Westward; b) eastward; c) northward; d) southward location

The mean values given from all five locations and their standard deviations are depicted in Tab. 2. Compared to the values given in ITU [3], the parameters valid in the Czech Republic are almost one third lower for every time percentage. In particular, when a higher availability is required e.g. 99.999 or 99.99 %, the difference for areas with a 5 km radius, ranging between 33 mm/h (ITU) and 19.5 mm/h (our simulation), and between 17.1 mm/h (ITU) and 11 mm/h, respectively are substantial. This could be significant during a preliminary calculation of the area coverage, since if we assume lower rain rates, a larger radius can be served by a single base station. Problems involving the calculation of area coverage will be examined more closely in the next chapter.

TABLE 2: MEAN AREA-AVERAGED RAIN RATE OBTAINED FROM SIMULATIONS

Percentage of time	Mean area-averaged R [mm/h]		Standard deviation [mm/h]	
	radius 2.5 km	radius 5 km	radius 2.5 km	radius 5 km
0.001	24.6	19.5	7.7	4.6
0.003	20.0	15.4	5.3	3.7
0.01	12.8	11.0	3.4	2.5
0.03	7.9	7.1	1.7	1.6
0.1	4.2	4.0	0.4	0.4
0.3	2.3	2.2	0.1	0.1
1	0.9	1.0	0.1	0.1

From the results shown in Tab. 2, it follows that the mean area-averaged rain rate describes typical values, especially at higher time percentages (i.e. low link availabilities). From 1 up to 0.03 percentage of time, almost the same mean area averaged rain rates occurred for both the 2.5 and the 5 km radii. The values tend to converge at the shorter time percentages. When combining all five locations, standard deviations range from 10 to 20 % of the mean area-averaged rain rate. It may be noted that only statistically small amounts of data (one year's rain radar data) were utilized in our simulations. Therefore although these results should not be taken as absolutely accurate, nevertheless useful conclusions have been drawn. To complete the analysis of the ITU-R P.1410 coverage method, the coverage calculations based on simulated area averaged rain rates will be investigated in the next section.

3. COVERAGE

In order to have a better understanding of the area-averaged rain rate concept, especially the most precise availability (better than 99.97 %) have to be subsequently investigated using coverage calculations. Let us assume that the LOS coverage among all RF designed links in clear air conditions is established, meaning that the area coverage is equal to the LOS coverage and no additional losses are considered. The cut off distance for a particular time percentage, the area covered, the link fade margin and the area-averaged rain rate can then be derived using the method mentioned in [3].

A significant difference between the cut off distances based on the ITU proposed values (red curve) and those based on results valid for the Czech Republic (black curve) can be seen in Fig. 5. The curves were computed for a system working at a frequency of 42 GHz with a horizontal polarization and a cell radius of 5 km. For a better understanding of the rain influence, a 0 dB fade margin was considered. Values of the mean area-averaged rain rate taken from Tab. 2 were utilized.

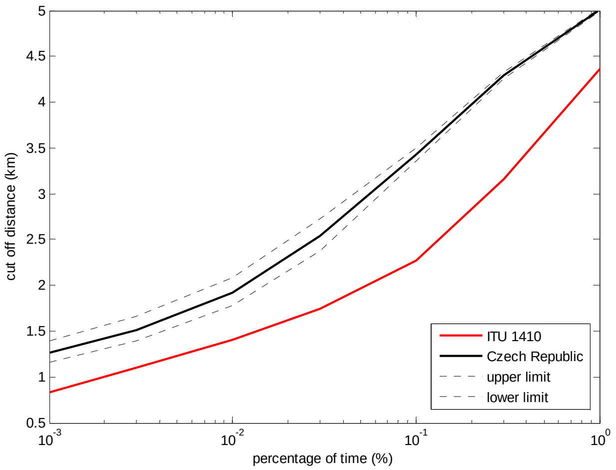


Fig. 5. Comparison of cut off distances calculated from ITU and our simulation results (42 GHz, horizontal. polarization, cell radius 5 km, 0 dB fade margin)

It should be emphasized that the cut off distances calculated from ITU and from our results differ throughout the time percentages ranging from 0.5 to 1 km. The option of setting up a longer cell radius based on the specific average rain rate is crucial for millimeter wave band system providers, since a huge amount of money could be saved on several base stations. Therefore the area-averaged rain rates valid for a given geographical region should be always considered when planning a millimeter point-to-multipoint system.

The dashed black lines in Fig. 5 delimit the variation of the cut off distance due to the position of the centre averaging. As was mentioned above, for time percentages from 1 down to 0.03 percent the changes in cut off distances with position of averaging are negligible. On the contrary, when a higher availability is required from the PMP system, the calculated cut off distance can vary significantly depending on the chosen location of the measurement.

4. Conclusion

The main result given in the paper is the modification of the existing ITU-R model for use in the local geographical environment of the Czech Republic giving also a discussion about validity of such a method. An underestimation of the required coverage area (to compensate for a given probability of rain outage by ITU-R) would result in the over-dimension of the PMP system which, in turn, would result in unnecessary system costs.

The methodology used in this paper can easily be applied to obtain similar parameters for an arbitrary geographical environment. The variation of such results in a given area with respect to the choice of the coverage centre has been discovered to be negligible for probabilities of rain outage ranging from 1 down to 0.03 percent and to be quite important when higher availabilities are required in the system – in this case, the variation in the calculated cut off distance and, consequently, in the area coverage has to be taken into account.

It should be emphasized that the validity of our results as well as the validity of results mentioned in ITU-R P.1410 are limited. Only one year's data from 2004 and two years radar data were considered in our simulations and published in the ITU, respectively. From a statistical point of view, this amount of rainfall data is insufficient. Especially for an accurate description of such random phenomena such as rain behavior and particularly at smaller time percentages, several years worth of rainfall data are needed (this will be next stage of our research). Nevertheless, the analysis in this paper has revealed the question of whether the method of coverage assessment based on the area-averaged rain rate is the right choice. It was confirmed that the area-averaged rain rate approach can only be used as a first attempt to assess coverage aspects in the case of rain affecting millimeter PMP systems. A much better and accurate approach can be accomplished by site-specific simulations as was shown for example in [6].

Acknowledgement

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