Quantification of a Wet Antenna Attenuation for a Measurement of Rainfall Intensity via the Metropolitan Network of Microwave Links in 10 GHz Band

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Abstract—Commercial microwave links can be utilized as an effective sensor network for a rainfall measurement. However, there are various obstacles that must be overcome, from which the most significant seems to be an effect of wet antenna attenuation. In this paper, the rainfall calculation has been performed in both a single-link way and an area calculation via the RAINLINK algorithm on the group of real 10 GHz metropolitan microwave links. Conclusion summarizes the resulting wet antenna attenuation values and evaluates the performed measurement.

Keywords—microwave link, commercial telecommunication network, precipitation, rainfall, wet antenna attenuation, rain intensity, rain gauge, meteorological radar, RAINLINK

1. INTRODUCTION

Measurement of rainfall by a network of commercial point-to-point microwave links seems to be a promising way to further refine existing meteorological precipitation measurement methods. Figure 1 shows a simplified diagram of the measurement principle. \( P_t \) is a transmitted electromagnetic power and \( P_r \) is a received electromagnetic power, while \( A_0 \) is a sum of a general attenuation due to a free-space path loss, wave reflection, diffraction etc., and \( A \) is an investigated attenuation due to rainfall (in fact it is a combination of a raindrops electromagnetic scattering and absorption and a wet antenna attenuation).

\[ P_r = P_t - A_0 - A \]

Figure 1: Simplified diagram of the measurement of a rainfall by a point-to-point microwave link

Regarding the state of the research, Dutch researchers R. Uijlenhoet, A. Overeem, and H. Leijnse are one of the first and most active contributors in this area. They have published a number of papers and conducted several practical experiments and were the first to write the RAINLINK algorithm [3] which source code is publicly available. In 2018, they published a comprehensive paper summarizing then current research in the field [1]. Other active researchers in this field are the Germans Ch. Chwala and H. Kunstmann who among other papers and experiments also published a summary paper in 2018 reviewing the whole research [2].

The most significant current challenge in the field of rainfall measurement by microwave links is the effect known as a wet antenna attenuation (WAA). [1, 2, 7] It is the attenuation caused by a thin layer of water which forms during the rains on the radome cover of the antenna. No model or method of calculating this phenomenon has been widely standardized so far due to missing need for WAA behavior specification until the beginning of experimentation with the measurement of rainfall by microwave links.

One of the researchers group which deal with the issue of WAA and precipitation attenuation in general are P. Valtr, P. Pechač, M. Fencl, V. Bareš and J. Pastorek from CTU in Prague. Among the papers they published there is the one [4] on quantifying of WAA on microwave links operating in Prague at frequencies around 38 GHz. Next paper specifies [5] on the basis of empirical measurements based on the same methods on links operating at 32 GHz a new model for determining WAA, given as a function

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of rain intensity $R$. Other paper confirms the significant underestimation of the calculated theoretical attenuations according to the ITU-R P.838 recommendation compared to the measured values [6], even when the calculation of the distance factor $r$ according to ITU-R P.530 recommendation is included. The difference is due to the lack of WAA compensation. The last cited paper compares the accuracy of precipitation measurements through the microwave network in Prague [7], using two methods of WAA compensation, with data validation against rain gauges and urban runoff sensors. The first method of compensation is WAA given by a constant value. The second way is to use the rain intensity function $R$ from the research in the previous article [5]. The results show that the use of a constant WAA value leads to less accurate results with underestimating the intensity of light rains and overestimating the intensity of heavy rains. The use of the function led to relatively accurate predictions of precipitation totals validated from values of water runoff in a given river catchment area.

2. PRINCIPLE

The most common method of calculating rainfall from microwave signal attenuation is via the expression of rain intensity $R$ from the power-law equation for calculating rainfall attenuation $A$ according to ITU-R P.838 [8]. This equation is an empirical approximation of the derived equations based on the complex scattering function of raindrops and spectrum of raindrops. Then the following applies to the intensity $R$:

$$R = \alpha \sqrt{\frac{A}{k \cdot d}}$$

where $R$ denotes rain intensity in mm/h, $A$ means attenuation due to rainfall in dB, $d$ is a link path length in m, and $\alpha$ with $k$ are empirical dimensionless coefficients gathered from table depending on frequency. However, the ITU-R P.838 was originally designed only for use in methods for a prediction of rain attenuation and it does not take WAA into account in any form.

The general procedure for measuring rainfall by microwave links is much more complex and consists of the following sequence of steps: 1. acquisition of input data, 2. identification of rain events, 3. determination of the reference value, 4. calculation of rain intensity, 5. data interpolation, 6. output generation [1].

3. SINGLE LINK MEASURES

First, a manual single calculations of rainfall was performed for four commercial microwave links in Prague operating in 10 GHz free frequency band. The aim was to measure the level of attenuation by the WAA on these particular links. All of the links used antennas with a diameter of 0.6 m on both sides of the link and three of them operated with vertical and one with horizontal polarization. The average values of the received signal power for an intervals of 5 minutes are used for the calculation, from which the average value of rain intensity $R$ for these intervals is calculated according to equation 1. The 5-minute intensities thus obtained are then integrated into hourly rainfall totals in a floating time window of 5 minutes. Apart from the net value of the rainfall total, the value affected by the application of the distance factor $r$ described in ITU-R P.530 is also calculated. These rainfall totals are validated by totals from the MERGE2 precipitation estimation system operated by Czech Hydrometeorological Institute (CHMI) at both endpoints A and B of the given microwave link. The choice of the WAA value was made empirically so that the calculated rainfall total with factor $r$ correlates as much as possible with at least one of the endpoint (A and B) rainfall courses from the MERGE2 application. A simple WAA model was chosen for this measurement, based on percentage calibration of each link.

Table I: Single measurements of rainfall totals validated against totals from the MERGE2 – WAA calibration event

<table>
<thead>
<tr>
<th>Link</th>
<th>Total $\cdot r$</th>
<th>Total $r$</th>
<th>MERGE A $r$</th>
<th>MERGE B $r$</th>
<th>$R^2$ with A</th>
<th>$R^2$ with B</th>
<th>WAA (%)</th>
<th>WAA (dB)</th>
<th>$d$ (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10.4</td>
<td>13.1</td>
<td>9.8</td>
<td>9.4</td>
<td>0.92</td>
<td>0.94</td>
<td>65</td>
<td>1.28</td>
<td>3.28</td>
</tr>
<tr>
<td>2</td>
<td>10.5</td>
<td>13.2</td>
<td>10.0</td>
<td>9.3</td>
<td>0.91</td>
<td>0.93</td>
<td>63</td>
<td>1.30</td>
<td>3.41</td>
</tr>
<tr>
<td>3</td>
<td>10.9</td>
<td>13.0</td>
<td>11.5</td>
<td>9.8</td>
<td>0.87</td>
<td>0.93</td>
<td>60</td>
<td>1.47</td>
<td>6.14</td>
</tr>
<tr>
<td>4</td>
<td>15.3</td>
<td>17.7</td>
<td>12.6</td>
<td>9.4</td>
<td>0.87</td>
<td>0.92</td>
<td>60</td>
<td>1.80</td>
<td>6.85</td>
</tr>
</tbody>
</table>
As can be seen in Table I, size of the fraction indicating, what percentage is attributable to WAA (and rain attenuation), was determined for each link on selected calibration rain event. The table also shows the WAA absolutes. The percentages are between 60 and 65 %, while the absolute values are ranging between 1.28 and 1.80 dB. In the next Table II, the percentages obtained from Table I have been made immutable and they have been verified on another rain event. It can be seemed while WAA absolutes are different, ranging between 1.23 and 1.63 dB, the microwave rainfall totals still show a good correlation with CHMI measurements.

**Table II:** Single measurements of rainfall totals validated against totals from the MERGE2 – WAA validation event

<table>
<thead>
<tr>
<th>Link</th>
<th>Total</th>
<th>r</th>
<th>Total</th>
<th>MERGE A</th>
<th>MERGE B</th>
<th>R² with A</th>
<th>R² with B</th>
<th>WAA (%)</th>
<th>WAA (dB)</th>
<th>d (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>21.8</td>
<td></td>
<td>27.1</td>
<td>21.6</td>
<td>18.6</td>
<td>0.91</td>
<td>0.95</td>
<td>65</td>
<td>1.35</td>
<td>3.28</td>
</tr>
<tr>
<td>2</td>
<td>21.4</td>
<td></td>
<td>26.6</td>
<td>21.8</td>
<td>19.1</td>
<td>0.93</td>
<td>0.94</td>
<td>63</td>
<td>1.23</td>
<td>3.41</td>
</tr>
<tr>
<td>3</td>
<td>25.1</td>
<td></td>
<td>28.2</td>
<td>22.2</td>
<td>21.1</td>
<td>0.93</td>
<td>0.95</td>
<td>60</td>
<td>1.63</td>
<td>6.14</td>
</tr>
<tr>
<td>4</td>
<td>18.5</td>
<td></td>
<td>21.8</td>
<td>20.2</td>
<td>12.8</td>
<td>0.93</td>
<td>0.88</td>
<td>60</td>
<td>1.33</td>
<td>6.85</td>
</tr>
</tbody>
</table>

### 4. AREA RAINFALL MEASUREMENT

For an area measurement the RAINLINK: Retrieval algorithm for rainfall mapping from microwave links in a cellular communication network [3] was used. It is a set of functions and scripts written in R language publicly available on GitHub. Since original RAINLINK with its configuration values is meant to be used with microwave links from cellular networks with paths covering large areas, several adjustments of parameters were done mainly to the interpolation method of ordinary kriging which is used in the calculation. For the purposes of this paper a custom interpolation grid was created, measuring \(35 \times 35\) km and completely covering the territory of Prague and the surrounding areas with a spatial resolution of 100 m. Therefore the generated interpolation grid for Prague contains a total of 122 500 interpolation polygons and covers an area of 1 225 km². Of the available set of 127 links located in the Prague metropolitan area, only 39 were left in the final phase for calculation in the RAINLINK. This significant decrease was caused by filtering links whose received signal data was not usable for the RAINLINK input, in almost all cases due to significant short-term fluctuations in received signal power with strong correlation to unit temperature. Locations of the four precipitation gauges operated by CHMI, labeled as A, B, C, and D, against which results were validated, are shown in the left part of Figure 2. Locations of the microwave links included in the calculation are displayed too but slightly randomly shifted due to the protection of the provider’s sensitive data, thus they are not at the exact coordinates.

The RAINLINK allows WAA compensation by only a constant value applied to all links included in the calculation. Therefore this value was empirically set to 1.55 dB which approximately corresponds to the values in the Tables I and II. Furthermore, variogram of the kriging interpolation was adjusted to suppress the highest local extremes.

![Figure 2: Left: Locations of the link paths and gauges; Right: Rainfall courses of the calculated data and gauges](image-url)
One of the calculated rain events in Prague took place on 1th of August 03:00 – 1th of August 2021 12:00 UTC. It was a medium convection rain with a double top. The time courses of the calculated interpolated values from RAINLINK were read on the positions of the A, B, C, D gauges. These and the gauges courses are shown in the comparison in the right part of the Figure 2. Good matches of the microwave courses with CHMI gauges can be observed with $R^2$ value ranging between 0.93 and 0.97 for the all four gauges locations. Also, the gauges A and D, where the highest differences between microwave data and gauges can be seen, are located in the areas where the link network is rather sparse, so in these locations microwave data depends more on the performed interpolation and they have higher estimation character.

5. CONCLUSION

When compensating WAA during the manual calculation, slightly different WAA values were obtained for each link, ranging from 1.23 dB to 1.80 dB. For measurement in this paper, simple method of WAA quantification model based on setting a percentage of the total attenuation individually for each link was created. Therefore, this model is bounded to rain intensity R. Despite the simplicity of the method, a comparison with another rain event showed that satisfactory results could be obtained. Overall, correlation coefficients ranging between 0.87 and 0.95 were achieved.

During the area rainfall measurement using the RAINLINK algorithm, a high agreement with the rain gauges was achieved on the rain gauges located in the areas densely covered by links (gauges B and C). It can be assumed that due to varying values across the links the WAA can be also linked to the physical state of a particular link, e.g. aging of the radom antenna cover etc. These results leads to a proposal of a WAA compensation method based on an individual WAA calibration for each link by a rain event with a known course of precipitation (e.g. from CHMI data). Currently there are no other studies on WAA on the microwave links operating in 10 GHz frequency band against which a comparison could be made.

ACKNOWLEDGMENT

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REFERENCES


