1. Introduction

High Altitude Platforms (HAP) [1] can bring a possibility of a very fast additional coverage e.g. in the case of catastrophes, when existing networks collapse, or could be utilised as alternatives to satellite or terrestrial systems. In this paper electromagnetic wave propagation aspects for HAP systems are discussed. In the first part, atmospheric gas attenuation for inter-HAP links is determined. Next part of the paper deals with the influence of rain on millimetre wavelength links between user stations and High Altitude Platform. Typical route diversity scheme given by the recommendation ITU-R P. 618 [2] used for satellite links cannot be accurately applied. Based on simulation results HAPs are analyzed and particular corrections for the Czech Republic are proposed.

2. Frequency separation of inter-HAP links

The proper choice of the working frequency is crucial within the millimetre wave band. Gaseous molecules in the atmosphere may absorb energy from radio waves passing through them causing attenuation. This has to be considered especially for frequency regions involving intense spectral lines of gases, where attenuation of electromagnetic waves can be enormous (tens of dB). The attenuation introduced by atmospheric gases can either be described for frequencies ranging from 1GHz up to 1 THz using an accurate physical model, such as Liebe’s model [3], or it can be approximated by probabilistic models such as the ITU-R P. 676 [4].

International telecommunication union (ITU) has allocated for HAP systems frequency bands of 31/28 GHz and 47/48 GHz [5]. Frequency band of 48 GHz is assumed to be used worldwide, while the other one is proposed for HAP systems in locations where 48 GHz is occupied by other services (South and North America). The frequency band of 60 GHz could be used for communication between HAP stations. In the high altitudes around 20 km the constitution of the atmosphere is quite different than at the ground and attenuation due to oxygen resonances is therefore substantially lower. The inter-HAP links should not interfere any terrestrial services due to enlarged attenuation in the bottom layers of atmosphere. The second reason of using 60 GHz is that they should not been listened by third party. Analyse of such case was accomplished in order to enumerate possible interferences of ground stations. With respect to layered environment the refraction of transmitted electromagnetic wave occurs. Dependences of electromagnetic wave attenuation due to atmosphere gases for links to HAP station (in altitude of 20 km) on elevations from 5 to 90 degrees enumerated via ITU-R P.676 [4] are depicted in Fig. 1a. Curves show attenuation for two possible frequency bands of HAP links 30 GHz and 48 GHz. Parameters of standard atmosphere from ITU-R P.835 [6] were utilised. For particular locations the atmosphere parameters measured on the base of column parameters atmosphere layers have to be used. Link attenuation between ground station and HAP base station at the frequency of 60 GHz is shown in Fig. 1b. It has to be emphasized, that Free Space Loss (FSL), which has value of 154 dB for 20 km long link at the frequency 60 GHz, is not included. Therefore, the loss of electromagnetic wave due to atmosphere gases is sufficient for whole scale of elevations and links between two HAP stations cannot be eavesdropped.
Electromagnetic wave attenuation in the case of interconnection between two HAP stations is depicted in Fig. 2. As it was mentioned, there is different constitution of atmosphere in the altitude of 20 km (parameters of atmosphere are [6]: humidity of 0 g/m³, temperature of 220.4 K, pressure of 65.2 hPa). Nevertheless, from Fig. 2 can be concluded gas attenuation up to 10 dB for more distant HAP stations has to be considered when design such type of links at the frequency of 60 GHz.

3. Analyses of Route Diversity

Considerably higher attenuation in millimetre wave bands is caused by hydrometeors. One of the rain fade mitigating approaches introduces a route diversity, i.e. two joint links to one HAP station from two different ground localities. This assures improvement in rain losses due to the non-homogeneity of rain event above area. Since parameters for enumerating of route diversity within ITU-R P. 618 [2] are given based on the measurements of Earth-space links and also for different geographical locality, it has to be necessary to optimise method for HAP links and for rainy conditions valid in the Czech Republic. For this reason, simulations of two diversity links were
performed based on rain distributions measured above Prague in years from 2002 to 2005. The diversity gain can be according to [2] determined by

\[
G_{\text{div}} = G_d \cdot G_f \cdot G_{\theta} \cdot G_{\psi},
\]

where \( G_d \) stands for gain contributed by the spatial separation, \( G_f \) is frequency-dependent gain, \( G_{\theta} \) is gain term dependent on elevation angle and \( G_{\psi} \) is gain dependent on the angular separation between sites. With respect to the large set of rain distributions included in calculation the parameters were derived only for the single frequency of 48 GHz. Frequency dependent gain in (1) has not been tested, instead of that \( G_f = 0.3 \) in accordance with [2] was considered.

At first, the dependence of diversity gain on distance between ground stations was derived. First user was positioned to the three different locations (straight under HAP station, 1 km from HAP station and a 2 km from projection of HAP station at the surface of Earth) while the second user was located in range of distances from 1 km up to 20 km. The route diversity was then calculated for each of these deployments and for every rain scan.

In the next stage, it was tested the utilization of methods in [2] based on obtained rain loss statistics. Unfortunately, a very high difference was observed especially in the case of \( G_d \) dependence on distance and as well on attenuation of main link due to rain - see Fig. 3, where only fraction of analyzed data is presented. Difference between simulation results and ITU method [2] results particularly from lower altitude of HAP station when compare to satellite station. From Fig.3 it can be distinguished that variance of diversity gains tends to increase with higher attenuations of electromagnetic waves due to rain. This was assumed in the optimization process, where resulting model was weighted by lower values of diversity gains.

![Figure 3: Comparison of simulated dependence of distance dependent diversity gain on rain attenuation of main links for the Czech Republic (blue points) with ITU-R P. 618 [2] (black line)](image)

The equation for distance dependent part of diversity gain [2] was corrected for HAP systems in the Czech Republic by genetic algorithm and with correction of statistic for availability of diversity gains lower than 99,99%. The derived dependence can be described by

\[
G_d = 1,65A \cdot \left(1 - e^{-2.64d}\right)
\]

where \( d \) stands for distance between Earths’ users in km and \( A \) is loss of the shortest link due to rain in dB.
In next step, the dependence of diversity gain on angular separation was optimised. In this case, the assumptions were based on knowledge of (2). Therefore, the same distance of both ground stations from projection of HAP station were set in the range of distances from 2 km to 20 km with step of 2 km. Statistics of diversity gain on angular separations form 1 to 180 degrees were derived based on simulations for each of these distances. Since such results involve part of diversity gain dependent on distance, this was normalised by $G_d$. Optimised dependence of $G_\psi$ on angular separation $\psi$ in degrees can be described by

$$G_\psi = 1 + 0.0164\psi$$

(3)

In the last stage, the parameter $G_\theta$ dependent on elevation $\theta$ (in degrees) of main link to HAP station was analysed. This parameter is different from satellite links that can have elevations from 90° (satellite over the user) up to the case of very low elevation when the satellite is on the horizon. There is no assumption of HAP systems to be on horizon; in many cases the distance would not exceed tens of kilometres from user, i.e. elevations from approximately 45° up to 90°. For given range of elevations the relationship between the parameter $G_\theta$ a elevation $\theta$ was derived as follows

$$G_\theta = 1 + 0.0032\theta$$

(4)

4. Conclusion

The propagation aspects that have to be considered during a design of links to High Altitude Platforms were discussed in the paper. The model for diversity gain from [2] was optimised for HAP systems and for the geographical region of the Czech Republic. Differences between new dependences of diversity gain and [2] are remarkable high especially in the case of dependence of diversity gain on distance between users and on attenuation of the shortest link due to rain. Particular results can provide background for possible planning of HAP systems or any other stratospheric links in the Czech Republic.

Acknowledgments

The simulations were supported by Czech Science Foundation grant 102/08/P346. The research is a part of the activities of the Department of Electromagnetic Field of the Czech Technical University in Prague in the frame of the research project no. OC09075 of the Czech Ministry of Education.

References


