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Outlook for the Propagation of Radiowaves

Perspektivy problematiky šíření rádiových vln

SUMMARY

Although the radiowave propagation phenomenon has been studied for decades, state-of-the-art communication systems utilizing new frequency bands have raised a number of challenges that still have to be addressed. To demonstrate this fact, and to outline prospects in the field of the wave propagation modeling, three examples taken from research activities at the Czech Technical University in Prague, Department of Electromagnetic Field are briefly presented. The corresponding references are provided for more detailed study.

The need for a new approach to fading description is demonstrated by the investigation of the dynamic effects caused by vegetation obstacles blocking a link in millimeter wave bands. Average propagation loss statistics are no longer sufficient for planning modern digital systems. The new model presented here features the flexibility required for the accurate simulation of the temporal as well as the spatial-temporal dynamical effects of a tree blocking the link. Using both laboratory and outdoor experiments, the behavior of the received signal level time series as a function of wind speed loading the obstacle and the influence of different tree types blocking the line-of-sight between the transmitter and the receiver were examined. This can either be used to make power margin estimations for a required quality of service or as a time-series generator for channel simulations.

Rain attenuation is the main factor limiting the availability of radio links in millimeter wave bands. A new approach to the investigation of rain events is also unavoidable. Besides the classical features of rain, such as maximum rain rate, other characteristics must be studied anew. A proposal for a new method of classifying the spatial properties of rain is introduced.

Completely new tasks for propagation modeling come with the new radio link geometries and frequency bands. Stratospheric High Altitude Platforms are presented as an example. It is shown that for some applications, like UMTS planning, propagation modeling cannot be separated from system level simulations.

In the field of propagation prediction for future systems, a full description of the propagation channel is required, i.e. (semi-)deterministic models are needed. Due to the stochastic nature of the natural propagation media, experiments still play a key role. It is obvious that synergy of system design, propagation modeling, and antenna design is becoming more and more essential.

SOUHRN

Šíření elektromagnetických vln v atmosféře je již zkoumáno po celá desetiletí, ale pokročilé systémy v nových frekvenčních pásmech přinášejí stále nové situace, které je třeba v dané oblasti řešit. Jako ilustraci perspektiv v oboru modelování šíření rádiových vln jsou zde vybrány a stručně popsány tři konkrétní příklady z vědeckovýzkumné činnosti na ČVUT v Praze, Katedře elektromagnetického pole. Pro hlubší studium jsou uvedeny příslušné odkazy na literaturu.

Na výzkumu dynamických efektů způsobených vegetací, která stíní milimetrový spoj, je demonstrována nutnost nového přístupu k posuzování úniků. Pro plánování moderních digitálních systémů již klasické statistické zpracování průměrných ztrát šířením nevyhovuje. Byl vyvinut nový model, který umožňuje simulovat v čase i prostoru úniky spoje způsobené vegetací. Vliv vegetace byl pozorován i experimentálně pomocí laboratorního a exteriérového experimentu. Byl sledován vliv rychlosti větru i typu vegetace. Model je použitelný jak pro odhad rezervy na únik, tak jako generátor časových posloupností úrovně signálu.

Spolehlivost rádiových spojů v pásmu milimetrových vln je především limitována útlumem způsobeným dešťovými srážkami. I posuzování srážkových událostí vyžaduje nový přístup – vedle maximální intenzity deště je nutné studovat i další charakteristiky dešťových srážek. Je zde navržena nová metoda klasifikace prostorových parametrů srážkových událostí.

Zcela nové úlohy v problematice modelování šíření vln představují nové geometrie uspořádání a frekvenční pásma rádiových spojů. Jako příklad jsou předvedeny platformy umístěné ve velkých výškách pro radiokomunikační aplikace. Na příkladu plánování sítí UMTS je demonstrována neoddělitelnost modelování šíření vln od simulací na systémové úrovni pro některé aplikace.

Závěrem je možné konstatovat, že v oblasti modelování šíření vln je pro perspektivní systémy požadován úplný popis kanálu. Použití (semi)deterministických modelů se tedy stává nevyhnutelným. Kvůli náhodné povaze prostředí, ve kterém se signál šíří, hraje experimentální pozorování stále klíčovou úlohu. Je zřejmé, že pro plánování nových rádiových systémů je nepostradatelné úzké propojení problematiky šíření vln s problematikou antén i problematikou systémovou.

Key Words

radiowaves, propagation of electromagnetic waves, modeling, millimeter wave propagation, shadowing, rain, diversity methods, High Altitude Platforms, 3G mobile networks, antennas, system simulations

Klíčová slova

rádiové vlny, šíření elektromagnetických vln, modelování, šíření milimetrových vln, zastínění, srážky, diverzita, platformy umístěné ve velkých výškách, mobilní sítě 3G, antény, simulace

CONTENTS

1. INTRODUCTION

The first wireless communication links date back over a hundred years and the first experiments by Marconi and others are even older. From that time on the propagation of radiowaves through atmosphere has been studied. Knowledge of propagation phenomena is necessary before planning or maintaining any radio communication system or network, which is why a research community has continued to be active in the field of radiowave propagation. Since it was obvious from the beginning that propagation problems are hard to separate from antenna design, this research field of interest is often entitled Antennas and Propagation.

Despite the fact that antenna design and the propagation of electromagnetic waves have a common denominator – Maxwell's equations, the actual modeling of wave propagation in the atmosphere is usually driven by many different factors. As the processes in the atmosphere influencing the propagation are random and difficult to describe in exact terms (e.g. the weather, irregular terrain, buildings, moving objects, changes in the ionosphere etc.), propagation modeling is not a trivial task with closed analytical solutions. In fact, key roles are played by experiments and empirical observations. Depending on the frequency band and the geometry of the link, several modes of propagation can be used – ground surface wave, space wave, sky wave etc. [1]. The only solution to providing a useful signal propagation model for system designers is to find a trade-off between the accuracy, computational complexity, and usage universality of the model. This necessarily leads to a different modeling approach for different frequency bands, scenarios and system applications.

During the era of analog communication links the most important factors were the propagation loss and signal to noise ratio. Statistical processing of experimental data to give the probability of a specific averaged propagation loss (fading) was the main tool used for propagation predictions to study the availability of radio links. This approach is being revised with digital systems. Much more information is requested beside the signal level for digital transmission and advanced modulation and coding techniques – wideband characteristics of a channel in the time domain, multi-path propagation description, third order fading statistics etc. New communication systems also bring completely different geometries when compared to a classical point-to-point link. In addition, the networking procedures for advanced mobile systems are closely related to signal propagation. Many examples can be found to show the new phenomena in the field of radiowave propagation – propagation modeling is not only inseparable from antennas but, in many applications, from the system aspects as well.

Although radiowave propagation phenomena have been studied for decades, state-of-the-art communication systems utilizing new frequency bands have meant that there are still many challenges which have to be addressed. To demonstrate this fact and to outline prospects in the field of signal propagation modeling, three concrete examples taken from research activities at the Czech Technical University in Prague, Department of Electromagnetic Field will be briefly presented. Corresponding references are always given for more detailed study of the presented work. In the following chapter modeling and measurement of dynamic effects caused by vegetation at millimeter frequencies will be described. In the third chapter a new method to classify rain events for the needs of availability studies of point-to-multipoint systems is introduced. Finally, in the fourth chapter, a future communication systems based on High Altitude Platforms in the stratosphere is presented to demonstrate the new challenges for propagation prediction. In conclusion, the trends and outlook for the field of radiowave propagation are summarized.

2. MODELING OF VEGETATION EFFECTS ON MILLIMETER LINKS

2.1 Vegetation Effects

Coverage of fixed wireless access systems working in millimeter frequency bands is commonly restricted by the line-of-sight (LOS) requirement. However, vegetation obstacles often block links between base and terminal stations. Up to about 20 % of blocked users were reported in [2].

Different approaches and field tests results have been published in order to evaluate the path loss in a vegetation environment [3-5]. Nevertheless, channel modeling for advanced digital systems requires a time-series of signal fluctuations caused by the vegetation. Under windy conditions the received signal fluctuates significantly due to tree movement. Deep fades can lead to unacceptable Quality of Service (QoS) degradation in spite of a power margin. In [6] a new model and its evaluation by both laboratory and outdoor test measurements [7] was introduced to provide tools for propagation impairment mitigation techniques development.

2.2 Model

The new model is based on a 3-D lattice with the capability to model dynamical effects. The 3D-lattice (Fig. 1) may be of an arbitrary shape and density in order to sufficiently match the behavior of different types of trees under different environmental conditions. Based on a decision algorithm, each node of the 3-D lattice could become a secondary elementary source. The random decision process and radiation pattern of each secondary elementary source could be arbitrary in order to match the behavior of the vegetation object.

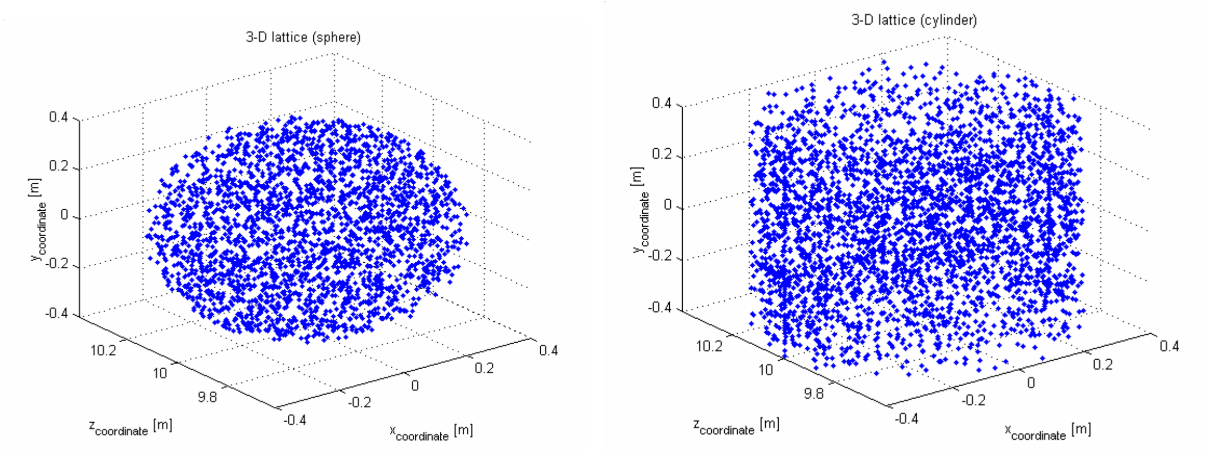

Fig. 1 Example of the 3D lattice; spherical and cylindrical shape

The primary source illuminating the 3-D lattice is located in such a way that the tree shadows a part of the receiving plane (Fig. 2). The origin of coordinate system is in the place where the primary source is located. The receiving plane is parallel to the *xy* plane, and the receiver trajectory is located in the *xz* plane.

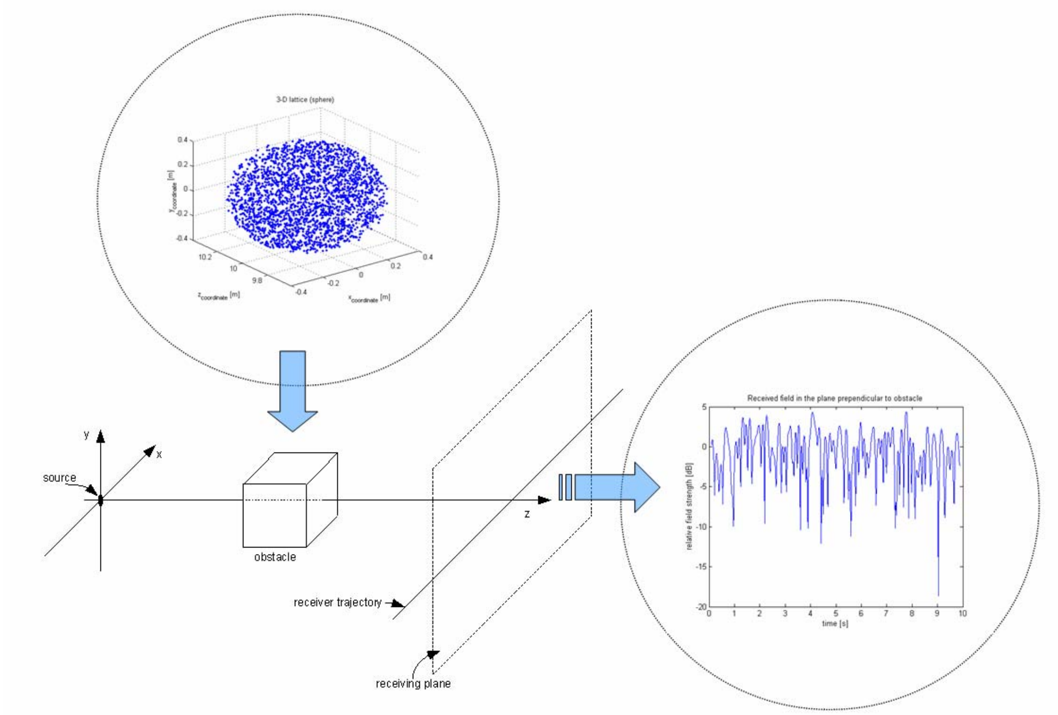

Fig. 2 The geometry for simulations of vegetation obstacle blocking effects

A point source located at the origin of the coordinate system emits a spherical wave towards the obstacle. At the receiving point the total received field is composed of contributions from all the secondary elementary sources (scattered field) as well as a direct field from the primary source in the unshadowed part of the receiving plane. The total field at the point of the receiver is then obtained as

$$E_{total} = E_{dir} + E_{scattered} = \frac{E_{tx}}{r} e^{-jkr} + \sum_i \frac{E_i \alpha_i}{d_i} e^{-j(kd_i + \varphi_{0i} + \varphi_{ri})} \tag{1}$$

where E_{tx} represents the amplitude of the transmitted field, r is the distance between the primary source and the receiver, E_i is the amplitude of the field component transmitted from the elementary source, α_i is a random attenuation factor, d_i is the distance between the secondary elementary source and the receiver, φ_{0i} is an initial phase, φ_{ri} is a random phase component, and k is the wave number.

The properties of the model can be set to model different types of trees under different conditions (in leaf, out of leaf) under different wind loads etc. The idea is to empirically calibrate the model properties by measurements. The model can be tuned to produce similar statistical characteristics as well as a time-series prediction. The mean field modeling in the shadowed area is controlled by the parameters defining generation of the random attenuation factor. The dynamic effects of the obstacle are modeled by combining the hypothetical movement of the receiver and changes in the random phase component in (1). The depth of fades is controlled by assigning significant amplitude to some of the secondary elementary sources. The fading frequency and average duration of fades are then optimized by the speed of the receiver movement and allowed range of changes of the random phase component.

This simple model is flexible enough to be able to simulate the attenuation of different obstacles as well as their dynamic effects. The parameters defining the model should be derived from experimental measurements. As an example, the instantaneous received signal level at 38 GHz as a function of time generated by the model is shown in Fig. 2.

2.3 Laboratory Experiment

To evaluate and calibrate the model, a laboratory vegetation scattering experiment at 38 GHz was performed first. A scattered field using a near-field scanner was measured behind a small tree. The configuration is shown in Fig. 3. 20 dB horn antennas were used at the transmitter site as well as at the receiver site. A 22 dB power amplifier was inserted in front of the amplitude detector. The output power of the generator was set to 3 dBm and 1 kHz keying was used. A cooling fan with the option of changing the rotation speed in four discrete steps was inserted in order to simulate the windy environment. The scattering from the tree under different wind speed conditions was measured with a sampling rate of 30 Hz. A small needle leaf tree (pine spruce) served as an obstacle. The receiving antenna was handled by a 2-D scanning device.

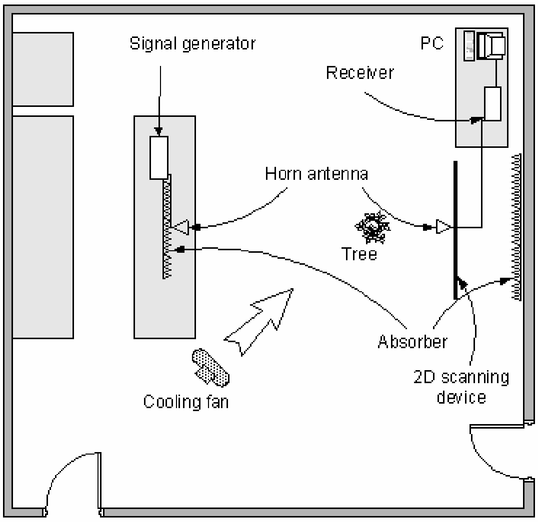

Fig. 3 Laboratory experiment configuration

The received signal when the tree was loaded by different speeds of wind is shown in Fig. 4. The fading distribution has been displayed in a Rayleigh probability plot.

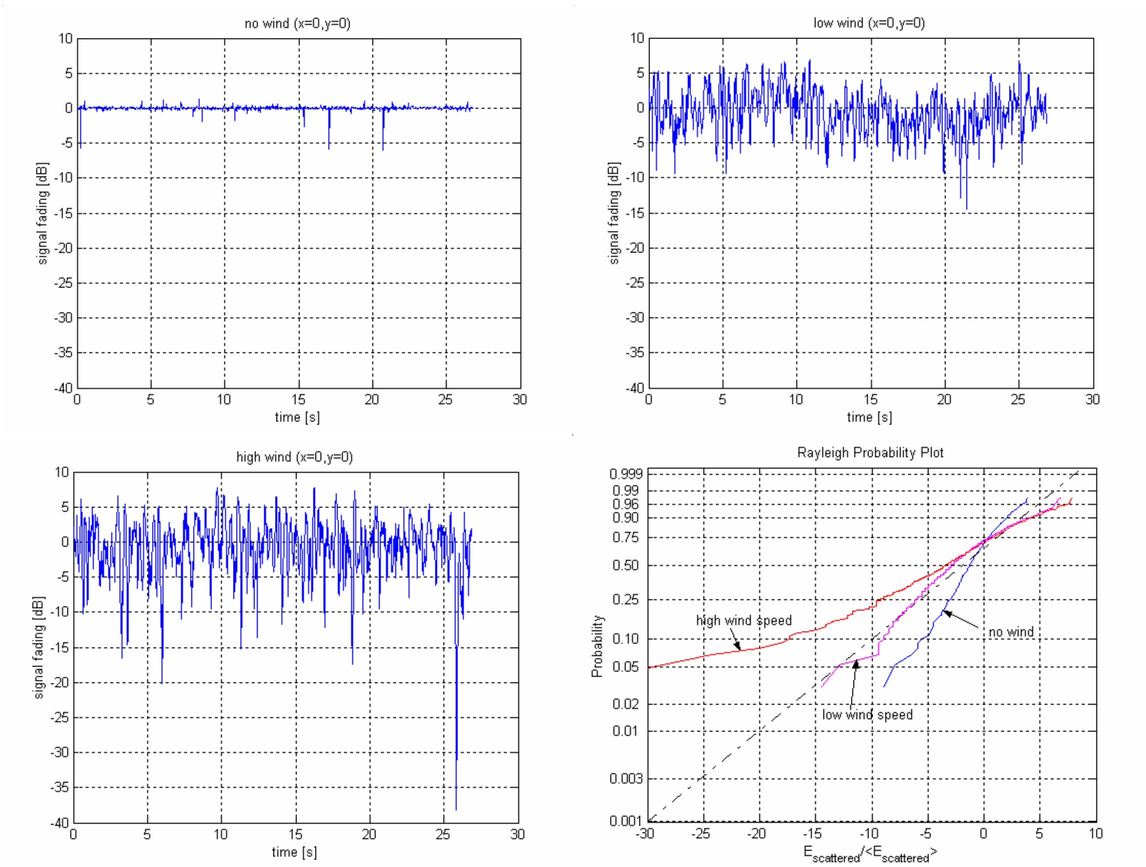

Fig. 4 Received signal level: a fading distribution in a Rayleigh probability plot

2.4 Outdoor Experiment

An outdoor field test experiment was designed and performed in cooperation with the CTU in Prague and TESTCOM. During the experiment, two different wind speeds were tested: "no wind" and "strong wind". In order to investigate the influence of different vegetation types on received signal fading characteristics, three vegetation types were tested: a dog-rose bush, an apple tree, and a pine (Fig. 5). The goal of the field test experiment was to confirm the results previously obtained during the scattering laboratory experiment. For the field test experiment, a real point-to-point microwave link at 37 GHz was utilized. Horn antennas with gain of 20 dB and 25 dB were used at the receiving side. A spectrum analyzer connected to a laptop served as a receiver. The measured time series and corresponding fading statistical distributions (displayed in a Rayleigh probability plot) are shown in Fig. 6 for one of the measured scenarios.

Fig. 5 Outdoor measurements: apple tree, and pine

The results confirmed a strong correlation between the wind speed loading the obstacle and the signal fading. The higher the wind speed the higher the standard deviation. Nevertheless, in the case of a "strong wind" the standard deviation is very similar for all vegetation types. In cases of "no wind", the difference between a particular standard deviation is higher than that in the "strong wind" situation. It should also be noted that the relatively high standard deviation for the "no wind" condition may be caused by a gentle wind, a factor that cannot be eliminated.

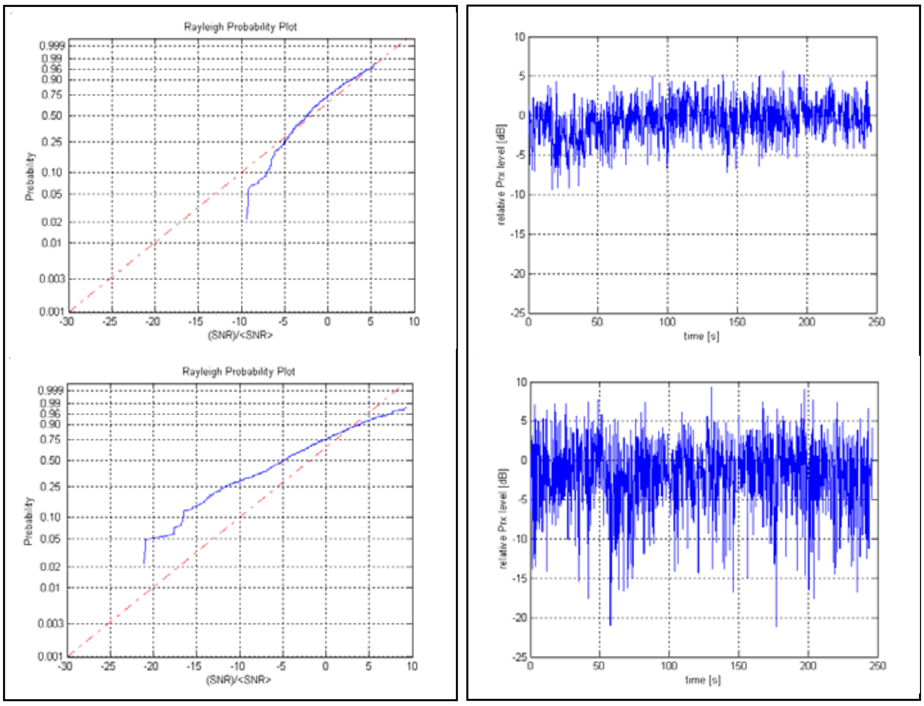

Fig. 6 Pine; no wind (upper), strong wind (lower)

2.5 Summary

A new model of dynamic effects caused by vegetation obstacles blocking a link in millimeter wave bands was introduced. As has already been stated above, the main goal was to create a simple universal model for either power margin estimations for the required QoS and for time series generations for channel simulations. The model presented offers enough degrees of freedom to be calibrated by a measurement. The results proved the approach to be extremely efficient. Fig. 7 presents a comparison between the statistical distribution obtained from one of the measurements and the distribution corresponding to the time series generated by the model. More details regarding the model and its evaluation are given in [6-8].

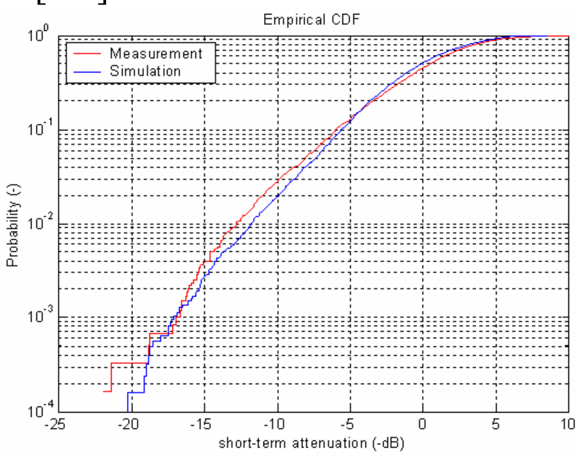

Fig. 7 Model evaluation and calibration

3 NEW RAIN EVENT CLASSIFICATION METHOD

3.1 Rain influence on PMP Systems

Point-to-multipoint (PMP) wireless access systems provide an alternative solution to traditional wired networks. The systems operating in the millimeter-wave band offer the capability to provide broadband wireless connection for the "last mile". Point-to-multipoint systems are often required to be highly reliable in various applications. Rain attenuation is the main factor limiting the range and reliability of the links working in the microwave and millimeter wave bands. The impact of rainfalls on point-to-point links is thoroughly addressed by ITU-R recommendations as well as by many authors in the literature [9-10]. Quite a different "point-to-area" approach must be used for point-to-multipoint systems. Rain rates during showers are horizontally non-uniformly distributed and hence, for example, the attenuation statistics for a single path and two diverse paths are different.

There are several ways of studying system performance during a rain event. In [11] an area-averaged rainfall rate concept is utilized. A single value of rain rate derived from long term rain attenuation and radar data statistics is considered for the whole investigated area. For more detailed simulations, rain cell models or actual radar data can be applied. Rain cell models valid in a given climatic area are basically derived from the long term rain attenuation measurements and radar data observations. The simplest models only simulate a single rain cell [12]. These models can only be used for simulations in a limited area, where more than one rain cell are unlikely to occur. More complicated rain cell models are able to generate several rain cells moving in a large area [13]. The best solution for realistic scenarios is the rain data obtained by meteorological radar.

3.2 Simulation Tool

A simulation tool for point-to-multipoint systems operating in the millimeter frequency band was developed to study the system performance under different signal propagation conditions and in various configurations [14]. In an urban environment a network of base stations (BSs) can be generated. The environment can be read from realistic input or generated randomly using statistical models. Finally, terminal stations (TSs) are randomly generated based on user defined rules for urban centers etc. (Fig. 8). Each connection of the terminal is calculated separately so that overall statistics of the system performance can be generated for different conditions, network arrangements, etc. When a time series of rain rate distribution in time is entered - either generated from a rain cell model or as radar data - various system characteristics can be simulated in space and time: coverage, interference, site diversity improvements etc. An example of rain attenuation at 42 GHz for a specific time during a rain event is shown in Fig. 9.

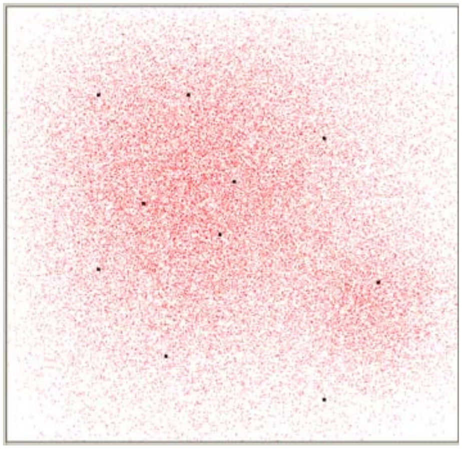

Fig. 8 Example of a point-to-multipoint system structure: base stations and randomly generated terminal stations based on an actual urban scenario; dimensions 50 x 50 km

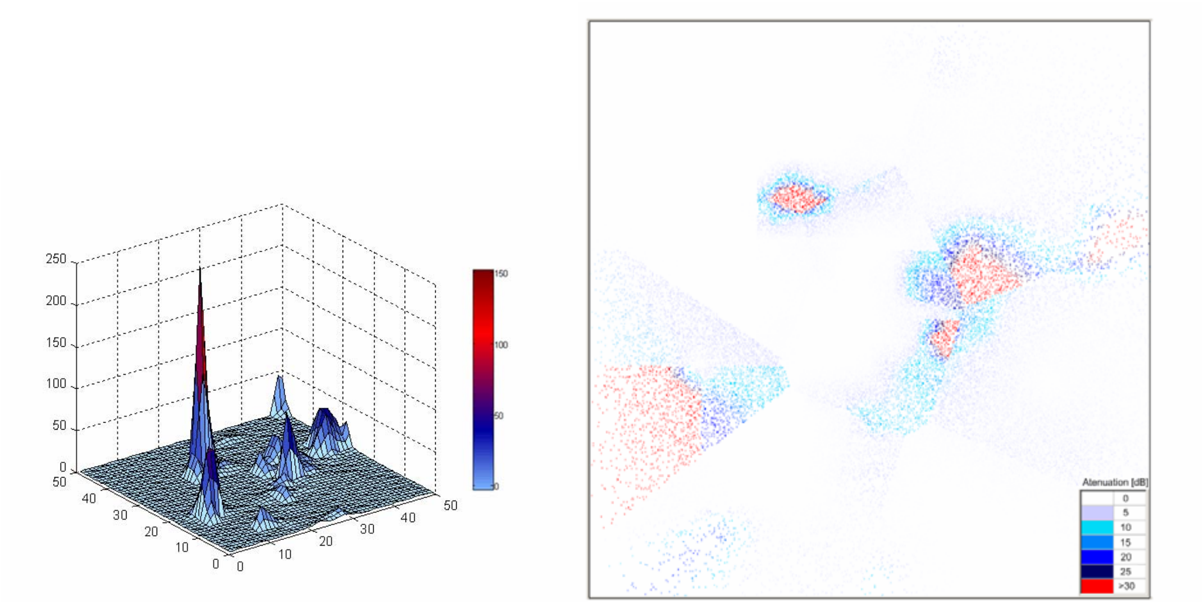

Fig. 9 Example of simulation results: left - rain rate (mm/h) distribution in 50 x 50 km area for a specific time; right - corresponding rain attenuation at 42 GHz as seen on terminal stations

Radar based rain data [15] have been utilized as an input for system simulations. There are several methods for obtaining the rain rate and attenuation from radar data given in reflectivity (dBZ). The Marshal-Palmer relationship (2) was used to convert reflectivity Z (dBZ) to rain rate values R (mm/h).

$$Z = 10\log\left(300 \cdot R^{1.6}\right) \tag{2}$$

A large rain event database containing over thousand events for Czech Republic was built for the simulations. Each rain event is represented by a sequence of radar images for a 50x50 km area with a 1 km grid resolution in 1-minute steps.

3.3 Site Diversity Outage Improvement

The site diversity, which exploits the non-uniform spatial distribution of rain rates, was selected as a system aspect to investigate the influence of rain spatial properties on PMP systems. Typically, the site diversity configuration utilizes two BSs: the main BS (the BS nearest to a TS) and a diversity BS. In general, the angular separation between the links to the BSs can range from 0 to 360 degrees; the maximum distance to a BS from a TS in a millimeter wave system can be up to about 6 km.

An outage improvement probability parameter was defined to examine the influence of rainfall on the whole PMP system in a given area. The outage improvement probability is defined as the percentage of TSs with a successfully established diversity link out of the total number of TSs receiving a level of power input from the nearest BS falling below the threshold due to rainfall. To obtain the outage improvement statistics, simulations of system performance during rain events were performed [16].

As was proved during site diversity simulations, when analyzing the site diversity techniques under various network topologies, the rainfall spatial influence is very sensitive to both the density of BS deployment and the particular BS location during a rain event. To study the rain spatial influence on the PMP system independently of the specific network deployment, the following method was used to obtain site diversity for specific spatial distributions. For each rainfall radar scan, the position of a hypothetical TS was changed on a 1 km step grid throughout the whole area. The position of the main BS was changed to create a circle around the TS with a fixed radius. The received signal strength was calculated for every azimuth of the hypothetical main link. If the signal strength dropped below the chosen threshold, the diversity links to hypothetical diversity BSs for angular separations ranging from 1 to 359 degrees and diversity link lengths ranging from 1 to 6 kilometers were investigated. As a result of these simulations, a dataset representing the dependence of the outage improvement probability on angle separation and a ratio of the main and diversity link lengths were derived for each radar image.

A closed analytical expression for outage improvement probability P (%) as a function of the angular separation ϑ (rad) and the ratio of the main and diversity link lengths d_{main}/d_{div} was derived

$$P = a_{const} \cdot \left(1 - \left(\frac{\vartheta - \pi}{\pi - b_{const}\sqrt{1 - \frac{d_{main}}{d_{div}}}} \right)^2 \right) \cdot \left(\frac{d_{main}}{d_{div}} \right)^{c_{const}} \tag{3}$$

Specific values for empirical parameters a_{const}, b_{const}, c_{const}, were obtained for every radar scan as the best fit of (3) to simulation results using genetic algorithms [16]. The outage improvement probability statistics calculated by (3) using a fade margin of 17 dB for a particular rain rate spatial distribution is demonstrated in Fig. 10.

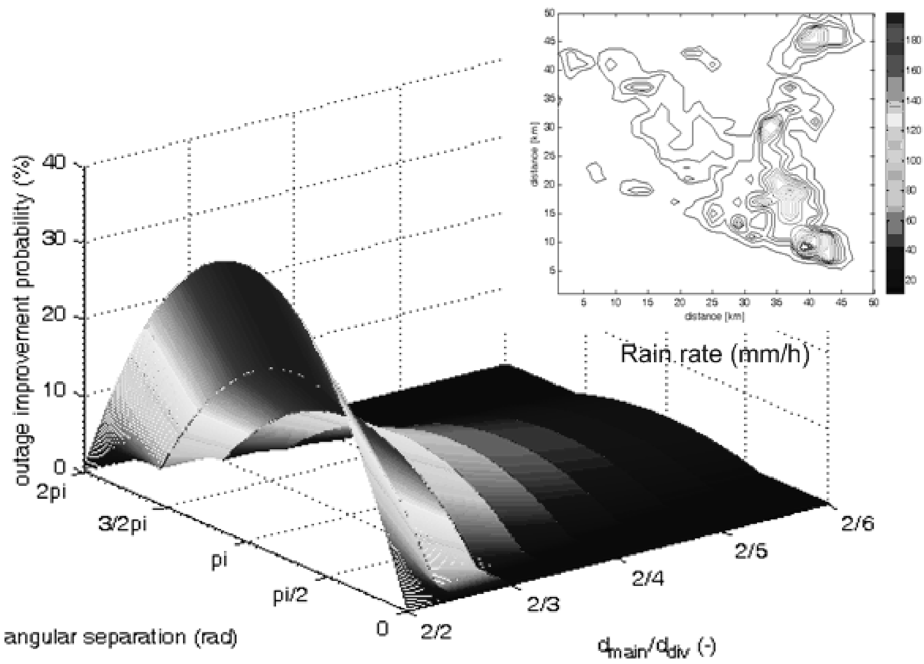

Fig. 10 Calculated outage improvement probability
for a rain fade margin of 17 dB using (3)

3.4 Rain Spatial Classification

A new concept was introduced to describe the spatial properties of rain using a limited number of parameters. To maintain the spatial description, three-dimensional contours of every normalized rain rate scan were determined for levels ranging from 0.1 to 0.9 (Fig. 11).

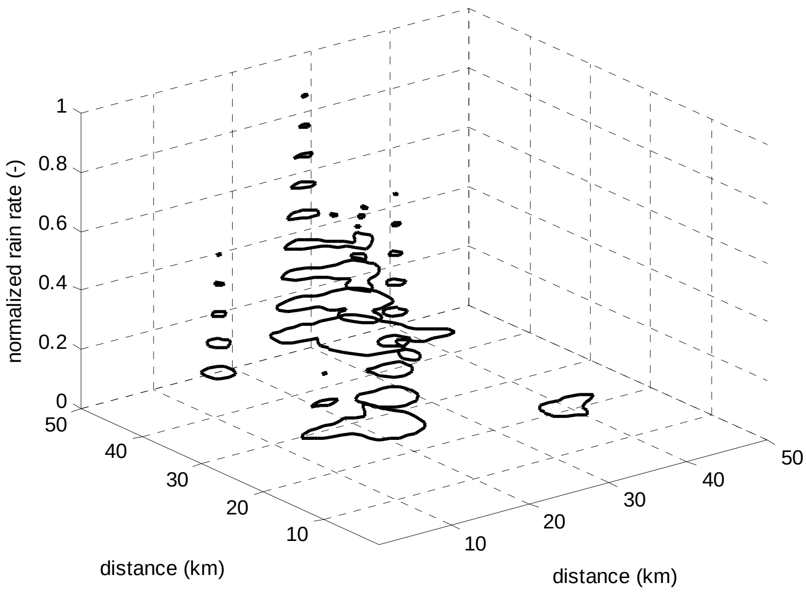

Fig. 11 Normalized rain rate - decomposition to contour levels from 0.1 to 0.9

Subsequently, the dependencies of site diversity on several features of normalized rain rate contours were investigated in a large number of scenarios. It was shown that only a single parameter that fully describes rain rate spatial distribution is sufficient. The new rainfall spatial parameter is expressed as the average area of the rain cell, taking into consideration all 9 contour levels. To assess its value for a particular rain scan, the average areas of the rain cell have first to be derived for each contour threshold by dividing the total rain-occupied area by the number of rain cells. Thereafter, the resulting value of the rainfall spatial parameter can be obtained as the mean value of the average rain cell areas for all contour levels. Simulations proved that even so the rainfall spatial parameter does not exhaustively describe the distribution of rain cells in a specific region, it does, however, sufficiently characterize rain spatial distribution for site diversity improvement planning issues in the case of PMP systems. Both the rain cell sizes as well as the rain rate slopes are considered.

Fig. 12 shows CDFs of the rainfall spatial parameter conditioned to the rainy period (when the maximum rain rate within the area is higher than 3 mm/h). Radar data were utilized to derive the results for three different locations in the Czech Republic. The rainfall spatial parameter has a lognormal distribution in each of the locations. It was observed that there is no significant difference between cumulative distributions of the rainfall spatial parameter taken from different locations inside this particular climatic area. The rainfall spatial parameter offers an effective way to characterize the spatial features of rainfalls for various applications in the field of radiowave propagation. More detailed information can be found in [17].

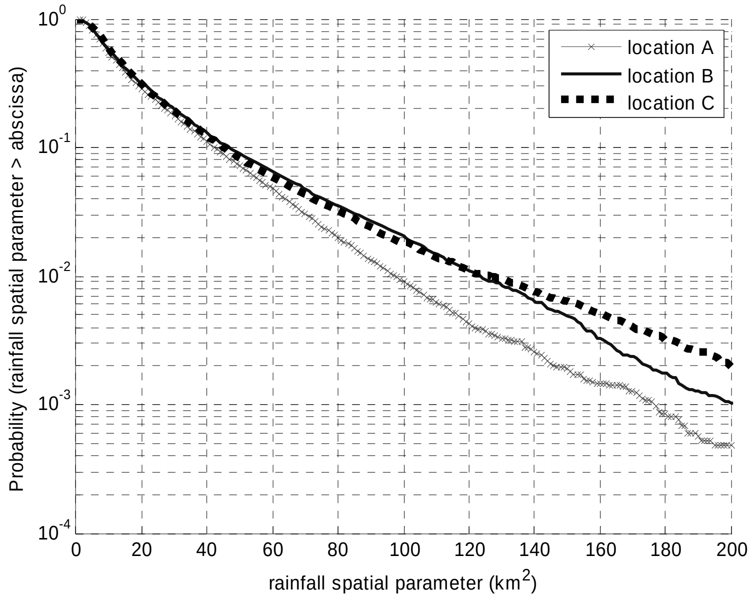

Fig. 12 CDFs of the rainfall spatial parameter conditioned to rainy periods

3.5 Summary

A new method relevant to rainfall influence on PMP radio systems was proposed to classify the spatial properties of the rain. Site diversity was utilized to quantify the system performance during rainfalls. A single parameter – the rainfall spatial parameter – is able to characterize the spatial properties of the rain event, in terms of rain cell sizes and rain rate slopes, relating to their impact on the system within a given area. The rainfall spatial parameter offers an effective way to characterize the spatial features of rainfalls for various applications in the field of radiowave propagation.

4. PROPAGATION MODELING FOR HIGH ALTITUDE PLATFORMS

4.1 High Altitude Platforms

High Altitude Platforms (HAPs) are airships or planes, operating in the stratosphere, at altitudes typically ranging from 17–22 km. When a quasi-stationary position is kept at this altitude, a range of communications services can be delivered (3G mobile networks, broadband communications, etc.) [18]. HAPs can provide the best features of both terrestrial and satellite links – low free space loss and good coverage. In principle there are two types of platform technology capable of stratospheric flight: unmanned aircraft and unmanned airships. However, so far there is no platform available so HAPs must be considered to be future technology. Nevertheless, intensive research has been conducted in the area of communications provided by HAPs .

4.2 Simulations of a 3G Mobile Network from HAPs

High Altitude Platform stations (HAPs) should be used, among others, as an alternative to the terrestrial component of third generation (3G) mobile networks UMTS or could be an element of terrestrial networks in terms of providing telecommunication and data services to extensive and sparsely populated areas, during disasters, etc. In comparison to terrestrial base stations, HAPs offer many advantages, such as no shadowing for high elevation angles or a large area of coverage, etc.

The advantages of the application of an iterative simulation approach instead of an empirical one in simulations of a radio interface of 3G networks were presented in [19]. A coverage prediction process in third generation mobile systems is specified by the interference estimation that is already crucial at this phase of the network planning and so it appears to be necessary to apply iteration-based simulations in order to study the behavior of 3G networks in realistic scenarios. For this reason, the whole prediction process should be done iteratively. In UMTS networks, the base station sensitivity is not constant, but depends on user numbers and the used bit rates in each cell. For this reason the base station behavior depends on the particular service and cell. In WCDMA systems all users share the same interference sources and so they cannot be analyzed independently. Each user has an impact on the transmission power of the others and thereby influences them. These changes then iteratively affect the user etc. Fig. 13 shows an example of the simulation results for a 37 cell scenario. It is obvious that propagating modeling and system level simulations are inseparable.

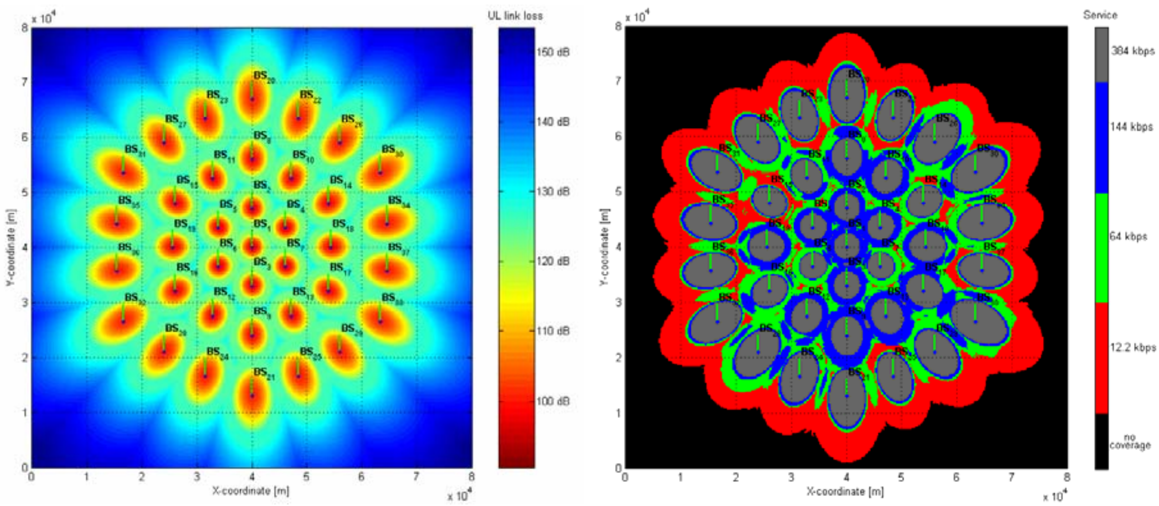

Fig. 13 Example of simulation results for 37 cell deployment;
left: uplink composite link loss for speech service;
right: composite uplink coverage based on the services

4.3 Propagation modeling for HAP Urban Scenarios

For satellite systems, where the propagation loss is huge and link power balance is tough, only the LOS condition is important. In HAP scenarios, obtaining coverage in shadowed areas or even inside buildings does not present a problem. That is why the conventional satellite propagation models available in the literature cannot be used for HAPs. The importance of accurate propagation modeling in the case of UMTS is demonstrated in Fig. 14. Coverage is simulated for a specific scenario using three different propagation models: a simple free space loss model, a model constant fade margin and a model with random fading.

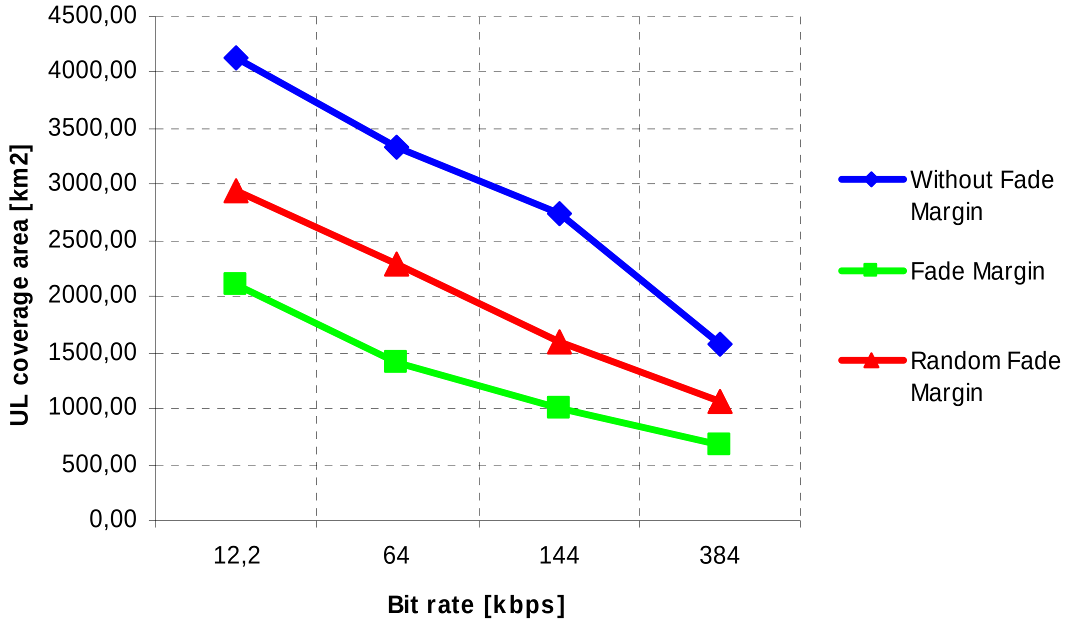

Fig. 14 Simulated uplink coverage for different propagation models

Unfortunately, there are as yet no data available from which to derive a realistic propagation model. An effective approach to overcome this was introduced in [20]. For the deployment of buildings in an urban area the statistical ITU-R model was used [11]. This model requires three empirical parameters to describe the built-up area, namely the ratio of land area cover by building to total land area (α), the mean number of buildings per unit area (β), and a variable determining the building height distribution (γ). α ranges from 0.1 to 0.8 and β from 750 to 100, respectively. The parameter γ models the Rayleigh statistic distribution of building heights. Fig. 15 illustrates an example of building distribution in a Manhattan grid structure randomly generated for α = 0.4, β = 750, and γ = 40.

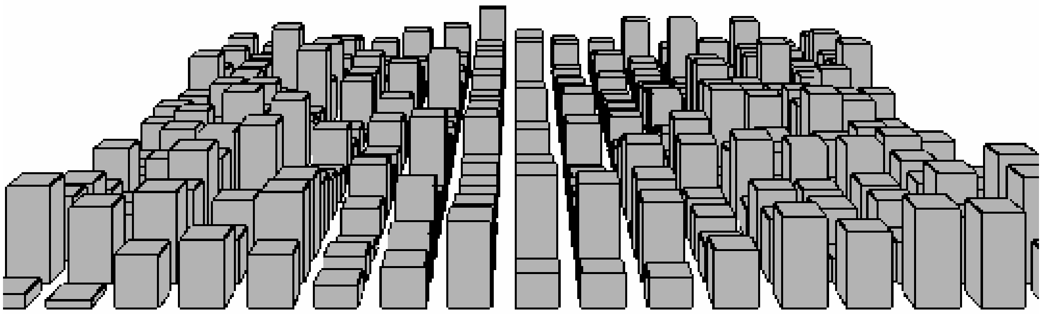

Fig. 15 Buildings randomly generated based on the ITU-R statistical model

In order to calculate the path losses, the uniform theory of diffraction was applied to calculate the diffraction losses via roof tops [21]. Fig. 16 shows the composite path losses including the antenna gain in a color scale for two scenarios – the effect of roof top diffraction is distinguishable from the figure.

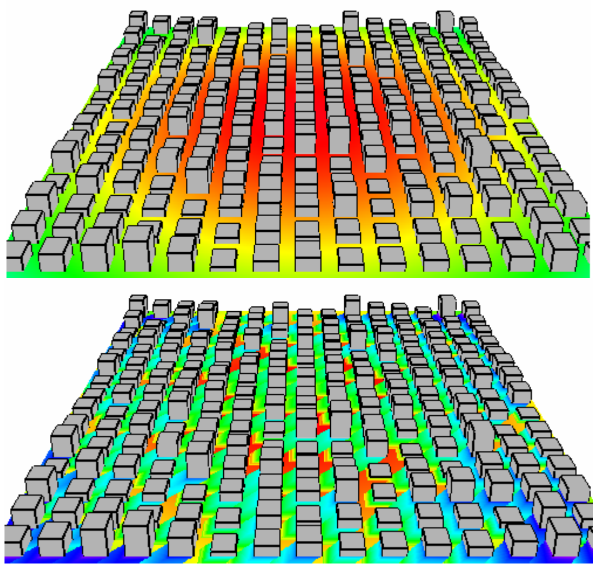

Fig. 16 Path loss; left: the HAP is situated in the middle of the 1×1 km area; right: the HAP station is situated 50 km to the side

Based on the simulations, a Cumulative Distribution Function (CDF) for the rooftop diffraction loss in the streets for different elevation angles was derived. Fig. 17 shows the result for an azimuth angle equal to 45 degrees. The probability of LOS connections can easily be obtained from this figure (diffraction loss equal to 0 dB). Random fade margin can be derived using the model for realistic system simulations.

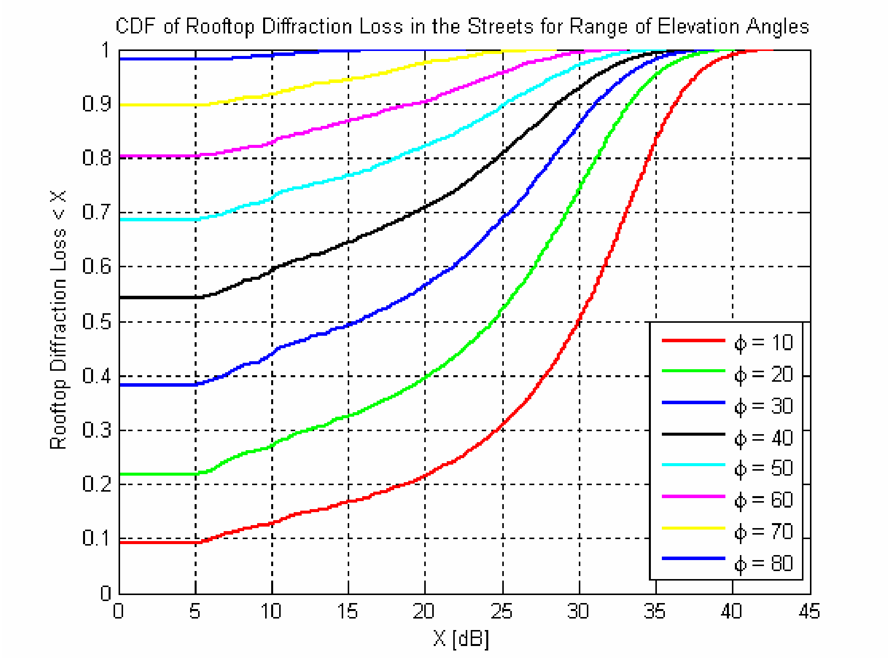

Fig. 17 CDF of additional rooftop diffraction loss for a 45 degree azimuth angle and different elevation angles

4.4 Influence of Antenna Radiation Pattern

The cell shape in HAPs is determined by the antenna radiation pattern more than by the terrain profile. In Fig. 13 the cells were deployed according to homogenous hexangular geometry. The main disadvantage of the classical circular beam antennas in cases of geometric hexangular cell structure is the increased cell overlapping - a circular antenna radiation pattern becomes more and more projected with a decreasing elevation angle from the cell center, creating an increasingly elliptical footprint on the ground. This problem is crucial in wireless systems, such as UMTS, with frequency reuse factors of 1. The best solution to cell overlapping seems to be the application of elliptical beam antennas [22]. Elliptical antenna beams can provide circular gain footprints on the ground independently of the HAP and cell center positions. However, a suitable antenna beam width must be used to ensure both good cell isolation and coverage. The antenna directivity reduction at the cell edge is known as the power roll-off factor. The interference is also given by the side lobe level of the antenna radiation pattern.

In [23] the optimal antenna power roll-of was investigated for both circular and elliptical beam antennas. One of the results is presented in Fig. 18 showing the average number of served users per cell for a selected simulation scenario where the cell radius is equal to 3 km. The optimal roll-off for each of the three cases is significantly higher than has been used in most of the 3G studies conducted to date for HAPs. Fig. 18 clearly shows how cell capacity increases with roll-off at the cell edge up to a breakpoint. The increase in cell capacity is caused by the other-cell interference suppression based on a better cell isolation for the higher antenna roll-off, because the overlapping of the main lobes is suppressed. After this breakpoint, cell capacity is lowered due to the other cell interference and a reduction in received power, which is caused to an increasing extent by the side lobe levels. The absolute power level of the side lobe floor, compared with the absolute level at the cell edge, becomes much closer as the antenna roll-off increases. For example, in the uplink the mobile station situated at the cell edge transmits at higher power than those towards the centre, causing a greater interference impact on the adjacent cells. Furthermore, in the downlink the power transmission limits play an important role.

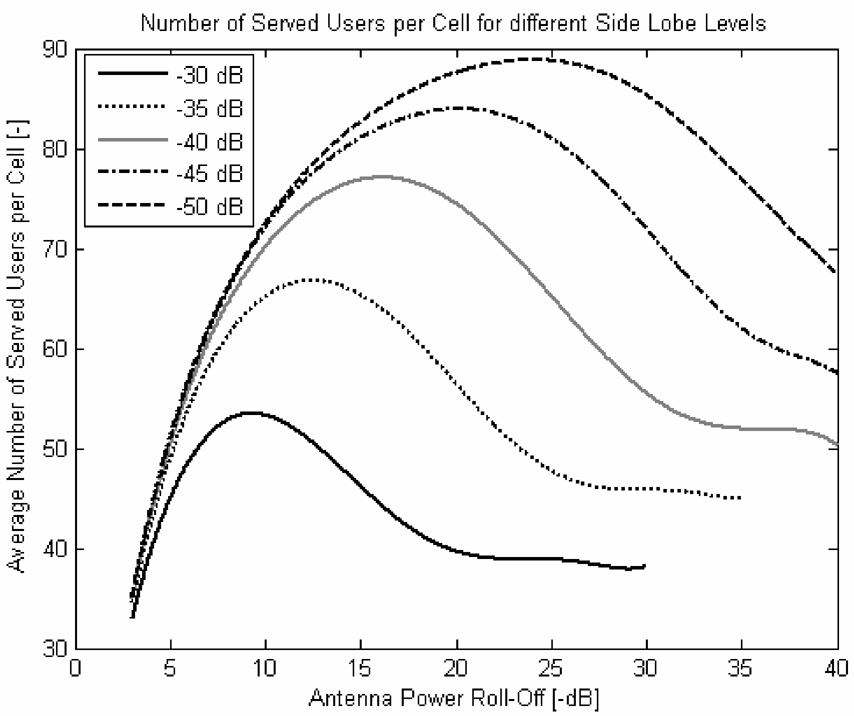

Fig. 18 Average number of served users per cell (for speech service) as a function of antenna roll-off for different side lobe levels

4.5 Experiment

There are no HAPs commonly available for experiments. For some application platforms at lower altitude can be sufficient. In [24] a trial using a 9 m long remote controlled airship at the site of the Czech Technical University in Prague is presented. The measurement was focused on investigations of rooftop diffraction and penetration loss measurement. The signal was transmitted with a 25 dBm CW generator using a patch antenna situated at the bottom part of the airship gondola. The experiment was performed at the 2 GHz frequency (3G frequency band). The location of the airship was monitored using a GPS terminal. Fig. 19 illustrates an example of the airship track while measuring rooftop diffraction. A ground plane antenna (linear polarization) and spiral broadband antenna (circular polarization) were used concurrently to receive the transmitted signal. The level of the received signal was measured by spectrum analyzers. During the rooftop diffraction loss measurement, the three spectrum analyzers were situated in the CTU courtyard and the airship was flying over the 8 storey-high building. A sample of the received signal level measurements is shown in Fig. 20. This figure depicts the measured data for approximately 10 minutes of measurement. 7 flights across the receiving stations can be distinguished in this figure. The experimental data are essential to verify and calibrate the theoretical model presented in the previous section. At the moment there are no empirical results available in the literature for HAP urban scenarios in the 3G frequency band.

Fig. 19 Remote control airship and an example of the airship track; the cross represents the location of the receiving stations

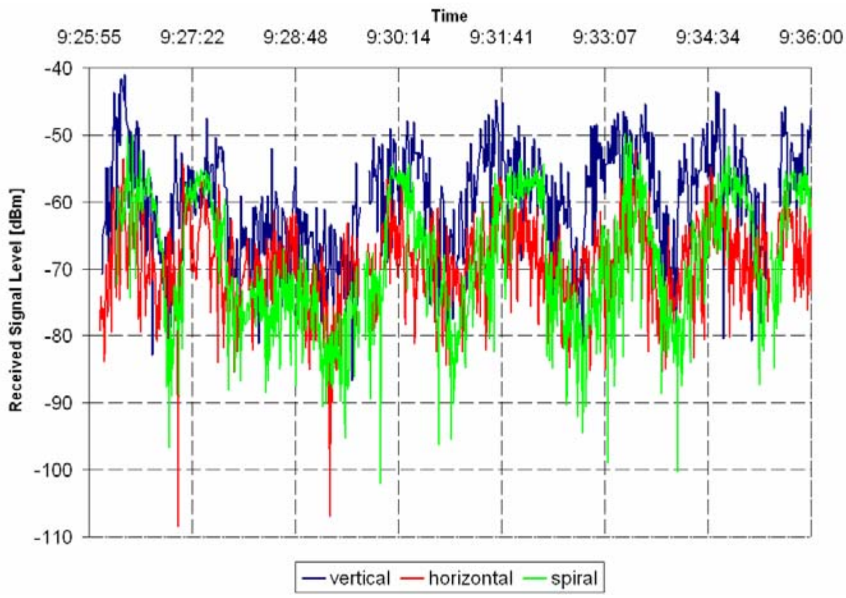

Fig. 20 Sample of measured data

4.6 Summary

The system-level simulations of UMTS networks provided by the High Altitude Platform stations were presented. Using the simulation results, the influence of propagation models and antenna radiation patterns were demonstrated. Optimization of antenna power roll-off parameter was introduced. The new urban propagation model is being developed utilizing unique experiments with a remote controlled airship. It was proven that for UMTS planning, it is difficult to separate the propagation modeling from system level simulations.

5. CONCLUSION

The new advanced communication systems are giving rise to a number of problems in the field of radiowave propagation. Three examples from three different applications were presented to depict future trends in this field:

- On the investigation of dynamic effects caused by vegetation obstacles blocking a link in millimeter wave bands, the need for a new approach to fading description was demonstrated. The statistics of averaged propagation loss are no longer sufficient for planning modern digital systems. A new model based on a 3-D lattice was introduced. The model is flexible enough to accurately simulate the temporal as well as the spatial-temporal dynamical effects of a tree blocking the link. It can be used either for power margin estimations for the required quality of service or as a time-series generator for channel simulations.

- A new approach to the investigation of rain events is also unavoidable. Besides the classical features of the rain, like maximum rain rate, other characteristics must be studied anew. A new method was proposed to classify space properties of the rain.

- Completely new tasks for propagation modeling come with the new radio link geometries and frequency bands. Stratospheric High Altitude Platforms were presented as an example. It was shown, that for some applications, like UMTS planning, propagation modeling cannot be separated from system level simulations.

It can be concluded that in the field of propagation prediction for future systems a full description of propagation channel is required, i.e. physical (semi)deterministic models are needed. Due to the stochastic nature of the natural propagation media the experiments play a key role. It is obvious that synergy of system design, propagation modeling, and antenna design becomes more and more essential. It leads to new challenges which must be addressed in the field of radiowave propagation.

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supervisor of student projects and diploma theses

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16 journal papers

43 international conference papers

1 international patent

4 expert's reports and many research reports

5 software tools for RF industry

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Antenna Centre of Excellence II

LABLINK - Virtual Student Exchange by Linking Lab.

COST Action 280

COST Action 255

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Zvanovec, S. - Pechac, P.: Rain Spatial Classification for Availability Studies of Point-to-Multipoint Systems, *IEEE Transactions on Antennas and Propagation*. 2006, vol. 54, no. 12, pp. 3789-3796, ISSN 0018-926X.

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