Budapest University of Technology and Economics

New models and algorithms in fixed and mobile wireless networks

Collection of Ph.D. Theses
by
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1 Introduction

The topic of my dissertation is the investigation of procedures which can be applied for interference mitigation, and related to this, for improving the end to end quality of wireless networks. Additional topic of my dissertation is the modelling of microwave radio channel. My new results are organised into three thesis groups.

The first thesis group deals with analysing the attenuation of precipitation, especially of rain, which occurs on terrestrial point-to-point microwave links operating at frequency above 10 GHz paying special attention to modelling the rain attenuation process. My parametrisation method for the known N-state Markov chain rain attenuation model is presented. The application of the parametrised model is shown with two examples.

The broadband terrestrial point-to-multipoint systems typically operate in the frequency range of 20 – 40 GHz, therefore considering of rain attenuation by planning such a system is very important. As countermeasure the popular diversity technologies can be applied. The second thesis group deals with the investigation of site diversity method used in terrestrial point-to-multipoint systems. The developed adaptive site diversity algorithm based on genetic algorithm is presented in details in my dissertation for the case of Broadband Fixed Wireless Access (BFWA) systems.

In the third generation terrestrial cellular mobile networks, during the soft handover process, Macro Diversity Combiner (MDC) algorithm can be applied against the fading occurs on the radio channel. For the MDC it is necessary to forward the uplink data flow between the base stations involved in the soft handover process. In the third thesis group my improvements for the known data forwarding algorithm which can be used during soft handover are presented.

2 Research objectives

The expected attenuation (attenuation is defined as the deviation from the median of the measured received signal level) of rain can be calculated with ITU-R P.530 model [ITU-R, 2005], but no usable model is known from the literature for calculating the attenuation of the rare non-rain events which occurs mainly in winter in Hungary. These attenuation events are caused by sleet or the deposited and melting ice on the radom. The non-rain events are very rare, therefore collecting appropriate high number of measured attenuation events requires a lot of time. Non-rain events can cause as high attenuation as the rain, therefore it is essential to develop a model which can be applied during planning of microwave links. The received signal level has been registered on point-to-point microwave links operating at frequency 14 – 38 GHz and rain intensity (and some other meteorological parameters) has been registered at measuring nodes since 1997, so non-rain attenuation effect could be modelled using our many years measured data, if its statistical characteristics were able to be determined with processing appropriate high number of unique events. It is possible to assort non-rain attenuation events from measured data; because time functions of non-rain and rain attenuation event can be visually distinguished. After analytically formulating the visually noticeable differences between rain and non-rain attenuation events, my goal was to develop a rain and non-rain attenuation event detection algorithm which exploits the differences between the statistics. In the course of the model development in the future the appropriate number of unique non-rain attenuation events can be easily and automatically assorted with this algorithm from the measured data series.

Generation of synthetic rain attenuation time series is an actual research topic. Castanet recognised in [Castanet, 2003] that, the N-state first order homogeneous Markov chain is capable to model rain attenuation events and to generate rain attenuation time series on Earch-Space links. Model parameters were determined from probability density of calculated fade slope of measured data. My goal was to improve model parametrisation method given by Castanet in [Castanet, 2003] and to apply the N-state Markov chain model for modelling rain attenuation on terrestrial Ka, K and Ku band microwave links and for modelling shadowing fading on land mobile satellite (LMS) channel. My further goal was to develop a procedure with which the N-state Markov chain model (parametrised from a data series measured on a link with given properties) can be applied for modelling the fading on arbitrary link using a transformation method. The final goal was to develop a general model which could be an alternative to the rain attenuation model described in ITU-R P.530 recommendation [ITU-R, 2005].

In terrestrial point-to-multipoint systems the rain attenuation effects can be remarkably reduced by applying site diversity. Conventional site diversity algorithms usually make decisions based only on downlink channel quality [Craig, 1996]. In case of the basic SD-SC (Site Diversity with Switched Combining) algorithm the terminal station (TS) selects the base station (BS) with the maximal downlink received signal level. The main problem with this approach is the following: when a TS connects to another BS to get higher downlink signal to interference plus noise ratio (SINR), the uplink interference situation will be changed, i.e. the TS will cause uplink interference at other BSs. Moreover the TS does not know what will be its uplink SINR after switching BSs. Apparently the solution could be simultaneously considering uplink and downlink SINR by making diversity decision, but additionally TS decisions cannot be made after each other, because if one of the terminals is assigned to another BS, the uplink SINR of those terminals that made their decision formerly may be varied. Therefore the problem leads to a global optimisation where the task is finding the TS-BS assignment set with the best joint uplink and downlink SINR conditions, in other words simultaneously optimising uplink and downlink SINR in the BFWA service area. Moreover in presence of a rain event this TS-BS assignment optimisation (i.e. system re-configuration) must be done adaptively. My goal was the optimisation of TS-BS assignments in the BFWA service area from the interference point of view.

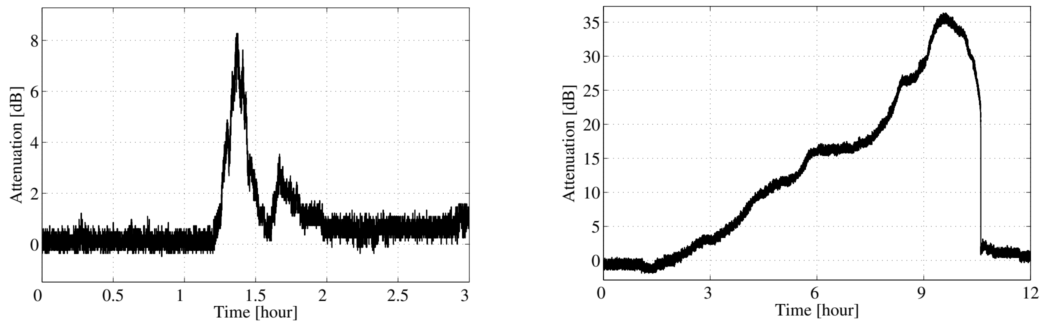
Star topology links of our countrywide measurement system provide facility to analyse the achievable gain with site diversity between different links. The diversity gain highly depends on the azimuth angle between the microwave links, this angular dependency must be considered during planning of diversity systems. The known models give the angular dependency of the site diversity gain in a sinusoidal form [Usman, 2003] [Tikk, 2003], but Hendrantoro stated in [Hendrantoro, 2002] that the slope of the function which describes the angular dependency of rain attenuation correlation is lower for smaller angles than the slope of the sinusoid. My goal was to develop a new model which describes the angular dependency of site diversity gain and which corresponds to the statement of Hendrantoro.

In the eHSPA (Evolved High Speed Packet Access) system during soft handover (SHO) the user equipment (UE) is connected with the serving eNode B and with one ore more drift eNode B(s). The drift eNode B forwards the user data over the Iur interface (which is defined between the serving eNode B and the drift eNode B) to the serving eNode B, where the error free data is selected and further forwarded to the core network. This procedure is the macro diversity combining [3GPP, 2008]. This data forwarding over the Iur interface during SHO is referred as SHO forwarding, whereas the SHO forwarding with MDC algorithm is referred as MDC strategy. In some cases the SHO forwarding causes significant, delay sensitive cross traffic between the eNode Bs, leading to efficiency degradation. 3GPP suggests using the Improved MDC strategy, which is based on selective forwarding of the frames upon the explicit request of the serving eNode B [3GPP, 2008]. The drift eNode-Bs forwards only those frames to the serving eNode B over the Iur interface, which could not be detected by the serving eNode B. This solution reduces the load caused by SHO forwarding but increases the delay of the frames and the latency. The increased latency might deteriorate the performance of the real time applications like VoIP calls. My goal was to develop alternative MDC strategies which reduces the load on the Iur interface so that the frame delay is not increased.

3 Methodology

During my research the following *investigative* methods were applied:

- analysing attenuation of precipitation on terrestrial point-to-point microwave links
- investigation of fading effects on land mobile satellite channels
- examination of first and second order statistics of received signal power measured on terrestrial point-to-point and land mobile satellite links
- studying radio channel models based on Markov chain
- analysing site diversity between terrestrial microwave point-to-point links deployed in star topology and in point-to-multipoint systems
- examination of interference situation in terrestrial microwave point-to-multipoint systems
- investigation of point-to-multipoint network optimisation with genetic algorithms, looking for suitable objective functions
- studying handover process in broadband terrestrial mobile networks
- literature search in libraries (conference proceedings, vocational publications, vocational periodicals, vocational books), literature search in the Internet (IEEE Xplore, SpringerLink, 3GPP and ETSI standards)
- debating ideas and results, getting new ideas at international conferences and during external delegations



(a) Rain attenuation event (b) Non-rain attenuation event

Figure 1.1: Rain attenuation and non-rain attenuation events

The applied *experimental* methods in the course of the pragmatic part of my research are:

- computer aided data processing and visualisation
- implementation of computer simulation environment under Matlab and NS-2
- computer aided evaluation of simulation results

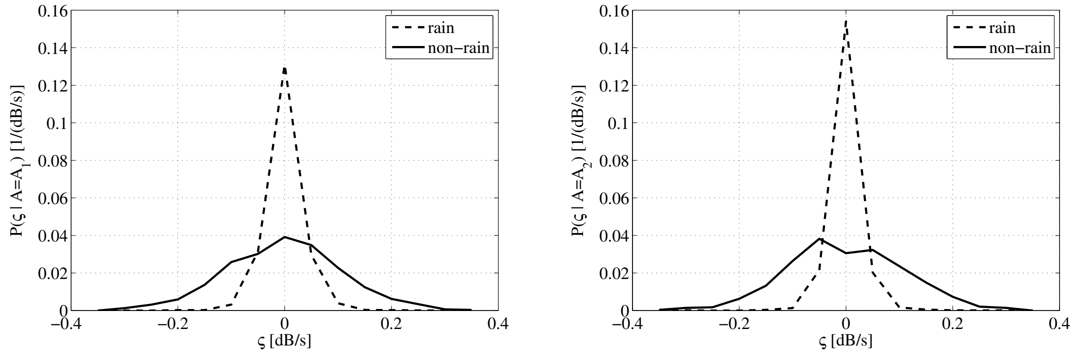
The aforementioned methods were applied in the required degree in order to get my new results described in the different thesis groups.

4 New results

4.1 Precipitation attenuation on microwave links

Automatic detection of rain and non-rain attenuation events

The rain attenuation event measured in April 2006 and the non-rain attenuation event measured in March 2004 are depicted in Fig. 1.1. The event with high attenuation depicted in Fig.1.2 was not caused by rain, therefore these type of event are referred as non-rain event in my dissertation. The probability density functions of fade slope calculated from several attenuation events are shown in Fig. 1.2. These fade slope statistics are typical for the two types of event. Note the differences both in the time functions and in the fade slope probability density functions between the rain attenuation event and the non-rain attenuation event. I developed an algorithm to automatically detect rain and non-rain attenuation events in measured attenuation data. This algorithm exploits the recognised differences between the statistics of rain and non-rain attenuation events.



(a) 1 dB attenuation level (b) 1.4 dB attenuation level

Figure 1.2: Fade slope density functions of rain attenuation and non-rain attenuation events

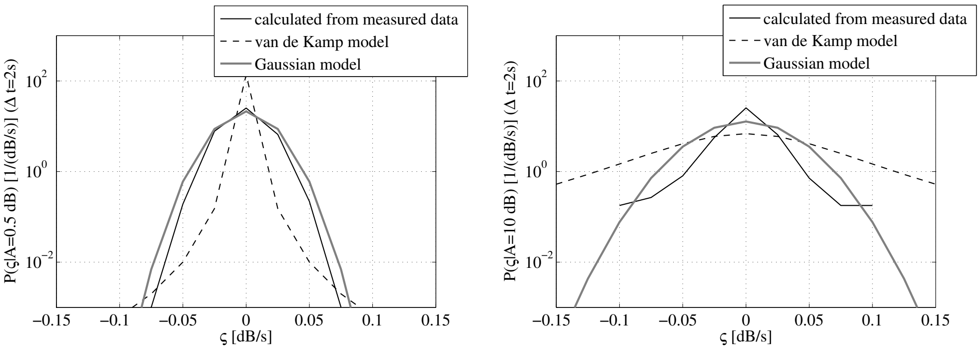
Thesis 1.1. *I recognised that the statistics of attenuation events on terrestrial microwave links caused by rain and non-rain are highly different. I worked out an algorithm which can automatically detect rain attenuation events and the rare non-rain attenuation events in measured attenuation data with using the fade duration and fade slope statistics.* **(Related own publication: [Héder, 2009a])**

Modelling of rain attenuation process

The Gaussian fade slope model

Max van de Kamp introduced a fade slope model which is applicable for Earth-Space links [ITU-R, 2003]. First I had to investigate if the van de Kamp model is applicable for parametrising the N-state Markov chain model used for modelling rain attenuation on terrestrial microwave links. I recognised that the van de Kamp model can be applied for terrestrial links, but it has two deficiency which are critical for the desired application: *a*) the model can not be evaluated at 0 dB attenuation level, *b*) the model fits worse to the measured fade slope statistics at attenuation levels lower than 0.15 dB, additionally it gives too high occurrence probability of fade slope values around 0 dB/s. These deficiencies were critical by parametrising the N-state Markov chain model, because it was important to model fade slope at 0 dB attenuation level and the suitable fade slope model must fit very accurately for fade slope values around 0 dB/s. This follows that the van de Kamp fade slope model can not be applied for parametrising the used N-state Markov chain model. Therefore I had to develop the Gaussian fade slope model which approximates the conditional probability density $P(\varsigma|A_i)$ of fade slope ς at attenuation level A_i with (1):

$$P(\varsigma \,|\, A_i) = \frac{1}{\sqrt{2\pi}\sigma_\varsigma(A_i)} \cdot e^{-\frac{1}{2} \cdot \left(\frac{\varsigma}{\sigma_\varsigma(A_i)}\right)^2} . \tag{1}$$



(a) A=0.5 dB (b) A=10 dB

Figure 1.3: Fade slope density functions for different attenuation levels calculated from rain attenuation data measured in 2004 and the approximation with van de Kamp fade slope model and with Gaussian fade slope model

The expected value of fade slope is zero, the attenuation dependent deviation parameter $\sigma_\varsigma(A)$ of density function $P(\varsigma|A_i)$ can be determined from fade slope density functions calculated from measured data: the fade slope density functions calculated from measured data at different attenuation levels must be approximated by Gaussian functions, then the $\sigma_\varsigma(A)$ approximation function which describes the attenuation dependency of the obtained deviation values of the Gaussian functions can be found by curve fitting. As can be seen from (1), in contrast to the van de Kamp model the Gaussian fade slope model can be evaluated at attenuation level A_i =0 dB. The fade slope density functions for attenuation levels 0.5 dB and 10 dB calculated from rain attenuation data and the approximation with van de Kamp fade slope model and with Gaussian fade slope model is depicted in Fig. 1.3. Note that especially at attenuation level 0.5 dB the Gaussian fade slope model fits more accurately to the density functions of calculated fade slope of measured data.

Thesis 1.2. *I found out that by parametrising the N-state Markov chain model the distribution of fade slope can be approximated with Gaussian distribution with expected value of zero. The attenuation dependent deviation parameter of Gaussian distribution can be approximated with simple functions.* **(Regarded own publications: [Héder, 2005c] [Héder, 2006f] [Héder, 2006d] [Héder, 2006e] [Héder, 2006c])**

Developed procedure for parametrising the N-state Markov chain model

The first order N-state Markov chain which is used by Castanet for modelling rain attenuation is discrete in time and state, homogeneous and irreducible. The Markov chain states represents attenuation levels with stated resolution [Castanet, 2003]. The N-state Markov chain model which I investigated applies resolution of ΔA=0.05 dB. I suggest a parametrisation method of the model which can be performed in three steps. First, if the parameters are being determined from several links with different properties, the measured data series must be transformed to a hypothetical reference link with stated properties. This transformation is necessary, because the occurred rain attenuation is highly influenced by the link properties. Transformation can be performed with (2) which is derived from the ITU-R P.530 recommendation [ITU-R, 2005]:

$$A_h[t_n] = \frac{k_h \cdot L_h}{1 + L_h/d_{0,h}} \cdot \left(\frac{A_m[t_n] \cdot \left(1 + \frac{L_m}{d_{0,m}}\right)}{k_m \cdot L_m} \right)^{\alpha_h/\alpha_m}, \tag{2}$$

where t_n is the n^{th} sampling time instant, lower index m is regarding to the measured link whereas the lower index h is regarding to the hypothetical reference link, A denotes the attenuation in dB, L is the link length in km and d_0 is the path reduction factor [ITU-R, 2005]. The geometrical location dependent rain intensity R exceeds $R_{0.01}$ mm/h in 0.01 % of one year time period. During the transformation the $R_{0.01}$ value which depends on the geometrical location of the microwave link must be considered via d_0. Second, the transformed data series have to be quantised with 0.05 dB step corresponding to the Markov chain resolution. Third, the parameters of the N-state Markov chain must be calculated from probability density functions of fade slope of the quantised data series. The transition probability $p_{i,i+j}$ which gives the probability of transition from attenuation level A_i to attenuation level A_{i+j} is calculated with (3) – (4) [Castanet, 2003]:

$$p_{i,i+j} = \int_{\varsigma_j - \Delta\varsigma/2}^{\varsigma_j - \Delta\varsigma/2} P\left(\varsigma_j \,|\, A_i\right)\, d\varsigma \tag{3}$$

$$\varsigma_j = (A_{i+j} - A_i)/\Delta t, \quad \Delta t = 2\ s, \quad \Delta\varsigma = \varsigma_{j+1} - \varsigma_j \tag{4}$$

The $P\left(\varsigma \,|\, A_i\right)$ probability density functions must be calculated with (1), the attenuation dependent deviation parameter of the Gaussian fade slope model must be determined in advance with curve fitting.

Application of the N-state Markov chain model

If the properties of desired microwave link being in planning phase differ from the properties of the hypothetical reference link from which the model parameters were determined, the states of the N-state Markov model have to be transformed. The transformation $T\{.\}$ is performed with using (5) similarly to (2):

$$A_{i,p} = T\{A_i\} = \frac{k_p \cdot L_p}{1 + L_p/d_{0,p}} \cdot \left(\frac{A_i \cdot (1 + L_h/d_{0,h})}{k_h \cdot L_h} \right)^{\alpha_p/\alpha_h}, \ \forall i \in \{0, \ldots, N-1\}, \tag{5}$$

where A_i is the attenuation level represented by the i^{th} Markov chain state, $A_{i,p}$ is the transformed value of A_i. Lower index p is regarding to the planned link whereas the lower

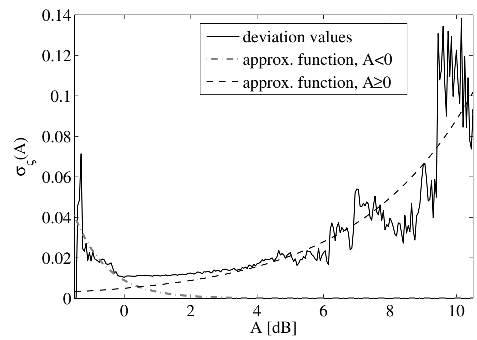


Figure 1.4: Approximation of deviation parameter of the Gaussian fade slope model

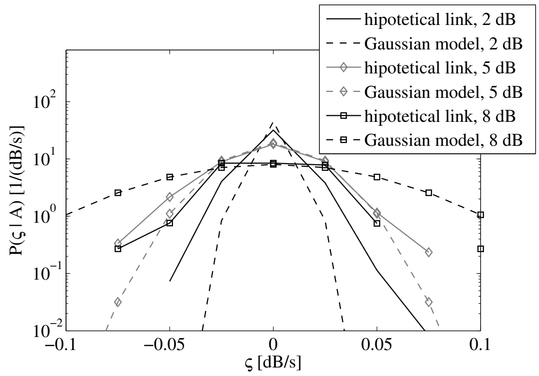


Figure 1.5: The probability function of fade slope for different attenuation levels calculated from measurements on hypothetical link and the approximation of probability functions using Gaussian fade slope model

index h is regarding to the hypothetical reference link. The distribution of the expected rain attenuation on the planned link equals to the steady state complement cumulative density function $P(A \geq A_{i,p}) = \sum_{j=i}^{N-1} z_j$ of the Markov chain states $A_{i,p}$, where z_j denotes the state probabilities. The steady state probability vector $\mathbf{z} = \{z_j\}$ is calculated from the steady state transition probability matrix $\mathbf{P} = \{p_{ij}\}$: $\mathbf{z} = \mathbf{z} \cdot \mathbf{P}$.

Thesis 1.3. *I improved the parametrisation method of the N-state Markov chain model which is known from the literature and which can be applied for modelling rain attenuation time series. If the parameters are determined from data measured on several links with different properties, the measured data series have to be first transformed to a hypothetical link, then the parameters must be determined from the transformed data series. In the course of the parametrisation the probability density function of fade slope must be approximated with the developed Gaussian fade slope model. I provided a parameter transformation method so that the model is applicable for links whose properties differ from the properties of the link from which model parameters were determined.* **(Regarded own publications: [Héder, 2006g] [Héder, 2007d] [Héder, 2008b] [Héder, 2008c])**

Examples of N-state Markov chain application

My goal was to develop a general N-state Markov chain model which can be applied in the planning phase of Ka, K and Ku band microwave links to calculate the one year first order statistics of the expected rain attenuation on the planned link irrespectively of the link length, geometrical location, frequency and polarisation. This general N-state Markov chain model with the calculated parameters is called BME N-state Markov chain model. The model parameters were determined from attenuation data series measured in 2004 on several microwave links. The measured data series were first transformed to a hypothetical reference link with known properties. The hypothetical reference link was assumed to be located in Miskolc. The transformed data series were quantised with 0.5 dB step corresponding to the Markov model resolution. The parameters of the BME N-state Markov chain model were calculated from the fade slope statistics approximating the probability density functions of fade slope with the Gaussian fade slope model. The approximating function which describes the attenuation dependent deviation parameter $\sigma_\varsigma(A)$ of the Gaussian fade slope model was found with curve fitting using the smallest RMS error method. As can be seen in Fig. 1.4 $\sigma_\varsigma(A)$ is approximated with exponential functions. The CPDFs (Conditional Probability Density Function) of fade slope at attenuation levels 2 dB, 5 dB and 8 dB are depicted in Fig. 1.5. The continuous curve denotes the deviation values calculated from the measurement, whereas the curves with broken line denote the CPDF given by the Gaussian fade slope model. The A_0, A_{N-1}, N and ΔA parameters of the BME N-state Markov chain model are listed in Table 1.1.

Table 1.1: The A_0, A_{N-1}, N and ΔA parameters of BME N-state Markov chain model

A_0	A_{N-1}	N	ΔA
−1.6 dB	13.25 dB	298	0.05 dB

The BME N-state Markov chain model was applied in link located in Szeged. The calculated CCDF (Complementary Cumulative Distribution Function) and the CCDF of a one year measured attenuation data series are depicted in Fig. 1.6. For the sake of comparison, the CCDF obtained with using rain attenuation CCDF model described in ITU-R P.530 recommendation [ITU-R, 2005] is also depicted in Fig. 1.6. The RMS error of the BME N-state Markov chain model and of the ITU-R P.530 rain attenuation CCDF model are listed in Table 1.2. Note that using the BME N-state Markov model the CCDF can be calculated with smaller RMS error than using ITU-R P.530 model. It must be emphasised that the properties of the planned link were only used for transformation of the model states.

Table 1.2: The RMS error of the BME N-state Markov chain model and of the N-state Markov chain model applied for LMS channels

BME N-state	ITU-R P.530	LMS city	LMS highway
0.25	0.41	0.20	0.31

The presented method can be applied for modelling the shadowing fading on LMS channels. In my dissertation the parameters of N-state Markov chain model were determined

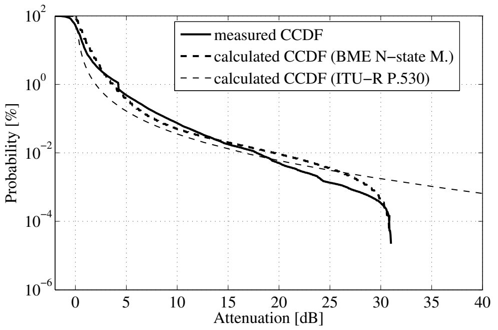


Figure 1.6: CCDF of rain attenuation measured on the planned link and calculated with BME N-state Markov chain model and calculated with ITU-R P.530 model

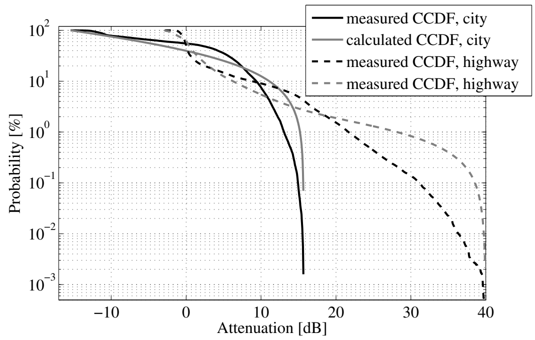


Figure 1.7: CCDFs of the measured attenuation data and the CCDFs calculated with the N-state Markov chain model in case of city and highway environments

for city and highway environments. The calculated and measured CCDF of attenuation are depicted in Fig. 1.7, whereas the obtained RMS errors are also listed in Table 1.2.

Thesis 1.4. *I developed the BME N-state Markov chain model with applying the parametrisation method concluded in Thesis 1.3 using a Hungarian measured data base. This model is applicable to calculate the expected rain attenuation on arbitrary terrestrial pont-to-pont link operating in Ku, K or Ka frequency bands. I demonstrated that using the BME N-state Markov chain model the distribution of expected rain attenuation can be estimated with smaller error than using the rain attenuation model described in ITU-R P.530 recommendation. I also demonstrated that the N-state Markov chain model parametrised with the developed method is applicable for modelling slow shadowing fading on land mobile satellite channel.* **(Regarded own publications: [Héder, 2005b] [Héder, 2006d] [Héder, 2006b] [Héder, 2006a] [Héder, 2006e] [Héder, 2006g] [Héder, 2006f] [Héder, 2007c] [Héder, 2007e] [Héder, 2007a] [Héder, 2007d] [Héder, 2008c] [Bitó, 2008] [Héder, 2008b])**

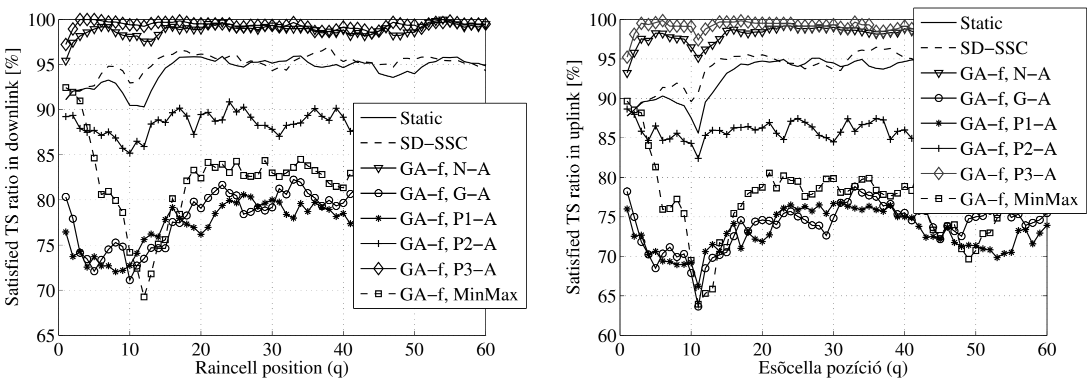
4.2 Adaptive point-to-multipoint wireless systems

The problem to be solved was to find (quasi-)optimal TS-BS assignments in a BFWA system from the evolved global SINR point of view. Genetic algorithm (GA) was applied to solve this problem, the algorithm had to be adapted for the special problem. In this case the individual is a TS-BS assignment set, the genes of the individual are the TS-BS assignments, the population is the set of individuals. The fitness score of an individual (TS-BS assignment set) is determined by the objective function, the fitness score of a population equals to the maximal fitness scores of the included individuals. At the beginning of the first iteration the GA creates the initial population: the selection operation selects the individuals with the highest fitness scores and puts them into the new population.

The crossover operation first determines the number of individuals which must be created (crossover children) then randomly selects the parent individuals. The half of the genes of the child comes from one of the parents, the other half of the genes comes from the other parent. The mutated child is generated by mutation operation: stated number of genes of the parent is randomly selected and the TSs belonging to the selected genes are assigned to other BSs paying special attention to the allocated TDMA slots. If there is no free TDMA slot in the new sector, the mutation operation tries to assign the TS to an other BS. If there is no BS with free TDMA slots in the monitoring set of the TS, the mutation fails for that TS. If mutation operation fails for every selected gene, the mutated child is the same as his parent.

Thesis 2.1. *I recognised that by adjusting the terminal station – base station assignments and the terminal station transmission powers with the developed genetic algorithm based adaptive site diversity algorithm the Broadband Fixed Wireless Access (BFWA) system can be optimised from the evolved signal to interference plus noise ratio point of view. Genetic algorithm was first time applied to solve terminal station – base station assignment optimisation problem, the operands and operators of the algorithm was adapted to this problem in point-to-multipoint networks.* **(Regarded own publications: [Héder, 2008a] [Héder, 2009f])**

The fitness score of an individual is given by the objective function. Applying different objective functions different individuals are considered to be optimal. The operands of the objective functions are the uplink and downlink SINR values belonging to the genes. In my dissertation several objective function were analysed which are classified into the different classes. Three objective function classes were defined: *a*) in case of the objective functions which are included in the *Average (A) objective function class* the fitness score of an individual equals to the average of the genes' fitness scores, *b*) the objective functions which are included in the *MinMax objective function class* maximises the minimum of the genes' fitness scores, therefore the fitness score of an individual equals to the minimum of the genes' fitness scores, *c*) with the objective functions which are included in the *Coverage (C) objective function class* the GA maximises the coverage in the BFWA system: the fitness score of an individual gives the sum of the genes' fitness scores for which the obtained downlink or uplink SINR is higher than the prescribed minimal value. The objective functions apply weight functions to calculate the fitness score of a gene. I developed several weight functions: *a*) the *Natural* (N), *b*) the *Gaussian-like* (G), *c*) and the *Polynomial*: *Polynomial1* (P1), *Polynomial2* (P2), *Polynomial3* (P3) weight functions. The objective functions are composed with the combination of an objective function class and a weight function: the Natural Average (N-A) objective function applies the N weight function and included by the A objective function class, the G-A and the G-C objective functions applies the G weight function and included by A and C objective function class, respectively. The P1-A, P1-C, P2-A, P2-C, P3-A and P3-C objective functions are similarly interpreted. From the MinMax objective function class only the N-MinMax objective function was analysed which uses the Normal weight function to calculate the fitness score of a gene,



(a) Downlink (b) Uplink

Figure 2.1: Ratio of satisfied terminal stations as a function of rain cell position in case of static TS-BS assignment, using SD-SSC (Site Diversity with Switched and Stay Combining) and in case of using genetic algorithm based based adaptive site diversity method with A and MinMax objective function classes

therefore the N-MinMax objective function is simply referred as MinMax objective function in the dissertation.

In order that the GA considers TS transmission powers, also the TS transmission powers have to be included by the genes. According to this, the operations of GA have to be modified as well: during the mutation the prescribed received power level is modified for the TS which belongs to the mutated gene, whereas crossover and selection operates with the modified genes. The objective functions had to be also modified considering the TS transmission powers so that the score of a TS-BS assignment is higher if the TS transmission power is low. The modified objective functions satisfy the following prescriptions: *a*) the higher the TS transmission power, the lower the fitness score, *b*) with decreasing the TS transmission power with ΔP until $\Delta P \cong -0.2$ dB value, the fitness score is higher than in case of ΔP=0 dB, *c*) further decreasing the transmission power, in case of $\Delta P > \approx -0.2$ dB, the fitness score is lower than in case of ΔP=0 dB, *d*) if the TS transmission power increases, the fitness score decreases. The objective function modification method described in the dissertation is effective for objective functions which use Gaussian-like, Polynomial1, Polynomial2 or Polynomial3 weight functions, but similar method can be developed for other objective functions as well.

To investigate genetic algorithm based adaptive site diversity method computer simulations were accomplished. As an example, in Fig. 2.1 the ratio of users with higher bit error ratio than 10^{-6} (satisfied terminal stations) is depicted in downlink and in uplink applying different diversity methods. In this case 9 base stations was located in the simulated 18 km x 18 km BFWA service area, cells were divided into 4 sectors and 25 terminal stations were assumed in each sector. During the simulation a rain cell with Gaussian rain intensity distribution was moved above the BFWA service area. Note that the ratio of the satisfied terminal stations is the highest both in downlink and uplink if GA based diversity method is applied with P3-A objective function.

Thesis 2.2. *Since the quasi-optimal terminal station – base station assignment found by genetic algorithm highly depends on the applied objective function, after introducing and analysing several objective functions, I made a proposal to use P3-A objective function, because this function ensures the highest ratio of satisfied users (terminal stations). I made a proposal to use a suitably modified P3-A objective function which considers uplink transmission power values in order to properly adjust the the terminal station – base station assignments and the uplink transmission power values. I recognised that in stated circumstances it is sufficient to run the genetic algorithm only at stated intervals and with limited iteration number to get satisfactory results.* **(Regarded own publications: [Héder, 2009b] [Héder, 2009e] [Héder, 2009f])**

Examination of site diversity gain

The diversity gain calculated at a given probability level depends on the correlation of the fading on the microwave links, i.e. in case of fading caused by rain and in case of star topology links the diversity gain mainly depends on the ω azimuth angle between the star topology links [Daru, 2002]. It follows that the angle dependent site diversity gain can be defined. Considering the correlation of rain attenuation on star topology microwave links, the model which describes the angular dependency of site diversity must have the following properties: *a*) At ω=0 and $\omega = 2\pi$ values the diversity gain is zero, because in these cases the correlation between the rain attenuation on the microwave links is 1. *b*) At $\omega = \pi$ the diversity gain has maximal value. In case of the developed model, the angle dependent $G(\omega)$ diversity gain is given by (6), where ω is in radian, $\nu_1(p)$ and $\nu_2(p)$ are the model parameters which depend on the p probability and $\nu_2(p)$ is a positive even number:

$$G^{(H)}(\omega|p) = -\frac{\nu_1(p)}{\pi^{\nu_2(p)}} \cdot (\omega - \pi)^{\nu_2(p)} + \nu_1(p),\ 0 \leq \omega < 2\pi. \tag{6}$$

This model is similar to the Usman model described in [Usman, 2003] and to the Tikk model described in [Tikk, 2003], but that models gives the angular dependency of diversity gain in a general $sin^k(\omega/2)\ , k \in \mathbb{R}$ form. The $\nu_1(p)$ and $\nu_2(p)$ parameters of the developed model can be determined by fitting (6) to diversity gain values which are calculated from measured attenuation data. The diversity gain values calculated from measured and transformed attenuation data on microwave links around measuring node Győr and the fitted model given by (6) is depicted in Fig. 2.2. The RMS errors of the proposed $G^{(H)}(\omega|p)$ model and the $G^{(T)}(\omega|p)$ model described in [Tikk, 2003] are listed in Table 2.1. Note, that the proposed model which is given by (6) has similar RMS error than the model described in [Tikk, 2003], at 0.1 % probability level and in case of link HU51 the proposed model produces more accurate fitting. The main difference between the models is the following: using (6) the slope of the diversity gain around $\omega = \pi$ radian is much lower comparing to the models of Usman and Tikk. According to the analysis made by Hendrantoro in [Hendrantoro, 2002], in point-to-multipoint systems in the ω interval of

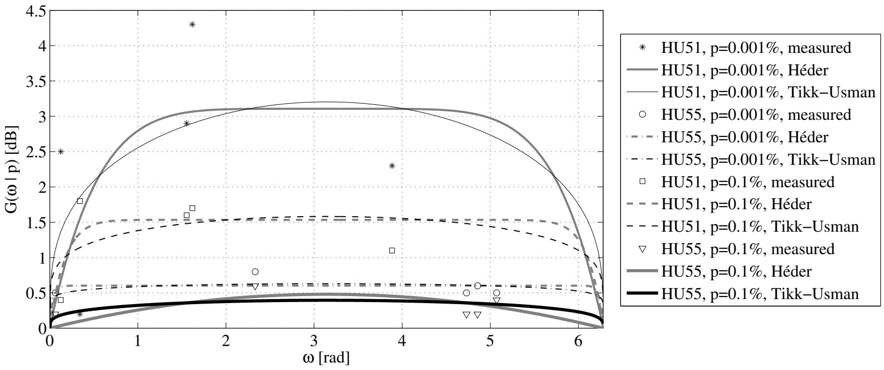


Figure 2.2: The measured and the modelled diversity gain values

0 – 1.74 radian the correlation of rain attenuation on microwave links decreases with high slope, in the ω interval of 1.74 – 4.54 radian the slope is much lower and in the ω interval of 4.54 – 2π the slope increases again. The proposed model given by (6) corresponds to this statement as can be seen in Fig. 2.2.

Table 2.1: RMS errors of the proposed diversity gain model (H) and of the diversity gain model described in [Tikk, 2003] (T)

Link	p [%]	RMS (H)	RMS (T)
HU51	0.001	1.0253	0.9776
HU55	0.001	0.1818	0.0881
HU51	0.1	0.2901	0.3793
HU55	0.1	0.1250	0.1194

Thesis 2.3. *I introduced a new model for describing the angular dependency of site diversity gain on microwave terrestrial links. The introduced model fits better for several measurement values than the site diversity gain model known from the literature.* **(Regarded own publications: [Héder, 2005a] [Singliar, 2005b] [Singliar, 2005c] [Héder, 2005d])**

4.3 The MDC strategies in eHSPA system

The eHSPA system is the improvement of the UMTS and HSPA (High Speed Packet Access) systems with reduced latency, higher user data rates and capacity. The eHSPA introduces flat radio access architecture, with distributed radio resource and mobility management. The RNC (Radio Network Controller) and the Node B are integrated in one device, in the eNode B (Evolved HSPA Node B), so handover decisions are done by the eNode B instead of the RNC. Soft handover (SHO) is supported between cells and during

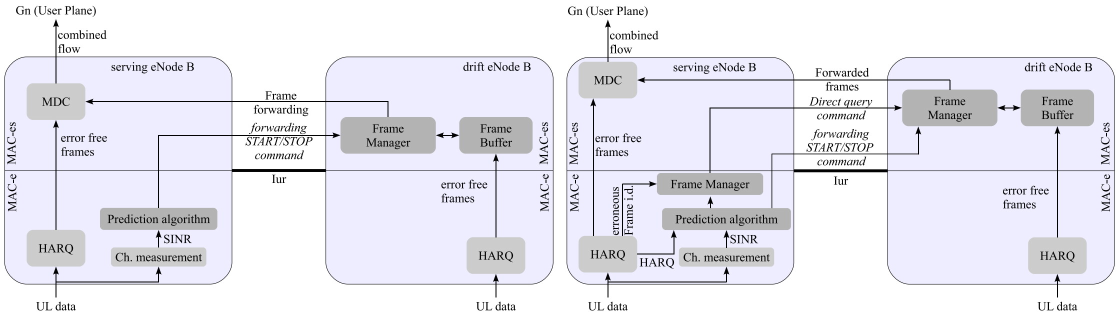


Figure 3.1: Elements of the Predictive MDC (on the left) and Hybrid MDC (on the right) strategies

SHO, if MDC is applied, the drift eNode B forwards the user data over the Iur interface (defined between serving eNode B and drift eNode B) to the serving eNode B.

In my dissertation two new MDC strategies are introduced which are based on prediction of uplink channel quality: *a*) *Predictive MDC strategy*, *b*) *Hybrid MDC strategy*. The necessary logical elements are depicted in Fig. 3.1. The Predictive MDC strategy continuously monitors the uplink channel quality and based on this information it tries to predict the quality of the next reception. It can be seen in Fig. 3.1 that the channel measurement block located in the MAC-e layer of the serving eNode B calculates the SINR on the uplink E-DPDCH (Enhanced Dedicated Physical Data Channel) and this SINR is sent to the prediction algorithm. If the algorithm predicts that channel will be have bad quality in the next TTI (Transmission Time Interval), i.e. the predicted SINR is below a stated lower threshold, the algorithm sends a *forwarding start* command via the Iur to the frame manager of the drift eNode B. If prediction was good, i.e. the frame can not be detected by the serving eNode B in the next TTI, this Prediction MDC provides in advance for the necessary data forwarding: the drift eNode B will forward this frame as soon as it is correctly detected. This proactive forwarding follows that the frame delay is reduced compared to Improved MDC, where the *direct query* command is only sent to the drift eNode B by the serving eNode B after the erroneous frame is received. The forwarding is continued until a *stop forwarding* command is received by the drift eNode B, this *stop forwarding* command is sent by serving eNode B when predicted SINR crosses the stated higher threshold with positive slope. The Hybrid MDC strategy is the compound of the Improved and Predictive MDC, it is developed to minimise frame drops caused by missed detections.

The Predictive and Hybrid MDC strategies can apply different channel prediction algorithms. In my dissertation two algorithms were investigated: *a*) in case of the *simple prediction* (SP) the moving average of the measured uplink SINR values are calculated, the predicted SINR equals to this calculated average. This prediction algorithm assumes that the SINR on the channel varies slowly. Although this assumption is not valid in the reality because of the effect of the Rayleigh fading, quite good prediction can be achieved with this simple prediction algorithm. *b*) The *adaptive Markov chain based prediction* (AMP) applies a first order adaptive (inhomogeneous) irreducible Markov chain to predict the SINR on the uplink channel, states of the Markov chain represent SINR intervals. State transition matrix of the adaptive Markov chain tells the probabilities of consecutive SINR values on the E-DPDCH which is referred as E-DPDCH characteristics in the following. The basic concept of the adaptive Markov chain based prediction algorithm is that the E-DPDCH characteristics known by the serving eNode B can be updated with a learning process in order to improve the prediction accuracy. The learning process is operating until the UE is connected to the serving eNode B.

Let $p_{ij}[n]$ denote the probability of transition from Markov chain state S_i to state S_j in the n^{th} TTI. At the beginning of the channel learning process (when the UE gets connected to the serving eNode B) the $p_{ij}[1]$ probabilities (for each $i, j \in \{1, \ldots, N\}$) are configured to $1/N$. When the first SINR values on E-DPDCH are measured by the channel measurement block of the serving eNode B, the prediction algorithm starts to learn the channel characteristics by updating the transition probabilities of the Markov chain in each TTI. If changing SINR between two TTI indicates a transition from Markov chain state S_k to state S_m, the algorithm recalculates the transition probabilities with increasing probability of transition $S_k \rightarrow S_m$ and decreasing the probability of transitions $S_k \rightarrow S_j$, $j = 1 \ldots N$, $j \neq m$. This can be achieved with the following method: a temporary $p'_{km}[n]$ value is determined by (7) incrementing $p_{km}[n-1]$ by 1:

$$p'_{km}[n] = p_{km}[n-1] + 1. \tag{7}$$

In the next step the $p_{km}[n]$ and the $p_{kj}[n]$, $\forall j \in \{1, \ldots, N\}$, $j \neq m$ probabilities are normalised with using (8) and (9) so that the condition $\sum_{j=1}^{N} p_{kj}[n] = 1$ is met.

$$p_{km}[n] = p'_{km}[n] \cdot \frac{1}{p'_{km}[n] + \sum_{j=1,j\neq m}^{N} p_{kj}[n-1]} \tag{8}$$

$$p_{kj}[n] \Big|_{j\neq m} = p_{kj}[n-1] \cdot \frac{1}{p'_{km}[n] + \sum_{j=1,j\neq m}^{N} p_{kj}[n-1]} \tag{9}$$

If data transmission is interrupted or terminated, the channel learning process stops. When the transmission is resumed, update of transition probabilities is continued starting from the state at which the transmission was interrupted.

Channel prediction is based on the already learnt channel characteristics which are described by the inhomogeneous transition probability matrix of the adaptive Markov chain. If the current Markov chain state is S_m, the next (predicted) state is randomly selected from the set of states $S_1 \ldots S_N$ using the discrete distribution of transition probabilities p_{mj}, $\forall j \in \{1, \ldots, N\}$. The predicted SINR is the SINR value which belongs to the randomly selected Markov chain state.

The results of the performed computer simulations are shown in Fig. 3.2 – Fig. 3.5. For the sake of easier understanding a linear curves are fitted to the discrete values obtained in the course of the simulation. Note that the developed Predictive and Hybrid MDC

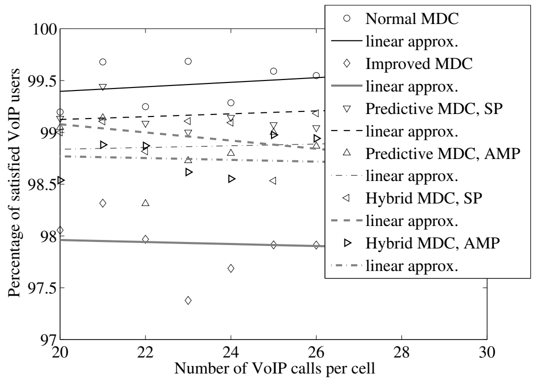


Figure 3.2: Percentage of satisfied VoIP users in eHSPA system applying different MDC strategies

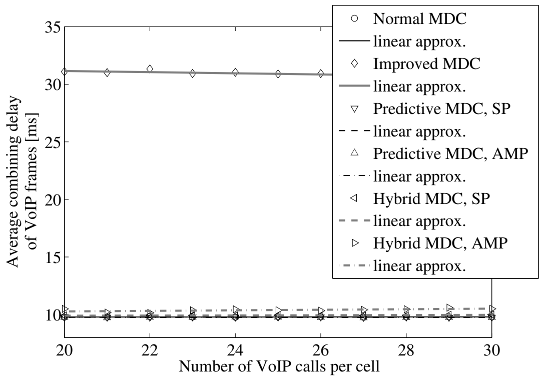


Figure 3.3: Average combining delay of VoIP frames in eHSPA system applying different MDC strategies

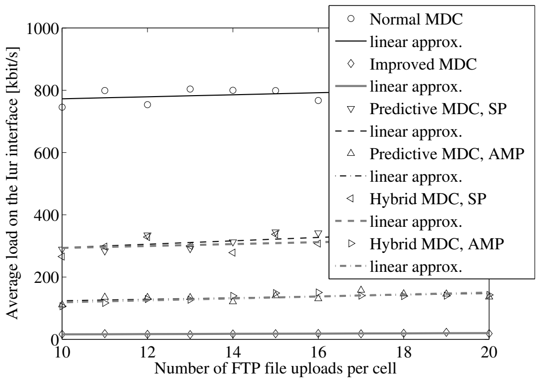


Figure 3.4: Average load on the Iur interface in eHSPA system applying different MDC strategies

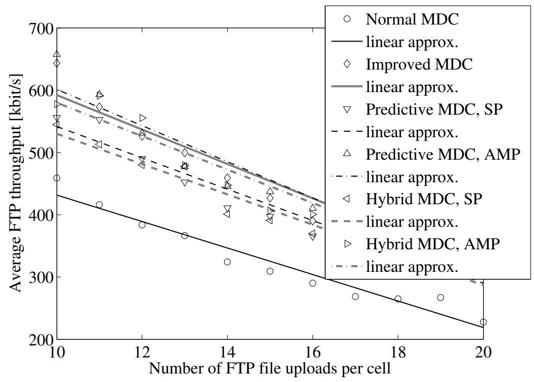


Figure 3.5: Average FTP throughput in eHSPA system applying different MDC strategies

strategies with the adaptive Markov chain based channel prediction algorithm produces similarly high FTP throughput as the Improved MDC strategy known from the literature and they do not cause increased delay in contrast to Improved MDC. Additionally the load of the transport network is significantly lower than in case of applying Normal MDC.

Thesis 3.1. *I stated that in case of applying the developed Hybrid MDC and Predictive MDC strategies which are based on channel prediction during soft handover process in eHSPA system, the frame delay is significantly reduced comparing to the Improved MDC strategy known from the literature. With Hybrid MDC and Predictive MDC strategies the throughput of the system reaches the value experienced by using Improved MDC. Nevertheless, in case of applying Predictive or Hybrid MDC the load of the transport network is slightly higher than in case of applying Improved MDC, but much smaller than in case of* *applying Normal MDC. Considering these statements I suggest using the developed Hybrid MDC strategy both for real time and non-real time applications.* **(Regarded own publications: [Héder, 2009d])**

Thesis 3.2. *I developed a prediction algorithm which can predict the quality of E-DPDCH in eHSPA system. The algorithm applies adaptive Markov chain which learns continuously the channel characteristics for each users in order to be the prediction more and more accurate. I demonstrated that the developed prediction algorithm can be effectively applied for the Predictive and Hybrid MDC strategies.* **(Regarded own publications: [Héder, 2009c])**

5 Applicability of the results

The results of my dissertation were published as Hungarian and international publications (conference papers, papers in periodicals, book chapters). The conference paper [Héder, 2006d] was awarded by *"Best Student Paper award"* and conference paper [Héder, 2006g] was awarded by *"Best Paper award"*. My new results were developed in the framework of Hungarian and international cooperations (Mobile Innovation Center Hungary - MIK, COST Action) and projects (MilliProp, IST – Broadwan, IST – SatNEx, Celtic MARCH), preliminary results were regularly published in "Project Deliverable" documents and in other reports. It must be mentioned that some results of the first and second thesis groups were used in COST Action 280 and COST Action IC0802. Some results of the first thesis group were verified at ONERA (The French Aerospace Lab) during my two-week stay within the confines of IST – SatNEx project. Over the past several years my publications has got seven independent citations.

References

[3GPP, 2008] 3GPP, "High Speed Packet Access (HSPA) evolution; Frequency Division Duplex (FDD)", Specification TR 25.999-710, 2008.

[Castanet, 2003] L. Castanet, T. Deloues, J. Lemorton, "Channel modelling based on N-state Markov chain for satcom systems simulation", in *Proc. of 12th International Conference on Antennas and Propagation (ICAP'03)*, Vol. 1, Exeter, United Kingdom, 31 March - 3 April 2003, pp. 119–122, Paper No.: 030, ISBN 0-85296-752-7.

[Craig, 1996] K. H. Craig, "Prediction of reliability when degraded by clear-air effects", in: M. P. M. Hall, L. W. Barclay, M. T. Hewitt (editors), *Propagation of Radiowaves*, Chapter 8, pp. 153–178, The Institute of Electrical Engineer, London, United Kingdom, 1996, ISBN 0-85296-819-1.

[Daru, 2002] A. Daru, Zs. Kormányos, J. Bitó, "Space and time correlation of rain attenuation in millimetre wave feeder network", in *Proc. of COST Action 280 1st International Workshop*, Malvern, United Kingdom, July 2002, Paper No.: PM3-008.

[Hendrantoro, 2002] G. Hendrantoro, R. J. C. Bultitude, D. D. Falconer, "Use of cell-site diversity in millimeter-wave fixed cellular systems to combat the effects of rain attenuation", *IEEE J. Select. Areas Commun.*, Vol. 20, No. 3, pp. 602–614, April 2002, ISSN 0733-8716.

[ITU-R, 2003] ITU-R, "Prediction method of fade dynamics on earth-space paths", Recommendation P.1623-0, Geneva, Switzerland, 2003.

[ITU-R, 2005] ITU-R, "Propagation data and prediction methods required for the design of terrestrial line-of-sight systems", Recommendation P.530-11, Geneva, Switzerland, 2005.

[Tikk, 2003] A. Tikk, J. Bitó, "Angular correlation of rain attenuation in star networks of point-to-point millimetre wave connections", in *Proc. of ITG International Conference on Antennas (INICA'03)*, Berlin, Germany, September 2003, ISBN 3-8007-2771-4.

[Usman, 2003] I. S. Usman, B. P. Lindhom, M. J. Willis, R. J. Watson, "Rain fade countermeasure prediction and performance for millimetre broadband fixed wireless communication systems", in *Proc. of 12th International Conference on Antennas and Propagation (ICAP'03)*, Vol. 1, Exeter, United Kingdom, 31 March - 3 April 2003, pp. 288–291, Paper No.: 070, ISBN 0-85296-752-7.

Publications related to the theses

Book chapters

[Bitó, 2008] J. Bitó, B. Héder, F. Cornet, F. Lacoste, C. Riva, U-C. Fiebig, A. Martellucci, L. Castanet, J. Lemorton, A. Núñez, F. Pérez-Fontán, "Time series synthesis", in: L. Castanet (editor), *Influence of the Variability of the Propagation Channel on Mobile, Fixed Multimedia and Optical Satellite Communications, Volume 2: Atmospheric Effects*, Chapter 2, pp. 2–35–2–96, Shaker Verlag, Aachen, 2008, ISBN 978-3-8322-6904-3.

[Héder, 2008b] B. Héder, J. Bitó, "Estimation of rain attenuation distribution on terrestrial microwave links generated with general N-state Markov model", in: I. Frigyes, P. Bakki, J. Bitó (editors), *Advances in Mobile and Wireless Communications, Views of the 16th IST Mobile and Wireless Communication Summit*, Chapter 8, pp. 149–152, Springer, Berlin, Heidelberg, 2008, ISBN 978-3-540-79040-2.

Journal papers

[Héder, 2006e] B. Héder, J. Bitó, "Joint modeling of terrestrial rain attenuation and land mobile satellite multipath fading time series with general N-state Markov model", *WSEAS Transactions on Communication*, Vol. 5, No. 3, pp. 572–577, 2006, ISSN 1109-2742.

[Héder, 2008c] B. Héder, J. Bitó, "General N-state Markov model for rain attenuation time series generation", *Springer Wireless Personal Communications Journal*, Vol. 46 , No. 1, pp. 99–113, 2008, ISSN 0929-6212.

[Héder, 2009e] B. Héder, L. Csurgai-Horváth, J. Bitó, "Adaptive terminal to base station assignment in BFWA systems", *IEEE Commun. Lett.*, Vol. 13, No. 8, pp. 588–590, 2009, ISSN 1089-7798.

Journal papers published in Hungary

[Héder, 2007c] B. Héder, J. Bitó, "Sztochasztikus csillapítás modellezése N-állapotú Markov modellel műholdas földi mozgó rádiócsatornán", *Híradástechnika folyóirat*, Vol. LXII, No. 3, pp. 24–27, 2007, ISSN 0018-2028.

[Héder, 2009a] B. Héder, A. Bertók, "Detection of sleet attenuation in data series measured on microwave links", *Infocommunications Journal*, Vol. LXIV, No. III, pp. 2–8, 2009, ISSN 0866-5583.

[Héder, 2009f] B. Héder, Á. Drozdy, J. Bitó, "Dynamic terminal to base station assignment technique in broadband fixed wireless access systems", *Periodica Polytechnica - Electrical Engineering*, 2009, ISSN 0324-6000, submitted.

Conference or workshop papers

[Héder, 2005b] B. Héder, J. Bitó, "Rain attenuation time series generation applying N-state Markov model parametrised from Hungarian measurement", in *Proc. of ESA Propagation Workshop (ESTEC'05)*, Noordwijk, The Netherlands, November 2005, p. 31.

[Héder, 2005c] B. Héder, R. Singliar, J. Bitó, "Second-order statistics of rain attenuation in Hungary especially the fade slope statistics", in *Proc. of COST Action 280 MC#9 Meeting*, Prague, Czech Republic, June 2005, Paper No.: PM9-113.

[Héder, 2005d] B. Héder, R. Singliar, J. Bitó, "Site diversity examination based on rain attenuation measurement", in *Proc. of IEEE 47th International Symposium Electronics in Marine focused on Multimedia Systems and Applications (ELMAR'05)*, Zadar, Croatia, June 2005, pp. 357–360, ISBN 953-7044-04-1.

[Héder, 2006b] B. Héder, J. Bitó, "Markov chain modelling of attenuation time series of land mobile satellite channel", in *CD Proc. of 3rd Advanced Satellite Mobile Systems Conference (ASMS'06)*, Herrsching am Ammersee, Germany, May 2006, pp. 70–75.

[Héder, 2006c] B. Héder, J. Bitó, "N-state Markov model using Gaussian fade slope assumption for rain attenuation time series generation", in *Proc. of Loughborough Antennas & Propagation Conference (LAPC'06)*, Loughborough, United Kingdom, April 2006, pp. 473–476, ISBN 0-947974-41-5.

[Héder, 2006d] B. Héder, J. Bitó, "General N-state Markov model applicable for attenuation time series generation parametrised from Gaussian fade slope model", in *Proc. of 5th WSEAS Int. Conf. on Electronics, Hardware, Wireless and Optical Communications (EHAC'06)*, Madrid, Spain, February 2006, pp. 182–186, Best student paper award, Paper No.: 512-481, ISBN 960-8457-41-6.

[Héder, 2006f] B. Héder, L. Csurgai-Horváth, J. Bitó, "Markov modeling of first and second order statistics of land mobile satellite fading", in *CD Proc. of IST Broadband Europe Conference (BBEurope'06)*, Geneva, Switzerland, December 2006, Paper No.: We4B5.

[Héder, 2006g] B. Héder, P. Horváth, J. Bitó, "Attenuation time series generation at 38 GHz with time and state discrete Markov model", in *CD Proc. of IST 15th Mobile and Wireless Communications Summit (IST-MobileSummit'06)*, Myconos, Greece, June 2006, Best paper award, Paper No.: 771.

[Héder, 2007d] B. Héder, J. Bitó, "Rain attenuation time series generation on terrestrial microwave links with general N-state Markov model", in *CD Proc. of IST 16th Mobile and Wireless Communications Summit (IST-MobileSummit'07)*, Budapest, Hungary, July 2007, pp. 1–5, Paper No.: C4.6, ISBN 978-963-8111-66-1.

[Héder, 2007e] B. Héder, J. Bitó, "First and second order statistics of land mobile satellite fading generated with N-state Markov model", in *CD Proc. of 12th Colloquium on Microwave Communications (Microcoll'07)*, Budapest, Hungary, May 2007, pp. 219–222, ISBN 978-963-87244-4-1.

[Héder, 2008a] B. Héder, J. Bitó, "Convergence analysis of genetic algorithm applied for dynamic optimization of terminal to base station assignment in satellite fed BFWA systems", in *Proc. of IEEE International Workshop on Satellite and Space Communications (IWSSC'08)*, Toulouse, France, October 2008, pp. 273–277, Paper No.: 13-3, ISBN 978-1-4244-1948-7.

[Héder, 2009b] B. Héder, J. Bitó, "Adaptation of terminal to base station assignment to terminal activities and rain event in Broadband Fixed Wireless Access Systems", in *Proc. of 3rd European Conference on Antennas and Propagation (EuCAP'09)*, Berlin, Germany, March 2009, pp. 1405–1409, Paper No.: 1569152831, ISBN 978-3-8007-3152-7.

[Héder, 2009c] B. Héder, Cs. Vulkán, “Adaptive soft handover forwarding in Evolved HSPA systems”, in *CD Proc. of ICT 19th Mobile and Wireless Communications Summit (ICT-MobileSummit’09)*, Santander, Spain, June 2009, Paper No.: 122, ISBN 978-1-905824-12-0.

[Héder, 2009d] B. Héder, Cs. Vulkán, “Improved uplink macro diversity combining in Evolved HSPA systems”, in *CD Proc. of IEEE 69th Vehicular Technology Conference (VTC’09 Spring)*, Barcelona, Spain, April 2009, Paper No.: 09-17-10, ISBN 978-1-4244-2517-4.

[Singliar, 2005b] R. Singliar, B. Héder, J. Bitó, “Site diversity improvement calculation based on rain attenuation”, in *CD Proc. of 9th International Student Conference on Electrical Engineering (POSTER’05)*, Prague, Czech Republic, May 2005, Paper No.: C37.

[Singliar, 2005c] R. Singliar, B. Héder, J. Bitó, “Site diversity gain model based on rain attenuation measurement”, in *Proc. of The Czech and Slovak 15th International Conference Radioelektronika 2005*, Brno, Czech Republic, May 2005, pp. 247–250, ISBN 80-214-2904-6.

Hungarian conference or workshop papers

[Héder, 2005a] B. Héder, “Állomás diversity vizsgálata mikrohullámú földi rádióösszeköttetéseken”, in *Proc. of HTE-BME Conference*, Budapest, Hungary, May 2005.

[Héder, 2006a] B. Héder, “Műholdas földi mozgó rádiócsatornán fellépő csillapítás idősorok modellezése Markov lánccal”, in *Proc. of HTE-BME Conference*, Budapest, Hungary, May 2006.

[Héder, 2007a] B. Héder, “Földi mikrohullámú összeköttetéseken fellépő esőcsillapítás modellezése általános N-állapotú Markov lánccal”, in *Proc. of HTE-BME Conference*, Budapest, Hungary, May 2007.

Other publications of mine

[Babits, 2008] L. Babits, L. Csurgai-Horváth, B. Héder, J. János, I. Frigyes, “Az 50-90 GHz frekvenciasávok alkalmazása ellátó hálózatokban”, in *Proc. of HTE 16. Távközlési és Informatikai Hálózatok Szeminárium és Kiállítás*, Zalakaros, Hungary, October 2008, pp. 94–103.

[Castro, 2007] M. Á. Vázquez Castro, J. Bitó, J. Erbert, B. Héder, O. Koudelka, P. T. Mathiopoulos, S. Morosi, Cs. Novák, A. Quddus, G. Seco Granados, A. Vanelli-Coralli, “Multiuser satellite communications”, in: G. E. Corazza (editor), *Digital Satellite Communications*, Chapter 9, pp. 367–415, Springer Science, New York, 2007, ISBN 978-0-387-25634-4.

[Frigyes, 2009] I. Frigyes, J. Bitó, B. Héder, L. Csurgai-Horváth, "Applicability of the 50-90 GHz frequency bands in feeder networks", in *Proc. of 3rd European Conference on Antennas and Propagation (EuCAP'09)*, Berlin, Germany, March 2009, pp. 336–340, Paper No.: 1569153941, ISBN 978-3-8007-3152-7.

[Héder, 2004a] B. Héder, "Bázisállomás hozzárendelés vizsgálata szélessávú, fix telepítésű, vezetéknélküli hozzáférési hálózatokban", in *Proc. of HTE-BME Conference*, Budapest, Hungary, May 2004.

[Héder, 2004b] B. Héder, J. Bitó, "Simulative investigation of dynamic site diversity method for Broadband Fixed Wireless Access networks using rain measurement", in *Proc. of IADAT-tcn International Conference on Telecommunications and Computer Networks (IADAT-tcn'04)*, San Sebastian, Spain, December 2004, pp. 151–155, ISBN 84-933971-1-3.

[Héder, 2004c] B. Héder, Cs. Sinka, J. Bitó, "Dynamic site diversity methods in Broadband Fixed Wireless Access Systems against rain fading", in *Proc. of COST Action 280 MC#8 Meeting*, Rome, Italy, November 2004, Paper No.: PM8-010.

[Héder, 2005e] B. Héder, R. Singliar, J. Bitó, "Fade dynamics investigation applying statistics of fade duration and level crossing rate", in *Proc. of 5th International Enformatika Conference, International Conference on Signal Processing (IEC-ICPS'05)*, Prague, Czech Republic, August 2005, pp. 97–100, Also published in World Academy of Science, Engineering and Technology electronic journal, Vol. 7, pp. 97-100, August 2005, ISSN 2070-3724, ISBN 975-98458-6-5.

[Héder, 2005f] B. Héder, R. Singliar, Z. Katona, J. Bitó, "Second-order statistics of rain attenuation in Hungary", in *CD Proc. of IEEE 5th Mediterranean Microwave Symposium (MMS'05)*, Athens, Greece, September 2005.

[Héder, 2005g] B. Héder, G. Szládek, J. Bitó, "Route diversity examination in BFWA systems", in *Proc. of IEEE 47th International Symposium Electronics in Marine focused on Multimedia Systems and Applications (ELMAR'05)*, Zadar, Croatia, June 2005, pp. 335–338, ISBN 953-7044-04-1.

[Héder, 2005h] B. Héder, G. Szládek, J. Bitó, "Investigation of interference conditions in BFWA system applying adaptive TDD", in *Proc. of 5th International Enformatika Conference, International Conference on Signal Processing (IEC-ICPS'05)*, Prague, Czech Republic, August 2005, pp. 125–130, Also published in World Academy of Science, Engineering and Technology electronic journal, Vol. 7, pp. 125-130, August 2005, ISSN 2070-3724, ISBN 975-98458-6-5.

[Héder, 2006h] B. Héder, J. Bitó, "Second order statistics of rain attenuation time series generated with N-state Markov chain model", in *CD Proc. of 1st European Conference on Antennas and Propagation (EuCAP'06)*, Nice, France, November 2006, Paper No.: 349770, ISBN 978-0-86341-842-6.

[Héder, 2007b] B. Héder, J. Bitó, "Angle dependent N-state Markov model for rain attenuation time series generation", in *CD Proc. of 2nd European Conference on Antennas and Propagation (EuCAP'07)*, Edinburgh, United Kingdom, November 2007, Paper No.: Fr1.10.3.

[Héder, 2007f] B. Héder, L. Csurgai-Horváth, J. Bitó, "Markov models for radio links and their application in attenuation time series synthesis", in *First JA 2310 SatNEx Workshop*, Toulouse, France, February 2007, Only presentation.

[Singliar, 2004] R. Singliar, B. Héder, L. Csurgai-Horváth, U.-C. Fiebig, F. Perez-Fontan, J. Bitó, "Comparison of rain attenuation models of satellite communication channels based on measured point rain intensity", in *Proc. of IADAT-tcn International Conference on Telecommunications and Computer Networks (IADAT-tcn'04)*, San Sebastian, Spain, December 2004, pp. 161–165, ISBN 84-933971-1-3.

[Singliar, 2005a] R. Singliar, B. Héder, J. Bitó, "Rain fade slope analysis", in *CD Proc. of IST Broadband Europe Conference (BBEurope'05)*, Bordeaux, France, December 2005, Paper No.: W03A01.

[Kovács, 2008] L. Kovács, A. Vidács, B. Héder, "Spectrum auction and pricing in dynamic spectrum allocation networks", *The Mediterranean Journal of Computers and Networks, Special Issue on Recent Advances in Heterogeneous Cognitive Wireless Networks*, Vol. 4, No. 3, pp. 125–138, 2008, ISSN 1744-2397.

Summary of publications

Total number of publications: 43
Number of conference or workshop papers: 33
Number of journal papers: 7, one is only submitted, notification has not been received.
Number of book chapters: 3

According to Google Scholar

- the total number of citations (including also self-citations): 38
- number of foreign citations (including also citations from the own research group): 9
- number of foreign (independent) citations: 5

According to Web of Science

- the total number of citations (including also self-citations): 11
- number of foreign citations (including also citations from the own research group): 3
- number of foreign (independent) citations: 3

Known foreign citations

[Miranda, 2009] E. C. de Miranda, M. C. Quesnel, L. A. R. da Silva Mello, "Empirical Model for the Statistical Characterization of Rain Fade Slope in Tropical Climates", *Journal of Microwaves, Optoelectronics and Electromagnetic Applications*, Vol. 8, No. 1, pp. 143S–153S, 2009, ISSN 1516-7399.

Citation to [Héder, 2005e] and [Héder, 2005c]. The first citation:

[5] Héder, B., Singliar, R. and Bitó, J. Fade Dynamics Investigation applying Statistics of Fade Duration and Level Crossing Rate, Proc. of the World Academy of Science, Engineering And Technology Volume 7 August 2005.

Context of the first citation:

"The study of fade slope has received a great deal of attention in recent years. From the statistical modeling point of view, important works have been carried out in the past 5 years. . . . Héder et al [5] explored the level crossing problem angle and presented the many difficulties in building a fade duration model (and thus an attenuation model) based on fade slope statistics."

The second citation:

[8] Héder, B., Singliar, R. and Bitó, J.,"Second-Order Statistics of Rain Attenuation in Hungary especially the Fade Slope Statistics", The third international Workshop of COST Action280, Prague, Czech Republic, June 2005.

Context of the second citation:

"In fade slope analysis, the preprocessing stage of the analysis is most crucial. This is because the decisions made at this stage influnce the results as a whole. Different authors have used different approaches to data filtering and to the choice of delay in calculating the rate of change in attenuation [8], [9]."

[Drougas, 2009] A. E. Drougas, A. D. Panagopoulos, P. G. Cottis, "Stochastic Verification of the First-Order Markovian Assumption of Rain Attenuation for Satellite Channel Dynamic Modeling", *IEEE Commun. Lett.*, Vol. 12, No. 9, pp. 663–665, 2009, ISSN 1089-7798.

Citation to [Héder, 2006h]:

[2] B. Heder and J. Bito, "Second order statistics of rain attenuation time series generated with N-state Markov chain model", in Proc. 1st Europ. Conf. Antennas Propagat. (EUCAP), Nice, France, 2006.

Context of the citation:

"FSMCs have been adopted in the literature to model the dynamic behavior of rain attenuation for satellite channels [2]. . . . Calculation of the first-order distributions for the DTMC is easily performed by raising the transition matrix to very high exponents, which results in the initial-state (steady-state) vector. Although first-order Markov models may have problems providing first-order statistics that are similar to those of measured data [2], [6], the resulting steady-state vector agreed with the lognormal distribution for every case examined, in terms of number of DTMC states. . . . It should be noted that second-order statistics, such as the fade duration, are of major importance as well and cannot always be well approximated by first-order modeling [2].”

[Mansor, 2007] Z. B. Mansor, “Attenuation Prediction for Sattelite Propagation from Point to Point Microwave Link Measurements”, M.Sc. Thesis, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, May, 2007

Citation to [Héder, 2005b]:

25. B. Heder, J. Bito, Rain Attenuation Time Series Generation Applying N-Sate Markov Model Parameterised from Hungarian Measurement. ESA Propagation Workshop 2005, Noordwijk, The Netherlands, November 2005.

Context of the citation:

“The transformed rain attenuation time-series is furthermore investigated by calculating some second order statistics like the rain fade slope in [25].”

[Cheffena, 2009] M. Cheffena, L. E. Braten, T. Ekman, “On the Space-Time Variations of Rain Attenuation” *IEEE Trans. Antennas Propagat.*, Vol. 57, No. 6, pp. 1771–1782, 2009, ISSN 0018-926X.

Citation to [Héder, 2005b]:

[26] B. Héder and J. Bitó, “Rain attenuation time series generation applying N-state Markov model parameterised from Hungarian measurement”, presented at the ESTEC 2005 Conf., Noordwijk, The Netherlands, Nov. 2005.

Context of the citation:

“Furthermore, different models for generating rain attenuation time series are reported in the literature. . . . An N-state Markov chain models for generating rain attenuation time series are presented in [25] and [26].”

[Liolis, 2009] K. P. Liolis, A. D. Panagopoulos, P. G. Cottis, B. D. Rao, “On the applicability of MIMO principle to 10-66GHz BFWA networks: capacity enhancement through spatial multiplexing and interference reduction through selection diversity”, *IEEE Trans. Commun.*, Vol. 57, No. 2, pp. 530–541, 2009, ISSN 0090-6778

Citation to [Héder, 2005d]:

[12] B. Heder, R. Singliar, and J. Bito, “Site diversity examination based on rain attenuation measurement”, in Proc. ELMAR 2005 Conf., June 2005.

Context of the citation:

“So far, most of the available literature related to cell site diversity has ignored interference related issues and focused only on the calculation of SNR increase. In this regard, several prediction models, both empirical (based on experimental propagation campaigns) [7], [10]-[12] and physical (based on general assumptions about the rain process) [8], [9], have been proposed for the characterization of the spatial correlation due to rain, as well."

[Gelenbe, 2009] E. Gelenbe, L. Györfi, "Performance of Auctions and Sealed Bids" in *Proc. of 6th European Performance Engineering Workshop (EPEW'09)*, London, United Kingdom, July 2009, pp. 30–43 ISSN 978-3-642-02923-3

Citation to [Kovács, 2008]:

19. Kovacs, L., Vidacs, A., Heder, B.: Spectrum auction and pricing in dynamic spectrum allocation networks. The Mediterranean Journal of Computers and Networks 4(3), 125-138 (2008)

Context of the citation:

"Models of auctions and sealed bids are amenable to rigorous analysis, as shown in early work on Martin Gardner's "Secretary, or Sultan's Dowry, Problem" where a recruiter selects the best candidate from a sequence of applicants, the quality of successive candidates are random variables, and the recruiter must make the irrevocable choice of a candidate from an initial sequence, without the possibility of further candidates being considered [1, 11] after the decision is made. Other analysis of auctions can be found in [8-10, 14, 15]. Of course there also direct links between auctions and networks due to the sale of wireless spectrum; however virtual auctions have also been suggested as a means of allocating network bandwidth [18] and the wireless spectrum, in real time, to competing users [19]."