AREA COVERAGE SIMULATIONS FOR MILLIMETER POINT-TO-MULTIPOINT SYSTEMS USING STATISTICAL MODEL OF BUILDING BLOCKAGE

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Abstract

Area coverage simulation results for LMDS or PMP systems in millimeter waveband are presented in this paper. Area coverage simulations were performed according to ITU-R P.1410 model, where Rayleigh statistical distribution with γ = 7.95 is used to model the building heights. Morphological data of the city of Prague were used to calculate a new set of values γ. The model was optimized to local conditions. Area coverage prediction results using the new set of values γ are also presented. Accuracy of the model was increased due to suggested modification.

Keywords

LOS coverage, Building blockage, LMDS, PMP, Millimeter waveband

1. Introduction

Due to high capacity, fast deployment, and relatively low cost, LMDS (Local Multipoint Distribution Systems) systems have become a good alternative to the traditional leased lines or to the PMP (Point-to-Point) access solutions for a last mile. Among the services provided by LMDS systems belong: internet connectivity, E1 replacement, video conferencing, voice telephony, frame relay, etc. Point-to-Multipoint structure (Fig. 1) of LMDS system enables multiple subscribers to access the same radio platform. LMDS utilizes the same, already well proven, concept of frequency reuse as was introduced in mobile cellular networks. The difference is that multiple subscribers connected to the base station are stationary, meaning that continuous coverage is not an essential requirement. The transport medium utilized in LMDS is a microwave radio. More information about LMDS can be found in [1], [2].

Coverage analysis of LMDS is a fundamental step in the system design process. Coverage analysis is based on marketing and sales requirements as well as on design criteria. Marketing and sales define locations of potential customers (coverage requirements), while RF design criteria determine the number of sites needed in order to meet the system requirements (Line-of-sight (LOS) coverage, capacity, reliability, BER, etc.).

Since the LOS coverage (existence of LOS between the transmitter and receiver) is usually required for LMDS system operating in millimeter waveband and is independent of the other system requirements it can be evaluated separately. Area coverage is then defined as an area where all system requirements are met. In this paper we will assume that the LOS coverage is the limiting factor, meaning that area coverage is equal to LOS coverage.

Area coverage calculation should be performed either with reliable underlying 3D building database when available or could be estimated based on a statistical model. Note that the statistical model could become very useful when the first studies about the network structure and infrastructure costs are required.

2. Area Coverage with 3D Database of Buildings Available

In case the reliable 3D database of buildings is available the area coverage should be calculated with suitable PC tool. Example of such a database is shown in Fig. 1. This is usually recommended solution and other methods should only be used when 3D database is not available or is too expensive for the given area.

3. Coverage Based on Statistical Model

3.1 ITU-R model

In ITU-R P.1410 [3] statistical model the probability of existence of LOS ray between transmitter and receiver position is given by combination of the probabilities that each rooftop of the building lying in the propagation path is below the height of the ray connecting the transmitter and receiver at the point where the ray crosses the building (Fig. 2). The model assumes that the terrain is flat or of a constant slope over the area of interest. For the purposes of this paper it was always assumed that the terrain is flat. Note that in practice the terrain must always be considered.

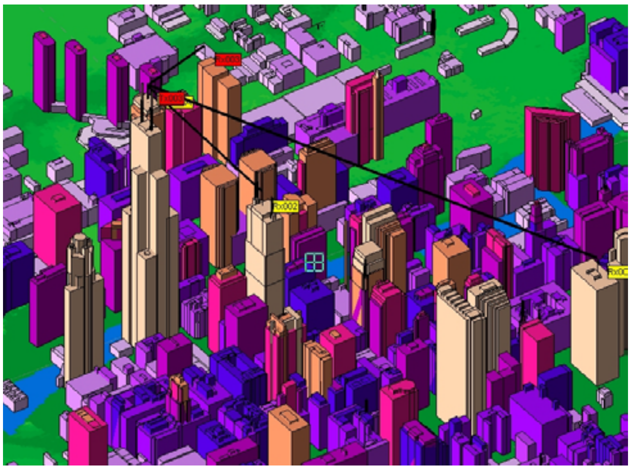

Fig. 1 3D Building database of Chicago (screenshot from EDX SignalPro planning tool, www.edx.com)

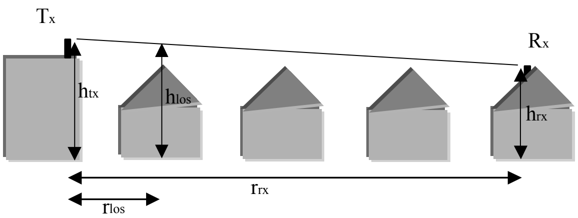

Fig. 2 ITU-R P.1410 model geometry

The probability that the LOS exists is calculated as follows

$$P(LOS) = \prod_{b=1}^{b_r} P(building\_height < h_{los}) \qquad (1)$$

where b_r is the number of buildings crossed. The estimation of b_r is based on assumption that the buildings are evenly spaced between the transmitter and receiver. The ratio of land covered by the buildings to total land area (α) as well as the mean number of buildings per unit area (β) area is taken into account when evaluating b_r

$$b_r = floor(r_{rx}\sqrt{\alpha\beta}) \qquad (2)$$

where r_{rx} is the link length (Fig. 2). Since it is assumed that the buildings are evenly separated between the transmitter and receiver, the i-th building distance from the transmitter is given as

$$d_i = (i + 1/2)\delta_r \qquad i \in \{0,1,\ldots,(b_r - 1)\} \qquad (3)$$

where $\delta_r = r_{rx}/b_r$ is the building separation.

The probability that the building height is below the LOS height is given by

$$P_i = 1 - e^{\frac{h_i^2}{2\gamma^2}} \qquad (4)$$

where $h_i = h_{tx} - d_i(h_{tx} - h_{rx})/r_{rx}$ is the LOS height in the place of i-th building and γ the parameter. One may identify that (4) is a CDF of Rayleigh statistical distribution. Since it has been observed that building heights distribution of Malvern city in UK is close to Rayleigh one, it is recommended in the ITU-R model. The result of ITU-R model is shown in Fig. 3, parameters used in the model where obtained from measurement of one town in UK and are given in Tab. 1.

α	β	γ
0.11	**750**	**7.63**

Tab. 1 Parameters from Malvern town (UK)

The results (Fig. 3) are given in the form of LOS probability in a given distance from the base station (radius of a cell). The terminal antenna height was assumed to be h_r = 7.5 m and the base station antenna height was assumed to be h_t = 5 m, 10 m, 15 m, 20 m, 25 m and 30 m.

In order to confirm the accuracy of ITU-R model and to evaluate the limitations and the problems, which might appear due to ITU-R model usage, several simulations were performed and the results were published in [4].

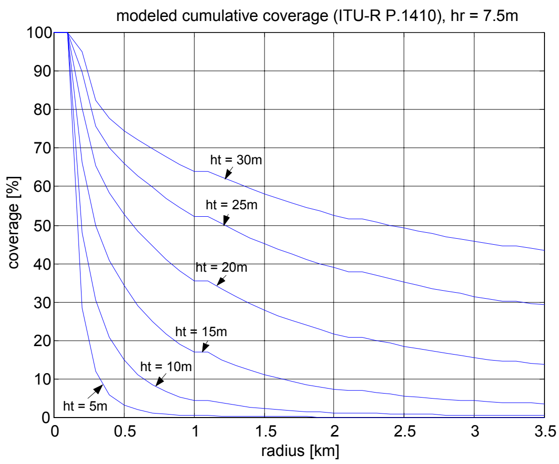

Fig. 3 Area coverage according to the ITU-R model

3.2 ITU-R model Tuning for Local Conditions

Because the parameters observed in the ITU-R model are based on a measurement in single town in UK it is necessary to find the key parameters in equations (2) and (4) (i.e. α,β, and γ) for local cities as well, in order to use the model in local conditions. In this section we will optimize the ITU-R statistical model for local conditions in terms of evaluation the key parameter γ needed. The other parameters (α, β) could either be estimated from a good knowledge of the given area or should be obtained from reliable 2D map (e.g. military maps). For the optimization purposes we used 3D morphological data of the area of Prague. The used data had already been pre-processed, meaning that the real data we obtained were in the form of occurrences of buildings of specific height class in a given area. The mentioned building height classes are defined in Tab. 2.

Height class	Building heights [m]
Class I	< 10
Class II	10 – 20
Class III	20 – 30
Class IV	> 30

Tab. 2 Building classes for ITU-R model tuning

Occurrences were always given per fraction of the total geographical area. Each fraction corresponds to five square kilometers (Fig. 4 – each square for which data were available is labeled with capital letter and number).

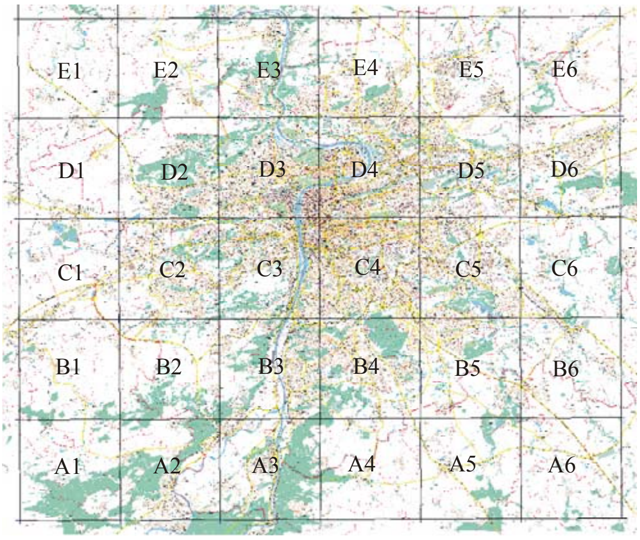

Fig. 4 Geographical location of 3D data

The optimization was based on a random number generator built in MatLab™. The heights generated according to the Rayleigh distribution with parameter γ were fitted into the previously mentioned height classes. The optimized γ was the one for which the resultant distribution causes the smallest error with respect to the measurement (see Fig. 5). The error was defined in terms of cumulative difference

$$error = \sum_{i=1}^{4} (N\_measured_i - N\_generated_i) \tag{5}$$

where $N\_measured_i$ and $N\_generated_i$ are number of occurrences of i-th height class of distribution in a given trial. The definition of Rayleigh distribution given by equation (4) was used during optimization meaning that values obtained (Tab. 3) could directly be used in the ITU-R model.

Because the accuracy was found to be very poor, it has been decided to use more general definition of Rayleigh statistical distribution given in [5]

$$P_i = 1 - \exp\left[-\frac{(h_i - a)^2}{2\gamma^2} \right]. \tag{6}$$

In this case two parameters must be optimized (γ, a). In order to use the ITU-R model the equation (4) must be replaced with (6). Obtained results are given in Tab. 4, see also Fig. 6 for comparison with Fig. 5.

Map square	γ
A3	9.83
B3	10.45
B4	10.55
B5	10.8
C2	10.48
C3	11.88
C4	16.9
C5	13.1
C6	12.4
D2	11.0
D3	15.78
D4	17.9
D5	13.05
D6	13.45
E3	10.53
E4	10.8
E5	13.33

Tab. 3 Optimized values for ITU-R model used in local conditions

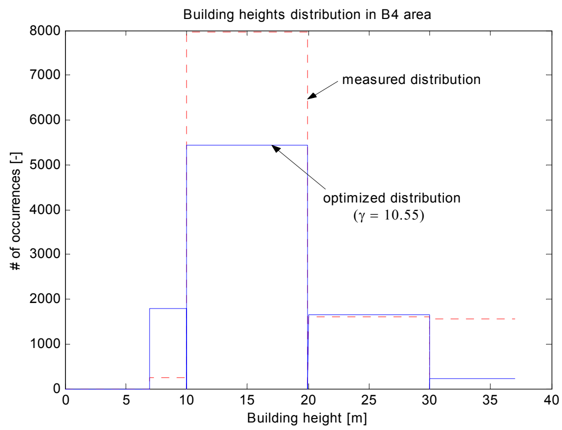

Fig. 5 Measured vs. generated sample distribution (Rayleigh)

3.3 Tolerance Analysis

In order to investigate the sensitivity of computed coverage probability (Fig. 3) to the changes of parameters γ and a obtained in the optimization process (Tab. 4), tolerance analysis was performed. Output of the tolerance analysis expresses the difference between coverage probability computed with "universal" parameters and coverage probability computed with optimized parameters for given map square (from Tab. 4). "Universal" parameters are the parameters optimized for the whole area of Prague and are given in Tab. 5. In the next step we investigated the influence of universal parameter on cumulative difference (5). It was observed that the increase of cumulative difference due to usage of universal (thus non-optimal) values from Tab. 5 compared to usage of optimal values from Tab. 4 for selected map square varies from 40 % to 350 %.

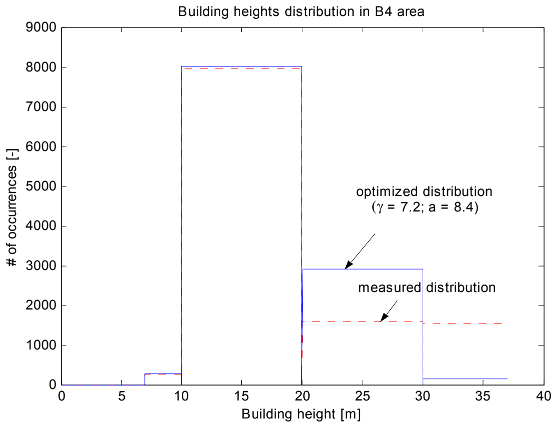

Fig. 6 Measured vs. generated sample distribution (Rayleigh)

In the last step we investigated the sensitivity of coverage probability to increased cumulative difference. For the base station antenna height it was assumed that h_t = 35 m and for terminal antenna height it was assumed that h_r = 8 m, h_r = 12 m, h_r = 16 m, and h_r = 20 m. One can see in Figs. 7 – 10, that usage of universal parameters could lead to significant differences in computed coverage probability, but on the contrary very small differences were observed as well. This means that key parameters selection for ITU-R model must be done carefully and usage of universal parameters should be avoided.

4. Conclusion

It can be concluded that the area coverage probability calculated by ITU-R P.1410 model is too sensitive to key parameters (a, γ) that should always be very carefully selected. Because the optimized values (Tab. 4) were given for each map square, thus for the different building characteristics, the engineer can select the values from Tab. 4 such that the building distribution in the corresponding map square (Fig. 4) is the most similar to the area of interest. Note that terrain was assumed to be flat in this case. In the real planning process the terrain must also be included.

Map square	γ	a
A3	5.1	10.4
B3	6.4	8.5
B4	7.2	8.4
B5	7.8	8.2
C2	7.1	8.8
C3	10.4	7.4
C4	12.8	7.2
C5	7.8	7.6
C6	9.7	11.0
D2	6.0	8.8
D3	11.2	8.4
D4	13.8	6.2
D5	7.4	8.2
D6	9.6	7.8
E3	6.6	8.0
E4	7.4	7.2
E5	8.6	6.2

Tab. 4 Optimized values for ITU-R model used in local conditions

The parameter γ for ITU-R P.1410 model was derived for local conditions - various parts of the city of Prague. The enhancement of the model was proposed using additional parameter a. The model parameters were derived for the modified model as well.

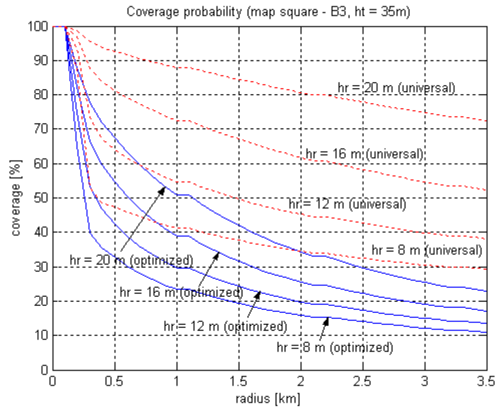

Fig. 7 Coverage prediction for B3 area with universal and optimized key parameters used

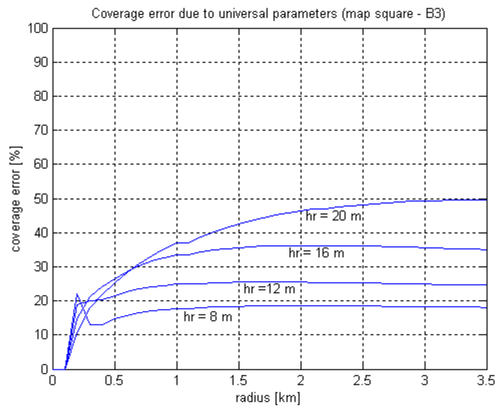

Fig. 8 Coverage error for B3 area when universal and optimized key parameters used

Map square	γ	a
A3 – E5	9.9	7.1

Tab. 5 Universal values for ITU-R model optimized for Prague

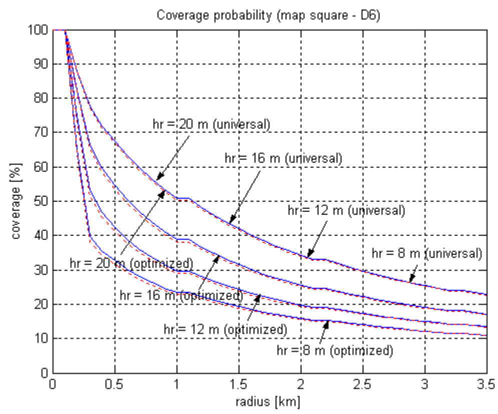

Fig. 9 Coverage prediction for D6 area with universal and optimized key parameters used

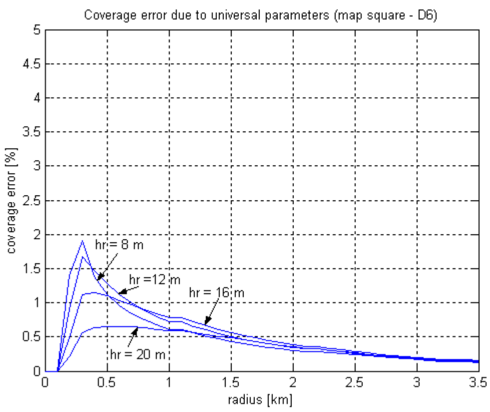

Fig. 10 Coverage error for D6 area when universal and optimized key parameters used

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