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Modeling and Simulation of Sceneries in Integrated Mobile Terrestrial and Satellite Communications Systems

Abstract - In this paper we present methods to generate terrain models for mountainous regions. For these regions analytical and statistical methods are unsuitable for predicting service coverage probability, call blocking and termination probabilities. Modeled terrains are used to simulate environmental conditions in integrated mobile terrestrial and satellite communications systems. A coverage analysis for non-geostationary satellite systems with the generated terrains shows probabilities of satellite visibility.

1 Introduction

To serve the expected increase of traffic in mobile communications systems in the coming years and to make the continuous decrease of transmission power of mobile stations possible, hierarchical cell structures will be used in future mobile communications systems [20]. Hierarchical cell structures include cells at pico, micro, macro and umbrella cell level. For the realization of umbrella cells the integration of a satellite system can be a suitable choice [1]. Especially satellite systems in non-geostationary orbits are suitable for this integration. These non-geostationary satellite systems have low power requirements and smaller round-trip-delay than satellite systems in geostationary orbits. However, these non-geostationary satellite systems lead to dynamic cell constellations and therefore to continuously changing environmental conditions for mobile stations. It is therefore difficult to predict the probability of service coverage, call blocking and termination. References [4, 6, 16] include several statistical models based on log-normal distribution for long-term fading, and Rayleigh and Rician distributions for short-term fading, respectively. These statistical models are not suitable for modeling urban regions or regions with natural obstacles, e.g. mountainous regions. The characteristics concerning propagation effects in these regions are determining factors for critical mobile communications system design parameters like topology and handover strategies. These characteristics can only be investigated through simulations. In this paper approaches for modeling mountainous regions and for investigating service coverage in these regions are developed. The developed terrain models can be used for terrain dependent satellite system optimizations as defined in [14].

2 Modeling of Mountainous Regions

The service coverage of satellite communications systems is dependent on the visibility of satellites. The visibility is a function of the terrain blockage and the overall characteristics of the satellite system. The influencing factors are type of valleys, width and length of valleys, and the gradient of the valley boundaries.

Distinctive features and types of mountainous regions are functions of their origin. The origin determines the geometry of mountains. The mountains can be classified in fold mountains and eroded mountains, which both have their distinctive features. Fold mountains have similar gradients of elevations independent of their height. They have a certain scale invariance, which permits the use of similar methods for mountain model generation for high- and low-mountains.

Mountains may be modeled by the method of height fields. Height fields are well known models in the field of computer graphics. A height field is represented in the Cartesian coordinate system by an equidistant unit grid in the xy-plane, where the node values contain the height values in the z-

direction. Three-dimensional planes defined by four points are called cells. Models of natural regions described by height fields are called terrains in the remaining of this paper.
The generation of terrains can be done in three ways. These are,

1. parametric automatic generation,
2. semi-automatic generation based on points representing the base geometry, and
3. non-automatic generation using topographical data.

2.1 Automatic Generation of Terrains

For the automatic generation of terrains, fractional Brownian surfaces, well known in the field of computer graphics, are suitable models. These surfaces can be generated by the application of fractional Brownian motion $B_H(t)$ in two dimensions [7]. The fractional Brownian motion $B_H(t)$ can be derived from the ordinary Brownian motion $B(t)$, generated with a cumulative Gaussian process $X(t)$. This process integrates a white noise random signal $x(t)$. The ordinary Brownian motion $B(t)$ is a Gauss-Markov process with stationary increases defined by $x(t)$. Known methods for the generation of a Brownian motion $B(t)$ are the Poisson relief, Fourier filtering, Gaussian midpoint displacement, successive random additions, and summing band-limited additions [8]. Models represented in this paper use the method of Gaussian midpoint displacements [10] since this method is easy to implement and is efficient concerning computation time. A disadvantage is that this method is only an approximation of the Brownian motion $B(t)$ [8]. However, for most applications this method is a good representation of the statistical behavior of the Brownian motion $B(t)$.
For the generation of Brownian motion $X(t)$ by the Gaussian midpoint displacement method the distance between two successive points is halved repeatedly and a random value is added to the half-way-point. Halving is called refinement. For the k-th refinements 2^{k-1} new points are generated. The k-th refinement is determined from the values of the $(k-1)$-th refinement by

$$X\left(\frac{i}{2^k}\right)=\frac{X\left(\frac{i+1}{2^k}\right)+X\left(\frac{i-1}{2^k}\right)}{2}+D_{ki}S_k \quad \text{with} \quad i=1,3,5,...,2^k-1 \quad \text{and} \quad k>0, \tag{1}$$

where D_{ik} are independent Gaussian variables. The scaling factor S_k decreases the magnitude of displacements with increasing k. S_k is determined by

$$S_k=\frac{1}{2}\left(\frac{1}{\sqrt{2}}\right)^{k-1} \quad \text{for} \quad k>0. \tag{2}$$

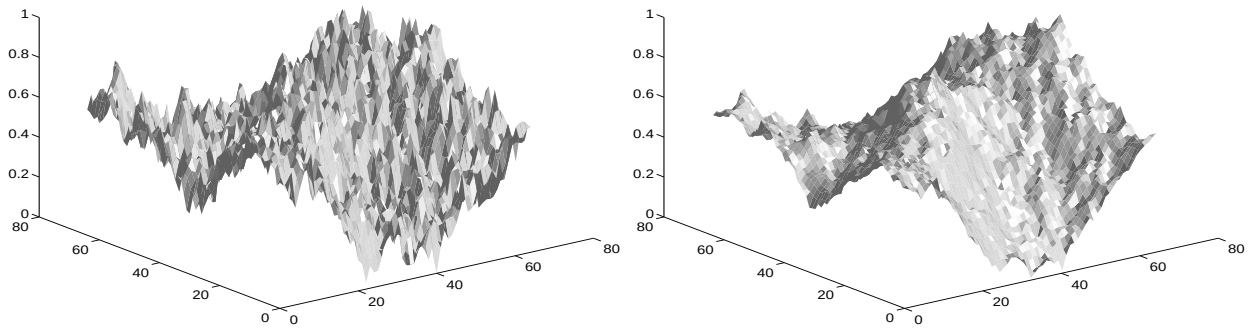

Fig. 1: Fractional Brownian Surfaces: a) H=0.5, b) H=0.999

Using the so-called Hurst exponent H, the fractional Brownian motion $B_H(t)$ is obtained from the ordinary Brownian motion $B(t)$ by extending the scaling factor in (2),

$$S_k=\sqrt{1-2^{2H-2}}\left(\frac{1}{2^H}\right)^{k-1} \quad \text{with} \quad 0<H<1 \quad \text{and} \quad k>0. \tag{3}$$

The Hurst exponent determines the relation between two successive increases and thus the property of the fractional Brownian motion $B_H(t)$ in the following way

- for $H = 0.5$ the increases are fully independent,
- for $H > 0.5$ the increases are positive correlated, and
- for $H < 0.5$ the increases are negative correlated.

The fractional dimension of the fractional Brownian motion $B_H(t)$ is $D = 2 - H$. Since the increases are fully independent for $H = 0.5$, the fractional Brownian motion $B_H(t)$ in this case is an ordinary Brownian motion $B(t)$. A fractional Brownian surface can be obtained by the application of the fractional Brownian motion $B_H(t)$ over a plane, whereby each cut in the vertical direction itself has to be a fractional Brownian motion $B_H(t)$. The dimension of fractional Brownian surface is $D = 3 - H$. The relations between successive increases for fractional Brownian motion $B_H(t)$ are also valid for the fractional Brownian surface depicted in Fig. 1.

Fig. 2 shows, that a fractional Brownian surface is too irregular and not suitable for representing mountainous regions without further processing. The surface firstly has to be smoothed and secondly the statistical identity of mountains and valleys has to be removed. In reality there is no statistical identity between mountains and valleys.

The surface can be smoothed by two-dimensional convolution using the convolution kernel method. The convolution kernel method is widespread in image processing [17]. The two-dimensional convolution is a two-dimensional digital non-recursive low-pass filter. The outputs of this filter are,

$$\tilde{z}(k,l) = \sum_{i=-n}^{+n} \sum_{j=-n}^{+n} b_{ij} z(k-i, l-j) \quad \text{with} \quad b_{ij} \geq 0, \quad n \text{ finite}, \quad \text{and} \quad \sum_{i=-n}^{+n} \sum_{j=-n}^{+n} b_{ij} = 1 \tag{4}$$

$$b_{ij} = \frac{1}{(2n+1)^2} \tag{5}$$

where n is the order of the filter and b_{ij} are the convolution coefficients.

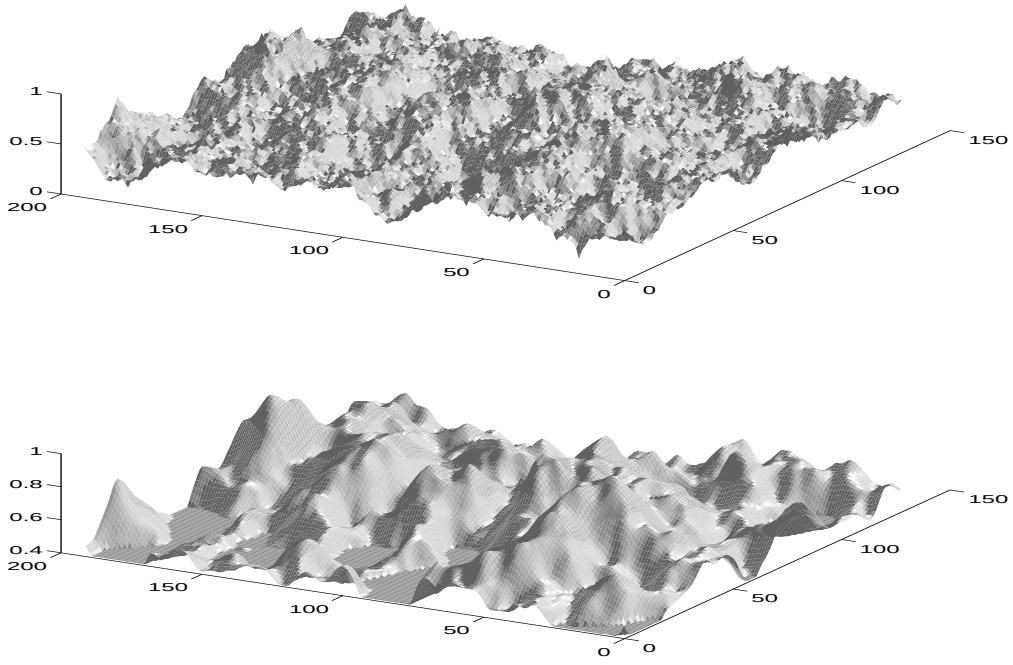

Fig. 2: Fractional Brownian surfaces generated from 6x4 squares and H=0.98 a) without modifications, b) filtered with n=2 and normalized

For smoothing of fractional Brownian surfaces it is sufficient if all coefficients have the same values (5), see Fig. 2 and Fig. 3. Filtering is then a moving averaging process. The statistical identity of valleys and mountain peaks can be removed by, e.g., cutingof deepest valleys or by scaling of height values dependent of their magnitudes. With different scaling functions different shapes of mountains can be generated.

2.2 Semi-automatic generation of terrains

Semi-automatic generation of terrains may be used in cases where the main geometric characteristics of regions are to be preserved. A few points which characterize the geometry of the regions are set before the generation of the fractional surface. To preserve the main geometry of the terrain during the generation, the generation must only be carried out with small midpoint displacements. This can be done by starting the generation of the surface at a high order refinement step with $k \geq 3$. By post filtering and normalization, different cases of low and high mountains can be generated, see Fig. 3.

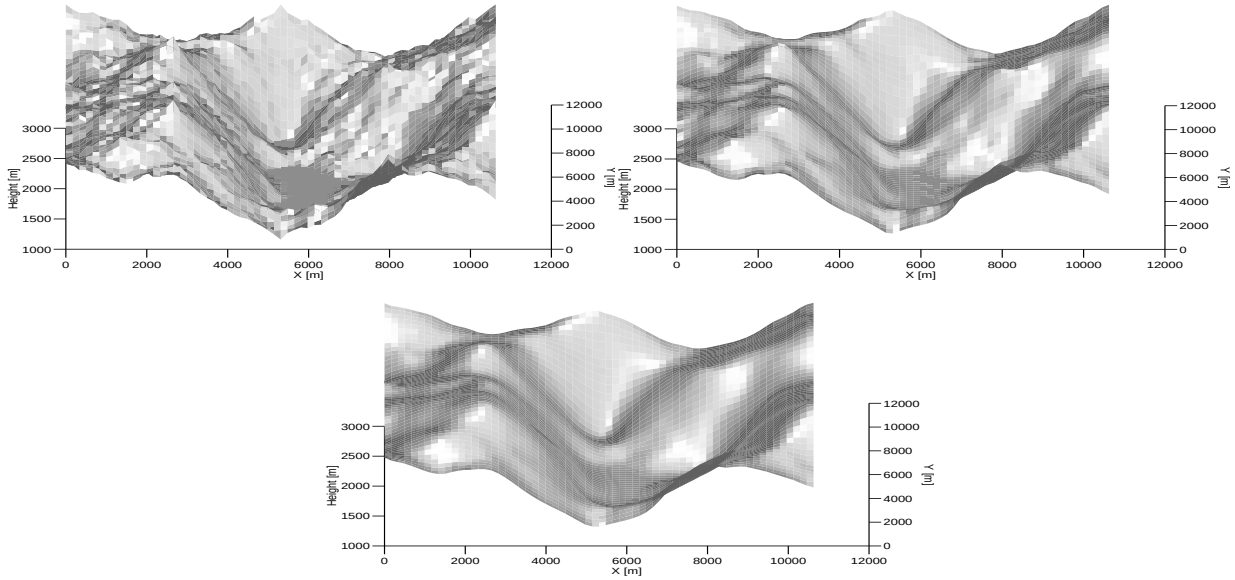

Fig. 3: Semi-automatic generated terrains a) not filtered, b) filtered n=1, c) filtered n=2

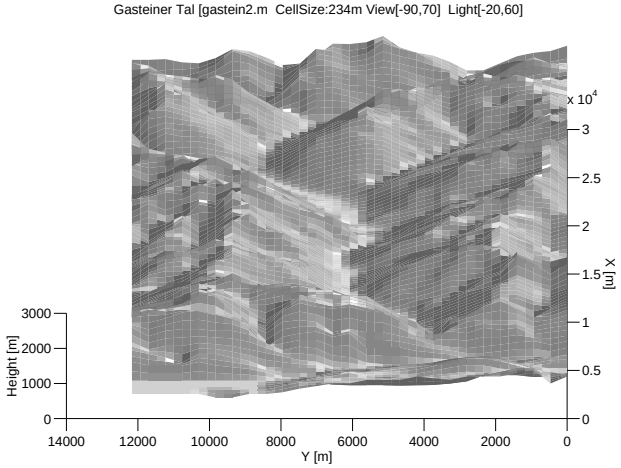

Fig. 4: Gasteiner Valley (Austria), cell size 234m

2.3 Use of Topographical Data

In the case where a specific geographical region is investigated and where the original geometry should be preserved fully, the topographical data need to be used for the modeling the terrain. A

grid with constant cell size is spanned over a region and the height values are taken at the location of grid points. These terrain values are included in a height field and can then be used for simulations in the same way as the automatic and semi-automatic generated models. As an example Fig. 4 depicts a typical valley of the mountains Hohe Tauern in Austria. The data were taken from a map at a cell size of 468 meters and were refined one times. The depicted cell size is therefore 234 m.

3 Simulation of Mobile Communications Systems in Mountainous Regions

For regions in which analytical and statistical methods for the evaluation of the probability of service coverage, call blocking, and call terminating are unsuitable for modeling environmental conditions in mobile communications systems, generated terrains must be used.
In the following the service coverage of several proposed future satellite systems in non-geostationary orbits is investigated for terrains generated by the method described in Chapter 2.3.
Satellites in non-geostationary orbits cause dynamically changing conditions for mobile stations. An important criterion for the usability of a satellite system is the number of satellites that are visible. The visibility of proposed future satellite system, shown in Tab. 1, is investigated [2, 12 ,13 ,19].

System	Number of satellites	Altitude over equator [km]	Inclination of orbits [deg]	Simulated time [s]	Step size [s]
Aries	48	1020	90	13600	10
Globalstar	48	1406	52	10800	5
Iridium	66	780	86	10000	5
Jocus	7	13900	75	86164	100
LEONET	15	6390	54	4800	30
MAGSS-14	14	10355	56	82800	60
Odyssey	12	10354	55	86400	60
Teledesic	840	700	98.2	2160	1

Tab. 1: Satellite systems and simulation parameters

For the investigation of visibility a modified Ray-Tracing algorithm for height fields, called Grid-Tracing [9], was used. In Grid-Tracing a ray is sent in the direction of a given azimuth and elevation for a mobile satellite link. A test for intersection between a cell and the ray is carried out for all cells the ray is traversing. In the case of intersection, the satellite is not visible and Grid-Tracing is terminated.
The probability of visibility is determined for the center points of all individual cells and the spatial statistics are computed. For each satellite system the spatial mean and minimum probability of visibility of at least one, two, three and four satellites is evaluated by the simulation. On first sight, all satellite systems have a spatial mean probabilities of visibility for at least one satellite close to one. This is sufficient to provide service to the investigated region. However, the results for the minimum probability of visibility show significantly lower values. In spite of outstanding mean spatial probabilities there are regions in which the probability of visibility of at least one satellite is much lower than the acceptance value of 95%. Therefore an analysis of the spatial mean probability distribution over the investigated terrain was carried out for the example of the Iridium system. Fig. 6 shows that there are regions in the terrain in which the probability of visibility of at least one satellite is lower than the acceptance value. The comparison of the height structure and the spatial probability distribution shows a strong correlation between the valleys and minimum values for the probability, see Fig. 7. This is caused by the higher elevation constraints at the bottom of the valleys. For the visibility of at least two satellites this relationship is much more obvious, Fig. 7.

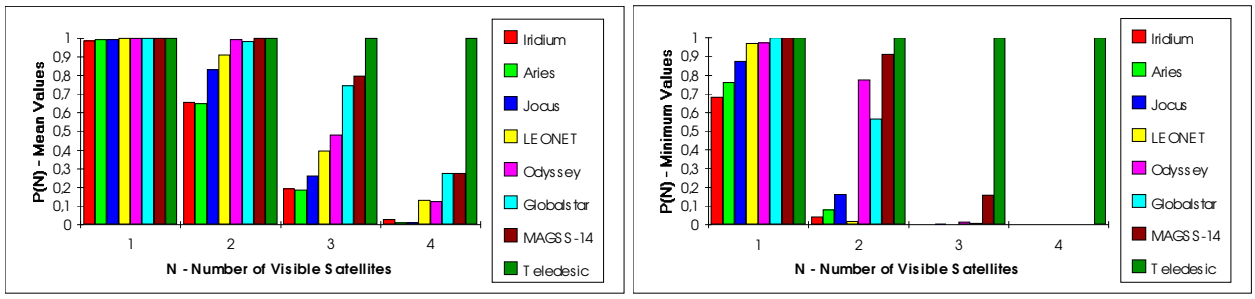

Fig. 5: Mean and minimum probability of visibility of at least one satellite P(N=1)

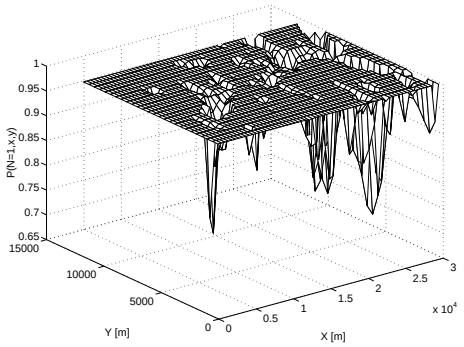

Fig. 6: P(N=1) for Iridium in the valley Gasteiner Valley

Further important information, which can be obtained from the simulative investigations of visibility of satellites in a terrain, is the distribution of occurrences of temporal gaps in the visibility. For the Iridium system, Fig. 8 shows such a distribution of temporal visibility gaps for a critical location in the example terrain.

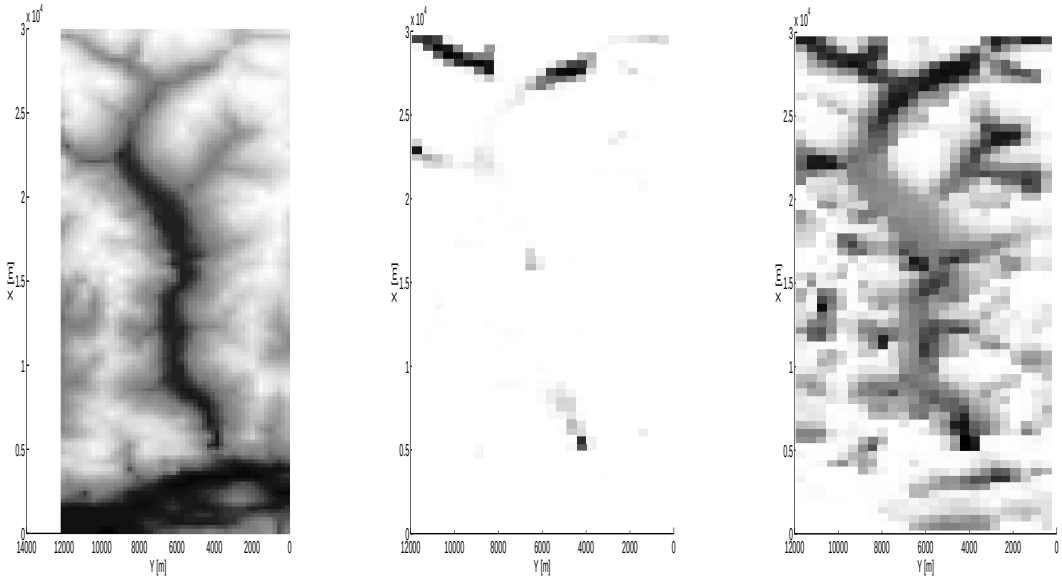

Fig. 7: a) Height structure of the terrain, b) P(N=1) Iridium c) P(N=2) Iridium

Since satellites in non-geostationary orbits are moving relative to the earth with velocities up to 8 km/s handover mechanisms need to be developed. For handovers between satellites, called inter-satellite handover, the visibility of at least two satellites is required. For our terrain the analysis of spatial mean probabilities of visibility of at least two satellites shows that only few of the satellite systems have sufficient probability of visibility. Systems like the Iridium system, which have extremely high relative velocities and exhibit mean times between handovers of about 10 minutes, the probability of visibility of at least two satellites is insufficient. From this one can conclude that

the Iridium system is not appropriate for serving of such mountainous regions. Fig. 5 shows, the more appropriate systems for the realization of inter-satellite handovers are systems like MAGSS-14 or Teledesic. The realization of full service coverage for mountainous regions with systems like Iridium can only be carried out through careful integration with terrestrial components, if these terrestrial systems are at all realizable. This integration of mobile terrestrial and satellite communications systems rais a number of new issues which will be investigated in upcoming studies.

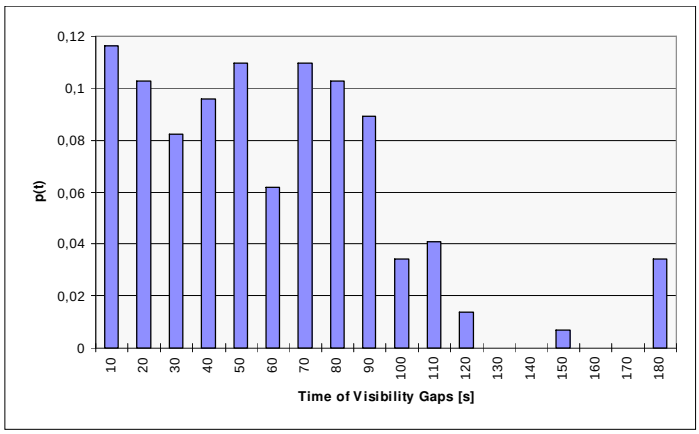

Fig. 8: Empirical distribution of the duration of visibility gaps

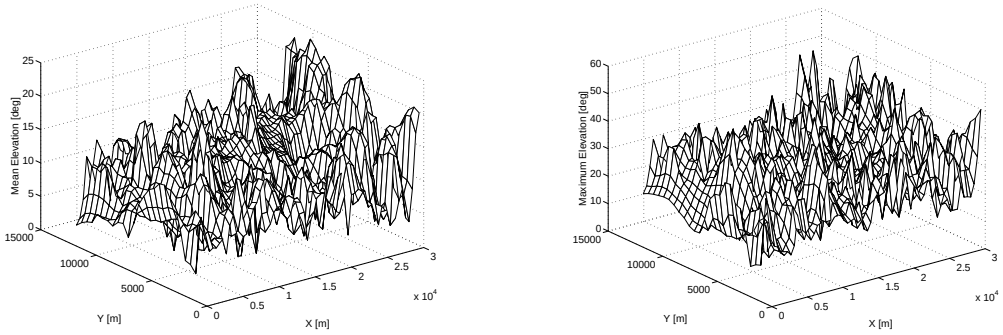

Fig. 9: Mean and maximum elevation in the Gasteiner Valley

Often it is necessary to compute the minimum elevation angle in a given direction from any point in a terrain. For such computations, the described Grid-Tracing algorithm was modified to increase the gradient of the ray for the case of intersection between ray and cell until the top the cell in the direction of the ray is reached. Simultaneously the elevation angle is increased. The application of this method to all traversed cells results in the minimum elevation angle from a starting point in the given direction. The described method can be used for several investigations, e.g., to determine a so-called elevation panorama in which the minimum elevation angle is represented for azimuth angles between 0 and 360 degrees.

4 Conclusions

In this paper we developed methods for generation of terrains for the investigating of environmental conditions in integrated mobile terrestrial and satellite communications systems. The results of such investigations can be used during the design phase of an integrated terrestrial and satellite communications system. This permits to develop systems with optimal service coverage also for mountainous regions. The results show that for satellite systems such as Iridium optimal service coverage can only be reached through integration with terrestrial components. The performance of a mobile communications system is often measured by its probability of service coverage, call blocking and terminating probability. Simulations need to complement analytical or

statistical methods to predict these probabilities in mountainous regions. Thus they are a critical element in the design of such systems.

References

[1] Ananasso, F.; Delli Priscoli, F.: *The Role of Satellites in Personal Communication Services.* IEEE J. Select. Areas Commun. Vol. 13, No. 2, p. 291-302, Feb. 1995

[2] Benedicto, J.; Fortuny, J.; Rastrilla, P.: *MAGSS-14: A Medium-Altitude Global Mobile Satellite System for Personal Communications at L-Band*. ESA Journal, Vol. 16, Feb. 1992

[3] Caile, J. P.: *MOTOROLAs Comment's on Developments in Cellular Technology.* Proc. 5th Annual Bear Stearns Media & Entertainment Conference, Carlsbad CA 1991

[4] Corazza, G. E.; Vatalaro, F.*: A Statistical Model for Land Mobile Satellite Channels and Its Application to Non-geostationary Orbit Systems.* IEEE Trans. Veh. Technol.,Vol. 43, No. p, S. 738-741, Aug. 1994

[5] Jeruchim, M. C.; Balaban, P.; Shanmugan, K. S.*: Simulation of Communication Systems.* Plenum-Press, New York NY 1992

[6] Lee, W. C. Y.: *Mobile Communications Design Fundamentals*. Wiley & Sons Inc., New York NY 1993

[7] Mandelbrot, B. B.: *The Fractal Geometry of Nature.* W. H. Freeman, New York NY 1983

[8] Musgrave, F. K.; Kolb, C. E.; Mace, R. S.: *The Synthesis and Rendering of Eroded Fractal Terrains*.

[9] Musgrave, F. K.: *Grid Tracing: Fast Ray Tracing for Height Fields.* Yale Dept. of Computer Science, Research Report RR-639, July 1988

[10] Peitgen, H.-O.; Jürgens, H.; Saupe, D.: *Chaos and Fractals: New Frontiers of Science.* Springer-Verlag, New York 1992

[11] Peitgen, H.-O.; Jürgens, H.; Saupe, D.: *Fractals for the Classroom, Part One.* Springer-Verlag, New York 1992

[12] Pennoni, G.: *JOCOS: 6+1 Satellites for Global Mobile Communications*. Proc. GLOBCOMM, San Francisco CA 1994

[13] Rusch, R. J.: *Odyssey, an optimized personal communications satellite system*. IOS Press space communications, Vol. 11(1993), p. 275-286

[14] Salzwedel, H.*: Optimization of Satellite Systems for Mobile/Personal Communications.* Proc. 39th IWK, Ilmenau 1994

[15] Tuck, E. F.; et al: *The Calling Network: a global telephone network*. IOS Press space communications, Vol. 11(1993), p.141-161

[16] Vatalaro, F.; et al: *Analysis of LEO, MEO, and GEO Global Mobile Satellite Systems in Presence of Interference and Fading.* IEEE J. Select. Areas Commun. Vol. 13, No. 2, p. 291-302, Feb. 1995

[17] Watkins, C.; Sadun, A.; Marenka, S.*: Modern Image Processing: Warping, Morphing, and Classical Techniques.* Academic Press Professional, Cambridge MA 1993

[18] Werner, M; et al: *Analysis of System Parameters for LEO/ICO-Satellite Communication Networks*. IEEE J. Select. Areas Commun. Vol. 13, No. 2, p. 371-383, Feb. 1995

[19] ----: *ETSI Technical Report: Possible European Standardization of Certain Aspects of Satellite Personal Communications Networks (S-PCN).* ETSI PT 37V, Apr. 1993

[20] ----: *RACE Final Document Part B*, RACE 1994

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