Simulation of UMTS Capacity and Quality of Coverage in Urban Macro- and Microcellular Environment

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Abstract. *This paper deals with simulations of a radio interface of third generation (3G) mobile systems operating in the WCDMA FDD mode including propagation predictions in macro and microcells. In the radio network planning of 3G mobile systems, the quality of coverage and the system capacity present a common problem. Both macro and microcellular concepts are very important for implementing wireless communication systems, such as Universal Mobile Telecommunication Systems (UMTS) in dense urban areas. The aim of this paper is to introduce different impacts – selected bit rate, uplink (UL) loading, allocation and number of Nodes B, selected propagation prediction models, macro and microcellular environment – on system capacity and quality of coverage in UMTS networks. Both separated and composite simulation scenarios of macro and microcellular environments are presented. The necessity of an iteration-based simulation approach and site-specific propagation modeling in microcells is proven.*

Keywords

UMTS, Radio network planning, microcell, macrocell, radiowave propagation.

1. Introduction

Third generation mobile systems (UMTS) are designed to support multimedia services, e.g. speech and video telephony, access into data networks, etc. In the radio network planning of third generation (3G) mobile networks problems of capacity and coverage cannot be separated. In the UMTS systems the base station sensitivity is not constant (as is the case for the GSM system), but depends on the number of users and the used bit rate in each cell. In WCDMA systems all users share the same interference resources and therefore they cannot be analyzed independently. Each user has impact on the transmission power of others, thus influencing them. These changes then iteratively have an impact on the user etc. To get realistic results of the quality of coverage analysis in the real scenarios, where different users employ different services, an iterative simulation approach, rather than an analytical one should be used. The coverage prediction process for third generation systems is specific due to the interference estimation that is crucial already in this phase of network planning, and so an application of iteration-based simulations seems necessary in order to study 3G networks behavior in realistic scenarios. For that reason, the whole prediction process should be done iteratively. The simulations were performed in NPSW – a static radio network planning tool for WCDMA [1]. This tool is implemented in Matlab and it is based on the computational methods of iterative loops. The tool is open to further development by a user so that an arbitrary network topology and parameters as well as propagation models can be employed.

2. Propagation Prediction

Empirical models for propagation prediction in UMTS networks could be successfully used in case of a macrocellular environment. Deterministic ray tracing techniques are usually used for propagation prediction in microcells. The results of deterministic methods are very accurate, but require very complex input. For propagation prediction in microcells the classical empirical model and the semi-deterministic site-specific Berg's Recursive Model [2] were utilized. For calculation of building penetration loss methods recommended by [3] could be easily and successfully implemented. All of the simulations were executed for a town plan with a dimension of 3 × 2 km. For the penetration of a signal into the buildings the external wall attenuation of 15 dB, the internal wall attenuation of 5 dB and internal walls distance of 15 m were considered.

2.1 Macrocellular Environment

For macrocellular environment, the empirical model for UMTS macrocells [4] was chosen. The classic empirical model converts a maximum allowed propagation loss L (dB) to a maxim cell range d (km) as

$$L = 80 + 21 \cdot \log_{10}(f) + 40 \cdot (1 - 0.004 \cdot \Delta Hb) \cdot \log_{10}(d) - 18 \cdot \log_{10}(\Delta Hb) \quad (1)$$

where f is the frequency in MHz, ΔHb the height difference between the base station antenna and the mean building rooftop level in m, d is the distance between the mobile station and base station in km. According to the basic macrocell definition the base station antennas are situated above the rooftops. Fig. 1 shows the uplink path losses calculated by the empirical model applied to a real town plan in the city centre of Prague for 33 Nodes B (11 third-sectored sites). For these simulations ΔHb of 5 m was selected.

2.2 Microcellular Environment

The basic definition of microcells is that the antennas of the base stations are mounted below rooftop level. For the propagation prediction the classic empirical model and the semi-deterministic site-specific Berg's Recursive Model were utilized. Suitability of the two models was investigated.

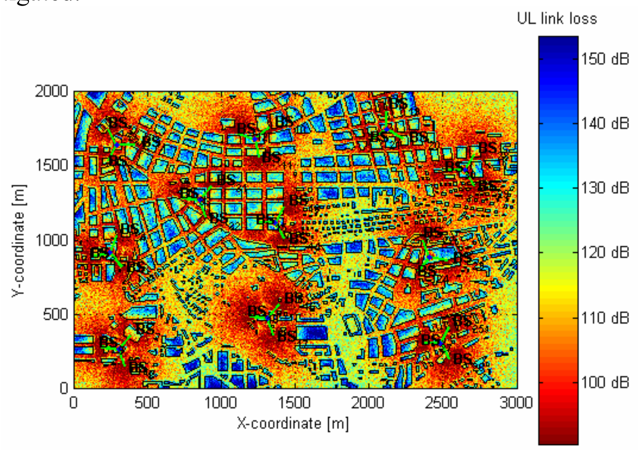

Fig. 1. Uplink path losses of macro layer.

2.2.1 Empirical Model

The NPSW offers the empirical propagation model for the microcellular environment [4].

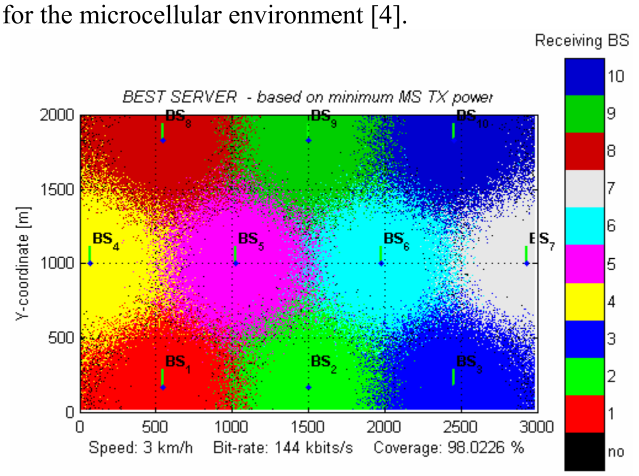

Fig. 2. The uplink coverage probability for the 144 kbps service and 50% uplink loading (best servers).

Path loss can be calculated as

$$L = 49 + 30\log_{10}(f) + 40\log_{10}(r) \qquad (2)$$

where f is frequency in MHz. It will be shown that the use of the empirical propagation model is unsuitable for a microcellular environment. Without the margin for the penetration into the buildings 10 Nodes B (with 15 dBi omni antennas) in a homogenous hexangular deployment were needed for full coverage of the target area (Fig. 2).

2.2.2 Berg's Recursive Model

Another way of a site-specific propagation prediction in microcells was introduced by Berg. Berg's Recursive Model was recommended for UMTS by ETSI [4] and was successfully used to determine the path loss in the microcells with reference to a 2D plan of buildings. Based on this model, a software tool was implemented for propagation predictions in UMTS microcells [5]. The Berg's Recursive Model was applied on the real town plan in the centre of the city of Prague. Fig. 3 shows the path loss calculated by Berg's Recursive Model, which takes into account a surrounding built-up area. 10 Nodes B covered about 55 % of target area for 144 kbps data service by 50 % uplink loading (black color depicts no coverage area). From comparison with Fig. 2 the necessity of a site-specific propagation model usage is obvious.

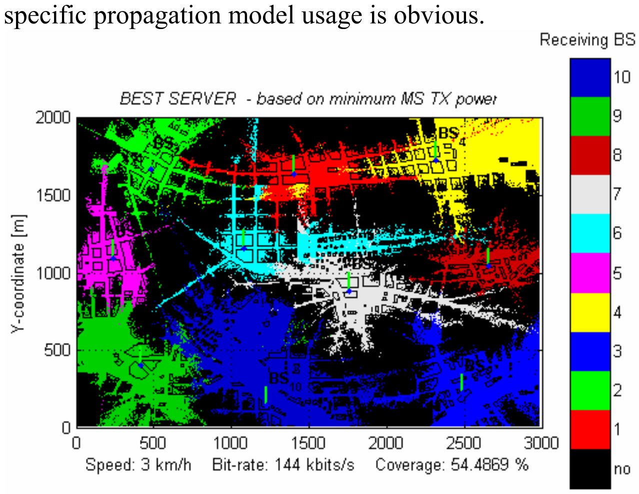

Fig. 3. The uplink coverage probability for the 144 kbps service and 50% uplink loading (best servers).

3. Simulations

All of the simulations were carried out for four different services independently (speech 12.2 kbps and three data services 64, 144, and 384 kbps). The simulations of mixed services with dominance of speech service (approximately 90 % of all users utilized the speech service) were also undertaken in order to approach a real-life situation. The mobile stations utilized OMNI antennas with a gain of 0 dBi situated at a height of 1.5 m. The users were randomly distributed in the target area. The maximum transmission power of the mobile stations was 125 mW. As overall Node B transmission power, 5 W in the microcellular and 20 W in the macrocellular environment were selected. The simulations were executed for different uplink loading: 50 % and 80 %.

3.1 Macrocellular Environment

The macrocellular base stations used sectored sites with 3 sectors and 17 dBi gain, 65 degrees horizontal beamwidth antennas with 6 degrees tilt. Fig. 4 illustrates the coverage probability as a function of service for 50 % uplink loading and for speech service. Fig. 5 shows the same for 384 kbps data service.

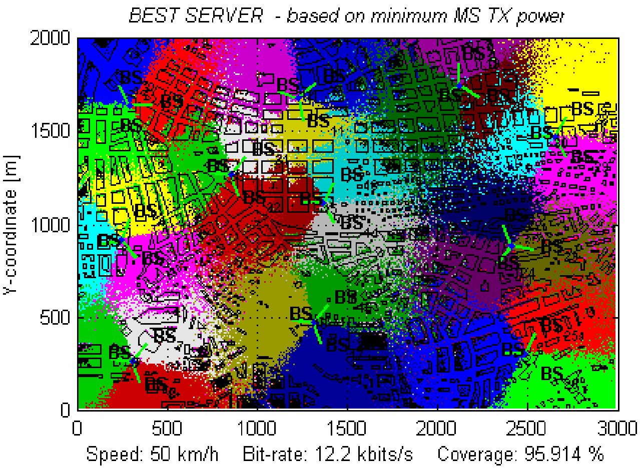

Fig. 4. The uplink coverage probability of the macro layer for speech service and 50% uplink loading.

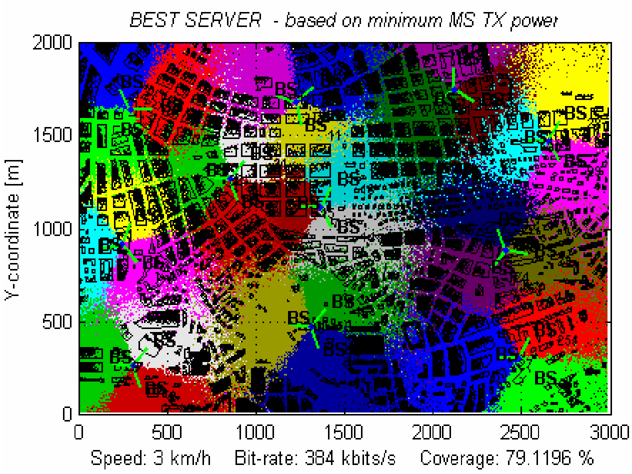

Fig. 5. The uplink coverage probability of macro layer for 384 kbps data service and 50% uplink loading.

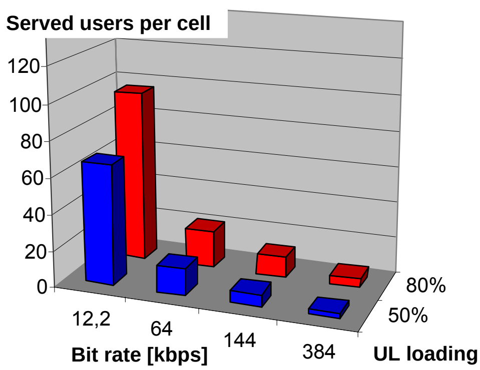

Fig. 6. The number of served users per cell.

From Fig. 5 the problem of the signal penetration into the ground floor of buildings for high-speed data services is evident (black color means no service inside buildings). This problem could be solved with the assistance of micro-cells. Fig. 6 interprets the average cell capacity as the number of served users per cell.

3.2 Microcellular Environment

Microcells were used in order to cover the ground floors of extensive buildings and to increase the system capacity in the city streets. The base stations used the OMNI antennas with a gain of 15 dBi situated at a height of 4 m. The simulations were executed for different uplink loading: 50 % and 80 %.

3.2.1 Simulations Based on Empirical Model

The Nodes B were situated as shown in Fig. 2 – in a homogenous hexangular deployment in order to reach full coverage of the whole target area for 144 kbps data service and 50% uplink loading. Fig. 7 illustrates the uplink coverage probability as a function of uplink loading and service based on the path loss calculated by the empirical model. The problem of breathing of the cell is evident. It is necessary to remark that these simulations reflected rather idealized conditions!

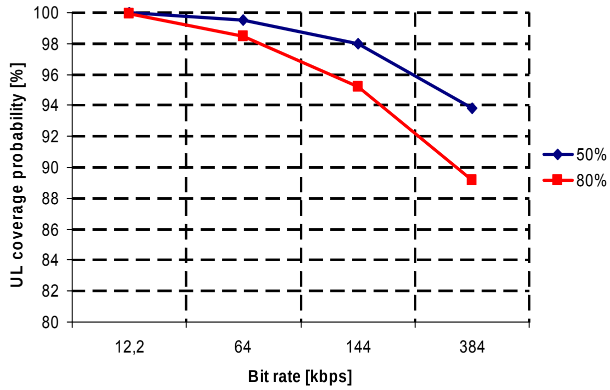

Fig. 7. The uplink coverage probability.

Fig. 8 illustrates the average number of served users per cell as a function of bit rate and uplink loading. The increase of the system capacity at cost of the decrease the coverage area is visible.

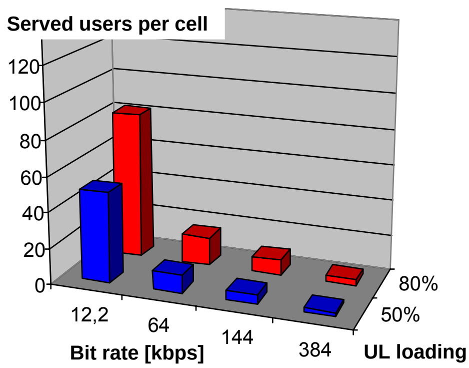

Fig. 8. The number of served users per cell.

The average ratio of the other-to-own cell interference *i* was equal to about 55% (it did not take into account the effect of cell isolations due to buildings). The number of Nodes B was raised to 43 including a reserve for the building penetration of 15 dB.

3.2.2 Simulations Based on Berg's Recursive Model

The following scenarios were analyzed based on the path loss calculated by Berg's Recursive Model. For full coverage of the whole target area for 144 kbps data service and 50% uplink loading 59 Nodes B were deployed (coverage of the ground floors of extensive buildings was required, for the coverage of streets around 30 Nodes B would be sufficient). The best server areas for 144 kbps data service and 50% uplink loading are shown in Fig. 9. Full coverage of the target area is obvious from this illustration.

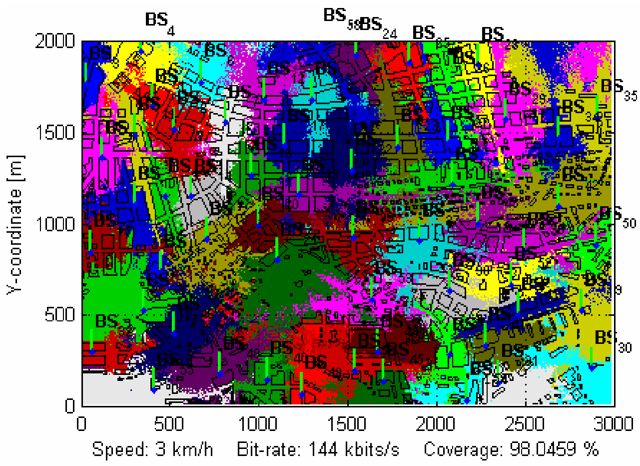

Fig. 9. The best server areas for 144 kbps data service and 50% uplink loading.

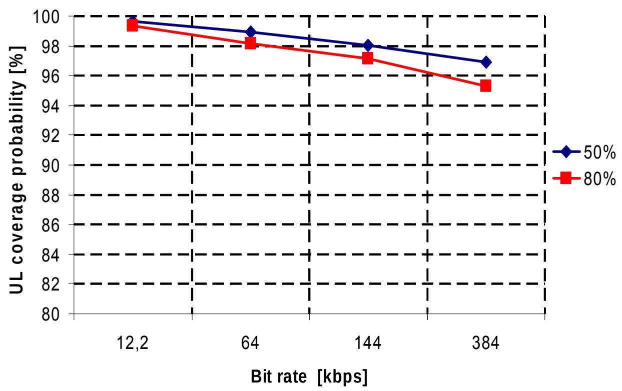

Fig. 10. Uplink coverage probability.

The average number of served users per cell as a function of uplink loading for a simulative scenario for full coverage of the target area is shown in Fig. 11. The services were simulated independently.

Fig. 12 illustrates the average number of served users per cell for the simulative scenario with mixed services. Mixed services were utilized in order to approach a real-life situation when 90% of all users were using speech service, and 10% any data service.

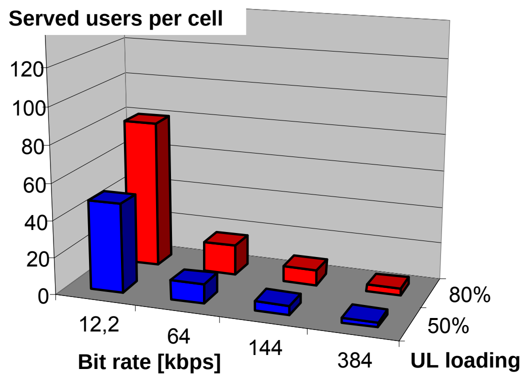

Fig. 11. The number of served users per cell.

The average ratio of the other-to-own cell interference i was equal to about 22 % for the simulation scenario with mixed services. This corresponds to the recommendation [6].

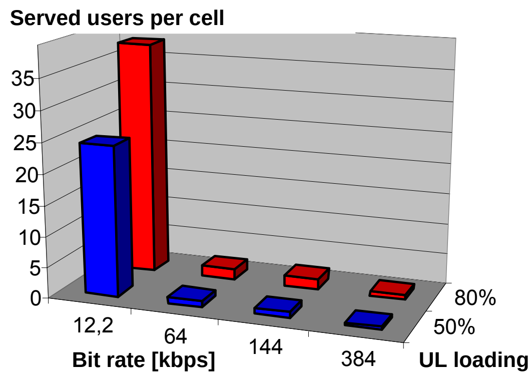

Fig. 12. The number of served users per cell.

The asymmetry of the bit rate in uplink and downlink (a combination of the data services 64, 144 and 384 kbps) was simulated as well. The results of these simulations in a form of the average number of served users per cell are shown in Fig. 12 for uplink loading of 50 % and for uplink loading of 80 % in Fig. 13, respectively.

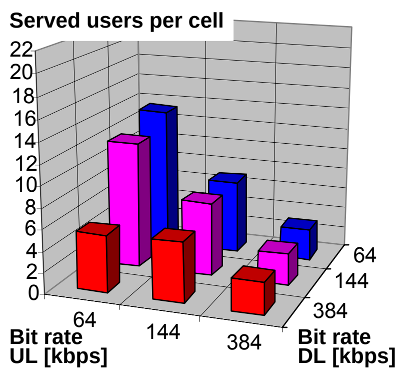

Fig. 13. The number of served users per cell for the asymmetry of bit rate and uplink loading 50 %.

From Fig. 13 it is obvious that the capacity of the network is limited by the uplink in case of 50% uplink loading. From Fig. 14 it is obvious that in case of 80% uplink loading the network capacity is limited more by the downlink.

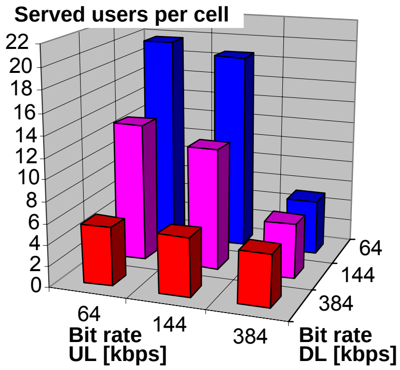

Fig. 14. The number of served users per cell for the asymmetry of bit rate and uplink loading 80%.

3.3 Combination of Macro and Micro-Cellular Environment

The allocations of Nodes B for macrocellular layer from the presented scenarios were utilized. The microcellular base stations (27 Nodes B) utilized the OMNI antennas with a gain of 12 dBi. Their deployment is shown in Fig. 15, which illustrates the uplink path losses for the speech service and uplink loading 80 %.

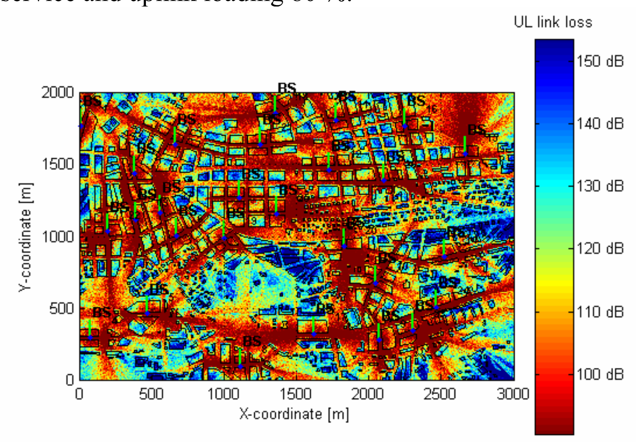

Fig. 15. Uplink path losses of micro layer.

For UL loading of the macro layer 50% was allowed, for the micro layer 80%. Micro layer and macro layer utilized different carrier frequencies f_1 and f_2. Average ratio other-to-own cell interference was equal to 13% for microcellular layer and 48% for macrocellular layer. Tab. 1 summarizes results of simulations.

4. Conclusions

In this paper, the iteration-based simulation approach for the study of different impacts on the system capacity and the quality of coverage in urban UMTS macro and microcellular environment of UMTS was presented. The simulations based on the path loss calculated via the empirical model for macrocellular environment and Berg's Recursive Model for microcells were executed for a real map of the centre of the city of Prague.

		Data rate [kbps]			
		12.2	64	144	384
Macrocells - 50% UL loading	Served users per cell	44.03	13.39	6.73	2.82
	Served users per cell - mix	34.18	1.48	1.12	0.39
	UL coverage probability [%]	95.82	87.91	84.06	79.01
Micro-cells - 80% UL loading	Served users per cell	119.56	26.26	13.37	5.78
	Served users per cell - mix	63.07	2.78	2.37	1.26
	UL coverage probability [%]	88.77	79.73	75.54	70.08
Total	UL coverage probability [%]	98.97	95.81	93.58	90.13

Tab. 1. Simulation results for combination of macro and micro layer.

From the simulations it is clear that in microcells, unlike in macrocells, a propagation model that takes into account the site specific information on the built-up area must be used. An empirical model cannot accurately capture the problem in a microcellular environment. In microcells a higher uplink loading is possible without the critical impact on the coverage area. A suitable choice of antenna positions of Nodes B can increase the system capacity. The suppression of breathing of the cells in the microcellular environment can be distinguished from the results of the simulations. While the signal fluctuations are of the order of tens of decibels due to diffractions, refractions or penetrations, cell breathing causes variations in the order of only units of decibels.

Our future work will be concerned with simulations of UMTS networks implemented with HSPDA, and with an alternative for providing 3G services via High Altitude Platforms Stations [7] and their coexistence with terrestrial UMTS networks.

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About Authors...

Jaroslav HOLIŠ received the M.Sc. degree from the Czech Technical University in Prague in 2005. Now he is working towards his Ph.D. at the Dept. of Electromagnetic Field. His main interest is in radiowave propagation modeling and simulation.

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Prof. Ing. Dušan Černohorský, CSc. - In Memoriam 1939 – 2005

On the 2nd November 2005, an outstanding Czech scientist and university teacher Professor Dr. Dušan Černohorský, professor emeritus of the Brno University of Technology, passed away at the age of 75.

From 1954 his activities have been associated with the Military Academy in Brno, in the years 1964 – 1965 with the Military Engineering College in Cairo, Egypt, and from 1969 with the Department of Radio Electronics, the Brno University of Technology. He was the teacher and the tutor of many hundreds of masters' and doctoral students. His educational and scientific activities were mainly focused on the field of antennas, propagation, the theory of electromagnetic fields and waves, and radio/optics. In these areas, he successfully educated young researchers, specialists, and followers.

Prof. Černohorský was well known in the Czech and Slovak academic and scientific community over many years. He has been engaged in state examination commissions at civil and military technical universities in Brno, and Prague. He served for several years as the head of the field office of the Department of Radio Electronics, the Brno University of Technology. He was a full member of the scientific council of the Faculty of Air Forces and Air Defence at the Military Academy in Brno, and he served for several years as a member of the Academic Senate of the Faculty of Electrical Engineering and Communication, the Brno University of Technology. In eighties, he was the chair of the commission B "Fields and Waves" of the URSI national committee.

Personally I was a student of Prof. Černohorský, and I had the opportunity and honor to cooperate with him at the Department of Radio Electronics, the Brno University of Technology for many years. We will remember him for a long time to come.

Professor Jiří Svačina
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