Computer Simulation of the GSM Signal Availability for Data Transmission on the Territory of the Forest Enterprise

Tibor Žatko, Milan Koreň, Ján Tuček

Abstract – Nacrtak

The work deals with the creation of digital maps of the intensity of GSM/EDGE signal on the territory of the Forest Enterprise at the Technical University in Zvolen, Slovakia. Simulation of electromagnetic radiation intensity was calculated using the prediction program TEMS Parcell, based on technical data of transmitters and receivers, as well as attenuation due to the environment. Calculated values were verified in field measurements by means of testing apparatus placed in the measuring vehicle. The output vector layer contains areas categorized according to the suitability of signal intensity for field use with data or voice services.

Keywords: mobile GIS, data communications, GPRS, forestry

1. Introduction – *Uvod*

With the development of various technologies and information systems, increasing need arises to work in the field with mobile devices for collecting data, interacting with digital maps, or for remote access to applications and databases. For interactive work with data sources, it is necessary to have a wireless connection with sufficient transmission capacity. A wide range of services in this area offers a choice between different systems as radio relay network, cell site, Wi-Fi, Bluetooth, etc. A technology of terrestrial mobile radio communications network seems to be the best solution for wireless data transmission in the field. Its signal covers more than 90% of the Slovak Republic. A great advantage of these systems is their high mobility and virtually universal reach, which is limited only by the availability of a signal. Cellular networks of national operators correspond to the Global System for Mobile Communications (GSM) standard, which was developed by the European Telecommunications Standards Institute (ETSI).

Coverage area and the services offered depend on the priorities set by the provider of telecommunication services. Most of operators prioritize areas with high population density, which follows logically from their commercial interests. Wireless technologies, supported by cellular radio communication networks, are used outside the populated areas, in mountain areas with very difficult access, in areas with a complex geomorphologic structure as well as in remote forest areas. In order to define the areas qualifying for use of data or voice services, it is useful to have the digital map that enables to determine precisely the GSM/EDGE signal intensity in the area of interest.

Any base transceiver station covers a limited area (cell), up to 37 km. High transmission capacity of the network is achieved by using multiple transmission frequencies. Mobile networks are constructed to have sufficient capacity for the needs of the areas they cover. Urban areas must comply with higher standards of quality and capacity than rural ones. Network capacity can be increased in two ways: using a larger number of channels per one cell, or by reducing the cell size. Cellular radio networks were designed to provide continuous communication services when moving the receiving station. When passing between the cells, mobile networks ensure the change automatically. The mobile station measures the level of signal of neighbouring base stations. Based on these measurements it decides which cell to switch it to.

According to the way of spreading, radio waves can be divided into direct, reflected, scattered, bent or with refraction. In the spreading of radio waves in the given frequency band, the following elements must also be taken into account: reflection of waves from the Earth's surface, terrain obstacles, diffraction (i.e. bending waves) and refraction in the upper layer of the atmosphere. Tracks of radio waves are curved only on such obstacles whose dimensions are smaller than the wavelength of the electromagnetic field. Bitirgan et al. (2011) worked out a model of radio signal spreading in the forest.

Performance of communication systems are affected by certain limiting factors that have a negative impact on signal transmission. Radio signals can be limited, for example, by attenuation, distance, noise, channel capacity and interference. On the territory with rugged morphology or in built-up area, the signal is affected by static objects (hills, vegetation, buildings) and movable obstacles (vehicles, trees branches movement). Leakage of the radio signal is divided into long-term (attenuation of the signal due to spreading, shading) and short-term (extending multi-way and Doppler effect).

Leakages caused by spreading may be characterized as signal attenuation between the transmitter and receiver. In open area, the intensity of electromagnetic waves decreases with the square of the distance. If the signal between the transmitter and receiver spreads directly, the received signal level decreases relatively slowly. A common problem for mobile services is that mobile station is shadowed during the travel by various objects like buildings, trees or moving truck. This results in a rapid reduction of the level of the received signal. Decrease in signal level, relative to the basic course, may be up to several tens of decibels. Sarabande and Koh (2002) noted that the method of ray tracing is modelling quite precisely the intensity of radio signal even to larger distances from the transmitter. Based on the results, the radio signal attenuation depends on the surface of forest stand, and it increases with wavelength.

Short-term leakages cause sudden and sharp signal fluctuations. It occurs frequently in situations when the mobile station has no direct visibility of the base transceiver station.

The received signal is formed by reflections from the objects, but none of the ways of signal spreading is dominant. Each reflected wave is directed to the receiver on differently long roads. The result is that the received signals come to the receiver at different moments of time, with different amplitude and different phase. This is the multi-way signal spreading that causes multi-way leakages of signal. Cavalcanti et al. (2002) and Tamir (1997) studied multi-way spreading of radio signals under specific conditions of forest environment.

Mobile services are characterized by a great dynamics in the network. Flexibility of movement with the receiver is very high. Mobile station can be used when walking as well as in vehicles moving relatively quickly. In this case, it is necessary to take into account the signal leakage caused by the Doppler shift of wavelengths. Meng et al. (2009) examined in detail leakages of radio signal in forest environment. They described the physical process of spreading and analytical techniques of modelling radio signal attenuation in the forest. They performed experiments with the change of factors that affect the signal intensity.

GSM networks were built mainly for the provision of voice services. They are able to provide 9 kilobits/sec data flow. Therefore, new GPRS (General Packet Radio Service) standards for data transmission over GSM network were developed. Operators had to make a technical innovation and modifications on their own networks to ensure an interconnection of mobile cellular network and public switched telephone network. GPRS is built on packet switching, so it is possible to reach transmission rate of 14.4 kilobits/sec. Since GPRS network enables integration of several communication channels for one user, the resulting rate grows by the number of used channels. Usually 4-6 channels merge, according to operator's settings and technical level of the mobile station. It is theoretically possible to achieve transmission rate of up to 86.4 kilobits/sec. However, it must be taken into account that IP-based applications consume a portion of resources for own purposes, and that final transmission rate depends on the quality and intensity of the radio signal. The actual rate of channel switch is, therefore, highly variable according to interference and signal leakage. The signal decreases to minimum in areas with low level of signal or high interference.

Another improvement of transmission rate was brought by the EDGE technology. EDGE was deployed in GSM network as an extension of the GPRS network. This standard is usually called the network of 2.75 generation. At present EDGE is implemented in all networks of Slovak operators, and it is successfully used for data transmission, especially in rural areas, where the networks of the third generation do not reach. The structure is similar to GPRS, but EDGE increases the network bandwidth several times. Transmission rate achieved depends on several factors: the number of allocated time-slots, code scheme of network, user location, network capacity and signal quality. When using the coding scheme MCS-9, the transmission rate can theoretically reach 354 kilobits/sec. Other factors that must be taken into account are the network capacity and number of users communicating at the same time. If simultaneously more users use data services, the resources are shared between them. The actually achieved high quality speed is about 260 kilobits/sec with a delay of about 200 ms.

The aim of this work was to create a digital map of the intensity of GSM/EDGE signal on the territory of forests belonging to the Forest Enterprise at the Technical University in Zvolen. Wireless computer network connection is needed for downloading real time corrections during precise measurements of position by global navigation satellite systems (GNSS), data transmission from monitoring stations, on-line access to databases and other research and practical activities in forest territory. The resulting maps will make possible to identify areas where services of mobile radio networks can be used, and on the other hand, to exclude parts where it is not appropriate to plan activities and measurements based on the GSM network support. Accuracy of prediction model of GSM signal quality was verified by field measurements of signal intensity and transmission rate.

2. Materials and methods – *Materijal i metode*

We developed GSM signal intensity model, located in the orographic area Kremnické hills. The area is located in the central part of Slovakia and it is mainly formed of lava bodies originating from volcanic activities with prevalence of andesitic rocks. From the geomorphologic point of view, this area is strongly influenced by endogenous and exogenous factors as evidenced by the considerable variability of relief. Forests cover the majority of the study area. In the forests, broadleaved tree species (72.9%) prevail, of which beech accounts for 36.7%, oak for 19.3% and hornbeam for 9.7%. Coniferous trees cover 27.1%, of which spruce accounts for 11.3%, pine for 7.4% and fir for 6.7%. Digital maps of forest stands and inventory data were provided by the Institute of Forest Resources and Informatics, National Forest Centre in Zvolen.

Data from the company Orange Slovakia were the basic source for the elaboration of simulation. In creating a prediction of the level of GSM signal on the territory of the Forest Enterprise, simulation was based on the exact data of base stations located near the study area. For this purpose, the Orange Slovakia gave us consent for using the necessary data from the corporate database, which became the basis for the prediction model. There are six transmitters of the Orange Slovakia near the study area. Four are located on pylons in the cadastral areas of the near municipalities. Two transmitters are located on high buildings. For the purposes of simulation, we input exact information about technological devices as they are actually set on the transmitter. In addition to the exact location and altitude, it is necessary to specify the number of sectors (cells), height of the antenna above the ground, the type of antenna, its emission characteristics, orientation and tilting, transmitting capacity of device and frequency spectrum.

To verify the simulation results, we used the measured values of signal intensity using the measuring device in selected parts of the study area. For measurements, we used a vehicle to which a device was installed for scanning, monitoring and storing the measured values of GSM signal (Fig. 1). Two GNSS receivers were also a part of scanning for determining the current position. A GNSS receiver was directly connected to the scanning apparatus, so a geographical location was assigned automatically to each measured value of the GSM signal. The second GNSS receiver was connected to the computer with mobile geographical information system (GIS) and digital map of the territory of the Forest Enterprise for navigation and monitoring the planned route of measurement. According to the location of base stations, it could be expected that the northern and north-western part of the territory conditions would not be favourable for communication and use of mobile stations. We planned the route with respect to geographical coverage, time-consuming measurements, battery capacity in measuring device, the amount of measured data, and the expected attenuation of radio signals caused by the distance from the transmitter, shading by relief, and land cover.

We performed simulation of the coverage of the territory by GSM signal in the environment of TEMS Parcell programme. TEMS Parcell is a computer application designed to support planning of cellular radio networks. It enables to display a prediction layer of signal intensity and to combine it with other thematic layers with the aim to achieve the best representation of the result. Simulation accuracy depends mainly on the quality and completeness of input data and perfect tuning of prediction model. In the calculation, the model considered many environmental factors that contribute to the reduction of electromagnetic waves spreading. The calculation was based on the principles of electromagnetic waves spreading, terrain, obstacles and land use. A layer of land use defined categories for groups of objects on the surface such as vegetation, water areas, road network, urban areas differentiated according to built-up areas, etc. that participate in the attenuation of the signal spread, and must therefore be included to the calculation. The value of radio signal attenuation was assigned to each category of the land use layer. For forest stands, the value of the attenuation is around 20 dB, but the exact

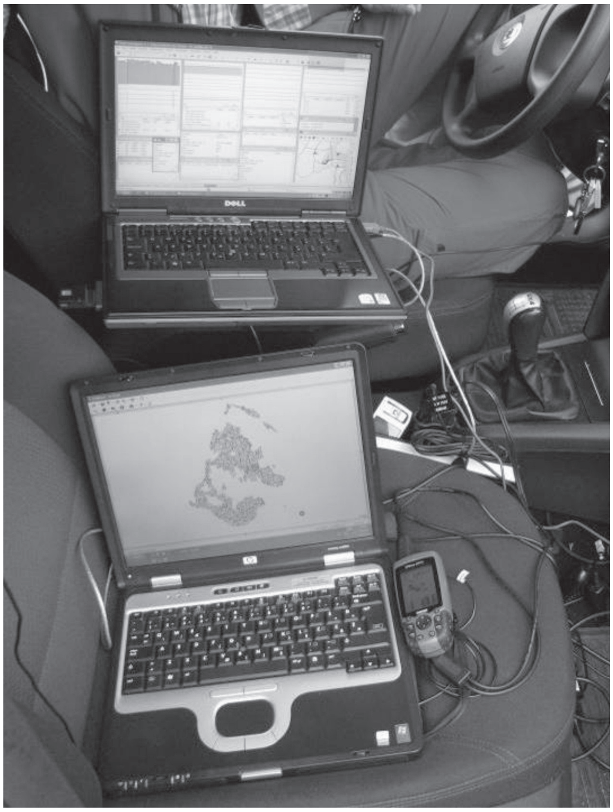

Fig. 1 Measuring set and GIS in mobile measuring vehicle
Slika 1. *Uređaji za mjerenje i GIS u mobilnom vozilu za mjerenje*

value is determined in real measurements and finalization of the model, according to regional area and vegetation zones. Forest stands in land use categories can be divided to more detailed groups: broadleaved stands, coniferous stands and mixed stands. Thereafter, values of radio signal attenuation can be defined separately for each type of forest stand. It contributes to obtaining more exact results of the prediction of radio signal intensity.

Many radio signal spreading models are used to predict signal attenuation during channel transmission. They differ from each other in the method of determining leakages and input parameters. All models take into account the distance between the transmitter and receiver, as a basic critical parameter. We can give as an example Lee's model used in ground communication, which takes into account obstacles between the base station and mobile stations, or Okumura-Hata model for densely built-up areas. Objects like buildings, trees, hills, cause further signal attenuation. Radio waves in these cases do not spread to the receiver only in straight line, but migrate by other ways (Doboš et al. 2002).

We used a set of tools included in TEMS (Test Mobile System) from Ericsson for measurements of radio signal quality and data processing. The package contains advanced applications for monitoring, evaluating and planning the radio access networks.

Scanning and monitoring of the radio network is a demanding process, in which a large amount of data is monitored at the same time. For this purpose, we used the testing mobile station TEMS Pocket. It is able to provide information on the quality and level of signal, errors in data transmission, the actual software setting of network as well as to monitor radio communication channel and to obtain information about surrounding cells, base stations, determine their distance and so on.

The application TEMS Investigation was used to collect and process data from field monitoring of the radio network. It is a tool for detecting and confirming the problems, optimisation, measuring and maintaining cellular radio networks. The set consisted of a scanning device, GNSS receiver, and laptop and software application. The testing mobile station TEMS Pocket and GNSS receiver were connected by cable to the computer and they provided application data on the exact position and monitored values. Scanned data were processed by the application TEMS Investigation. It enables to display the actual position of the measuring device on the map and graphical course of data on the communications between mobile and base station. At the same time, all obtained data were stored for further processing. From the results of measurement, we could determine unequivocally defects or problems of the network coverage, as well as intensity and quality of the radio signal.

The measurements were carried out in IDLE mode and DEDICATED mode simultaneously. The IDLE mode is the mode when there is no connection between the mobile station and base station. In this state, the mobile, if switched on and logged to the network, does not transmit. Practically, it only scans signals transmitted from the surrounding base stations, and based on the quality of the signal it makes reselection between the cells. DEDICATED mode is the state that occurs in the implementation of the connection. A phone call may serve as an example, when participants communicate in duplex mode. This means that it transmits and receives messages. For the measurement, we chose a call on testing number to maintain the station in DECICATED mode during the whole measurement. A software robot responds to testing number, which repeats in cycles a programmed message and does not end the connection spontaneously.

In contrast to the IDLE mode, in DEDICATED mode during the whole period of connection, the mobile station communicates with the base station and constantly responds to changing radio conditions. While driving, the changes occur very quickly and the signal intensity may change in jumps. For this case, both parties must respond flexibly and adapt the transmission power to the requirements of a situation. Performance adaptation plays an important role in observing necessary qualitative parameters of the connection. GSM specifications define several classes of mobile stations according to their maximum transmission power. In order to achieve the least possible inter-channel interference and maintain the performance, both the mobile station and base station try to communicate with the least possible energy consumption so as to maintain an acceptable signal quality. The signal level can move in increments of 2dB downwards or upwards. The mobile station and base station measure continuously the strength of the signal quality (bit errors) and adjust the power output. A function DTX (Discontinuous Transmission) is also used to reduce the transmission power. The mobile station does not transmit permanently (e.g. when the recipient of the call is silent), but only at certain time intervals necessary to maintain the connection. These reductions of power output have a positive effect on the battery life in mobile stations.

Due to these differences, both kinds of measurement were carried out. During the measurements, we monitored the scanned parameters of the signal and paid attention to areas, where the signal quality dropped below the level, when the mobile station was not able to communicate with the base station, and the connection in DEDICATED mode was interrupted. In such situations, we had to wait to get back to the field with the signal, and to be able to arrange a new connection. On the maps of scanned data in TEMS Investigation, these parts in DEDICATED mode can be distinguished as sections with the absence of measurement points. It is particularly evident in areas with poor quality.

Six control measurements of transmission data rate were made based on the projected positions close to permanent research areas. Testing of transmission data rate took place in stationary position, when the measuring vehicle was on a designated point. After establishing the data connection, a file with well-defined size was downloaded from the test server. Based on the time consumed for downloading the test file to the computer, the average bit rate for data receiving (download) was calculated.

An actual position of the vehicle was monitored by means of GNSS receiver Garmin 60CSx with external antenna fixed on the vehicle roof. The positional accuracy of several meters was sufficient for our needs. The device was connected to the laptop with installed program ArcPad from ESRI, Inc. ArcPad supports vector and raster layers, creating points, lines and area elements, and also setting their attributes. This makes possible to carry out effectively the collection, updating and editing of geographical data in the field. The attribute data can be assigned to geometric features. In practice, we checked the movement of the monitoring vehicle on the background map and recorded the set of points of the vehicle route.

During the final stage, we analyzed the created radio signal model and data collected from field measurements. For this purpose we used ArcGIS of the ESRI, Inc. The model of radio signal intensity as well as data collected by field measurements were imported to formats supported by ArcGIS system. Raster of the radio signal intensity was classified, and the boundaries of the categories were converted to vector data. The results of field measurements were divided into 25 log files, which were converted to the shape-file format. Finally, an overlay of thematic layers was made and output map compositions were created.

3. Results – *Rezultati*

A model of radio signal intensity in a raster representation with a 100 m resolution was the output of TEMS Parcell simulation model (Fig. 2). Each cell was assigned the value of GSM signal intensity, calculated according to the algorithm of the prediction model. The value was in units of dBm (decibel related to 1 miliwatt). Signal levels were divided into the categories used in radio telecommunication practice:

⇒ Indoor (less than or equal to –65 dBm): signal is sufficiently strong to penetrate buildings without windows and ensure a smooth connection.

⇒ Indoor window (–66 dBm to –82 dBm): signal level is sufficient for communication in buildings with windows.

⇒ In Car (–83 dBm to –89 dBm): communication in vehicles is ensured.

⇒ Outdoor: (–90 dBm to –92 dBm): signal level allows the participant to communicate outdoor.

⇒ Car kit (–93 dBm to –99 dBm): an external antenna for improved receiving needed.

⇒ No signal (greater than or equal to -100 dBm): communication is impossible.

English names of groups are symbolic. They indicate the scope and possibilities of the use of radio signals at a given level of intensity. Dividing into categories is only approximate, because each area or building has a different structure that causes differences in signal attenuation.

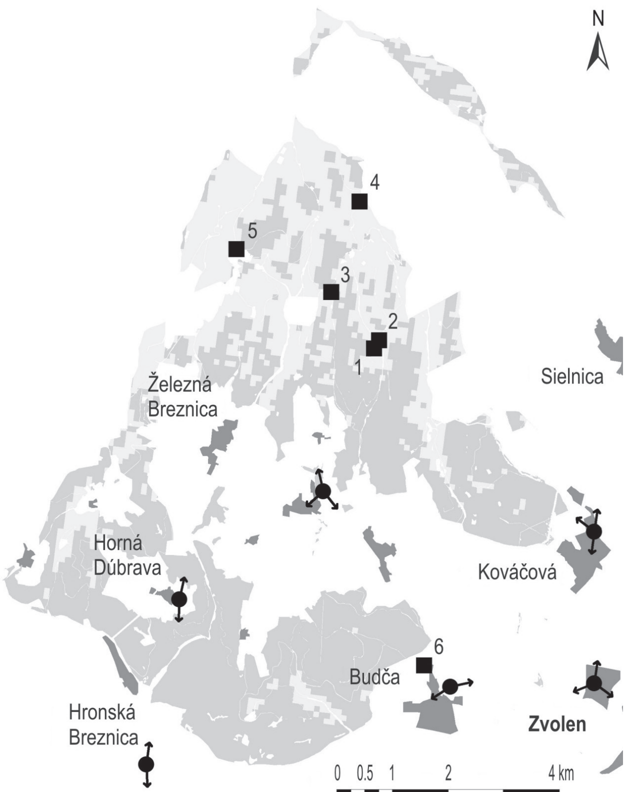

Fig. 2 Map of GSM/EDGE signal availability for data communication (squares – measurement positions; circles – location of transmitters; light gray – forests with a low level of the GSM signal; dark gray – forests with a sufficient level of the GSM signal)

Slika 2. *Karta dostupnosti signala GSM/EDGE za podatkovni prijenos (kvadrati – lokacije izmjere; krugovi – lokacije odašiljača, svjetlosivo – šume s niskom pokrivenošću GSM-ovim signalom; tamnosivo – šume sa zadovoljavajućom pokrivenošću GSM-ovim signalom)*

Thematic layers (borders of forest stands, road network, rivers and reservoirs, settlements, orthophoto) were added to the output maps. It increased their informative value, transparency and simplified the search. In the map, areas can be identified with available voice and data services of the company Orange Slovakia. The resulting layer of the radio signal intensity was overlapped with the boundaries of forest stands. The percentage of the level of radio signal was calculated for each unit of spatial forest arrangement and stored in the attribute table.

The rate of transmitted data is closely connected with the intensity and quality of the radio signal. Table 1 shows the transmission rate and intensity of the radio signal in the IDLE and DECICATED mode found on site. The best signal was found close to the urban areas, where good quality signal comes from nearby transmitters. An increased transmission rate was also achieved there. The results of measurements in the northern part of the Forest Enterprise demonstrate impaired level of the radio signal. The northernmost point of measurement was interesting. According to the map of coverage by radio signal, there should not be any signal. After careful examination of the data from the measured area, we found that this connection was achieved through a base station located at the distance of 20 km. This is also proved by low transmission rate caused by bad signal quality, although the intensity of signal reaches relatively good values. Stand opening and low age classes of tree species caused this discrepancy. This enabled signal penetration to the stand and improvement of its own intensity in a short section. It is also probable that for such small area, we were unable to predict the simulation of signal intensity correctly, as it was calculated with the resolution of 100 m.

Table 1 Transmission rates and intensity of radio signal at static measurements

Tablica 1. *Brzina prijenosa i intenziteta radijskoga signala statičkim mjerenjem*

Number of measurement *Mjerno mjesto*	Name of measurement *Ime mjernoga mjesta*	Transmission rate, KB/s *Brzina prijenosa,* KB/s	Signal intensity in IDLE mode, dBm *Intenzitet signala u IDLE modu,* dBm	Signal intensity in DEDICATED mode, dBm *Intenzitet signala u DEDICATED modu,* dBm
1	Včelien 1	3.47	–100	–99
2	Včelien 2	3.68	–88	–94
3	Sviniarka	5.35	–76	–92
4	Žliabky	5.30	–85	–86
5	Jablonka	5.38	–94	–83
6	Budča	14.75	–72	–74

The resulting map of the coverage by GSM/EDGE signal provides an overview of the areas, where data transmission via the mobile communication network can be used. For example, in demarcation of forest ownership boundaries by GNSS devices and access to RTK, correction is inevitable. Current services provide users with three formats for correcting the accuracy of positional data on the Earth's surface (RTCM 2.3, RTCM 3.0, RTCM CMR +). In the worst case, when the use of RTCM 2.3 is required, the transmission rate of about 600b will be needed. Measurement results confirm that even at relatively low quality or intensity of signal, mobile devices have no problem to transmit this amount of data. Coverage by the mobile communication services is a decisive factor. To transmit the required volume of data in GPRS / EDGE network, a code scheme (MCS-1) is sufficient, where minimal transmission rate reaches 8.8 kilobits/sec.

The output of TEMS Parcell is a grid of radio signal level with the resolution of 100 meters. We calculated the arithmetic mean and standard deviation of signal intensity measurements for corresponding grid cells. The arithmetic means were converted into six categories used in radio telecommunications practice. During measurement in IDLE mode of the total number of 5.719 measured points, 2.903 were included to the cells of predicted radio signal level values (Table 2). In DEDICATED mode, 6.882 points of the total number of 11.743 measured points coincided with the grid cells of simulated signal level values (Table 3). The overall accuracy of prediction of radio intensity levels in IDLE mode was 53% and the overall accuracy of prediction of radio intensity levels in DEDICATED mode was 36%.

Discrepancies in the simulation in DEDICATED mode were somewhat greater than in IDLE mode. They were caused by prediction model adjustment mainly to IDLE mode. Another reason was that during the communication in DEDICATED mode between mobile and base station, an active control of power output was made, which modified the intensity of the transmitted signal on both sides and adapted the signal to surrounding conditions.

We found that in marginal areas, where the signal intensity of selected transmitters dropped to the minimum (especially in the northern part of the Forest Enterprise), testing mobile stations received signals from base stations being distant also several kilometers from the Forest Enterprise, which were not considered in the prediction. This signal spread from high-placed transmitters. However, the signal quality was very low and unstable. Based on the measurement results and data provided by the Company Orange Slovakia, the results of the simulation were corrected in marginal zones and

Table 2 Predicted and measured signal intensity levels in IDLE mode (Count – number of measurements; Avg – arithmetic mean; Std – standard deviation)

Tablica 2. *Predviđena i izmjerena razina intenziteta signala u IDLE modu (zbroj – broj mjerenja; X – aritmetička sredina; SD – standardna devijacija)*

Cell number *Broj stanice*	Predicted level *Predviđena razina*	Measured signal intensity *Intenzitet izmjerenoga signala*					
		Count *Zbroj*	Min *Min*	Max *Maks*	Avg *X*	Std *SD*	Level *Razina*
3	1	395	–88	–52	–66.7	6.1	2
4	1	152	–109	–57	–71.5	8.6	2
5	1	73	–72	–55	–64.6	5.0	1
9	1	252	–80	–48	–61.3	9.6	1
12	1	92	–92	–45	–61.5	14.7	1
18	2	33	–83	–77	–79.1	2.0	2
19	2	55	–100	–55	–76.0	14.1	2
20	2	210	–92	–56	–72.1	6.9	2
21	2	29	–93	–83	–87.2	3.5	3
22	2	82	–99	–70	–80.8	8.1	2
23	2	9	–88	–77	–79.2	3.5	2
24	2	51	–97	–75	–82.8	7.6	2
25	2	97	–95	–52	–63.2	13.1	1
29	2	10	–95	–89	–92.0	2.2	4
32	3	18	–100	–91	–94.4	3.0	5
35	3	20	–89	–83	–85.2	2.4	3
36	3	145	–102	–79	–91.8	4.7	4
37	3	20	–98	–57	–89.4	9.1	3
40	3	54	–101	–84	–90.4	5.0	4
44	3	265	–92	–73	–82.0	3.8	2
47	4	18	–96	–90	–93.7	2.2	5
49	4	2	–99	–98	–98.5	0.7	5
52	4	17	–101	–91	–97.0	3.7	5
56	4	25	–98	–78	–90.9	4.5	4
58	4	609	–106	–71	–84.9	8.8	3
64	5	3	–87	–87	–87.0	0.0	3
66	5	10	–108	–89	–97.6	4.8	5
69	5	16	–101	–89	–97.6	3.7	5
71	5	133	–105	–73	–84.5	7.7	3
74	5	8	–99	–99	–99.0	0.0	5
0	6	2816	–110	–72	–93.9	7.5	5

Table 3 Predicted and measured signal intensity levels in DEDICATED mode (Count – number of measurements; Avg – arithmetic mean; Std – standard deviation)

Tablica 3. *Predviđena i izmjerena razina intenziteta signala u DEDICATED modu (zbroj – broj mjerenja; X – aritmetička sredina; SD – standardna devijacija)*

Cell number *Broj stanice*	Predicted level *Predviđena razina*	Measured signal intensity *Intenzitet izmjerenoga signala*					
		Count *Zbroj*	Min *Min*	Max *Maks*	Avg *X*	Std *SD*	Level *Razina*
3	1	613	–88	–59	–72.2	6.4	2
4	1	306	–95	–58	–74.5	5.7	2
5	1	234	–89	–59	–74.1	5.7	2
9	1	701	–91	–57	–74.7	4.8	2
12	1	284	–95	–60	–76.9	7.7	2
18	2	113	–92	–70	–81.5	5.0	2
19	2	115	–96	–56	–77.3	10.2	2
20	2	370	–98	–53	–76.4	9.0	2
21	2	66	–100	–82	–91.2	4.0	4
22	2	163	–93	–68	–82.0	6.1	2
23	2	12	–93	–77	–86.2	5.2	3
24	2	140	–102	–77	–87.6	5.0	3
25	2	329	–100	–64	–76.3	6.7	2
29	2	13	–102	–99	–100.9	1.4	6
32	3	53	–96	–90	–94.4	0.9	5
35	3	76	–100	–81	–91.5	4.3	4
36	3	296	–101	–79	–92.5	4.1	4
37	3	53	–106	–73	–95.5	9.6	5
40	3	54	–93	–86	–89.9	2.2	3
42	3	9	–101	–97	–100.3	1.4	6
44	3	866	–106	–75	–89.4	5.7	3
47	4	44	–104	–89	–97.7	4.4	5
52	4	31	–102	–95	–96.9	1.5	5
56	4	85	–106	–71	–91.1	9.6	4
58	4	1390	–106	–75	–92.8	6.0	4
64	5	7	–92	–86	–88.7	2.6	3
65	5	2	–91	–90	–90.5	0.7	4
66	5	14	–106	–106	–106.0	0.0	6
69	5	33	–102	–91	–97.2	3.8	5
71	5	410	–106	–77	–93.9	6.1	5
0	6	4861	–110	–74	–96.9	6.4	5

a new map layer illustrating the coverage by GSM signal was created for the given territory.

With the help of visual interpretation of differences displayed in the map, we found that most differences occurred in three types of regions:

⇒ In urban areas, where the signal changes depend on the density and height of buildings.

⇒ In areas with big variability of stand heights, caused by regeneration, and mainly in forest stands of lower age classes that do not reach the height of mature stands as well as on forest roads going from the south to north. This phenomenon can be attributed to the fact that the simulations calculated for the sectors of base stations, which broadcast signals, were directed to the north and also included attenuation of forest region as a whole, not taking into account gaps in the forest stands formed by roads.

⇒ Radio signal intensity could be affected by humidity, as it was raining during the measurement. Similarly, seasonality might have had some effect, because the measurements were carried out in non-vegetation period. A study assessing the impact of environment humidity on the intensity of GSM signal confirms the conclusions (Helhel et al. 2008).

The data obtained confirmed the reliability of the prediction model. The quality of the model was limited by the scope and accuracy of input data. Relatively high general character of the output layer of the signal intensity was caused by two main factors. First, it was incorrect raster layer of digital elevation model with the resolution of 100m and not properly elaborated layer of landscape cover with a small number of categories, when only one category defines the forest areas without more detailed specification of stands. With the aim of making the calculation more accurate in forested regions, the structure of forest stands should be described more consistently, mainly including tree species composition, as well as size and age structure of forests. Considering that broadleaved tree species prevail, the simulation should also consider defoliation and the actual humidity that contribute to the variability of results. Contemporary prediction models do not work with such detailed input parameters. We cannot incorporate the exact short-term leakages to the calculations, as they have stochastic character, and therefore cause quick fluctuation of the signal level in short sections.

4. Conclusions – *Zaključci*

Nowadays, the networks of the third generation (UMTS - Universal Mobile Telecommunications System) are preferred for data transmission via mobile radio networks. With using the protocol HSPA (High Speed Packet Access), transmission rate in these networks reaches several megabits. A main factor limiting their use in the field work is that the operators concentrate these networks in urban areas.

In comparison with GSM networks, they only cover a minimal part of forested areas. GSM network operates in lower frequency bands and spreads better in the environment. For the purposes of mobile communication in forestry practice and research, the GMS network is still unanimously the most available source. Due to the above reasons, the created layer of GSM/EDGE signal intensity is good material for using in forest practice and for obtaining information on the availability of data transmission services in the area of interest.

Prospective areas of mobile communication in forestry are, for example, an access to RTK corrections in high precision measurements of locations by GNSS equipment, data transmission from measuring stations to research plots, online access to databases and applications. Information on the availability and quality of the radio signal is an important factor for effective planning and introducing of wireless data transmission technologies to forest research and practice.

Acknowledgements – *Zahvala*

We would like to thank Orange Slovakia Company for providing documents and renting the devices and software used in the implementation of our work. Our thanks go also to the Institute of Forest Resources and Informatics, National Forest Centre Zvolen for data providing.

We carried out the work within the research project of the Scientific Grant Agency of the Ministry of Education and Slovak Academy of Sciences 1/0764/10 (VEGA) »Research principles and methods for precision forestry«.

5. References – *Literatura*

Bitirgan, M., Yoruk, Y. E., Celik, S., Kurnaz, O., Helhel, S., Ozen, S., 2011: Generation of An Empirical Propagation Model for Forest Environment at GSM900/GSM1800/CDMA2100. Proceedings of the XXX General Assembly and Scientific Symposium of the International Union of Radio Science, August 13–20, 2011, Istanbul, Turkey. Available at: Ursigass 2011.org/abstracts/ursi/F02-9.pdf.

Cavalcanti, G. P. S., Sanches, M. A. R., Oliveira, R. A. N., 1999: Mobile radio propagation along mixed paths in forest environment. Journal of Microwaves and Optoelectronics 1(4): 42–52.

Doboš, Ľ., Rainbow, J., Marchevský, S., Wieser, V., 2002: »Mobile radio network« published by EDIS Žilina, ISBN 80-7100-936-9, 312 p.

Helhel, S., Ozen, S., Goksu, H., 2008: Investigation GSM signal variation of dry and wet climatic effects. Progress in Electromagnetic Research B 1: 147–157.

Meng, Y. S., Lee, Y. H., Ng, B. C., 2009: Study of propagation loss prediction in forest environment. Progress in Electromagnetic Research B, 17: 117–133.

Sarabande, K., Koh, I. S., 2002: Effect of canopy-air interface roughness on HF-VHF wave propagation in forest. IEEE Trans. Antennas Propag. 50(2): 111–121.

Tamir, T., 1977: Radio wave propagation along mixed paths in forest environments. IEEE Trans. Antennas Propag. AP-25(4): 471–477.

Sažetak

Računalna simulacija dostupnosti GSM-ova signala za prijenos podataka na području šumarskoga poduzeća

Cilj rada i istraživanja provedenoga na Tehničkom sveučilištu u Zvolenu bio je stvoriti digitalnu kartu zastupljenosti GSM-ova odnosno EDGE-ova signala na području kojim gospodari šumarsko poduzeće. Točnost modela za predviđanje kakvoće GSM-ova signala potvrđena je i terenskim mjerenjima intenziteta signala te brzine prijenosa podataka. Simulacija se temeljila na egzaktnim podacima baznih stanica smještenih u blizini istraživanoga područja, a stanice su dobivene od nacionalnoga mobilnoga operatera »Orange Slovačka«. Baza podataka uključuje točnu lokaciju i nadmorsku visinu odašiljača, broj sektora (stanica), visinu antene iznad tla, vrstu antene, njezine emisijske karakteristike, orijentaciju i ekspoziciju, kapacitet odašiljanja uređaja i frekvencijski spektar.

Za provjeru rezultata simulacije upotrijebljene su stvarne izmjerene vrijednosti intenziteta signala pomoću mjernoga uređaja u odabranim dijelovima istraživanoga područja. Pri mjerenju je korišteno vozilo kojemu je ugrađen uređaj za skeniranje, praćenje i spremanje stvarne izmjerene vrijednosti GSM-ova signala (slika 1). Mjerenja su provedena u IDLE modu i DEDICATED modu istodobno. Korišten je skup alata uključenih u TEMS (testni mo-

bilni sustav) iz Ericssona za mjerenje kakvoće radijskoga signala i prijenosa podataka. Paket sadrži napredne aplikacije za praćenje, vrednovanje i planiranje pristupnosti radijskoj mreži.

U radu je napravljena simulacija pokrivenosti teritorija GSM-ova signala u okruženju programa TEMS Parcell. TEMS Parcell je računalna aplikacija dizajnirana kako bi podržavala planiranje mobilnih radijskih mreža. Program omogućuje da se kroz slojni prikaz predviđa intenzitet signala te da se kombinira s drugim tematskim slojevima, sve radi postizanja najboljih prikaza rezultata. Rezultat TEMS Parcell simulacijskoga modela (slika 2) jest model intenziteta radijskoga signala u obliku rasterske zastupljenosti s rezolucijom 100 m. Svakoj je stanici dodijeljena vrijednost intenziteta GSM-ova signala u jedinicama dBm (decibel u odnosu na jedan milivat), izračunat sukladno algoritmu za model predviđanja. Razine su signala podijeljene u kategorije koje se koriste u radiotelekomunikacijskoj praksi.

Tablica 1 u radu prikazuje brzinu prijenosa i intenzitet radijskoga signala u IDLE i DECICATED modu, izmjerenoga statičkim mjerenjem na lokalitetu. Tijekom mjerenja u IDLE modu od ukupnoga broja 5719 mjerenih točaka 2903 uključene su u stanice predviđanja razine vrijednosti radijskih signala (tablica 2). U DECICATED modu 6882 točke od ukupnoga broja izmjerenih točaka (11 743) poklopile su se s mrežnim stanicama simulirane razine vrijednosti signala (tablica 3). Za odgovarajuće mrežne stanice izračunate su aritmetičke sredine i standardne devijacije intenziteta signala mjerenja. Ukupna točnost predviđanja razine radijskoga intenziteta u IDLE modu iznosi 53 %, a ukupna je točnost predviđanja razine radijskoga intenziteta u DECICATED modu 36 %. Nepodudarnost simulacije u DECICATED modu nešto je veća nego u IDLE modu. One su uglavnom uzrokovane prognostičkim prilagodbama modela u IDLE modu. Drugi razlog obuhvaća tijek komunikacije u DECICATED modu između mobilne i bazne stanice, gdje je napravljena aktivna kontrola snage izlaznih podataka, čime je modificiran intenzitet emitiranoga signala na obje strane te prilagodba signala okolnim uvjetima.

Istraživanjem je utvrđeno da je najbolji signal u blizini urbanih područja u kojima signal visoke kakvoće dolazi iz obližnjih odašiljača, što se istodobno odražava na povećanu brzinu prijenosa. Rezultati mjerenja u sjevernom području kojim gospodari šumarsko poduzeće pokazali su oslabljenu razinu radijskoga signala. U rubnim područjima istraživanja mobilna je stanica primala signale iz baznih stanica udaljenih nekoliko kilometara od šumarskoga poduzeća.

Kakvoća dobivenoga modela intenziteta radijskoga signala ograničena je opsegom i točnošću ulaznih podataka. Dva su glavna ograničavajuća čimbenika: niska prostorna rezolucija digitalnoga modela reljefa i netočan opis sastojinske strukture šuma. S obzirom na prevladavajuću zastupljenost listopadnoga drveća simulacija treba uzeti u obzir osutost i stvarnu vlažnost jer one pridonose varijabilnosti rezultata. Suvremeni modeli predviđanja ne uzimaju u obzir takve detaljne ulazne parametre.

Nastale digitalne karte omogućit će utvrđivanje područja u kojima se usluge mobilnih radijskih mreža ne mogu koristiti. Informacije o dostupnosti i kakvoći radijskoga signala važan su čimbenik pri učinkovitom planiranju i uvođenju tehnologije bežičnoga prijenosa podataka u znanstvenim istraživanjima u šumarstvu, ali i u šumskoj praksi. Moguća su područja primjene mobilne komunikacije u šumarstvu, na primjer, pristup RTK korekturi visoke preciznosti izmjere lokacija pomoću GNSS-ove opreme, prijenos podataka iz mjernih postaja na istraživačke plohe, on-line pristup bazama podataka te raznim aplikacijama i sl.

Ključne riječi: mobilni GIS, podatkovna komunikacija, GPRS, šumarstvo

Authors' address – *Adresa autorâ*:

Tibor Žatko, BSc.
e-mail: tibor.zatko@orange.sk
Orange Slovakia Company
Jegorovova 22, 974 01 Banská Bystrica

Milan Koreň, PhD.*
e-mail: milan.koren@tuzvo.sk
Prof. Ján Tuček, PhD.
e-mail: jan.tucek@tuzvo.sk
Department of Forest Management and Geodesy
Forestry Faculty, Technical University in Zvolen
T. G. Masaryka 24, 960 53 Zvolen
SLOVAKIA

* Corresponding author – *Glavni autor*

Received (*Primljeno*): May 18, 2012
Accepted (*Prihvaćeno*): January 10, 2013