Radio Sensor for Monitoring of UMTS Mobile Terminals

Filip KOZAK, Premysl HUDEC

Dept. of Electromagnetic Field, Czech Technical University in Prague, Technicka 2, 166 27 Prague 6, Czech Republic

kozakfi1@fel.cvut.cz, hudecp@fel.cvut.cz

Abstract. *Relatively simple and low-cost radio sensor for monitoring of 3rd generation (3G) UMTS mobile terminals (i.e., phones) has been designed and practically tested. The main purpose of this sensor is to serve as an extending module that can be installed into systems used for monitoring of standard 2nd generation (2G) GSM and DCS mobile phones in highly guarded buildings and areas. Since the transmitted powers of UMTS mobile terminals can be very low in relation to GSM and DCS specifications, the new UMTS sensor is based on a highly sensitive receiver and additional signal processing. The radio sensor was practically tested in several scenarios representing worst-case mobile terminal – base station relations. The measured detection ranges attain values from approx. 11 m inside of rooms to more than 30 m in corridors, which seems to be sufficient for the expected application. Results of all performed tests correspond fairly well with the presented theoretical descriptions. An extended version of the radio sensor can be used for monitoring of mobile terminals of all existing voice or data formats.*

Keywords

Radio sensor, UMTS detection and monitoring, sensor network, security applications, 3G mobile phone.

1. Introduction

Given the boom in mobile phone services during the last two decades, problems linked to undesired or even illegal usage of mobile phones (mobile terminals, MTs) in certain areas and buildings have emerged. This phenomenon concerns, above all, prisons, where illegal employment of MTs can be misused with intention of continuation in illegal activities, witnesses tampering or escape preparation. Monitoring of illegally transmitting MTs, their detection, measurements of signal parameters ensuring the identification of active radio service, and their localization represent one of the possibilities to solve this problem. In practice, detection and measurement of signal parameters can be performed by a distributed sensor network; its example is described in [1]. The concerned guarded buildings can be covered by a set of radio sensors (RSs), while each of them monitors one room. A digital serial bus interconnects all sensors and enables their control and communication with the master computer. The above-described detection system enabled monitoring of 1G and 2G mobile terminals (NMT 465 MHz, GSM 900 MHz, DCS 1800 MHz, DECT 1900 MHz formats). Since their transmitted powers are considerably high, the monitoring of the above stated mobile services is relatively easy. Another security application of detection of the GSM system MTs can be found in [2]. The system is intended for prevention of even idle MTs to enter any airplane.

The detection of CDMA based radio signals, particularly UMTS signals in our case, seems to be a substantially bigger problem. Generally, main reasons for that are very low transmitted powers and wider channel bandwidths. The available publications concerned with security detection of the UMTS MTs are not numerous but show different attitudes towards solving the sensitivity problems. In reference [3], the authors make effort to improve the detection by using additional signal processing of recorded signal sections. The applied methods can lower the detection floor, but suffer from modulation format dependences, and are inapplicable in case of newer modulation schemes. Another proposed method of improving detection sensitivity can be found in [4]. This solution is based on the breaking off of the connection between the MT and the current cell by means of a jammer, and forcing the MT to make a new connection with a pseudo-cell generator. Authors report that during the process, the MT can easily be detected. The primary problem of employing this system is legal, since in many countries application of jammers is not allowed. Beside that, the detection time can be very long (up to 20 s), and system functionality is dependent upon the current UMTS version. For the given purposes (detection of MTs in prisons), this solution is likely to be also too expensive.

The present paper shows that the monitoring of CDMA based mobile services is feasible using a relatively simple and low-cost solution. Moreover, its reaction time is very fast (< 1 s), and the concept is, to a relatively high degree, resistant to UMTS format changes.

Section 2 brings theoretical analysis of the given problem, including detection range dependences. Section 3 shows the description of developed radio sensor, while Section 4 presents procedures and results of the detection tests performed inside rooms, in a corridor and in an open area. Conclusions presented in Section 5 evaluate the overall outcomes.

2. Theoretical Background

For correct and reliable detection and measurement of the UMTS format MTs it is necessary to take into account the following principal system parameters (UMTS release 99, 3GPP Releases 6 and 7, especially), which can be found together with the basic formulas (1) - (6) used for system calculations in, e.g., [5]-[11], see Tab. 1.

Operational frequency band-uplink	1920 – 1980 MHz
Channel bandwidth	5 MHz
Modulation	QPSK 16-QAM
Max. transmitted power	21 dBm
Min. transmitted power	-50 dBm
Chip frequency	3.84 Mcps

Tab. 1. Principal parameters of UMTS system.

For the transmission of UMTS MTs, the 1920–1980 MHz frequency band is used. The latter is divided into 12 channels that are 5 MHz wide. The maximum transmitted power equals to 21 dBm. However, it is true that this maximum power is employed relatively rarely. The UMTS system controls the transmitted power of each MT very carefully in order to ensure that the power levels received from all MTs in the given radio cell by base station (BS) antennas are approximately the same and as low as possible. This is essential for the proper operation of the code division of all transmitters (CDMA) operating within the same frequency band (i.e. channel). The minimum power levels at inputs of BS receivers are given by the required E_b/N_0 ratios, where E_b represents the received energy per one bit and N_0 stands for the total energy of noise and interferences. Table 2 shows the minimum E_b/N_0 values required for different UMTS transmission modes. The UMTS system loops control the transmitted powers so that the real E_b/N_0 values stay close to the minimal values. The E_b/N_0 parameter is defined by the following formula:

$$\frac{E_b}{N_0} = \frac{R_c}{R_b}\frac{P_{RXBS}}{I_{own}+I_{other}+P_{nBS}} = \frac{t_b}{t_c}\frac{P_{RXBS}}{I_{own}+I_{other}+P_{nBS}}. \quad (1)$$

In the aforementioned equation, R_c and R_b stand for the chip and bit rates respectively, P_{RXBS} represents the power received by the BS receiver, t_b indicates the duration of one bit, t_c means the duration of one chip, I_{own} denotes the power of interferences from the own radio cell, I_{other} is the power of interferences from the neighboring radio cells and P_{nBS} represents the total noise power related to the input of the BS receiver. The E_b/N_0 parameter relates both, the signal and noise, to unequal time durations. The bit duration t_b is relatively long, whereas the chip duration t_c is relatively short. The parameter E_c/I_0, defined by (2) indicated below, approximates the definition of the standard S/N parameter:

$$\frac{E_c}{I_0} = \frac{t_c}{t_c}\frac{P_{RXBS}}{I_{own}+I_{other}+P_{nBS}} = \frac{E_b}{N_0}\frac{R_b}{R_c}. \quad (2)$$

In this definition, E_c represents the energy received in duration of 1 chip and I_0 indicates the total spectral density of interferences and noise. The E_c/I_0 parameter refers to the signal and interferences + noise to the same time duration. The de-correlation gain (sometimes called the processing gain) is defined as follows:

$$G_p = R_c/R_b. \quad (3)$$

The noise power P_{nBS} can be expressed as:

$$P_{nBS} = kT_sB_c. \quad (4)$$

In (4), B_c represents channel bandwidth and the system noise temperature T_s consists of the antenna noise temperature T_A (for terrestrial radio links $T_A \approx T_0 = 290\,\mathrm{K}$) and the equivalent noise temperature of the receiver T_{RX}, while k stands for Boltzman's constant ($k = 1.3810^{-23}$ J/K):

$$T_s = T_A + T_{RX} = T_0 + T_0\left(F_{RX}-1\right) = T_0F_{RX}. \quad (5)$$

In (5), F_{RX} stands for the noise figure of the BS receiver. The formula (6) can be derived for the calculation of the minimal receiver input power $P_{RXBSmin}$, provided that $I_{own} = I_{other} = 0$:

$$P_{RXBSmin} = \frac{E_c}{I_0}P_{nBS}. \quad (6)$$

Table 2 shows important system values corresponding to the UMTS Release 99 standard. The R_b and minimum E_b/N_0 values were adopted from [5], the G_p, E_c/I_0 and $P_{RXBSmin}$ parameters were calculated using (1) - (6). The standard values $R_c = 3.84$ Mcps and $F_{RX} = 6$ dB were also applied, while the calculated noise floor value $P_{nBS} = -101$ dBm corresponds to $B_c = 5$ MHz wide channel.

Mode	R_b [kbps]	E_b/N_0 [dB]	G_p [dB]	E_c/I_0 [dB]	$P_{RXBSmin}$ [dB]
Voice	12,2	4	25	-21	-122
Data 64k	64	2	17,8	-15,8	-116,8
Data 144k	144	1,5	14,3	-12,8	-113,8
Data 384k	384	1	10	-9	-110

Tab. 2. Required and calculated UMTS system parameters.

The $P_{RXBSmin}$ values correspond to the minimal received power at the input of receiver in the BS that ensures the minimal required E_b/N_0 values. Tab. 2 shows that the $P_{RXBSmin}$ values can be substantially lower than the sensor noise floor ($P_{nRS} \approx -105$ dBm in case of the developed RS). That means that without knowledge of spreading sequences used and performance of de-correlation, the detection of UMTS signals will always be restricted to the definite and often rather limited range, where the power P_{RS} received by the RS receiver is high enough (typically of 10 dB), i.e. above its noise floor P_{nRS}. Even quite detailed studies, such as [12], confirm this fact. Detectability of the UMTS MTs should not be influenced by the newer 3GPP releases significantly, even in case of faster data transfers when 2 neighboring channels can also be used in the uplink (Release 9).

Using formula for the ideal free-space propagation of electromagnetic waves, the detection range r_{det} can be estimated as

$$r_{det} = r_{MTRSmax} = \frac{c}{4\pi f}10^{\frac{P_{TXmin}-P_{RSmin}}{20}}. \quad (7)$$

In this formula, the values $f = 1.95\,\text{GHz}$, $P_{TX} = P_{TXmin} = -50\,\text{dBm}$, $P_{RSmin} = -95\,\text{dBm}$ (see Section 3.) lead to $r_{det} = 2.18\,\text{m}$, which is the minimum value in the open area, provided that the BS is very close to the MT and isotropic MT and RS antennas used. The value is slightly disappointing, yet owing to various reasons, the situation can be more favourable in practice.

Firstly, the RS is always substantially closer to MT than to BS. The further the BS, the better detection conditions can be expected. The system is also incapable of setting the transmitted power to a level lower than P_{TXmin} = -50 dBm. Moreover, it can be expected that I_{own} and I_{other} will not equal zero values. It can be, therefore, assumed that the system sets a higher transmitted power of the MT. If there is a significant attenuation of walls between the BS and the MT, it has to transmit with a higher output power.

Beside that, within the RS, it is possible to use LNA with a slightly lower noise figure than in the BS. In fact, the LNA in the BS has to demonstrate a higher level of orientation to linearity. In the RS, there is also no attenuation of the cable between antenna and LNA. Consequently, a lower system noise temperature can be reached (the noise floor of the test sensor is equal to $P_{nRS} \approx -105\,\text{dBm}$, see Section 3). With a 10 dB separation, the detection floor can be, therefore, set to $P_{RSmin} = -95\,\text{dBm}$. On the other hand, the gain of antennas in the BS usually exceeds the gain of antennas in RSs.

In order to scrutinize the above-described phenomena, parameters of radio links MT-BS and MT-RS were inscribed as indicated in Fig. 1.

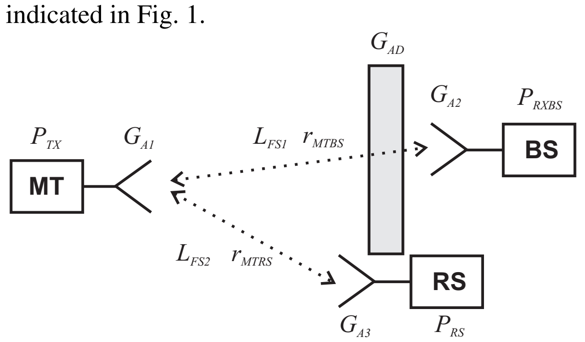

Fig. 1. Parameters of MT-BS and MT-RS radio links.

The radio link MT-BS between the mobile terminal and base station can be described by the following power budget formula (all values are stated either in dBm or dB):

$$P_{RXBS} = P_{TX} + G_{A1} - L_{FS1} + G_{A2} + G_{AD}. \tag{8}$$

In this formula, G_{A1} represents the gain of transmitting antenna and G_{A2} stands for the gain of BS antenna. The power P_{TX} is controlled by the BS in order to ensure, if it is possible, the required $P_{RXBSmin}$ value; see Tab. 2. The radio link is influenced by the additional gain G_{AD} covering e.g. the attenuation of walls, multiple reflections or influences of interferences I_{own} and I_{other}. The free-space loss L_{FS1} models the propagation of electromagnetic waves between MT and BS. The radio link MT-RS between the mobile terminal and radio sensor can be described by the following formula (all values indicated in dBm or dB):

$$P_{RS} = P_{TX} + G_{A1} - L_{FS2} + G_{A3}. \tag{9}$$

In this case, G_{A3} represents the gain of the RS antenna. The free-space loss L_{FS2} models the propagation of electromagnetic waves between MT and RS. The parameter r_{MTBS} embodies the distance between MT and BS which provide, if manageable by the UMTS power controlling loop, the required $P_{RXBSmin}$ value:

$$r_{MTBS} = \frac{c}{4\pi f} 10^{\frac{L_{FS1}}{20}}. \tag{10}$$

The parameter $r_{MTBSmax} = r_{det}$ describes the maximum detection range, i.e. the distance (corresponding to the free-space propagation) between MT and RS, resulting in $P_{RSmin} = -95\,\text{dBm}$:

$$r_{MTRSmax} = r_{det} = \frac{c}{4\pi f} 10^{\frac{L_{FS2}}{20}}. \tag{11}$$

Figure 2 shows the calculated plot $r_{det} = f(r_{MTBS}, G_{AD})$. The used parameters are listed below: $G_{A1} = 0\,\text{dB}$, $G_{A2} = 10\,\text{dB}$, $G_{A3} = 3\,\text{dB}$ and $P_{RXBSmin}$ corresponds to the 12.2 kbps voice service, see Tab. 2. Configurations with very low r_{MTBS} values, e.g. in case that the BS is located at the roof of the monitored building, show apparently unsatisfactory potential of detecting illegally transmitting UMTS terminals. Yet the longer the MT-BS distance, the better results can be reached. That concerns also the scenario described by the practical measurement, where the r_{MTBS} values range between 130 and 170 m (dotted vertical lines). Inside buildings, where additional -10 to -20 dB negative additional gain G_{AD} can be expected, approx. 10 m detection range can be reached, which can be a satisfactory value often. In open areas, where G_{AD} evinces close to zero values, conditions for proper detection of UMTS MTs are likely to be more difficult.

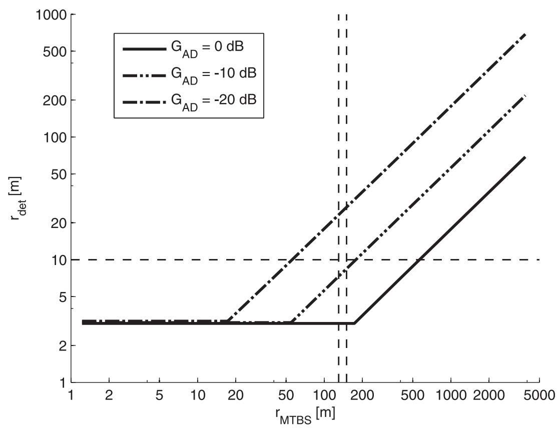

Fig. 2. Dependence of detection range upon distance between MT and BS and additional gain G_{AD}.

Since not all system parameters are precisely known and factual conditions of propagation of radio waves through walls and inside buildings are hard to describe, all above-presented assumptions were verified by a series of practical measurements.

3. Radio Sensor

For verification of the above-calculated values, the test radio sensor was designed and manufactured; its block diagram is involved in Fig. 3.

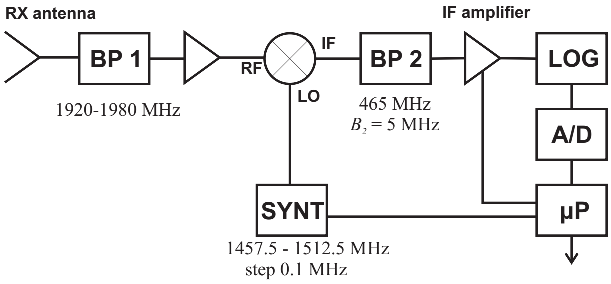

Fig. 3. Block diagram of developed measurement sensor.

The designed radio sensor employs the input SAW band-pass filter BP1, followed by the LNA. These two components exercise a dominant influence on the receiver noise figure, whose value is (in this case) $F_{RS} \leq 2.5$ dB. The RF mixer, together with the synthesizer SYNT, converts the input signals to the 5 MHz wide IF band-pass filter BP2. The logarithmic detector LOG at the output of the IF amplifier measures the received power in 80 dB-wide ranges. The micro-computer controls the input frequency, A/D conversion as well as the gain of IF amplifier. The measured values are indicated using a simple LCD display. The RS noise floor represents one of the most important detection parameters, it can be expressed using formula similar to (4) and (5):

$$P_{nRS} = kT_{RS}B_c = kT_0F_{RS}B_c. \qquad (12)$$

The obtained value of the RS noise figure $F_{RS} = 2.5$ dB leads to $P_{nRS} = -104,5$ dB, therefore the detection floor was set to $P_{RSmin} = -95$ dBm. The measurement process performed by the sensor is the following:

- The synthesizer sets the frequency of the local oscillator LO to a value corresponding to a centre of the first UMTS channel.
- The micro-computer sets the maximum value of IF amplifier's gain, whereas the A/D converter measures the received power.
- In case that the power measured by the detector attains a level lower than the detection floor, the sensor starts the measurement in another channel.
- If the RF power measured by the detector reaches a level higher than the detection floor, the micro-computer sets the optimal value of IF gain and starts a "convolutional" identification of the UMTS signal. The synthesizer changes the LO frequency in fine steps and the detector measures the corresponding power levels. Presence of a wideband UMTS signal gives rise to a relatively wide convolution of the UMTS spectrum and frequency response of the BP2 filter. On the contrary, the presence of any narrowband interfering signal results in a convolution equal or similar to frequency response of the BP2.
- If the detected signal is identified as the UMTS type, the measured value is displayed and the sensor can inform the superordinate computer.

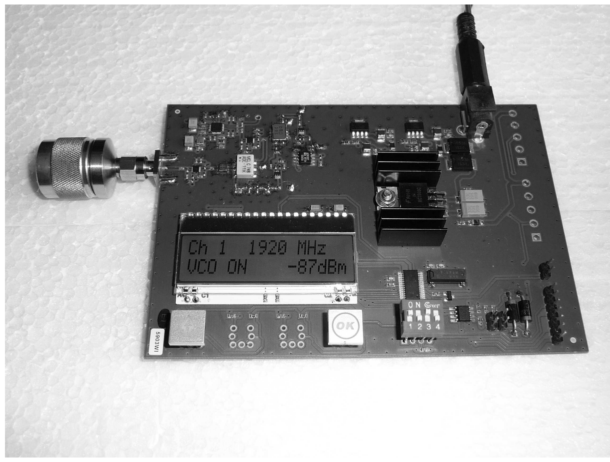

Fig. 4. Test UMTS radio sensor.

Figure 4 depicts the practical realization of the test measurement radio sensor. It was powered from a 12 V battery and equipped with a simple antenna (folded dipole, $G_{A3} \approx 3$ dB, vertical polarization) for all measurements.

4. Experimental Results

All tests were performed at the campus of the Faculty of Electrical Engineering of the Czech Technical University in Prague in rooms, corridor and open area situated in a relatively near proximity to the UMTS BS. From the measurement point of view, these conditions can be considered as close to the worst-case ones.

The rooms and corridor used during tests are situated on the 6^{th} floor. The nearest BS is situated at the roof of the nearby building approx. 130 m apart and more or less at the same height. Since the outer wall between BS and MT is approx. 400 mm thick (concrete, bricks), relatively high attenuation and additional gain G_{AD} in the -10 to -20 dB ranges can be expected. During measurements performed inside rooms, the tested RS was fixed at the inner side of the outer wall, i.e. approx. 130 m from the BS. A person bearing the UMTS mobile terminal moved in rooms in the direction away from the BS (up to 141 m from the BS). Inside the building, 1 or 2 relatively thin (200 mm) inner walls were present between the RS and the MT. Due to the expected multiple-reflections effects, the measurements were performed at more locations with approx. the same distance from the BS marked as Lines A, B, C, see Tab. 3.

During all measurements, the testing person was holding the UMTS MT near the right ear. The measurements were carried out for a number of conditions simulating possible relations of the MT, head and BS; see Tab. 4.

Line	RS-MT distance	BS-MT distance	Outer wall	Inner walls
A	6,5 m	136,5 m	1	1
B	8,5 m	138,5 m	1	1
C	11 m	141 m	1	2

Tab. 3. Measurement lines used for tests inside rooms.

Relation	Head aiming	Polarization of MT
FV	Forward	Vertical
FH	Forward	Horizontal
RV	Right	Vertical
RH	Right	Horizontal
BV	Backward	Vertical
BH	Backward	Horizontal
LV	Left	Vertical
LH	Left	Horizontal

Tab. 4. Measurement relations used for tests inside rooms.

Figure 5 shows histogram of the P_{RS} values measured at the Line A (approx. 6.5 m RS-MT distance, 1 inner wall between the RS and the MT). The measurement was performed at several points at this line, at each point relations according to Tab. 4 were tested. Since all received values exceeded the -95 dBm detection floor, the detection at this distance can be considered as 100% positive and correct.

Figure 6 corresponds to histogram of the P_{RS} values measured at the Line B (approx. 8.5 m RS-MT distance, 1 inner wall between the RS and the MT). Also in this case, all received values exceeded the -95 dBm detection floor, and the detection was 100% positive and correct.

Figure 7 depicts histogram of the P_{RS} values measured at the Line C (approx. 11 m RS-MT distance, 2 inner walls between the RS and the MT). With one exception, all received values exceeded the -95 dBm detection floor, and the detection can be considered as highly positive and correct. Since propagation of electromagnetic waves inside buildings is very complex, direct comparison of measured and calculated $r_{MTRSmax} = r_{det}$ values is not possible. But the measured r_{det} values correspond fairly well to G_{AD} lying in the expected -10 to -20 dB range, see Fig. 2.

The RS was also tested in the nearby 2.1 m wide corridor running nearly parallel with the BS-RS connecting line. During these measurements, the RS was fixed at the end of the corridor at a height of 2.4 m, and approx. 170 m from the BS. The measurements were also performed for a series of positions of the MT alongside the corridor in a direction to the BS, both in the centre and close to the wall. The results are shown in Fig. 8. and Fig. 9.

The aforementioned results show a very positive impact of the waveguide effect on the received power, and therefore, on the detecting range. At distances more than 30 m between RS and MT, the received power is reliably above the detection floor. That is why monitoring of MTs in corridors should not represent the major issue.

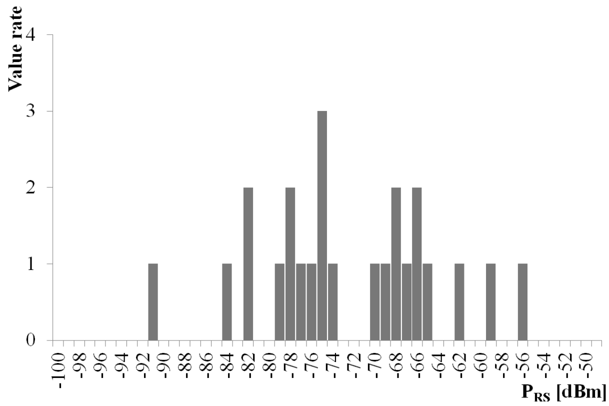

Fig. 5. Measured P_{RS} values - histogram for line A.

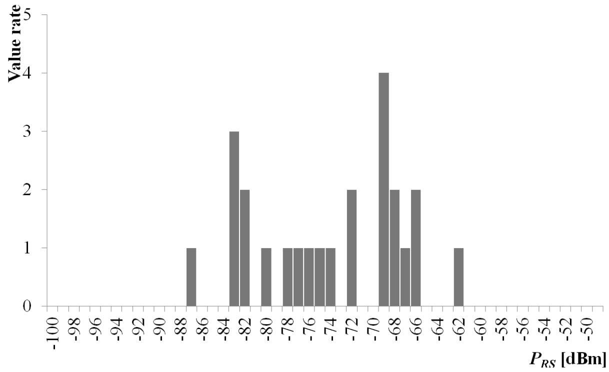

Fig. 6. Measured P_{RS} values - histogram for line B.

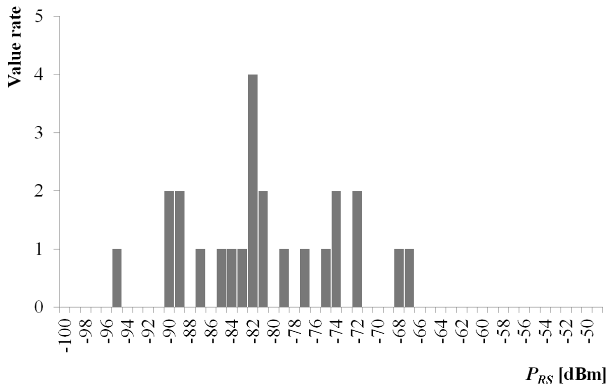

Fig. 7. Measured P_{RS} values - histogram for line C.

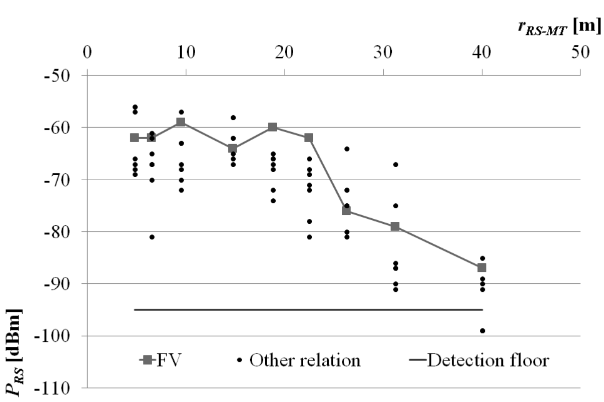

Fig. 8. Measured P_{RS} values as function of r_{RS-MT} at centre of corridor.

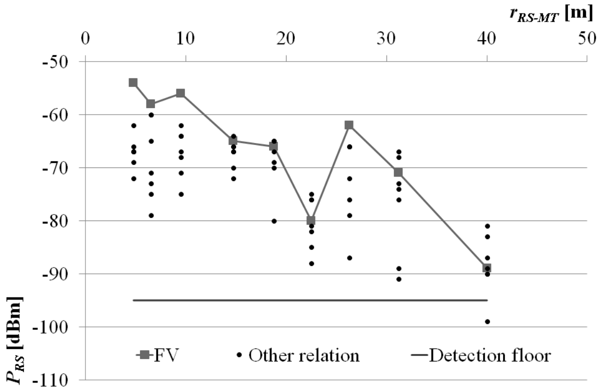

Fig. 9. Measured P_{RS} values as function of r_{RS-MT} at corridor close to wall.

The last set of measurements was carried out in open area in the faculty yard - situated roughly 150 m far from the BS antennas and about 20 m below their height. The radio sensor was fixed at a height of 2 m. During the measurement, the MT moved from RS towards the BS; for results see Fig. 10.

The measured r_{det} values are slightly higher than those expected according to Fig. 2. This can be explained by several phenomena influencing the test:

- Both MT and RS were situated below maxima of radiation pattern of BS antennas;
- Reflections from the ground;
- Non-zero I_{own} and I_{other} values.

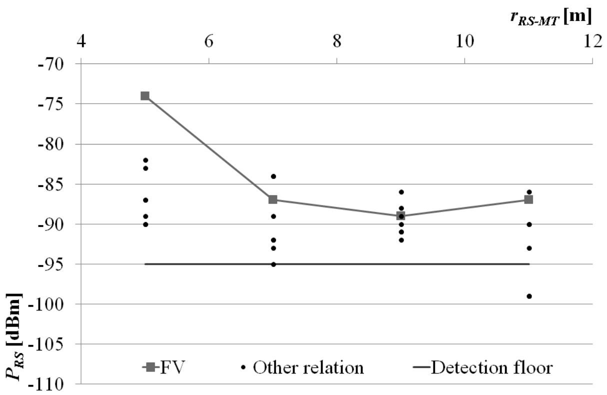

Fig. 10. Measured P_{RS} values as function of r_{RS-MT} in open area.

Generally, in open area in close vicinity to the BS, the MT transmits with the lowest power possible (i.e., -50 dBm) usually, and values of the additional gain G_{AD} can be close to zero dB. That is why the detection range can be limited to merely several meters. The situation can be positively influenced by BS antenna radiation patterns and interferences, and must be considered from case to case. As further development, a more universal measurement sensor based on the structure depicted in Fig. 3 was designed. By using more antennas, input switch, wideband synthesizer and digital down-conversion, it is capable of monitoring all important mobile and wireless services in the 400 MHz - 2.5 GHz frequency band.

5. Conclusions

The detection and measurement of 3G mobile formats based on the CDMA is far more complicated than detection and measurement of the standard 2G formats. This is predominantly due to the fact that transmitted power levels are frequently very low, while the channel bandwidths tend to be relatively wide. The corresponding detection range can be as low as 2.18 m. Nevertheless, under practical circumstances, it can be substantially longer. The main reasons for that are presented in the Section 2. The designed and realized radio sensor is based on the sensitive receiver with a digital frequency and gain control and employs convolutional method for CDMA signal identification. The sensor was tested indoors and also in open area in a close vicinity of the UMTS BS. This represented conditions that were comparable to the worst possible case. Inside the rooms, the measured detection range attained (with a definite reserve) about 11 m including 2 inner walls. In corridors, the detection range was, thanks to the waveguide effect, even longer than 30 m. The measured values indicate that the monitoring of an illegal usage of UMTS MTs inside highly guarded buildings should be considered as a solvable problem. In open area, the measured detection range was noticeably shorter, with zero or very low reserve it attained $7-9$ m. Consequently, the detection of MTs in open areas can be more demanding and difficult, especially in case that the BS is located nearby. The measured detection ranges correspond fairly well with values estimated by using the presented formulas and Fig. 2. The derived procedures can be used for evaluating detection ranges of the majority of other CDMA based radio devices. Extended units based on this concept can be used for monitoring of illegal radio traffic of all existing (and to a definite degree also future) voice and data mobile and wireless systems.

Acknowledgements

This work was supported by the Grant Agency of the Czech Technical University in Prague, grant no. SGS14/190/OHK3/3T/13. The authors would also like to express special gratitude to Dipl. Ing. Libor Daněk (danek@rcd.cz) from the company RCD Radiokomunikace Ltd. (www.rcd.cz), who manufactured the test radio sensor and assisted with the measurements.

References

[1] HUDEC, P., POLIVKA, M., PECHAC, P. Microwave system for the detection and localization of mobile phones in large buildings. *IEEE Transactions on Microwave Theory and Techniques*, 2005, vol. 53, no. 6, p. 2235 - 2239.

[2] VALES-ALONSO, J., DE VICENTE, F. I., GONZALEZ-CASTANO, F. J., POUSADA-CARBALLO, J. M. Real-time detector of GSM terminals. *IEEE Communications Letters*, 2001, vol. 5, no. 6, p. 275 - 276.

[3] SKOKOWSKI, P., LOPATKA, J. Methods of detection and analisys of UMTS signals. In 2nd *International Conference on Signal Processing and Communication Systems (ICSPCS)*. Gold Coast (Australia), 2008, p. 1 - 6.

[4] VALES-ALONSO, J., GONZALEZ-CASTAO, F. J., POUSADA-CARBALLO, J. M., DE VICENTE, F. I. Real-time 3G UMTS terminal detection. *IEEE Communications Letters*, 2002, vol. 6, no. 3, p. 123 - 125.

[5] HOLMA, H., TOSKALA, A. *WCDMA for UMTS*. Wiley, 2004.

[6] NAWROCKI, M., DOHLER, M., AGHVAMI, A. *Understanding UMTS Radio Network - Modelling, Planning and Automated Optimisation*. Wiley, 2006.

[7] MURATONE, F. *UMTS - Mobile Communications for the Future*. Wiley, 2001.

[8] LAIHO, A., WACKER, A., NOVOSAD, T. *Radio Network Planning and Optimisation for UMTS*. Wiley, 2006.

[9] CASTRO, J. *The UMTS Network and Radio Access Technology.* Wiley, 2001.

[10] SAUTER, M. *From GSM to LTE*. Wiley, 2011.

[11] HOLMA, H., TOSKALA, A. *WCDMA for UMTS - HSPA Evolution and LTE*. Wiley, 2007.

[12] DILLARD, R., DILLARD, G. *Detectability of Spread-Spectrum Signals*. Artech House, 1989.

About Authors ...

Filip KOZAK was born in Rymarov, Czech Republic, on July 2, 1985. He received his Master's degrees in electrical engineering from Brno University of Technology (BUT), Brno, Czech Republic in 2010. Nowadays he is working toward the Ph.D. degree at the Department of Electromagnetic Field, Czech Technical University in Prague, Czech Republic (CTU). His research interests include design and measurement of microwave systems and calculations of electromagnetic fields.

Premysl HUDEC graduated from the Czech Technical University in Prague in 1982. In the same year he joined its Department of the Electromagnetic Field, where he now works as an associated professor. His teaching duties include CAD of microwave circuits and microwave measurement. In the recent years, his research activities are focused on employment of microwave technology in security applications. This concerns detection of mobile phones in highly guarded areas, design of different types of microwave radar sensors for active defense systems and development of RFID systems for long-range identification. He is an author of numerous conference papers, journal articles and patents.