Design of Measurement System for Determining the Radioclimatology Effect on the Radio Signal Propagation Using Universal Software Radio

Martin TOMIS, Libor MICHALEK, Marek DVORSKY

Department of Telecommunications, Faculty of Electrical Engineering and Computer Science, VSB–Technical University of Ostrava, 17. listopadu 15, 708 33 Ostrava–Poruba, Czech Republic

martin.tomis@vsb.cz, libor.michalek@vsb.cz, marek.dvorsky@vsb.cz

Abstract. *In this paper, a developed point-to-point wireless link using Universal Software Radio Peripheral (USRP) is presented. The aim of the research is focused on the monitoring and analysing the transmission characteristics on the physical layer of such wireless communication link with the consideration that these parameters could be affected by atmospheric phenomenon and air pollution. For that reason, the wireless link is situated to heavily loaded environment of Ostrava agglomeration where it is assumed extreme atmospheric phenomena such as smog or inverse situation. In the next part, a developed application which perform a fully automatic long term measurement of the transmission characteristics using a wireless link is presented. Finally, the first experimental results based on mathematical regression are presented.*

Keywords

Interference, SDR, signal attenuation, radioclimatology, USRP.

1. Introduction

The Universal Software Radio Peripheral (USRP) product by NI company has become a popular platform for a large number of complex measuring applications. These applications had been previously available only with professional tools such as RF Signal Generators and Analyzers.

Universal Software Radio Peripheral (USRP) [1] is a universal software-programmable radio transceiver controlled by a Personal Computer (PC). The device is designed as separated direct-conversion transmitter and receiver.

Frequency bandwidth for transmission and reception can be adjusted by changing the sampling frequency of transmitted data in the range of 0,2 to 50 $\mathrm{MS\cdot s^{-1}}$. However, sampling rates of AD and DA converters in the baseband are significantly higher, i.e. in the hundreds of mega-samples per second. The Field Programmable Gate Arrays (FPGA) converts high sample rate to lower sampling rate for the data transfer between USRP and PC.

Due to the extremely expensive hardware generators and analyzers, the common practice is to simulate real Radio Frequency (RF) signals using software simulators such as Matlab [2] or LabVIEW [3]. On the other hand, the USRP device is significantly cheaper, however, it does not reach such frequency accuracy as NI-RFSA (Radio Frequency Signal Analyzer) [4]. NI-RFSA is a measurement plug-in card made by National Instruments (NI) within a modular system PXI (PCI eXtensions for Instrumentation) [5].

The adverse weather causes microwave signal degradations mostly due to rain and suspended particles like fog and water vapor. Atmospheric gases cause signal attenuation through molecular absorption in certain characteristic frequency bands. In the case of Free Space Optical (FSO) connection, the most important impairment factor is the fog, which can be well characterized by its density. In [6], [7] some measurement results regarding the Free Space Optics (FSO) impacted by fog has been presented.

In [8], the aim was to find out the different types of losses to be incurred at the conventional window frequencies i.e., 30 and 94 GHz along with the losses at the first and weak water vapour resonance line i.e., around 22 GHz in the microwave/milimeter wave band.

In [9], [10], [11] some models have been proposed for satellite communication affected by rain attenuation. In [12] radio link have been adapted by radio channel state prediction method.

Up to present, it has not been comprehensively discussed the issue of measurement the attenuation and other transmission parameters for wireless data link in heavily loaded industrial areas such as the area of Ostrava agglomeration, Czech Republic. Ostrava's geomorphology and poor dispersion conditions both contribute to the air pollution and cause the pollution to concentrate here, especially in winter [13]. Therefore, significantly interesting and scientifically useful could be consider to follow the changes in states of extreme atmospheric phenomena such as smog or inverse situation. The smog and inverse situation are characterized by chemical or mechanical atmospheric pollution (e.g. increased content of suspended particulate matter PM10), which can affect the transmission characteristics of wireless links. In the concrete, atmospheric particulate matter (PM) can be classified as PM10, PM2.5 and PM1 by size with mass median aerodynamic diameter less than 10 μm, $2,5$ μm and 1 μm respectively.

2. Experimental Wireless Link

Using the Software Defined Radio in the form of USRP device, a complex measurement system which monitors the influence of atmospheric phenomenon and air pollution on the physical layer of wireless communication link has been proposed. The system consists of two identical stations located in Ostrava-Poruba and Petrvald city respectively. Therefore, the wireless link itself is situated to the the Ostrava city environment. The general architecture of the proposed system is sketched in Fig. 1. It is based on two main classes of devices:

- RF units: designed using Software Defined Radio (SDR) device with external GPS synchronization.
- Supervisor system: consist of personal computers devoted to saving measured data into the database and remotely access to measured data.

RF units consist of SDR by National Instruments USRP 2920 with the directional antenna, which are directed against each other. For the synchronization between RF units, an external GPS module Meinberg GPS164 has been used.

The supervisor system is a workstation equipped with the software for retrieving, storing, and viewing measurement data collected by RF unit as well as for managing the data elaboration. Since the USRP is a product of NI, the LabView environment has been used for support the application (see next chapter).

If the time or frequency errors have to be measured, the exact time synchronization of RF units has to be

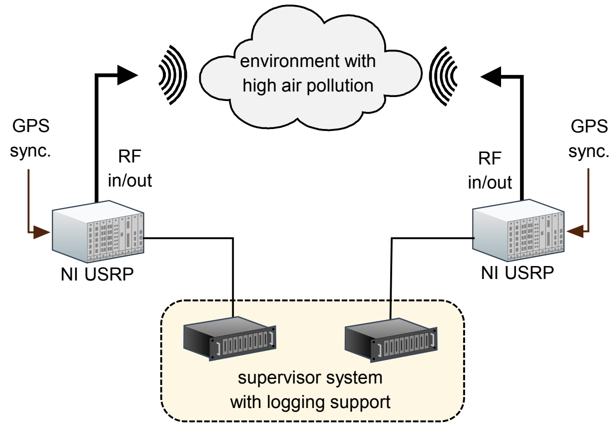

Fig. 1: General architecture of the measurement system.

observed. The sync pulse ensures that the transmitter and the receiver start the measurement at the same time. Moreover, information about the current exact time is used to synchronize workstations. This is performed via serial line.

3. Application

The measurement and control application have been developed in LabView [3] environment. The aim of the developed application is to control, manage and perform fully automatic long term measurement of transmission characteristics using the proposed wireless link. With regards to common practice, Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK), Quadrature Phase-Shift Keying(QPSK) and 16-Quadrature Amplitude Modulation (16-QAM) have been chosen as the main representatives of modulation/ keying types. For this purpose, a testing sequence of bits, which is keyed and then transmitted by wireless link, have been proposed. The sequence consists of guard bits, synchronizing bits and data bits, see Tab. 1.

Tab. 1: Parameters for testing sequence.

	guard bits [−]	sync. bits [−]	data bits [−]	bit rate [$\text{kbit}\cdot\text{s}^{-1}$]	symbol rate [$\text{kS}\cdot\text{s}^{-1}$]
ASK	10	20	500	19,2	19,2
FSK	50	40	1000	100	100
QPSK	100	80	4000	200	100
16-QAM	200	160	5000	400	100

The sequence of bits is transmitted with the interval of 5 seconds while the type of keying is always changed. Figure 2 shows the general architecture of the application.

The following parameters are being determined and calculated.

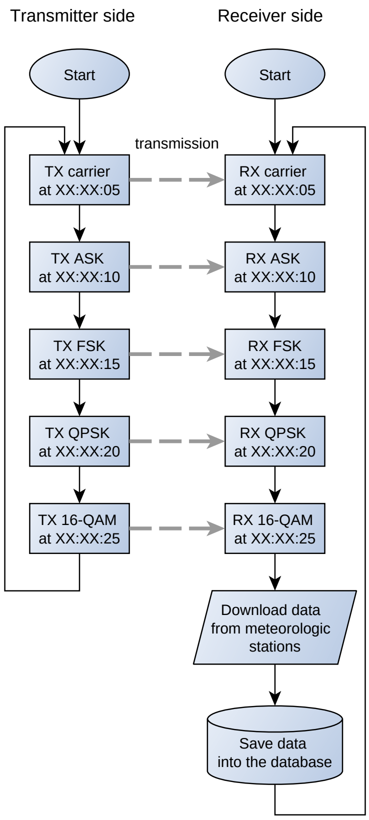

Fig. 2: The architecture of the developed application.

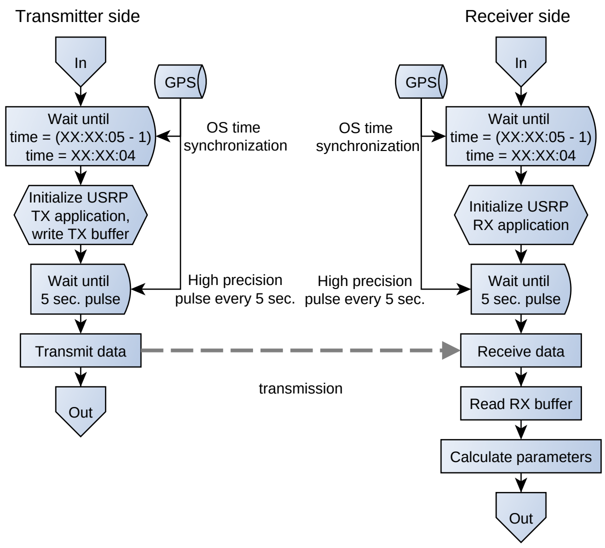

Fig. 3: The architecture of the carrier fluctuation measurement.

- **Carrier:** On the transmitter side, an amplitude modulated (AM) signal with modulation sine tone of 10 kHz is transmitted with constant radiated power. As the carrier frequency, the 869, 5 MHz sine has been used which belongs to ISM band according to [14]. At the receiver side, the carrier is demodulated, and the resulting tone is sampled by 200 kS $\cdot$ s^{-1} sample rate. Both transmitter and receiver side have to be time synchronized with high precision. The second phase comprises calculation and determination of transmission parameters such as Carrier Fluctuation. Figure 3 depicts the architecture of amplitude fluctuation measurement.

- **ASK, FSK, QPSK, 16-QAM:** Here, the same carrier frequency (869,5 MHz) is used and then keyed by testing sequence. At the receiver side, the demodulation is being processed. In further analysis, we focus on parameters such as Modulation Error (MER), Carrier to Noise Ratio (CNR), Carrier Frequency Offset, Carrier Frequency Drift, Error Vector Magnitude (EVM), Magnitude Error, Phase Error, DC offset, Quadrature Skew or IQ Gain Imbalance. Figure 4 depicts the Labview block diagram for QAM transmission parameters determination.

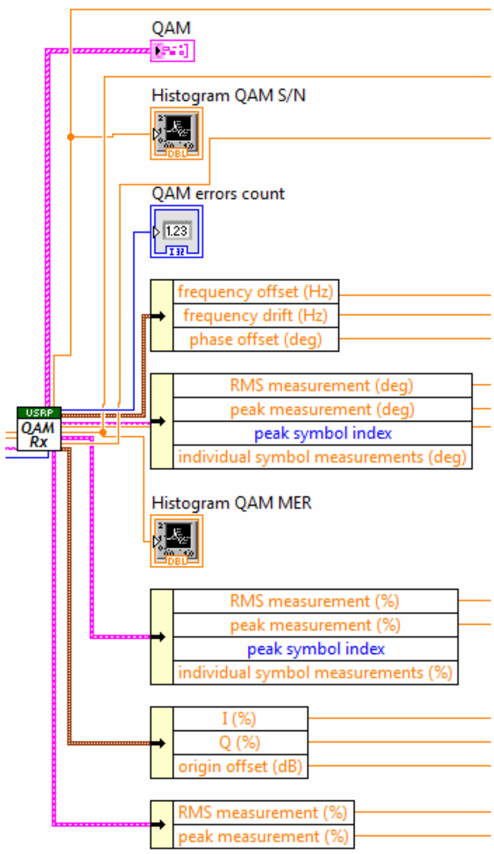

Fig. 4: Block diagram for QAM transmission parameters determination.

4. Experimental Results

The purpose of all above mentioned measurements through the proposed wireless link is to find some mathematical relationship between transmission parameters and fluctuations in the properties of the atmospheric phenomenon or air pollution. For this purpose, the meteorological data from the automated weather stations (Czech Hydrometeorological Institute) located in the explored area are stored to the database together with the data containing the transmission parameters.

A simple regression [15] analysis has been used to assess the association between transmission parameters and properties of the atmospheric phenomenon or air pollution. A simple linear regression uses only one independent variable, and it describes the relationship between the independent variable and dependent variable as a straight line. A wide analysis has been done using the Statgraphic as the professional tool concerning statistical analysis. As the independent variables, the properties of the atmospheric phenomenon have been used. As the dependent variables, the transmission parameters, as mentioned in chapter 3., have been used.

The results of simple regression analysis show that some association between transmission parameters and properties of the atmospheric phenomenon or air pollution exists. Figure 5 shows a result of simple regression for Carrier Fluctuation parameter versus PM10 concentration. Since the P-value is less than 0,05 there is a statistically significant relationship between Carrier Fluctuation and PM10 concentration at the 95,0 % confidence level. The plot of the fitted model shows the original observations (blue dots), the fitted regression line (blue curve), the 95 % confidence limits (green curves) and the 95 % prediction limits (grey curves).

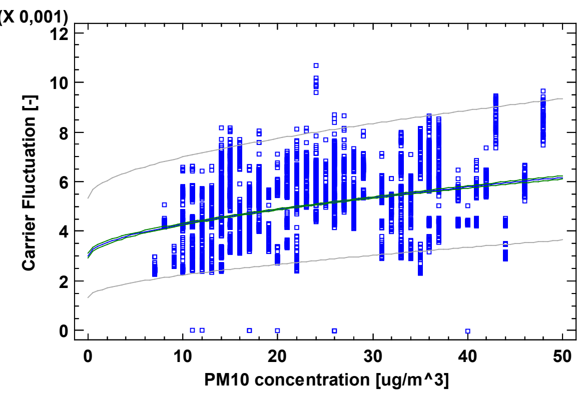

Fig. 5: Plot of Simple Regression - Carrier Fluctuation vs. PM10 concentration.

The output on the Fig. 6 shows the results of fitting an exponential model to describe the relationship between QAM Magnitude Error and PM10 Concentration. Since the P-value in is less than 0,05 there is a statistically significant relationship between QAM Magnitude Error and PM10 Concentration at the 95,0 % confidence level.

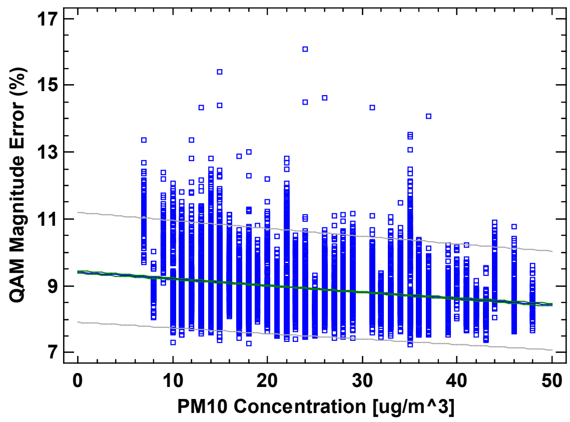

Fig. 6: Plot of Simple Regression - QAM Magnitude Error vs. PM10 concentration.

After the comprehensive analysis through the Statgraphic tool, the parameters of atmospheric phenomenon, which affected the transmission parameters at most, has been determined, see Tab. 2. It should be noted that, due to the lack measured data, the results show only direction on which parameters we have to focus in further analysis.

Tab. 2: Transmission parameters affected by atmospheric phenomenon.

	PM10	Temperature	Humidity
Carrier Fluctuation	+	++	
FSK Drift		-	
FSK Error	-		
QPSK Offset	-	++	-
QAM MER		+	
QAM Magn. Error	-		

Where:
+ Increases the level of parameter as $(x \cdot 0{,}001)$
++ Increases the level of parameter as $(x \cdot 0{,}01)$
− Decreases the level of parameter as $(x \cdot 0{,}001)$
−− Decreases the level of parameter as $(x \cdot 0{,}01)$

If the cell is empty, no affecting has been found.

5. Conclusion

This paper describes a developed point-to-point wireless link that is situated to Ostrava agglomeration environment. The distance between the receiver and transmitter is about 14 km which allows to observe the changes in transmission parameters such as carrier fluctuation, MER, C/N, QAM magnitude error which can be affected by changes in states of atmospheric phenomenon. Even if the proposed wireless link using a very well known module USRP, the combination with the detecting if the transmission parameters are associated with concentration of PM10 as well as with other weather parameters is novel.

In the next part, a developed application for controlling and fully-automatic measurement using a wireless link is presented. Although the lack of the measured data does not allow us determine exactly whether the changes of atmospheric phenomenon affect the transmission parameters or not, some partial results have been presented. Using the statistical analysis, it was proved that the concentration of Particular Matter (PM10) affects the amplitude of carrier and QAM magnitude error. This confirms the fact that we should do the further research in this direction and examine the association of PM10 on these parameters in detail. The determination whether the PM1 or PM2,5 affects transmission parameters or not is not considered mainly because of these concentrations are not measured by automated weather stations.

The long-term measurements will continue for two years at least. We expect to expand the working frequency band to 433 MHz and 2,4 GHz in order to evaluate the influence of meteorological phenomena in these bands.

The aim of the presented research is, among others, to propose a mathematical model that describes the behavior of the communication channel and its transmission parameters depending on long-term changes of atmospheric phenomena, the concentration of PM10 primarily. The research of such type has not been published yet.

Acknowledgment

The research leading to these results has received funding from the Grant SGS SP2013/94 'Research on the influence of environment on the properties of the radio channel and the development of new approaches to the evaluation of quality of service (QoS) in 4G networks'.

References

[1] National Instruments. *NI USRP Lab: DQPSK Transceiver Design*, 2012.

[2] HUANG, Y. G. Z., Y. LI, J. SHAO and H. WEI. Processing digital signal using power spectral density function analysis in matlab toolkit. In: *International Conference on Computer Science and Network Technology (ICCSNT)*. Harbin: IEEE, 2011, vol. 1, pp. 553–556. ISBN 978-145771584-6. DOI: 10.1109/ICCSNT.2011.6182018.

[3] HIGA, M. L., D. M. TAWY and S. M. LORD. An introduction to labview exercise for an electronics class. In: *32nd Annual Frontiers in Education*. Boston: IEEE, 2002, vol. 1, pp. T1D/13–T1D/16. ISSN 0190-5848.

[4] FARES, A., A. KHACHAN, A. B. KASBAH, M. ZEIDAN and A. KAYSSI. GSM RF equipment testing and performance analysis. In: *International Symposium on Communications and Information Technology*. Sapporo: IEEE, 2004, vol. 2, pp. 807–811. ISBN 978-078038593-1. DOI: 10.1109/ISCIT.2004.1413828.

[5] GLADKOV, M. N. and G. S. RUDANOV. Programmable radio; platform on the basis of national instruments pxi-system. In: *18th International Crimean Conference Microwave and Telecommunication Technology*. Crimea: IEEE, 2008, pp. 10–11. ISBN 978-966335169-8. DOI: 10.1109/CRMICO.2008.4676677.

[6] CSURGAI-HORVATH, L., E. LEITGE, and J. TURAN. Measurement data for FSO and e-band radio propagation modeling. In: *Proceedings of the 5th European Conference on Antennas and Propagation (EUCAP)*. Prague: IEEE, 2011, pp. 2742–2745. ISBN 978-888202074-3.

[7] CSURGAI-HORVATH, L., J. BITO, P. PESICE and O. FISER. The impact of liquid water content on free space optical propagation. In: *6th European Conference on Antennas and Propagation (EUCAP)*. Prague: IEEE, 2012, pp. 323–325. ISBN 978-1-4577-0919-7. DOI: 10.1109/EuCAP.2012.6206177.

[8] KARMAKAR, P. K., L. SENGUPTA, M. MAIRI and C. F. ANGELIS. Some of the atmospheric influences on microwave propagation through atmosphere. *American Journal Of Scientific And Industrial Research*. 2010, vol. 1, iss. 2, pp. 350–358. ISSN 2153-649X. DOI: 10.5251/ajsir.2010.1.2.350.358.

[9] RAMACHANDRAN, V. and V. KUMAR. Modified rain attenuation model for tropical regions for ku-band signals. *International Journal of Satellite Communications and Networking*. 2007, vol. 25, iss. 1, pp. 53–67. ISSN 1542-0973.

[10] OJO, J. S., M. O. AJEWOLE and S. K. SARKAR. Rain rate and rain attenuation prediction for satellite communication in ku and ka bands over nigeria. *Progress In Electromagnetics*

Research B. 2008, vol. 5, pp. 207–223. ISSN 1937-6472. DOI: 10.2528/PIERB08021201.

[11] MANDEEP, J. S. and J. E. ALLNUTT. Rain attenuation predictions at ku-band in south east asia countries. *Progress In Electromagnetics Research*. 2007, vol. 76, pp. 65–74. ISSN 1070-4698.

[12] ZIACIK, P. and V. WIESER. Mobile radio link adaptation by radio channel state prediction. *Electronics and Electrical Engineering*. 2011, vol. 114, iss. 8, pp. 27–30. ISSN 1392-1215.

[13] KALICAKOVA, Z., V. MICKA, K. LACH and P. DANIHELKA. Urban air pollution by nanoparticles in ostrava region. *Journal of Physics: Conference Series*. 2013, vol. 429, iss. 1, 2013. ISSN 1742-6588. DOI: 10.1088/1742-6596/429/1/012005.

[14] Czech Telecommunications Institute. General license no. vor/10/04.2012-7. 2012.

[15] SEBER, G. A. F. and A. J. LEE. *Linear Regression Analysis*. Hoboken: Wiley, 2012. ISBN 978-1118274422.

About Authors

Martin TOMIS was born in 1987. He received his master degree from Department of Telecommunications, Faculty of Electrical Engineering and Computer Science, VSB–Technical University Ostrava in 2011. His research interests include virtual instrumentation.

Libor MICHALEK was born in 1979. He received his Ph.D. from Department of Telecommunications, Faculty of Electrical Engineering and Computer Science, VSB–Technical University Ostrava in 2008. His research interests include new digital telecommunication technologies.

Marek DVORSKY was born in 1981. He received his Ph.D. from Department of Telecommunications, Faculty of Electrical Engineering and Computer Science, VSB–Technical University Ostrava in 2009. His research interests include new digital radio-communication technologies and antennas engineering.