The Influence of Atmospheric Radio Refractivity on the WiMAX Signal Level in the Areas of Weak Coverage

M. Zilinskas[1,2], M. Tamosiunaite[3], S. Tamosiunas[2], M. Tamosiuniene[3], and E. Stankevicius[4]

[1]Department of Radio Communication
Communications Regulatory Authority of the Republic of Lithuania, Vilnius, Lithuania
[2]Faculty of Physics, Vilnius University, Vilnius, Lithuania
[3]Center for Physical Sciences and Technology, Vilnius, Lithuania
[4]Vilnius Gediminas Technical University, Vilnius, Lithuania

Abstract— The influence of weather conditions on the signal level of the fourth generation (4G) wireless mobile network, working on the WiMAX standard, has been examined. The data of measurements are presented. The power level of the received signal was continuously measured and compared to the calculated values of atmospheric radio refractivity. The International Telecommunication Union (ITU) method for determination of radio refractivity-value has been used. In the ITU method, the measured data of air temperature, pressure, and relative humidity are used. It was examined if changes of signal level and variations of the radio refractivity-value occur at the same time. The long-term measurements were carried out at the same time and place. The experiment was carried out in an area of weak coverage. It was concluded that in the areas of weak coverage, 4G (WiMAX) signals are strongly influenced by variations of the atmospheric radio refractivity.

1. INTRODUCTION

The European Commission's Strategy [1] states that all European citizens must have access to fast internet by the year 2020. Internet connection speed must not be less than 30 Mb/s, and up to 100 Mb/s speed internet connection must be accessible to at least half of the households. To achieve these goals, fourth generation, or 4G, broadband wireless network is used. However, there are some limitations, which restrain the expansion of the 4G network. In Lithuania, there are extremely strict hygiene norms, which state that electromagnetic energy flux density limit is 10 $\mu W/cm^2$ for the radio frequency range from 300 MHz to 300 GHz. Since it leads to additional investments for the telecommunication companies and public fear of possible health effects for people living near base stations, the new base stations should be build in the most reasonable locations and set to the optimum performance.

When the new base stations are designed, all propagation losses must be taken into account. Lower frequency signals can propagate through longer distances without significant distortions. Therefore, providers are seeking to occupy the lower frequency bands. But these bands are already congested. It is known that the frequency band of 10–100 GHz is vulnerable by various meteorological factors (i.e., rain, fog, clouds) [2], but during heavy rain events some effects might show at much lower frequencies, starting from 1 GHz [3]. The developers of telecommunication links usually ignore any influence of the meteorological events at frequencies up to 3 GHz. At 3–10 GHz, the effects become visible, but still the influence is considered to be acceptable. At 10 GHz, the effects become significant. In Europe, the most popular operating frequencies of the 4G networks are 800 MHz, 1.8 GHz, and 2.6 GHz. For 4G (WiMAX), the most widespread WiMAX frequency bands are from 2.3 GHz to 3.6 GHz [4].

The mentioned frequencies are lower than 10 GHz, therefore it could seem, that there should be no noticeable influence of the meteorological events. But weather conditions are closely related to refractivity variations in the troposphere. The radio refractivity determines the curvature radius of the propagation path. Due to refractivity variations in the atmosphere various phenomena might occur in the path of the propagation: ducting, refraction, fading, range and elevation errors in radar acquisition and radio-station interference [5]. These effects might cause major losses of the signal quality and even its path. Under these circumstances, actual 4G coverage maps might differ from the ones published by the providers. Therefore it is necessary to foresee these losses and take them into account whenever new base stations are designed.

2. RADIO REFRACTIVITY

All propagating radio waves are affected by the properties of the atmosphere; they can be reflected, refracted, scattered, and absorbed by different atmospheric constituents [5]. In principle, the electromagnetic wave propagation characteristics during quiet or disturbed air conditions are straightforwardly determined by the state of atmospheric refractivity [6]. Various phenomena in the radio wave propagation such as ducting, scintillation, radar acquisition, refraction and fading of electromagnetic waves are due to refractivity variations in the troposphere [7]. In [8] and [9], the radio refractivity N (in N-units) is expressed as:

$$N = (n-1) \times 10^6, \tag{1}$$

where n is an atmospheric refractive index.

When characterizing a radio channel, surface (ground level) and elevated refractivity data are often required; and in particular, the surface refractivity is very useful for prediction of some propagation effects [10]. As was mentioned in [9], the estimation of the refraction effect in troposphere is possible only by modelling the troposphere medium. According to [2, 5, 8] and [11], the expression (2) might well be used for all frequencies up to 100 GHz with an error less than 0.5%. It means that the value of N can be defined only by properties of the troposphere:

$$N = \frac{77.6}{T}\left(p + 4810\frac{e}{T}\right), \tag{2}$$

where T (K) is a temperature; p (hPa) is an atmospheric pressure; e (hPa) is a partial water vapour pressure. Refractivity is dimensionless size and it is expressed in N-units.

The relationship between water vapour pressure and relative humidity is given by:

$$e = \frac{He_s}{100}, \tag{3}$$

where H is a relative humidity (%); e_s is saturation vapour pressure (hPa) at the given temperature. The value of the e_s should be calculated using method specified in [8].

The atmospheric refractivity consists of two parts — a dry term N_{dry} and a wet term N_{wet}:

$$N = N_{\text{dry}} + N_{\text{wet}}. \tag{4}$$

The dry term is due to non-polar nitrogen and oxygen molecules; it is proportional to pressure, p, and therefore, related to the air density [5]. The wet term is proportional to vapour pressure and dominated by polar water contents in the troposphere [5]. The importance of the liquid water and water vapour in the atmosphere, when the measurements are carried in the air, are highlighted in [12].

Lithuania is situated in the intermediate zone between maritime Western Europe, continental Eastern Europe, and Asia climates. Lithuania, being in the transitional geography zone from the Baltic Sea climate to Atlantic and continentals East Europe climate, distinguishes by variable humid climate. Having in mind the variable character of Lithuanian climatic conditions, the influence of the climatic peculiarities on the radio refractivity was analysed in [13] where analysis of the seasonal and daily variations of the atmospheric radio refractivity at the ground surface in Lithuania in the year 2009 is presented.

Model for determination of territorial distribution of surface radio refractivity in the localities, where the data of air presure, temperature, and reliative humidity, are not collected and only meteorological data, measured in the surrounding localities can be used is presented in [14].

3. MEASUREMENTS

The impact of variations of the atmospheric radio refractivity on the reliability of the 4G wireless network (WiMAX technology, IEEE 802.16e-2005 Standard, working frequency 3.5 GHz) was examined. The experiment took place in an area of weak coverage. The long-term measurements were carried out at the same time and place (for measurements scheme see Figure 1).

The weather station and the router were connected to the data logging system. Due to the limitations of the equipment, the measurements from the weather station were continuously logged in 5-minute intervals. The measurements from the router were continuously logged in 1-minute

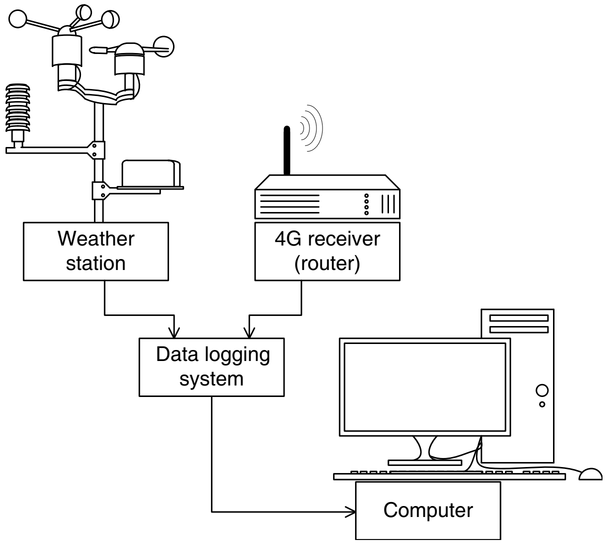

Figure 1: The scheme of the measurement system.

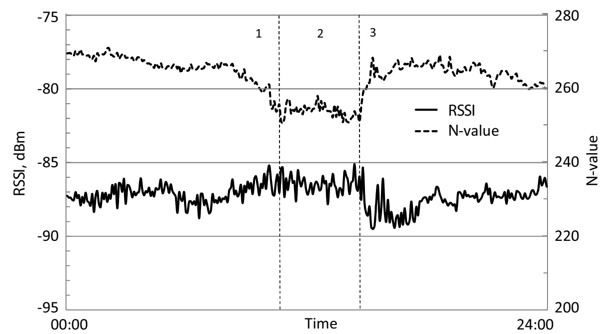

Figure 2: The comparison of variaton of the measured *RSSI*-value and the calculated *N*-value (during twenty-four hour period).

intervals. The data collected in the logging system were processed in the computer. The measured power level strength, *RSSI* (in dBm) [15], of the received signal was compared to the calculated values of atmospheric radio refractivity. The higher the *RSSI*-value, the stronger the signal.

The values of atmospheric radio refractivity, the N-values, were calculated using the (2) equation and measured values of temperature, atmospheric pressure, and partial water vapor pressure.

It was examined if variations of the N-values and changes of signal level occur at the same time.

4. RESULTS AND DISCUSSION

In Figure 2, the measured *RSSI*-values and calculated N-values are compared (during twenty-four hour period). It in obvious, that variations of the N-value coincide with changes of the *RSSI*-value. The graph is divided into three areas, marked as 1, 2, and 3. The boundaries of these areas indicate the tendency, that the increase of the N-value is related to the decrease of the *RSSI*-value, and vice versa.

The comparison of the *RSSI*-value and meteorological factors, included in the (2), revealed, that there is no obvious correlation between the *RSSI*-value and atmospheric pressure. The comparison of the *RSSI*-value with the temperature and relative humidity are presented in Figure 3 and Figure 4, respectively. Although some coincides might be seen, there is no evident correlation. Therefore, it can be concluded, that the changes of the *RSSI*-value are affected by the atmospheric radio refractivity, as combination of the temperature and relative humidity (see (2)).

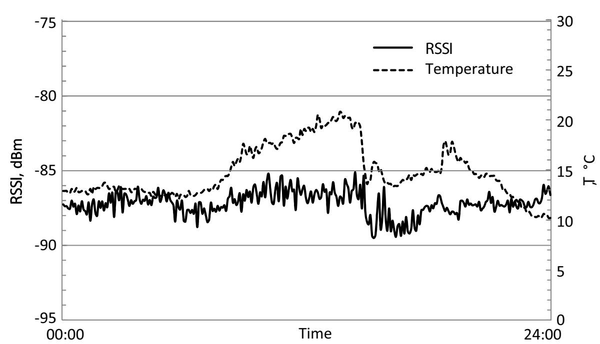

Figure 3: The comparison of variaton of the measured *RSSI*-value and the measured temperature (during twenty-four hour period).

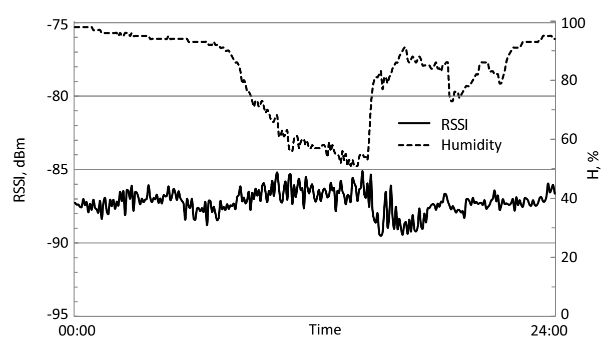

Figure 4: The comparison of variation of the measured *RSSI*-value and the measured relative humidity (during twenty-four hour period).

5. PROSPECTS IN THE THZ FREQUENCY BAND

The analysis of the data showed, that in the regions of poor coverage the level of the 4G signal (WiMAX) is influenced by the variations of the atmospheric radio refractivity, caused by the meteorological factors. Therefore, there is a need for new technological solutions. Prospects appear in the terahertz (THz) frequency band, which has not yet been allocated for specific uses, and is expected to reach up to 100 Gb/s connection speed and eliminate dependence on meteorological conditions. However, there are still unsolved problems, such as the long-distance losses, and the need for high-quality THz sources. In [16], it is suggested, that good candidates for such THz sources could be the resonant tunneling diodes. Since the problem of the long-distance losses remains unsolved, currently the THz communications are more suitable for indoor applications.

The aim of the future works is to foresee possibilities to combine the advantages of 4G technology and THz frequency band, on purpose to reduce the impact of meteorological conditions in the regions of poor coverage.

6. CONCLUSION

In the areas of weak coverage, the 4G (WiMAX technology, IEEE 802.16e-2005 Standard, working frequency 3.5 GHz) signals are strongly influenced by the variations of the atmospheric radio refractivity as a combination of the temperature and relative humidity. Therefore, actual coverage maps might differ from the ones published by the providers. There is a need for new technological solutions in the areas of weak coverage. Prospects appear in the terahertz (THz) frequency band, but there is a need for additional research.

REFERENCES

1. European Commission, "A strategy for smart, sustainable and inclusive growth EUROPE 2020," (http://ec.europa.eu/europe2020/) [retrieved Apr. 7, 2015].
2. Freeman, R. L., *Radio System Design for Telecommunications*, 3rd Edition, Wiley-Interscience, New York, 2007.
3. Maral, G. and M. Bousquet, *Satellite Communications Systems — Systems, Techniques and Technology*, 5th Edition, John Wiley & Sons Ltd., 2009.
4. Information about 4G WiMAX services in Lithuania "Mezon", http://www.mezon.lt/Apie_MEZON/Technologija/ [retrieved Apr. 7, 2015].
5. Ali, S., S. A. Malik, K. S. Alimgeer, S. A. Khan, and R. L. Ali, "Statistical estimation of tropospheric radio refractivity derived from 10 years meteorological data," *Journal of Atmospheric and Solar-Terrestrial Physics*, Vol. 77, 96–103, 2012.
6. Okoro, O. N., G. A. Agbo, J. E. Ekpe, and T. N. Obiekezie, "Comparison of hourly variations of radio refractivity for quiet and disturbed days during dry and rainy seasons at Minna," *International Journal of Basic and Applied Sciences*, Vol. 2, No. 1, 58–63, 2013.
7. Agbo, G. A., "Tropospheric refractivity dependence on atmospheric weather conditions in Jos-Nigeria," *Journal of Basic Physical Research*, Vol. 2, No. 2, 1–6, 2011.
8. "The radio refractive index: Its formula and refractivity data," Recommendation ITU-R P.453-10 (Feb. 2012).
9. Olasoji, Y. O. and M. O. Kolawole, "Seasonal effect on atmospheric refractivity in diverse terrains," *Journal of Environmental Science and Engineering*, Vol. 5, 1537–1541, 2011.
10. Adediji, A. T. and M. O. Ajewole, "Variation of radio refractivity gradient and effective Earth radius factor (k factor) over Akure, South Western Nigeria," *URSI General Assembly and Scientific Symposium of International Union Of Radio Science*, Aug. 2011.
11. Bean, B. and E. Dutton, *Radio Meteorology*, Dover Publications, 1968.
12. Li, J., L.-X. Guo, L.-K. Lin, Y. Zhao, Z. Zhao, T. Shu, and H. Han, "A dual-frequency method of eliminating liquid water radiation to remotely sense cloudy atmosphere by ground based microwave radiometer," *Progress In Electromagnetics Research*, Vol. 138, 629–645, 2013.
13. Zilinskas, M., S. Tamosiunas, M. Tamosiunaite, and M. Tamosiuniene, "Yearly, seasonal and daily variations of radio refractivity," *Acta Physica Polonica A*, Vol. 119, No. 4, 533–536, 2011.
14. Zilinskas, M., M. Tamosiunaite, S. Tamosiunas, E. Brilius, and M. Tamosiuniene, "Model for determination of territorial distribution of surface radio refractivity," *PIERS Proceedings*, 1525–1529, Stockholm, Sweden, Aug. 12–15, 2013.
15. Sauter, M., *From GSM to LTE — An Introduction to Mobile Networks and Mobile Broadband*, John Wiley & Sons, 2011.

16. Ikeda, Y., K. Okada, S. Kitagawa, S. Suzuki, and M. Asada, "Resonant-tunneling-diode oscillator with high-frequency modulation structure for high-capacity terahertz communication," *2014 39th International Conference on Infrared, Millimeter, and Terahertz waves (IRMMW-THz)*, 1–2, Tucson, AZ, Sep. 14–19, 2014.