Statistical characteristics of WiMAX 802.11e signals from the perspective of improving spectrum utilisation

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Abstract—**5G networks promise to provide 1000 times more capacity than existing networks. Among other things this can be achieved by allocation of more spectrum but also through efficient spectrum sharing methods (such as LSA, CBRS). Implementation of dynamic spectrum sharing can be realized if measurements of statistical behaviour of current legacy systems are provided. Obtaining such a statistical analysis will allow to define what is the best way to utilise bandwidth unused by existing systems. Analysis presented in this paper is an exemplary analysis of the use of WiMAX 802.16e in the 3.6-3.8GHz band.**

I. Introduction

It is widely envisaged that the 5G wireless networks have to face with various stringent requirements, widely recognized as 5G *key performance indicators* (KPIs). Based on [1] and [2], the following KPIs can be identified:

- 1000-fold increase in mobile data volume in certain geographical area
- 10 to 100 times higher typical user data rate
- 10 times reduced energy consumption
- reduced end-to-end latency to be below 1 ms
- 10 to 100 times increased number of simultaneously connected devices
- it is assumed that the ubiquitous access will include also low density areas.

Such wide set of requirements entails that the delivery of various classes of services to the end-users will be possible under the umbrella of 5G networks. However, it is also widely foreseen that the practical realization of the above requirements enforces the usage of new technologies and solutions. In that context, an advanced approach to spectrum utilization is envisaged as one of the key technical enablers. One of the possible approach is to utilize new frequency bands higher than 6 GHz (such as centimetre and millimetre waves) due to the possibility of allocation of wide spectrum for short-range technologies. On the other side, flexible utilization of sub-6GHz frequencies is considered as a technical enabler for guaranteeing of long-distance service delivery and better spectrum utilization.

The future of communication networks will be shaped by the requirements imposed by the *5G networking policies* and identified above, that entail the on-going development of new paradigms for flexible yet accurate designs of access and core parts of network architecture. The application of virtualization techniques together with further expansion of software defined (radio) networks are among the possible enablers [3], [4], [5], [6]. Moreover, extremely demanding values of expected data rates, stated in the KPIs, lead to the development of new radio access solutions (such as the utilisation of millimetre waves [7], [8], massive multiple-input multiple-output (MIMO) schemes [9], [10], or new waveforms [11], and to the design of a novel approaches towards spectrum usage and regulation (such as the already mentioned use of higher frequencies and flexible spectrum management allowing for spectrum sharing [12], [13], [14], [15], etc.). The above mentioned effective spectrum management is one of the promising approaches for the success of 5G networks. Given that the spectrum is allocated to different operators, the classical coexistence solutions within the licensed as well as unlicensed spectrum may not provide required isolation. Also, classical approaches based on orthogonal spectrum sharing among operators in licensed bands may be inefficient in future scenarios . In consequence, a new vision for spectrum utilization is required, and it is highly expected that in the context of future wireless communication systems two traditional models of spectrum management and licensing schemes, i.e. exclusive use and license-exempt, will be complemented by more flexible versions. One may notice that numerous solutions to advanced resource sharing have been foreseen so far, such as infrastructure sharing (as in multi-operator core network, MOCN, approach), licensed shared access (known as LSA, and standardized in Europe by ETSI for 2.3-2.4 GHz band [16]) or three tier sharing model (promoted in USA for band 3550 - 3700 MHz, and known as citizen broadband radio service with spectrum access system, CBRS/SAS [17]). However, practical implementation of these standards is still in the trial phase, and numerous field-tests and experiments have to be conducted to verify the applicability of the proposed solutions. At the same time, network operators would like to maximize their revenues from the already deployed infrastructure. One particular example is the utilization of 3.5 GHz band for new wireless communication systems, as this is the band already allocated for such systems as WiMAX. As the LTE/LTE-A technology has in some sense supersedes the WiMAX networks, the number of clients connected to that network is continuously going down. So, even though family of WiMAX standards is not part of 5G and moreover it is considered as dead, these networks still operate and occupy radio spectrum resources. However, the radio resources associated with the WiMAX technology may be also shared with other technologies. In general, future 5G radio systems may need to share radio spectrum with legacy radio systems such as WiMAX. It is then important to analyse the real characteristics describing the existing systems, and draw conclusions regarding prospective utilization of WiMAX frequency bands for 5G purposes. In our paper we have made an initial field analysis on the key parameters of the WiMAX system which have to be considered while deploying the new radio systems. In that context, the analysis presented in the rest of this paper may be especially useful for operators which need to keep their WiMAX networks running for the next years, but in the mean time want to utilise allocated spectrum in more efficient way by sharing it with other radio systems.

The reminder of the paper is organized as follows: in Section II we present briefly the WiMAX deployment within the INEA network, and we discuss its key system parameters and the considered spectrum sharing. The two consecutive sections discuss results of the long-term (two years) and short-term (two weeks) observations. Sec. V concludes the paper.

II. Considered Spectrum Sharing Scenario

A. WiMAX deployment at INEA

INEA is the largest regional fixed-access telecommunications operator in the Greater Poland Voivodeship and provides advanced multimedia services to over 250,000 of homes, businesses, and institutions through different access mediums and technologies, i.e., Hybrid Fibre-Coaxial (HFC), Gigabit Passive Optical Network (GPON), point-to-point Carrier Ethernet optical fibres, IEEE 802.16e WiMAX [18], IEEE 802.11 Wi-Fi [19], as well as, twisted pair based xDSL and IEEE 802.3 Ethernet.

In 2010, INEA S.A. decided to roll-out new WiMAX-based services aimed to meet the needs of home users across the Greater Poland region of western Poland. It was decided to follow the 802.16e-2005 [20] standard and the time division duplexing (TDD) mode that offer the ability to adjust the downlink / uplink ratio and thus are well suited for data transmission. After an extensive testing period of equipment from various vendors, engineers at INEA have chosen the Motorola (currently, Cambium Networks) PMP320 solution because it is compact and its components are space- and energy-efficient. The company choice was also influenced by its simple operation, management and installation, which ensured low costs of ownership. So far, this deployment has provided fast and affordable connectivity for Internet and telephony services to almost 6000 households across the 30,000 sq km region.

B. WiMAX Parameters

In this paper we have focused on the WiMAX signal parameters which mostly affect system capacity. Knowledge of a statistical behaviour of these parameters may allow coexistence of two or more systems in the same spectrum space in order to share available radio resources.

Capacity in a WiMAX network is not fixed [21]. Each customer-premises equipment (CPE) operates with spectral efficiency that changes in time and is influenced by three parameters: modulation, forward error correction (FEC) coding and MIMO mode. Therefore, the network capacity of a given access point (AP) is a function of the number of CPEs and their spectral efficiency. For example, if one CPE operates with modulation of 64-QAM, then its spectral efficiency is 6 bits/s/Hz. If it is using 5/6 FEC, then the spectral efficiency is reduced to 5 bits/s/Hz, whereas for MIMO-B, then its spectral efficiency is doubled and reaches about 10 bits/s/Hz. The three parameters: modulation, FEC coding and MIMO mode are mostly affected by carrier to interference and noise ratio (CINR) values. Therefore, the following analysis are focused on statistical changes in CINR.

C. Spectrum Sharing of 3.5 GHz resources

As it has been mentioned, it is in general economically justified for the network operator to maximize its revenue from the existing infrastructure and acquired spectrum licenses. If it would be possible to either offer new services by means of the existing infrastructure or utilize available spectrum resources in more efficient way, such approach will be highly beneficial to the network operator. In INEA case, we consider the second option, as the WiMAX network has to be kept alive and must be protected (as the highest priority, incumbent network), the question to be answered is the following: can we deploy other services, in particular microwave lines or other point-to-point transmissions, that will operate at 3.5 GHz band? In order to make such a solution practically applicable, stable methods for protection of incumbent (WiMAX) network from harmful interference have to be implemented. However, this will be only possible, if the key operating parameters that describes the behaviour of WiMAX network will be precisely identified. For example, in order to calculate the impact of the induced interference originated from the new network to the WiMAX network, one needs to know what are the required average values of SINR observed in UL and DL in the WiMAX system. However, it is also important to analyse the potential changes of these parameters as a function of time. Thus, having in mind the main goal of this work, which is the future coexistence of two wireless systems operating in the same frequency band, we have focused in our study on the analysis of the changes of measured RSSI and CINR values as the function of time. Two approaches have been tested, i.e., we analysed

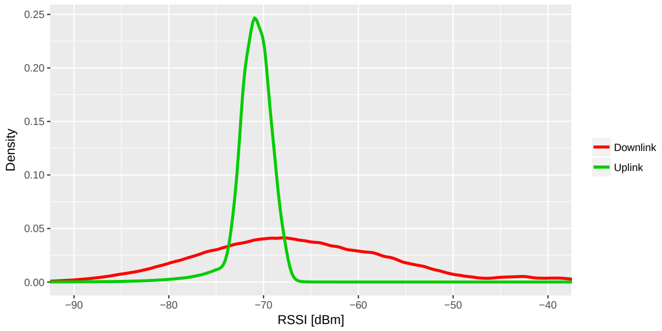

Figure 1. Distribution of RSSI

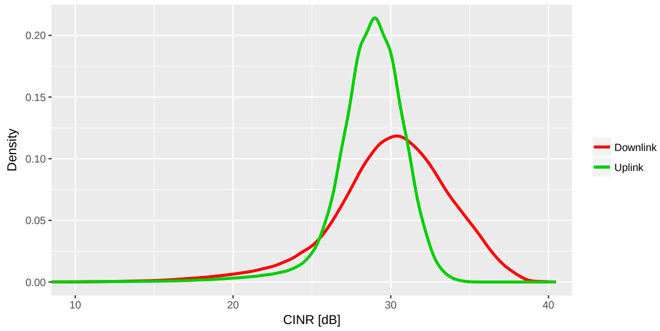

Figure 2. Distribution of CINR

two years long observations to detect the long-term trends, and also discussed it in the context of short, two-weeks long measurement campaigns.

III. Two years long signal observations

At INEA every customer device is queried using Network Diagnostics System every hour in order to collect statistical data about the quality of the connection. These queries are typically performed using Simple Network Management Protocol (SNMP). The results are stored for at least one year. In the case of WiMAX network we were able to obtain data for last two years, covering period form April 2015 till April 2017. This data provided us with information collected from about 6000 CPEs. It included network parameters (such as MAC address, IP address, Base Station ID) and two PHY layer signal parameters:

- Received Signal Strength Indicator (RSSI) for both downlink and uplink
- Carrier to Interference and Noise Ratio (CINR) for both downlink and uplink

First of all we have verified how RSSI and CINR values are distributed. Therefore in Figure 1 we have plotted distribution of RSSI values in Downlink (DL) and Uplink (UL) direction. It can be observed that DL RSSI values are spread across wide range of values from -50 dBm to -90 dBm, with the mean value at -66 dBm; the UL RSSI values are located very close the the mean -71 dBm. This can be explained by transmit power control mechanism implemented on uplink. The WiMAX access point implements power control in order to mitigate path loss, shadowing, etc. The WiMAX access point is configured with a target RSSI values, which for INEA is set at -71 dBm. WiMAX access point instructs all the connected CPEs to adjust their TX power in order to meet the target RSSI value. Therefore, the RSSI values are located close to the mean value which in turn is equal to configured target RSSI value. In downlink each access point transmits at maximum power, therefore all the DL RSSI values are proportional to the path loss, shadowing, etc. Thus, the range of values for DL RSSI is much wider than for UL RSSI.

In Figure 2 we have shown CINR density function. CINR follows similar trends like RSSI, and DL values occupy much wider range than UL. We can observe that DL CINR values are ranging from 15 dB to 40 dB, with mean at 30 dB. While most UL CINR values are located within range from 25 dB to 33 dB, with mean at 28.5 dB.

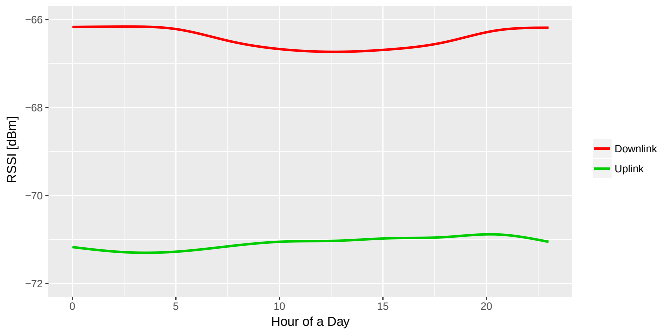

Figure 3. Average RSSI (dBm)

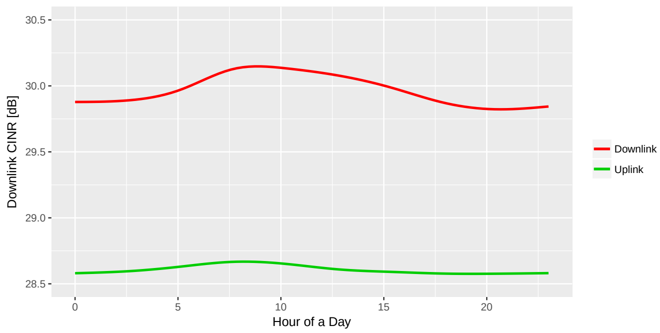

Figure 4. Average CINR (dB)

Moreover, we have analysed how signal parameters vary for an average day (calculated as an average for all the CPEs during the two year observation period). Therefore, in Figures 3 and 4 we have plotted average RSSI and CINR values during a day. We can observe that the values oscillate around mean values. The variation is much smaller for UL parameters than for DL. Moreover, one can observe that DL RSSI values are inversely proportional to typical temperatures trend.

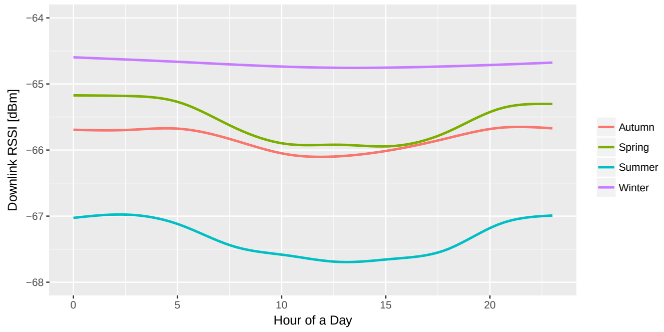

Figure 5. Average RSSI (dBm) for each season

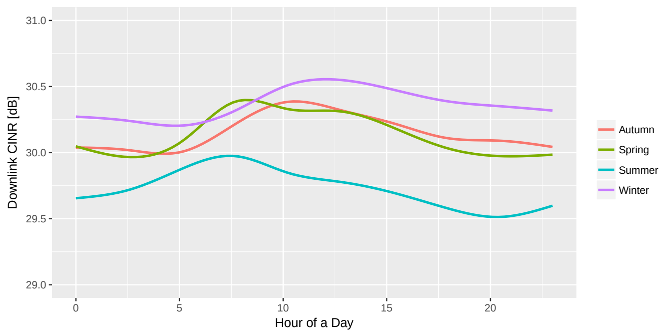

Figure 6. Average CINR (dB) for each season

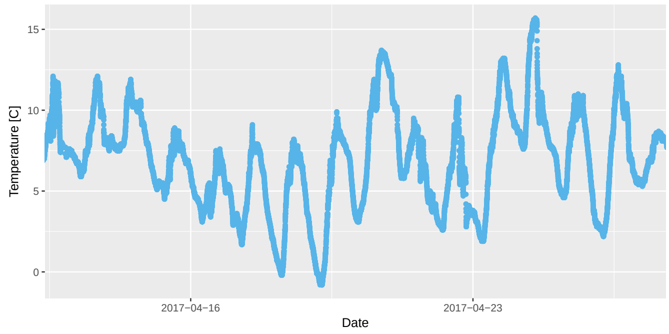

Figure 7. Temperature for the two weeks period

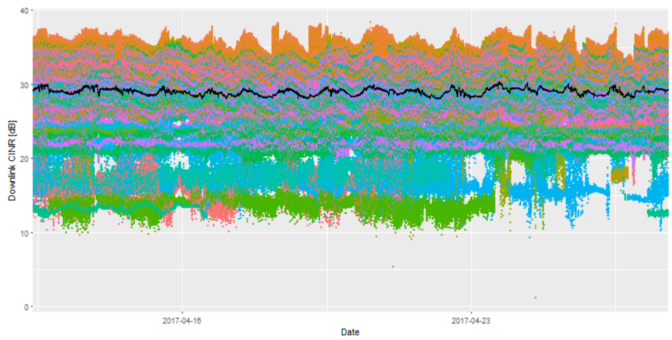

Figure 8. DL CINR for the two weeks period

In order to verify that there is any correlation between the RSSI values and temperature, we have plotted in Figure 5 RSSI and in Figure 6 CINR for downlink for different seasons of the year (calculated as an average for all the CPEs during given season for the two year observation period). Indeed Figure 5 suggests that there is an inverse correlation between RSSI and temperature, because highest RSSI values can be observed during winter, while in spring and autumn RSSI values are lower and also exhibit an significant decrease during day hours. In summer the RSSI values are lowest.

Figure 6 shows ambivalent trends. On one hand, in each season there is a CINR increase during a mid day. However, also in summer the CINR values are lowest, and highest in winter.

IV. Two weeks long signal observations

Since two years of observations presented in previous section did not exhibit clear correlation of CINR values with temperature, we have decided to capture more dense data from WiMAX network and also combine it with humidity and temperature values from PIMR Weather station[1]. In this experiment we have used 200 CPEs located in close proximity to PIMR weather station. Each CPE was queried using SNMP every minute during two week period from from 14th of April 2017 till 28th of April 2017. In this way, we have collected information about :

- RSSI for both downlink and uplink
- CINR for both downlink and uplink
- average throughput [kbps] for both downlink and uplink
- modulation and coding scheme (MCS) index for both downlink and uplink
- TX power for uplink
- temperature
- humidity.

For example in Figure 7 we demonstrate varying temperature values during this two weeks period.

Due to frequent and transient changes of CINR and RSSI we have decided to calculate mean values of RSSI and CINR over all the 200 CPEs. These mean trend lines as well as data points for each minute within these two weeks for all CPEs are shown in Figures 8 and 9. On both diagrams each of the 200 CPEs was assigned with a different colour and the black line in the middle represents mean value for all the CPEs. The mean line exhibits trends which are not specific to any given CPE but to the whole network under consideration.

A. *Parameters correlation*

In order to analyse correlation between CINR, RSSI and other network and environmental parameters we have plotted correlation matrix, shown in Figure 10. This correlation matrix presents Pearson correlation between all pairs of parameters.

Analysis of the correlation matrix provides some interesting insights such as:

[1]measurement available at http://www.pimr.poznan.pl/bup/gethd2003.php

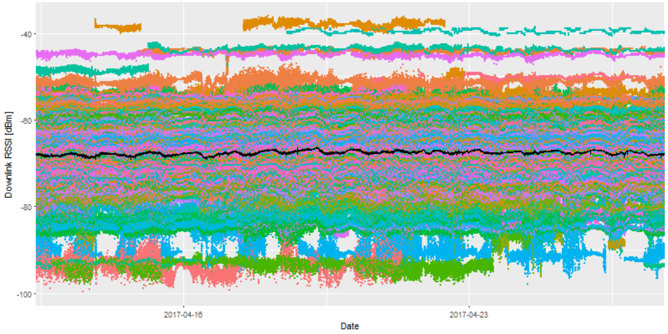

Figure 9. DL RSSI for the two weeks period

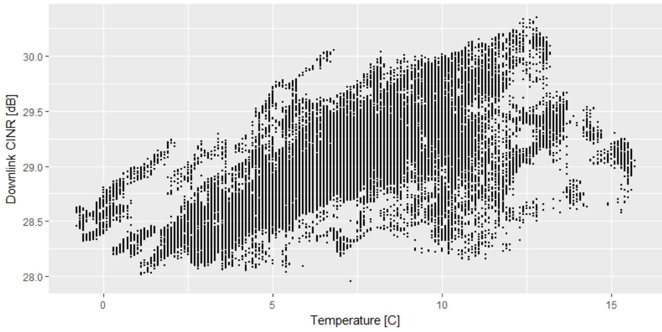

Figure 11. Temperature vs DL CINR

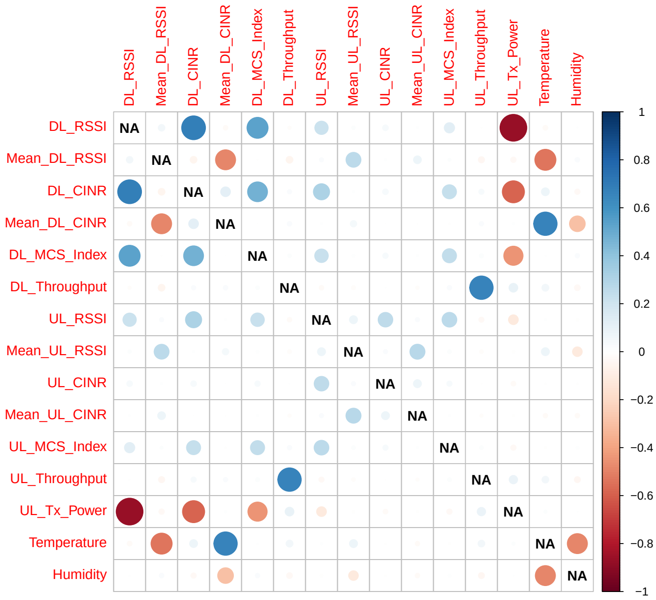

Figure 10. Correlation matrix

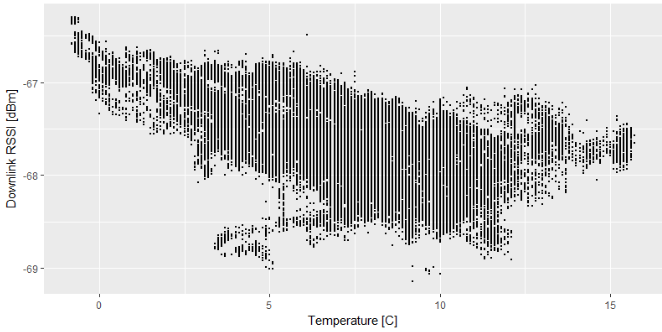

Figure 12. Temperature vs DL RSSI

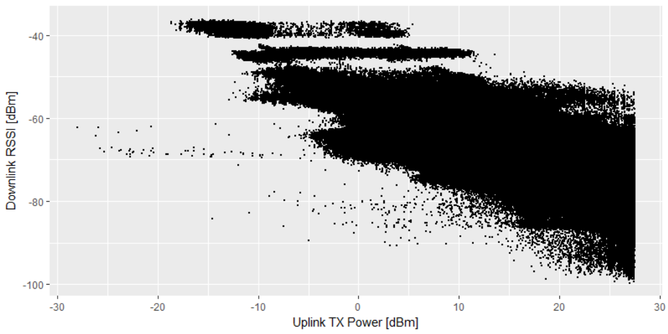

Figure 13. UL TX Power vs DL RSSI

- mean DL CINR exhibits positive correlation with temperature and negative correlation with Humidity and Mean DL RSSI
- mean DL RSSI exhibits negative correlation with temperature and Mean DL CINR
- mean DL RSSI seams to affect DL CINR and DL MCS Index
- mean DL CINR also seams to affect DL MCS Index
- DL Throughput is correlated with UL Throughput (since TCP required communication in both directions)
- most of uplink parameters do not demonstrate any strong correlation with any other parameter, except of uplink TX Power which affects DL RSSI, DL CINR and DL MCS Index. We consider this finding as the most intriguing, since we cannot identify any reason for such an behaviour. TX Power on the uplink is controlled by adaptive power control, and it should mitigate path loss and shadowing on the uplink, without affecting downlink parameters.

To further investigate correlation between parameters in Figures 11, 12 and 13 we have plotted three pairs of parameters exhibiting highest correlation. In Figure 11 we can observe positive DL CINR correlation with temperature. In Figure 12 we can observe negative DL RSSI correlation with temperature. In Figure 13 we can observe negative DL RSSI correlation with uplink TX Power. The three figures indeed show almost linear correlation trend with some limited variations.

V. Conclusion

In this paper, we have presented statistical characteristics of WiMAX 802.11e signals from the perspective of improving spectrum utilisation by means of simultaneous use of given frequency bands by two wireless systems. As interference will play key role in such a scenario, in our discussion we have revealed what are the changes of RSSI and CINR parameters as a function of time. Based on the achieved results one can draw the following conclusion – there is a direct correlation between, first, the observed mean RSSI and CINR values, and second, time season and phase of a day. However, in the context of season changes, these changes are rather negligible (in terms of around 1 dB), and in practice appropriate interference margin can be included to reflect these changes. On the other hand, there are high variation of observed RSSI and CINR changes but observed in a shorter time scale and analysed per CPE (not per network, as the average RSSI and CINR per network are again more or less stable). These may reach even up to some dB, and such a change has to be taken into consideration while deploying the new wireless network. Finally, the specificity of WiMAX system (i.e., power steering in UL) entails that the system will adjust to the changes in ambient environment in UL, probably without any loss in average RSSI or CINR. The key problem will be there in DL, and for that situation one may need to apply careful network planning algorithms.

This analysis demonstrated that some changes in transmission parameters are natural even in the fixed/stationary WiMAX network that INEA operates. It is also worth to point out that spectrum sharing requires long measurements of the characteristics of the radio system (WiMAX in the presented case) in order to identify limits and characteristics of the signal. For example, a deterioration in CINR values may not necessarily be due to interference from the secondary spectrum user. It may even be due to the ambient temperature as shown in the article.

As it has been stressed, even though currently the WiMAX technology is said to be dead, these networks still operate and occupy radio spectrum resources. Moreover, they have to be maintained due to the legal commitments to the clients. Therefore presented analysis may be useful for operators which need to keep their WiMAX networks running for the next years, but in the mean time plan to utilise allocated spectrum in more efficient way by sharing it with other radio systems.

Acknowledgment

The work has been funded by the EU H2020 project COHERENT (contract no. 671639).

References

[1] 5GPPP, "What Will The 5g-Infrastructure-PPP Deliver?." https://5g-ppp.eu/kpis/.

[2] 5GPPP, "5G Vision The 5G Infrastructure Public Private Partnership: the next generation of communication networks and services." https://5g-ppp.eu/wp-content/uploads/2015/02/5G-Vision-Brochure-v1.pdf, 2015.

[3] C. Liang and F. R. Yu, "Wireless Network Virtualization: A Survey, Some Research Issues and Challenges," *Communications Surveys & Tutorials, IEEE*, vol. 17, no. 1, pp. 358–380, 2015.

[4] I. Khan, F. Belqasmi, R. H. Glitho, N. Crespi, M. Morrow, and P. Polakos, "Wireless sensor network virtualization: A survey," *CoRR*, vol. abs/1503.01676, 2015.

[5] A. Blenk, A. Basta, M. Reisslein, and W. Kellerer, "Survey on network virtualization hypervisors for software defined networking," *CoRR*, vol. abs/1506.07275, 2015.

[6] Y. Li and M. Chen, "Software-defined network function virtualization: A survey," *IEEE Access*, vol. 3, pp. 2542–2553, 2015.

[7] T. Rappaport, R. Heath, R. Daniels, and J. Murdock, *Millimeter wave wireless communications*. Prentice Hall, 2015. Includes bibliographical references (pages 585-651) and index.

[8] S. Kutty and D. Sen, "Beamforming for millimeter wave communications: An inclusive survey," *IEEE Communications Surveys and Tutorials*, vol. 18, no. 2, pp. 949–973, 2016.

[9] M. Agiwal, A. Roy, and N. Saxena, "Next generation 5g wireless networks: A comprehensive survey," *IEEE Communications Surveys and Tutorials*, vol. 18, no. 3, pp. 1617–1655, 2016.

[10] T. L. Marzetta, "Noncooperative cellular wireless with unlimited numbers of base station antennas," *IEEE Trans. Wireless Communications*, vol. 9, no. 11, pp. 3590–3600, 2010.

[11] P. Banelli, S. Buzzi, G. Colavolpe, A. Modenini, F. Rusek, and A. Ugolini, "Modulation formats and waveforms for 5g networks: Who will be the heir of ofdm?: An overview of alternative modulation schemes for improved spectral efficiency," *IEEE Signal Process. Mag.*, vol. 31, no. 6, pp. 80–93, 2014.

[12] M. Mustonen, M. Matinmikko, M. Palola, S. Yrjölä, and K. Horneman, "An evolution toward cognitive cellular systems: licensed shared access for network optimization," *IEEE Communications Magazine*, vol. 53, no. 5, pp. 68–74, 2015.

[13] A. Kliks, O. Holland, A. Basaure, and M. Matinmikko, "Spectrum and license flexibility for 5g networks," *IEEE Communications Magazine*, vol. 53, pp. 42–49, July 2015.

[14] H. Bogucka, P. Kryszkiewicz, and A. Kliks, "Dynamic spectrum aggregation for future 5g communications," *IEEE Communications Magazine*, vol. 53, pp. 35–43, May 2015.

[15] R. H. Tehrani, S. Vahid, D. Triantafyllopoulou, H. Lee, and K. Moessner, "Licensed spectrum sharing schemes for mobile operators: A survey and outlook," *IEEE Communications Surveys and Tutorials*, vol. 18, no. 4, pp. 2591–2623, 2016.

[16] ETSI, "Reconfigurable Radio Systems (RRS); System requirements for operation of Mobile Broadband Systems in the 2 300 MHz - 2 400 MHz band under Licensed Shared Access (LSA)." https://5g-ppp.eu/wp-content/uploads/2015/02/5G-Vision-Brochure-v1.pdf, Oct 2014. TS 103 154 V1.1.1.

[17] FCC, "Order on reconsideration and second report and order in the matter of amendment of the commission's rules with regard to commercial operations in the 3550-3650 MHz band." http://transition.fcc.gov/Daily_Releases/Daily_Business/2016/db0502/FCC-16-55A1.pdf, May 2016. FCC 16-55.

[18] K. Kowalik, D. Dudek, M. Kołodziejski, B. Musznicki, E. Grzybek, and J. Jarzina, "Lessons Learned from WiMAX Deployment at INEA," *Journal of Telecommunications and Information Technology*, pp. 34–41, September 2014. http://www.itl.waw.pl/czasopisma/JTIT/2014/3/34.pdf.

[19] P. Walkowiak, R. Szalski, B. Musznicki, D. Dudek, K. Kowalik, and P. Zwierzykowski, "Evaluation of CARMNET System in INEA HOTSPOT Network," in *Proceedings of 2014 IEICE ICTF, Information and Communication Technology Forum*, (Poznań, Poland), 28–30 May 2014. http://i-scover.ieice.org/proceedings/ICTF/2014/pdf/ALIEN-4.pdf.

[20] "IEEE standard for local and metropolitan area networks part 16: Air interface for fixed and mobile broadband wireless access systems amendment 2: Physical and medium access control layers for combined fixed and mobile operation in licensed bands," tech. rep., 2006.

[21] C. So-In, R. Jain, and A.-K. Tamimi, "Capacity evaluation for ieee 802.16e mobile wimax," *J. Comp. Sys., Netw., and Comm.*, vol. 2010, pp. 1:1–1:12, Jan. 2010.

* All websites accessed on 24 April 2017, if not stated otherwise.