Lessons Learned from WiMAX Deployment at INEA

Karol Kowalik[1], Dawid Dudek[1], Michał Kołodziejski[1], Bartosz Musznicki[1], Eugeniusz Grzybek[1], and Jacek Jarzina[2]

[1] *INEA S.A., Poznań, Poland*
[2] *Tele-Com Sp. z o.o., Poznań, Poland*

Abstract—Home broadband access is continuously demanding more bandwidth fueled by video streaming, entertainment and gaming applications. In 2010, a company INEA decided to roll-out new WiMAX-based services aimed to meet the needs of home users across the Wielkopolska region of western Poland. It was decided to follow the 802.16e 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 around 5,500 households across the 30,000 sq. km region. After 3 years of experience, INEA would like to share the lessons learned from this roll-out.

Keywords—interference, radio capacity, radio planning, WiMAX.

1. Introduction

Currently mobile WiMAX, as defined by the IEEE Standard 802.16e-2005 [1], is a well-established wireless technology for providing both fixed and mobile access. In Poland, most of WiMAX deployments use 3.400–3.800 GHz band. This follows a decision to publish a public tender for 3.5 MHz channels from 3.600–3.800 GHz band issued by President of the Office of Electronic Communications (UKE in Polish) in 2007 [2]. The Marshal Office of the Wielkopolska Region decided to participate in this public procurement, and is currently sharing its channels with the local operators: INEA, Promax, and ASTA-NET. Despite the fact that the 802.16e standard supports mobile access, the Polish WiMAX networks provide only fixed or nomadic access. This is due to high cost of achieving coverage that would offer mobile access in 3.600–3.800 GHz band.

Since 2010 INEA has started to roll-out its WiMAX 802.16e network. The network is based on the Motorola (currently Cambium Networks) PMP320 solution and supports mostly data and VoIP transmissions. An example of INEA's base station is presented in Fig. 1.

As it is shown in Table 1, the INEA WiMAX network currently supports 5,500 users. The network consists of 72 WiMAX stations and 252 access points (AP) being in-

Fig. 1. One of INEA's WiMAX base station.

Table 1
INEA WiMAX network in numbers

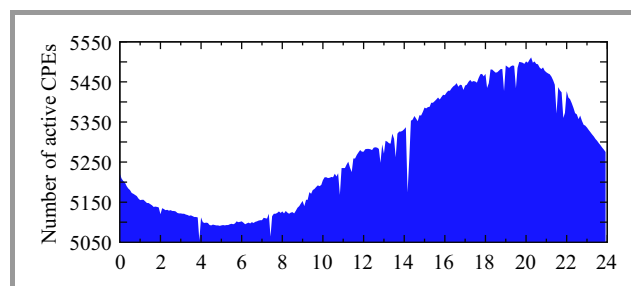|	In total	In Poznań
Stations/Towers	72	11
Access points/Sectors	252	32
CPEs	5500	1000
Average CPEs per AP	22	30

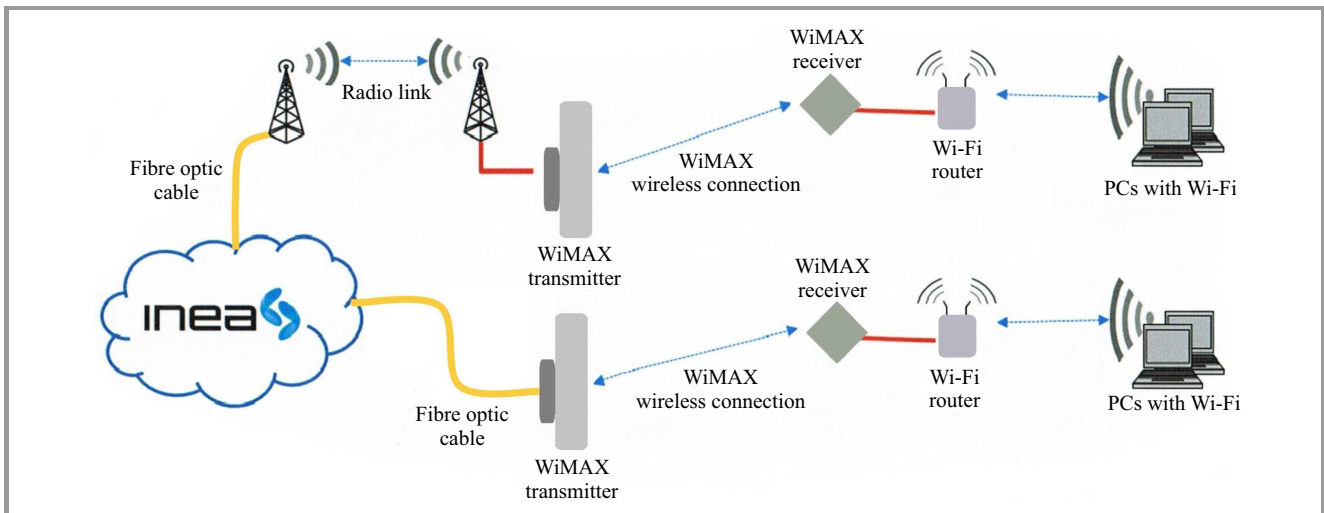**Fig. 2.** Number of active CPEs (users) within 24 hours on 26 January 2014.

Fig. 3. General topology of INEA WiMAX network.

stalled across the region, which gives the average number of 22 clients per AP. In the city of Poznań it provides services to more than 1,000 clients, using 11 base stations with 32 AP. Figure 2 shows the changes in the number of active users within 24 hours.

The connection between our core network and the WiMAX station is executed either using a microwave link or optical fiber connection. The latter option is most commonly used by INEA, since it is more stable and resilient. The base station realized using Cambium Networks PMP 320 products is composed of: Cluster Management Module 4 (CMM4), GPS antenna, and a number of access points with attached antennas. The CMM4 is a managed L2 (or L3) device that provides power and GPS synchronization for APs. Physically, it consists of two separate devices: EtherWan and Motorola CMM. EtherWan has 12 FE (Fast Ethernet) ports and 2 GE (Gigabit Ethernet) ports.

PMP 320 AP is a Layer 2 (or Layer 3) device and it has a 90 degree antenna attached. The configuration of Transmit/Receive Transition Gap (TTG) and Receive/transmit Transition Gap (RTG) guarantees to achieve a maximum range of 15 km for 7 MHz channel. The definitions of INEA's set of service flows are stored on each and every AP.

Customers are provided with Cambium Networks 3630SM (or 3530SM). This CPE (Customer-Premises Equipment) is a Layer 2 (or Layer 3) device controlled by SNMP and HTTP. The device allows to achieve maximum throughput of 11/5 Mb/s. Customers also have the ability to use VoIP services using dedicated ertPS (Extended Real-Time Polling Service). This service is realized using Linksys SPA2102 VoIP gateways. A diagram of the network is shown in Fig. 3.

In this paper the technical lessons learned from the roll-out are presented. The article does not intend to present any procedural or psychological challenges which the authors needed to overcome in order to allow INEA – cable operator to introduce wireless technology into its portfolio.

Despite quite extensive number of research papers [3]–[11] which evaluate theoretical performance or present system level analysis of WiMAX systems, authors of this paper are not aware of similar deployment analysis being published so far.

2. Radio Planning

Radio planning is an essential aspect of maintaining optimal network coverage and capacity. In real WiMAX networks, especially in high density areas, radio planning is a major challenge for the operator. Before setting up each station, radio planning should at least consist of the following elements:

- a determination of the total coverage of each base station and each of its sectors separately,

- a preparation of the list of addresses in coverage area of each base station (BS),

- channel allocation for (new or changed) sectors of each station,

- a determination of (or a change in) the set of radio parameters for each coverage sector: azimuth, tilt and other constraints if applicable.

The key task is to choose a proper method for a determination of areas to be served by each radio station (access point). This procedure is called a "coverage prediction", but the term is rather meant to denote the use of one of commonly used propagation algorithms and models. Previous studies (e.g. [3], [6], [7], [9]) have show that commonly known algorithms cannot be simply used for WiMAX networks. Summarizing the conclusions of mentioned papers, for gigahertz bands and WiMAX standard some of the algorithms give results close to real performance in urban area while others in suburban or rural area. The key point is modeling the path loss in LOS and NLOS condition:

each of the models under studies (Ericsson 1999, COST, Free Space, Okumura, SUI and other) should be used for well defined signal path conditions – either LOS or NLOS. But in real life scenario both propagation conditions occur simultaneously for each access point sector. Over the last three years even the authors have been continuously working on improving the propagation models (starting from ITU-R P.1546 and ITU-R P.1812, SUI [4]). Despite the three-year effort, the real live conditions didn't match with the theoretical results.

Hence, INEA's radio planning team was forced to create its own unique procedure of finding service areas round the station. The procedure nowadays uses as a basis a combined model composed of a modified free space model and a diffraction term in order to match real-live installation success and failure rates.

Having taken into account signal levels measured by terminals (CPEs) installed in different locations, including different cities, towns and villages, the team were in position to construct a useful algorithm based on an algorithm previously constructed and a selected model parameter list. The basis for the model was provided by one of broadcast models used in Germany [12]. Because of various installation and propagation conditions, such a model obviously does not give accurate results, but thus prepared prediction is good enough to become a basis for acquiring new subscribers in a given area. To minimize the risk of launching a marketing action in a wrong part of the area, it was divided into two sub-areas: the zone near the station, where the probability of good reception (in both directions of transmission) is high, and the outer ring, where the risk of unsuccessful installation is higher, but still there are reasonable grounds for an attempt to acquire new subscribers. In Fig. 4 both areas are depicted in two shades of gray. The described method for a determination of the coverage around each station gives surprisingly good results.
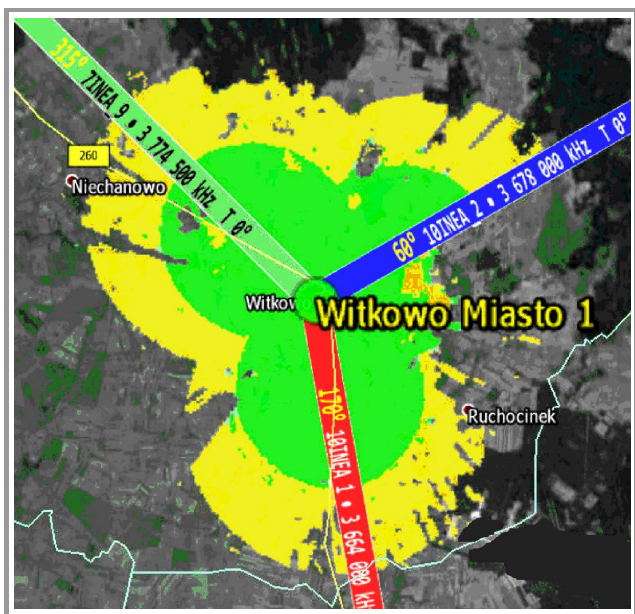

Fig. 4. Example of results of coverage prediction.

Another set of radio planning issues is the channels allocation for each sector. This is relatively simple for rural sites, or generally for sites located far away from other stations using the same channels. In such cases the network may use the widest possible radio channels provided by the equipment (PMP320 AP and CPE), i.e. 10 MHz. A wide channel provides high throughput for subscribers but, at the same time, has some disadvantages as well. The basic quantum of spectrum given by the regulatory office is 3.5 MHz. Thus, for 10 MHz useful spectrum a four such basic neighboring elements were used, which means that $4 \cdot 3.5 - 10 = 4$ MHz (two sections of 2 MHz each) remains unused. In very dense areas the problem is not trivial, because the channel allocation layout may look like the one depicted in Fig. 5 where the same radio channels use the same hue.
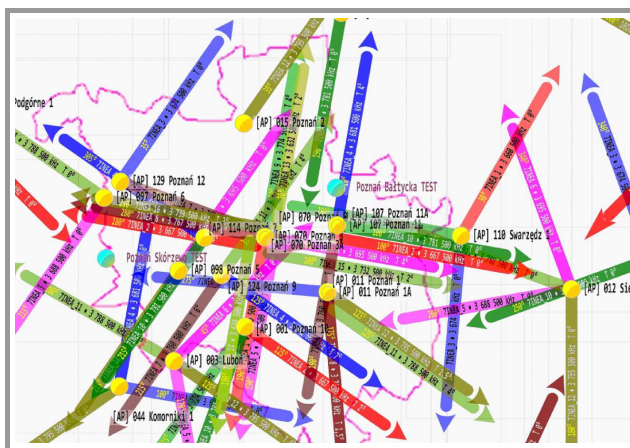

**Fig. 5.** Example of a dense network in large urban area of Poznań.

In such cases the 4 MHz of spectrum can not be wasted, as described above. Therefore, the authors had to decide to narrow the WiMAX radio channels down to 7 MHz. Fortunately, it still can provide the same throughput for a single subscriber as the 10 MHz channel, and the use twice as many channels as before is possible. Moreover, we have experienced that, thanks to good characteristics of the currently used WiMAX radio equipment, the use two neighboring "halves" of previous 14 MHz block for two sectors of the same station – even if their azimuths are relatively close to each other is still possible.

The introduction of each new station to the network might force some relocation of existing radio channels. Such changes should be performed with care. The issue is not difficult if a new station is created in the area so far unsupported. In some cases, however, a rapidly growing number of subscribers forces us to built a new station (or a new sector on the same location, parallel to the existing one). Sometimes the expansion can be predicted, so particular channels were often reserved for it in advance. In some areas the services offered by INEA are so attractive that the number of subscribers grows much faster than it is expected. It is always good news, but it might necessitate

a total reconstruction of the radio channel network in the whole urban agglomeration. Interestingly enough, that such situations occur usually in large centers, such as Poznań and Konin, that already have good wire-line infrastructure in place and thus can hardly be regarded as having no existing access to the Internet (being thus a potential market for wireless services).

Each new WiMAX station in dense population areas, with existing WiMAX stations and subscribers, causes changes of assignments to a service station for many of the CPEs. If a new station is located so that the direction from subscriber location toward the old and the new station is almost the same, such a reassignment is straightforward. However, if both directions differ significantly (for instance, the difference exceeds a change in signal levels of 2 dB, taking into account the antenna patterns and change in the distance between CPE and AP), we should try to rotate the subscriber terminal antenna in a new direction. In some cases it is not possible, or too expensive, so the subscriber must remain with the assignment unchanged. The above describes one of existing limitations of the network optimization.

When a radio network grows, the possibility of co-channel interferences grows up as well. To avoid this as early as at the planning stage of the radio channels assignment, we have to take into account interference range prediction. For this purpose the ITU-R P.1546 algorithm that yields reasonable results is still used. Figure 6 shows an
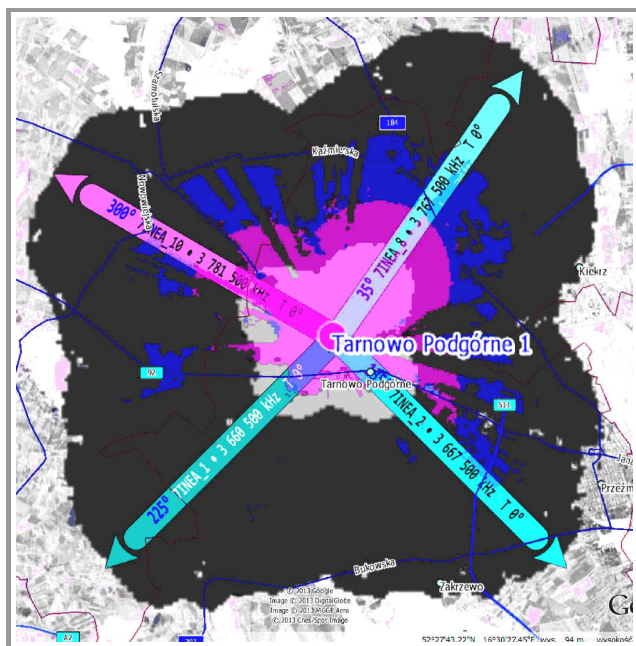
Fig. 6. Predicted interference areas for non-synchronized (other than our own) networks and for the own network of the operator.

example of interference range prediction for a typical four-sector WiMAX station compared with useful coverage of the same station (light gray areas in the center, for explanation see above comments). Light and dark gray regions distinguish between non-synchronized co-channel interference areas and the synchronized ones.

The interference problem is particularly important in high density areas (Poznań, Konin, further expected), not only because of the density of deployed stations. Because of the method of changing CPEs assignment described earlier, after creating a new station the operator should reassign a significant part of subscribers to the new site. As stated earlier, it is possible only for a fraction of existing CPEs. As a result, there still exist terminals associated with a "far away" station using channel interfering with the same channel used in a "near" station. In high density areas neighboring stations are located only a few kilometers apart, so this situation is relatively frequent. For such areas the radio planning team prepares a special "good assignment" map that shows areas of service for each particular sector. The operator should try to force all the terminals located in particular area to use an appropriate sector. It helps the operator keep the interference risk as low as possible. Figure 7 shows an example of the described "good assignment" map.
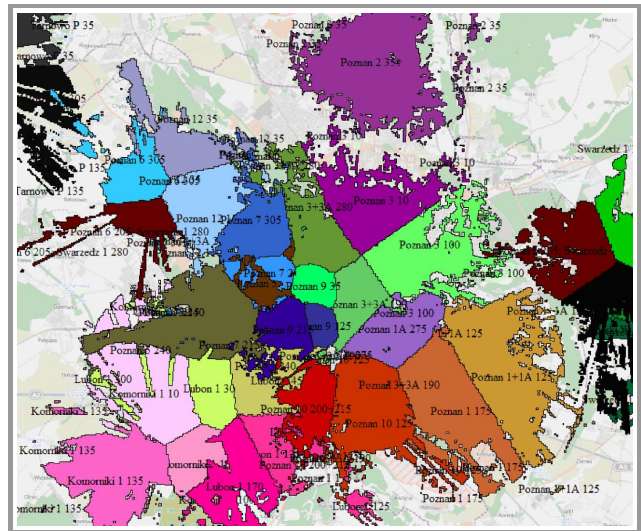
Fig. 7. "Good sector assignment" chart of Poznań urban area.

Lessons learned:

- although for the WiMAX network, where the propagation path looks very different for each CPE and there is no single algorithm for determining coverage, a reasonable method for a prediction of a serving area for each sector and radio station have been found;

- in some areas saturation of a sector occurs faster than expected – we may support the sector with the parallel one, but a better solution is to predict such situation in the initial study phase; otherwise some problems with network optimization and radio channels resources may ensue;

- WiMAX network expansion is favorable for the operator and the subscribers; in dense areas, interference during switching the CPEs into a new station are hard to avoid. The radio planning team should cooperate with network administrators in determining all the possible conflicts.

3. Interference

Interference is often identified as a key cause of performance degradation in wireless networks [5], [8]. In presented network the GPS synchronization to eliminate self-interference between neighboring APs is used. Nevertheless, the network still requires a careful radio planning in order to minimize self-interference. At the time, this was a particularly pronounced problem when the number of base stations in Poznań is increased.

In [13], the vendor of the PMP320 platform provides insights into what needs to be done in order to minimize interference. Among others, the following actions that help reduce interference, are listed [13]:

1. AP down-tilt,

2. Lower AP transmit power,

3. Re-orienting AP sectors,

4. CPE up-tilt to tower on especially short links as required,

5. CPEs registered to correct AP sector,

6. Lowering AP Recv target from –70 to –73 dBm.

In day-to-day operation the first 5 actions is used. We also wanted to use the sixth method. So we were ready to trade uplink CINR and RSSI values for lower interference observed by other APs operating on the same channel. Therefore, after some extensive testing, the AP target receive level was decreased from –70 to –75 dBm. Despite the effort, however, we have never observed avg uplink CINR to increase on other APs.

In summary, a proper radio planning is a key technique of interference mitigation.

4. Capacity

Capacity in a WiMAX network is not fixed [10]. Each CPE operates with spectral efficiency that changes in time and is a product of three parameters: modulation, Forward Error Correction (FEC) coding and Multi Input Multi Output (MIMO) mode. Therefore, the radio capacity of a given 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 b/s/Hz. If it is using 5/6 FEC, then the spectral efficiency is reduced to 5 b/s/Hz. If it is using MIMO-B, then its spectral efficiency is doubled and reaches about 10 b/s/Hz. The INEA WiMAX network uses 10 MHz channels. When all active CPEs use 64 QAM5/6, then the capacity is about 43.2 Mb/s. Thus, if we have 10 CPEs operating at 64 QAM5/6 and all are fully busy, then each of them is able to achieve 4.3 Mb/s resulting in the total capacity of about 43 Mb/s. However, when two new CPEs connect to give AP with modulation QPSK1/2, then the capacity drops to 21 Mb/s

and each CPE is able to achieve about 1.8 Mb/s. This explains why spectrum is a valuable resource and needs to be properly managed.

Because the three parameters: modulation, Forward Error Correction (FEC) coding and MIMO mode are changing quite frequently, hence the capacity of a WiMAX channel and its utilization also changes significantly. This can be observed in Fig. 8 that demonstrates the utilization of OFDMA symbols in the WiMAX frame.
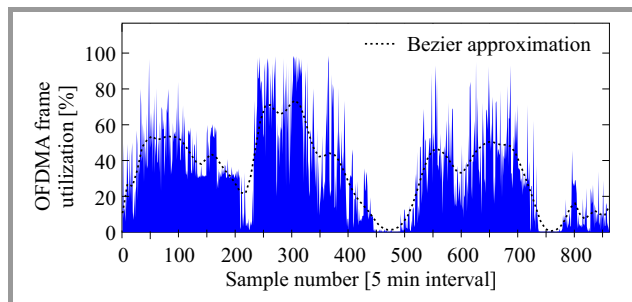

Fig. 8. Example radio utilization of one AP.

In order to maintain high capacity, the network operator needs to control modulation, FEC and MIMO mode. Moreover, WiMAX 802.16e products do not implement load balancing functionalities. Soft handoff of CPE allows the connection to be re-established though does not offer load balancing functionality across APs covering the same area. Due to this limitation, INEA has implemented the following mechanisms that help maintain high capacity:

– fixed assignment of CPEs to AP by fixing frequency or BSID,

– assignment of CPEs to AP, which allows for the highest modulation, FEC and MIMO mode,

– monitoring of radio capacity (utilization of OFDMA symbols).

It is only when the operator uses mechanisms similar to those developed by INEA that it is possible to maintain a high capacity WiMAX network. Moreover, only properly planned and restricted installation conditions allow the operator to fully exploit MIMO multi antenna technology and OFDMA technologies for providing maximum throughput in multi-path environment. Chaotic roll-outs result in networks with unpredictable capacity level.

5. Signal Strength

In the INEA WiMAX network each AP is transmitting at maximum power, but CPEs transmit power is not fixed and it is controlled by Auto Transmit Power Control (ATPC). ATPC is a mechanism implemented by vendor (Cambium Networks) in order to allow each AP to control the output power of all connected CPEs. AP tells each CPE to transmit with such an output power so it can receive it at the

target receive level of –70 dBm. It was expected that out of N active CPEs, the k-furthest CPEs (or those that were operating in non-line-of-sight (non LOS) environment) would transmit at the maximum power (+27 dBm), whereas the other remaining $N - k$ CPEs would operate with reduced power, as shown in Fig. 9.
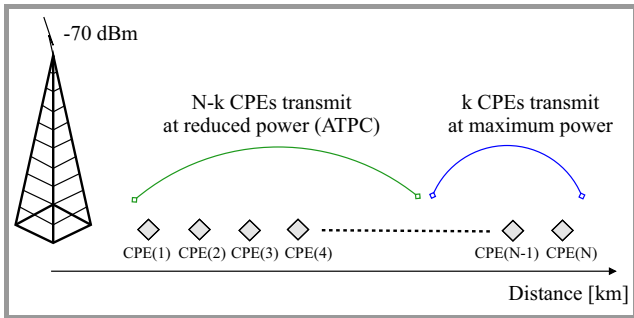

Fig. 9. ATPC – Auto Transmit Power Control.

Received Signal Strength Indication (RSSI) is the measurement of the received power present in a radio signal. These measurements were collected from all CPEs in order to evaluate their performance. Both downlink RSSI measurement (DL RSSI) and uplink RSSI measurement (UL RSSI) can be expressed by the following simple formulas:

$$RSSI_{DL} = TX_{AP} + AntennaG_{AP} - Pathloss + AntennaG_{CPE}$$
$$RSSI_{UL} = TX_{CPE} + AntennaG_{CPE} - Pathloss + AntennaG_{AP} \tag{1}$$

Assuming that the pathloss component in both directions is the same, the difference can be calculated as:

$$RSSI_{DL} - RSSI_{UL} = TX_{AP} - TX_{CPE}. \tag{2}$$

When the AP transmits at its maximum power (+25 dBm) and the CPE is transmitting at its maximum power (+27 dBm), we obtain:

$$RSSI_{DL} - RSSI_{UL} = 25 \text{ dBm} - 27 \text{ dBm} = -2 \text{ dB}. \tag{3}$$

However, since the CPE TX power is controlled by ATPC, then its TX power is $\leq +25$ dBm, therefore:

$$RSSI_{DL} - RSSI_{UL} <= -2 \text{ dB}. \tag{4}$$

At the time of the implementation the above formula would hold true for all our measurements, however this turned out not to be true. This is shown in Fig. 10.

Figures 10 and 11 present the measurements collected from all 6000 CPEs during 5 days long experiment. The location of each APs and CPEs was fixed. Therefore, these figures present variance of propagation conditions observed by all 6000 CPEs which have occured during the experiment.

When CPEs are close to the AP, they reduce their output power to meet the receive target level of –70 dBm set by the AP. In such a close proximity Formula 4 is satisfied. However, when the CPEs are far away from the AP, the results of our measurements do no satisfy Form. 4. This happens
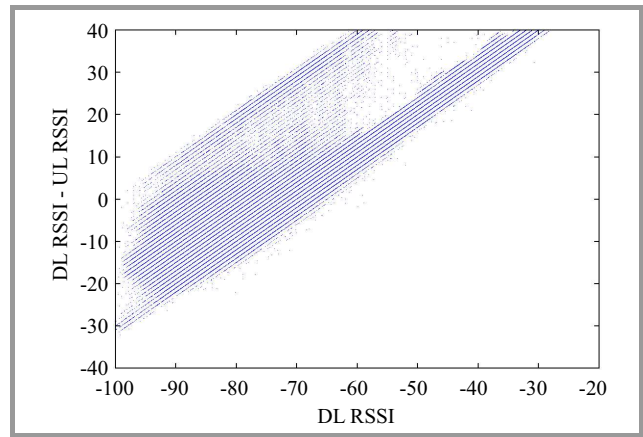

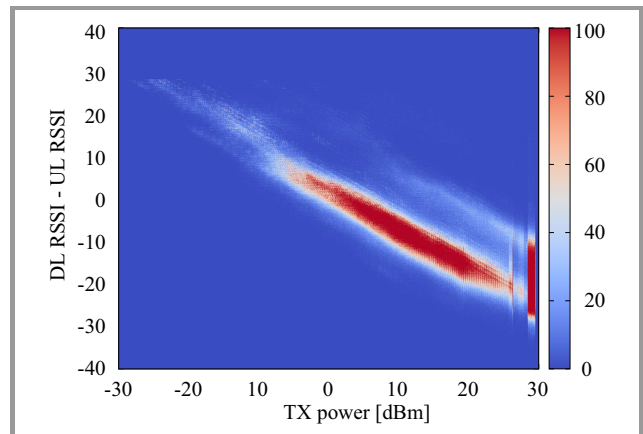***Fig. 10.*** DL RSSI vs. DL RSSI – UL RSSI.

Fig. 11. CPE TX power vs. DL RSSI – UL RSSI.

due to the so-called sub-channelization gain. When CPEs is far away from the AP and has only a small amount of data to send, the power density of its transmission is increased by the use of only a subset of available sub-channels. This allows it to meet the target receive level set by AP but it only happens if CPE has a small amount of data to be transmitted. If that CPE has a large amount of data, then it will use more sub-channels, and hence it will lower the power density. When this is the case, Form. 4 is not valid. Only properly planned and restricted installation conditions allow the operator to fully exploit the MIMO and OFDMA technologies to provide maximum throughput in a multi-path environment. Chaotic roll-outs result in a network with an unpredictable capacity level.

The sub-channelization gain is a helpful mechanism, but when it occurs it also suggests that the CPE has troubles with transmission that would satisfy target receive level.

6. Summary

Over the last three years INEA has made an enormous effort to provide reliable broadband service over a wireless connection. Within this time, INEA wanted to provide

Karol Kowalik, Dawid Dudek, Michał Kołodziejski, Bartosz Musznicki, Eugeniusz Grzybek, and Jacek Jarzina

the reliability associated with wire-line services with the cost advantage of the wireless technology. In the paper, the technical lessons learned from the WiMAX roll-out are presented.

One of the most important learned lessons is that, despite existing theoretical propagation models that are well described in literature, we need to tune them carefully in order to match real world measurements. In addition, the theoretical coverage is only an approximation of real coverage and thus includes internal uncertainty. The radio capacity is probably the most tricky element that the operator needs to maximize. In order to do so, the Quality of Service features provided by the 802.16e standard (in particular the best effort and ertPS flows) have been utilized, but also we have restricted the installation conditions. Only properly planned and restricted installation scenario allows to exploit the MIMO and OFDMA technology to provide successfully the maximum throughput in multi-path environment.

Lastly, the authors have also found out that some measurements (described in Section 5) may at first glance look invalid. However, they may be explained with the help of a professional support offered by the vendor.

Although operators need to learn how to deal with problems specific to WiMAX and wireless medium, we observe that it allows to reduce installation time and provides great installation flexibility as compared to wire-lines technologies. Therefore, it will continue to co-exist in presented network with GPON, DOCSIS, VDSL networks for a number of years to come.

Acknowledgements

References

[1] "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.

[2] "Informacja o zajętości widma w zakresie 3600–3800 MHz (Radio spectrum occupancy information for 3600–3800 MHz)" [Online]. Available: http://www.uke.gov.pl/uke/index.jsp?&news_id=4299 (accessed: 22 Jan. 2014)

[3] J. Milanovic, S. Rimac-Drlje, and K. Bejuk, "Comparison of propagation models accuracy for WiMAX on 3.5 GHz", in *Proc. 14th IEEE Int. Conf. Electron., Circ. Syst. ICECS 2007*, Marrakech, Morocco, 2007, pp. 111–114.

[4] V. Erceg, K. V. S. Hari, M. Smith, and D. S. Baum,"Channel models for fixed wireless applications", Tech. REP., July 2001.

[5] K. Jain, J. Padhye, V. N. Padmanabhan, and L. Qiu, "Impact of interference on multi-hop wireless network performance", in *Proc. 9th Ann. Int. Conf. Mob. Comput. Netw. MobiCom 2003*, New York, NY, USA, 2003, pp. 66–80.

[6] M. Shahajahan and A. Q. M. Abdulla Hes-Shafi, "Analysis of propagation models for WiMAX at 3.5 GHz", Tech. rep., Department of Electrical Engineering, Blekinge Institute of Technology, Karlskrona, Sweden, Sept. 2009.

[7] D. Alam and R. H. Khan, "Comparative study of path loss models of WiMAX at 2.5 GHz frequency band", *Int. J. Future Gener. Commun. Netw.*, vol. 6, no. 2, pp. 11–24, 2013.

[8] J. Padhye *et al.*, "Estimation of link interference in static multi-hop wireless networks", in *Proc. 5th ACM SIGCOMM Conf. Internet Measur. IMC 2005*, Berkeley, CA, USA, 2005, pp. 305–310.

[9] S. S. Kale and A. N. Jadhav, "Performance analysis of empirical propagation models for WiMAX in urban environment", *OSR J. Electron. Commun. Engin. (IOSR-JECE)*, Febr. 2013.

[10] C. So-In, R. Jain, and A.-K. Tamimi, "Capacity evaluation for IEEE 802.16e mobile WiMAX", *J. Comp. Sys., Netw. Commun.*, vol. 1, no. 1, pp. 1:1–1:12, 2010.

[11] F. Wang *et al.*, "IEEE 802.16e system performance: Analysis and simulations", in *Proc. IEEE 16th Int. Symp. Pers., Indoor Mob. Radio Commun. PIMRC 2005*, Berlin, Germany, 2005, vol. 2, pp. 900–904.

[12] "CHIRplus_BC User Manual 4.4.1", LS Telcom AG, Lichtenau, Germany, 2006.

[13] B. Dahleh, "Minimizing self-interference in multiple tower PMP 320 deployments using ABAB frequency re-use", Tech. Rep., Cambium Networks, Nov. 2010.

Karol Kowalik received his M.Sc. from Poznan University of Technology in 2000 and Ph.D. from Dublin City University in 2004. He is currently Technical Development Manager at INEA S.A. and is responsible for technical innovation and validation on new ideas. His research interests include networking, switching, routing, wireless and wired access.
E-mail: karol.kowalik@inea.com.pl
INEA S.A.
Klaudyny Potockiej st 25
60-211 Poznań, Poland

Dawid Dudek received his M.Sc. in Electronics and Telecommunications from Poznan University of Technology in 2013. Currently, he is Junior Network and Services Administrator at INEA S.A. and is responsible for WiMAX technology. His research interests include wireless networks, routing, switching, and network security.
E-mail: dawid.dudek@inea.com.pl
INEA S.A.
Klaudyny Potockiej st 25
60-211 Poznań, Poland

Michał Kołodziejski received his M.Sc. in Electronics and Telecommunications from Szczecin University of Technology in 2008. In the meantime he spent half a year at Technical Faculty CAU Kiel, Germany. After graduation, he started to work at Atos IT Services Poland in September 2008. As a network operator he got to know how to monitor WAN and LAN networks, how to solve small network issues reported by global customers. He also attended to transferring a part of IT services from Germany to Polish department of Network Operation Center. At the beginning of 2010 he joined INEA S.A. where he works as Senior Network and Services Administrator. He is mainly responsible for management of Wi-Fi network and radio links of Ceragon, Ericcson and NEC. He deals with WiMAX network since 2011.
E-mail: michal.kolodziejski@inea.com.pl
INEA S.A.
Klaudyny Potockiej st 25
60-211 Poznań, Poland

Bartosz Musznicki received the M.Sc. degree in Telecommunications from Poznan University of Technology, Poland, in 2010. He currently holds the position of Business Services and Core Network Department Manager at INEA S.A. With the postgraduate diploma in Human Resource Management, he leads a team of networking professionals. Since 2009, in the pursuit of Ph.D., Bartosz Musznicki has been engaged in research in the area of routing with focus on Wireless Sensor Networks. He is the author of four book chapters, five journal papers, and five articles in conference proceedings.
E-mail: bartosz.musznicki@inea.com.pl
INEA S.A.
Klaudyny Potockiej st 25
60-211 Poznań, Poland

Eugeniusz Grzybek received the M.Sc. degree in Electronics and Telecommunications from Poznan University of Technology in 1990. Between 1997–2012 he was Chief Executive Officer at designing and system integration company HFC Systems Sp. z o.o. specializing in CATV and FTTH networks design. In the years 2005–2009 he was the Board Member in Internet Cable Provider Sp. z o.o. In INEA S.A. he is a Technical Board member since 2005. Mr. Grzybek is also a Board Member of the Polish Chamber of Electronic Communication and member of Wielkopolska ICT Cluster.
E-mail: eugeniusz.grzybek@inea.com.pl
INEA S.A.
Klaudyny Potockiej st 25
60-211 Poznań, Poland

Jacek Jarzina received the M.Sc. in Electronics and Telecommunications from Poznan University of Technology in 1987. After graduation he started working at one of the radio link nodes in Poznań where he led the team for the operation of the facility and a team of dispatchers for a state owned radio communication network in the area of Poznan. Since 1996 he has been a radio communication specialist and designer in Tele-Com company. For 15 years he has been a leader of radio communication designing team and Technical Supervisor of accredited research laboratory for EMF according to Environmental law and according to work safety regulations. He is the main author of radio planning methods, procedures and radio planning tools for the INEA WiMAX network. He also runs educational section of his parent company.
E-mail: j.jarzina@tele-com.poznan.pl
Tele-Com Sp. z.o.o.
Jawornicka st 8
60-968 Poznń 47, Poland