Chapter 16
EMC between WIMAX 1.5GHz and WLAN 2.4GHz Systems Operating in the Same Area

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Abstract. The chapter presents the data rates measurements of WiMAX operating in 1.5GHz and WLAN 802.11g conducted in a reverberation chamber. The goal of the measurements was to perform a compatibility study between these systems working simultaneously. The motivation to perform the compatibility study was that these systems were chosen for operation in underground mining environment during research on telecommunication system for mine excavations. A short description of these measurments as well as the general concept of the above-mentioned systems are also shown. All tests were performed in the reverberation chamber which is widely used for electromagnetic compatibility studies. Beside the data rates measurement results, the chapter also presents a testbed, procedures for performance tests and a short decription of the reverberation chamber.

16.1 Introduction

In recent years one can observe a rapid development of technology and prevalence of electronic equipment, including transceivers (e.g. terminals and mobile base stations, wireless system terminals and access points). As a consequence, unwanted emissions of electromagnetic fields and strong interactions between devices and systems occur. This is observed especially in the radio systems, which are sources of both the desirable (in-band) as well as the unwanted (out-of-band) radio emissions. At the same time, they are prone to interferences from other systems, which limits their performance. These unwanted emissions may be a result of their shared operation in the same frequency band while working in the immediate vicinity of each other. Such adverse events can be easily observed in the 2.4GHz frequency

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R. Klempous et al. (eds.), *Advanced Methods and Applications in Computational Intelligence*, Topics in Intelligent Engineering and Informatics 6,
DOI: 10.1007/978-3-319-01436-4_16,

band, which was designed for industrial, scientific and medical applications (ISM) and is commonly used by many wireless systems. Both in-band and out-of-band interference can significantly degrade transmission quality or, in some cases, make it impossible, especially when the effect of receiver blocking by a strong radio signal takes place. Immunity against the influence of external fields on electronic devices and reduction of electromagnetic emission are important elements of increasing the likelihood of smooth coexistence of all the devices and systems. This can be achieved through compliance with emission limits on radiated power levels (either in-band or out-of-band). The regulator (Administration) in each country sets the maximum levels for the equivalent radiated power in each spectrum band for radio transmission.

The problem of coexistence on the same area of systems based on IEEE 802.11 and IEEE802.16 standards is still up-to-date due to growing popularity of hybrid networks and wireless modules. This topic is widely discussed in literature, both as a possible source of interference and in the context of mutual coexistence methods. One can find many ways to avoid those problems, usually based on time scheme (Time Divison Operation based on Time Division Multiplexing), code scheme or power control. Also, dynamic frequency allocation using RSSI measurement or cognitive radio functionality are quite popular. Schemes mentioned above can be found among others in [1],[8],[9],[10],[19]. Nevertheless all of them are dedicated to IEEE802.11 systems working in 2.4GHz ISM band and IEEE802.16 in 2.3 and 2.5 GHz.

16.2 Wireless Communications in Mine Excavation

Why is the detailed investigation between WiMax 1.5GHz and WLAN 2.4GHz so important? To answer this question the results of the other project shall be presented. In years 2007 to 2010 the possibility of applying wireless systems to a build communications system for underground mine excavation was investigated. One of the objectives was to examine the propagation conditions in the underground corridors. Among the many system available on the market, four were selected for investigation: WiMax 1.5 GHz band (Airspan), WiMax 3.5 GHz band (ExcelMax from Axxcelera), WLAN 900 MHz band (SuperRange9 from Ubiquiti Networks) according to Spec. IEEE 802.11 b/g (bandwidth 5, 10 and 20 MHz) and WLAN 2.4 GHz (WRT350N with Notebook Adapter WPC300N from Linksys) according to Spec. IEEE 802.11 n. The typical WiMax throughputs are shown in Tab. 16.1. The WiMax system under test was operating with 3.5MHz bandwidth.

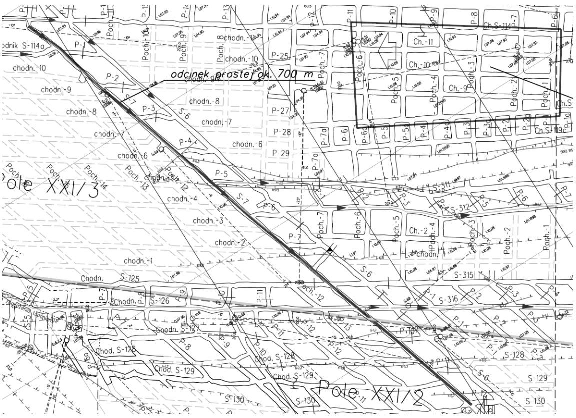
Poland is the fourth largest producer of copper in the world. All the propagation measurements were done in one of its mines at the depth of 600 m below the surface of the earth. The plan of the undergound mine coridors with two investigated areas (a long straight walkway and the corridors grid, which is a very difficult area in terms of propagation of the electromagnetic waves) is presented in Fig. 16.1. The investigations led to the conclusion, that the best results can be obtained with the use

Table 16.1. Typical throughputs of WiMax

Modulation / Coding	QPSK 1/2	QPSK 3/4	16QAM 1/2	16QAM 3/4	64QAM 2/3	64QAM 3/4
1.75MHz	1.45	2.18	2.91	4.36	5.82	6.55
3.5MHz	2.91	4.36	5.82	8.73	11.64	13.09
7MHz	5.82	8.73	11.64	17.45	23.27	26.18
14MHz	11.64	17.45	23.27	34.91	46.55	52.36
20MHz	16.26	24.40	32.53	48.79	65.05	73.19

of WiMax 1.5GHz and 2.4GHz WLAN. The topology of the underground wireless communication system is shown in Fig. 16.2. The system consists of a backbone based on the WiMax 1.5 GHz base stations (WBS), that are located approximately within 300 - 400m from each other. The WiMax terminals (WT) collaborate with these stations. Each terminal is directly connected to a WLAN access point (AP). These hotspots cooperate with the WLAN terminals (T).

Fig. 16.1 Plan of the investigated area underground with the two different marked areas



The proper operation of these systems requires locating the WiMax terminal close to the WLAN access point. Fig. 16.3. presents the WiMax terminal (at the top) with the WLAN access point attached (bottom). Both devices s hall operate in the same time and area, i.e. in adverse conditions, which was the reason for the EMC investigations.

It is very difficult to carry out EMC investigations underground. Therefore, another environment shall be used to simulate such adverse propagation conditions. Experience shows that similar conditions can be achieved in the reverberation chamber. Typically, it is used to test the sensitivity or emission of the equipment. But it can also be used to study properties of wireless systems in the extremely difficult propagation conditions and to test the compatibility between systems.

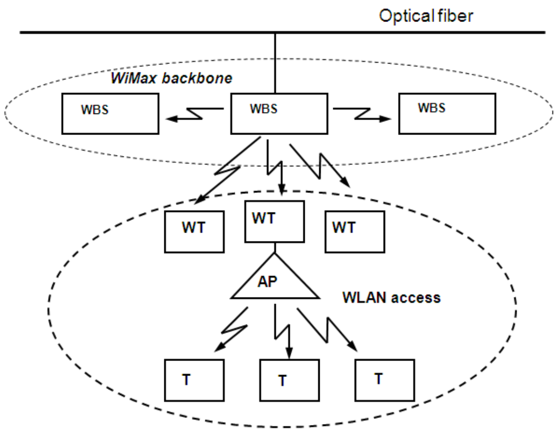


Fig. 16.2 Topology of wireless underground communications system (WiMax Base Station - WBS, WiMax Terminal - WT, WLAN Access Point - AP, WLAN Terminals - T)

Fig. 16.3 The WiMax terminal (top) and WLAN AP (bottom) located close to each other on a single mast during the measurement in the mine excavation

16.3 Reverberation Chamber

The electromagnetic compatibility study in real conditions is not unambiguous because of the possible additional impact of other devices and systems. In addition, the selection and configuration of the test environment can significantly affect the obtained results. A reverberation chamber is a laboratory environment, where the statistical measurements of te radiated power of a radio equipment in an environment with multipath propagation can be performed. These chambers are now commonly used in EMC device testing (both immunity to electromagnetic fields tests and measurements of unwanted emissions). The chamber can also be used to test the electromagnetic compatibility of radio systems, wherein the propagation conditions in the interior of the chamber are extremely unfavorable due to the very large number of reflections of radio waves and the occurrence of resonances. The usefulness of the chamber for this type of testing is described i.e. in [2],[5],[17].

The reverberation chamber is a space limited by walls made of materials with very high conductivity. Radio waves radiated in this closed space, due to multiple reflections from walls and equipment, create an environment of three-dimensional standing wave. Typically, the chamber has a shape of a cuboid. For achieving the large number of modes with different resonant frequencies it is recommended, that chambers are constructed in this way that each of its linear dimensions was not a multiple of any of the other dimensions and all of three dimensions are of the same order.

During research a statistically homogeneous distribution of the electromagnetic field should be provided inside the chamber - in its test set. So, it is necessary to apply techniques to change its parameters, shape, location of walls or pieces of equipment to change directions of waves reflections and thereby change the field distribution. For this purpose, one or more stirrers are used, what is the most commonly technique applied in the chambers. The continuous stirrer rotation during the test causes the redistribution of field minima and maxima inside the chamber.

The stirrer (its shape, size, position in the chamber) has a big impact on getting adequate homogeneity of the field inside the chamber. It should be made, as well as walls, from material with high conductivity (e.g. aluminum). The stirrer should also be large relative to the size of the chamber and positioned in asymmetric way relative to the chamber walls. Linear dimensions of the chamber should be large enough to provide adequately low the Lowest Useable Frequency (LUF) and also to ensure free-hold in the interior of the test equipment, antennas, field probes and metal stirrers.

The typical capacity of the reverberation chambers ranges from 70 to 100m^3, therefore, the lowest useable frequency is about 200MHz. Measurements below 200MHz require chambers with larger than the typical linear dimensions. The resonant frequency depends on the dimensions of the chamber and for the rectangular-shaped can be determined from the following relationship:

$$f_{ijk} = \frac{c_0}{2}\sqrt{\left(\frac{i}{l}\right)^2 + \left(\frac{j}{w}\right)^2 + \left(\frac{k}{h}\right)^2} \tag{16.1}$$

where

- l,w,h - chamber dimensions [m] (for chamber used: l - length 7.76m, w - width 4.3m, h - hight 3.05m);
- i,j,k - integer constans;
- c_0 - wave velocity in chamber.

The lowest useable frequency of the chamber is determined as approximately triple value of the first resonance frequency (f_{001}). Its exact value also depends on the stirrer operation and the quality factor Q of the chamber.

The field strength present in the reverberation chamber is greater than in other test beds, which is related to the effect of temporary energy accumulation, which depends on the Q factor. The quality of the chamber is also dependent on the frequency and the test equipment. Therefore the loaded chamber - with additional test equipment and the device under test - has greater homogenity of the field, but lower levels of the induced field due to the lower value of the Q factor. The quality factor Q determines the ability of the chamber to accumulate an energy. It is determined by the losses introduced directly by the chamber. These losses depend on the material properties of the walls, the floor and the ceiling and on the quality of the connection of individual elements of the chamber. Additional equipment such as antennas, measuring equipment, peripherals and the device under test can also affect the value of the Q factor [7],[15],[18]. For sufficiently high frequencies, this factor could be calculated as:

$$Q = \frac{3}{2}\frac{V}{S\sigma} \tag{16.2}$$

where:

- V - the chamber capacity [m^3];
- S - the total area of internal walls [m^2];
- σ - the penetration depth of the wave [m] - it depends on electrical parameters of the walls.

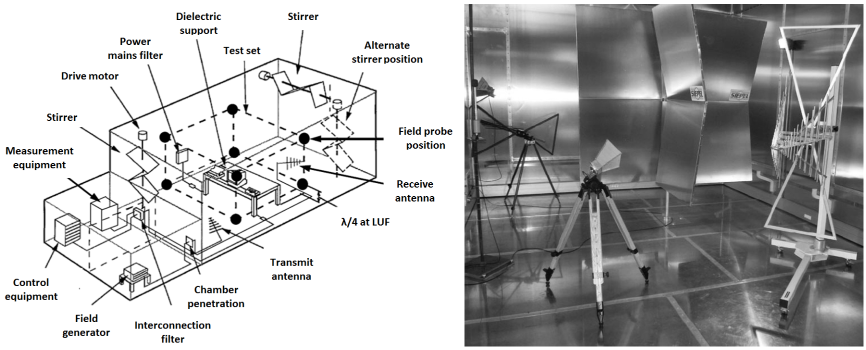


Fig. 16.4. Reverberation chamber

Due to the statistical nature of the electromagnetic environment in the interior, the reverberation chambers are increasingly used in measurements of the transmission efficacy of the radio systems and the immunity to radio signals emitted by other radio communication systems [3],[13],[16]. However, it is necessary to reduce the quality factor of the chamber by placing inside it elements absorbing the electromagnetic energy. These elements reduce the effect of accumulation of the energy and change the Power Delay Profile (PDP) [6],[14]. So, during the tests of the wireless systems, it reduces the possibility of the receiver blocking by too strong signals and excessive inter-symbols errors. The scheme of the reverberation chamber and antennas placed inside it were shown in Fig. 16.4.

16.4 Systems under Tests

Based on the preliminary research conducted in the hallways of buildings of the Wroclaw Technical University and then during the test in real conditions of the excavation mine [12] the two systems has been chosen for testing in the reverberation chamber. One of them was Airspan's WiMAX system, operating in the 1.5GHz band, and the second one was WLAN operating in 2.4GHz band. Based on the architecture shown in [11] the devices of these two systems are placed next to each other. Therefore, to achive proper operation of both systems they should not interact with each other. Therefore the transmission properties of both systems were tested in the same conditions, by sending data streams between each pairs of computers connected via tested system and measuring the transmission rates. The automatic settings option were chosen in both systems during the tests, allowing to dynamically adjust the transmission parameters of both systems to the conditions of propagation.

Table 16.2. Parameters of the tested systems [21]

	Airspan BS	Airspan CPE	802.11g
Freq. Band	1426.5-1524MHz	1426.5-1524MHz	2400MHz
Air Interface	Adaptive TDMA	Adaptive TDMA	CSMA/CA
Architecture	Point to Multipoint	Point to Multipoint	Point to Multipoint
Duplex	TDD	TDD	N/A
RF Channel Sizes	5MHz, 3.5MHz, 1.75MHz	5MHz, 3.5MHz, 1.75MHz	20MHz
Modulation	64QAM, 16QAM, QPSK, BPSK	64QAM, 16QAM, QPSK, BPSK	64QAM, 16QAM, QPSK, BPSK
Coding Rates	1/2, 2/3, 3/4	1/2, 2/3, 3/4	1/2, 2/3, 3/4
Transmit Power	+27dBm	+24dBm	+17dBm
Receive Sensitivity	-104dBm @ 1.75MHz, -100dBm	-104dBm @ 1.75MHz, -100dBm	-70dBm for 54Mb/s
Antenna Beam Width	60°	Azimuth - 60°, Elevation - 30°	N/A
Antenna Gain	10.5dBi	10.5dBi	9dBi

16.5 Testbed

The results of the measurements are highly dependent on the chambers load (additional equipment). So, measurements of properties of each system in the reverberation chamber were performed for the case of the simultaneous installation of both systems in the chamber. The tests performed for each system with other devices turned off were a reference to compatibility tests of both systems operating. The study was performed for several configurations, changing the orientation and antenna settings and the number and location of the absorbers.

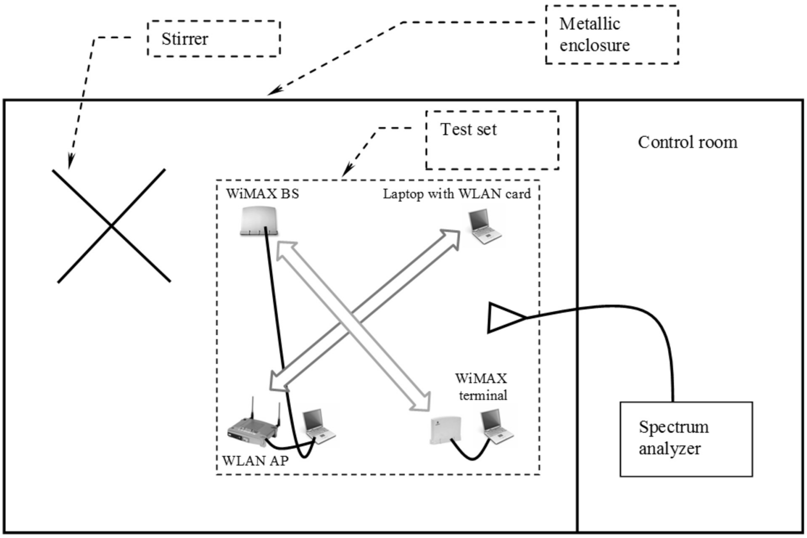


Fig. 16.5. Testbed in reverberation chamber

The observation of the interaction between WLAN and WiMAX systems was limited to record the transmission rate changes in both systems during their simultaneous transmission. Both systems operate in different frequency bands (Airspan WiMAX in the 1.5GHz band and the WLAN system in the 2.4GHz band). So, their simultaneous work should not degrade the quality of transmission, unless the out of band emissions of transmitters of both systems will be sufficiently low - acceptable by each of the systems. Fig. 16.5 shows the measurement site in reverberation chamber. Three laptops were used for testing, two of them were sources of data transmitted by the terminals of each of the systems (Iperf clients). The third one with Iperf server was the recipient of two streams of data. The measurements were provided for four different set-up configurations:

1. WiMAX terminal and WLAN AP next to each other;
2. WiMAX terminal and WLAN AP separated by absorber;
3. WiMAX terminal on the floor with one absorber;
4. WiMAX terminal on the floor with two absorbers.

The WiMAX base station in all configurations was covered with two absorbers. The WLAN AP with the antenna were placed on the small dielectric table during all measurements. Only the position and the radiation direction of the WiMAX terminal were changed. All configurations of the test set-up were shown in Fig. 16.6. The change of the devices placement (and adding additional absorbers) was only supposed to change the electromagnetic field distribution in the chamber.

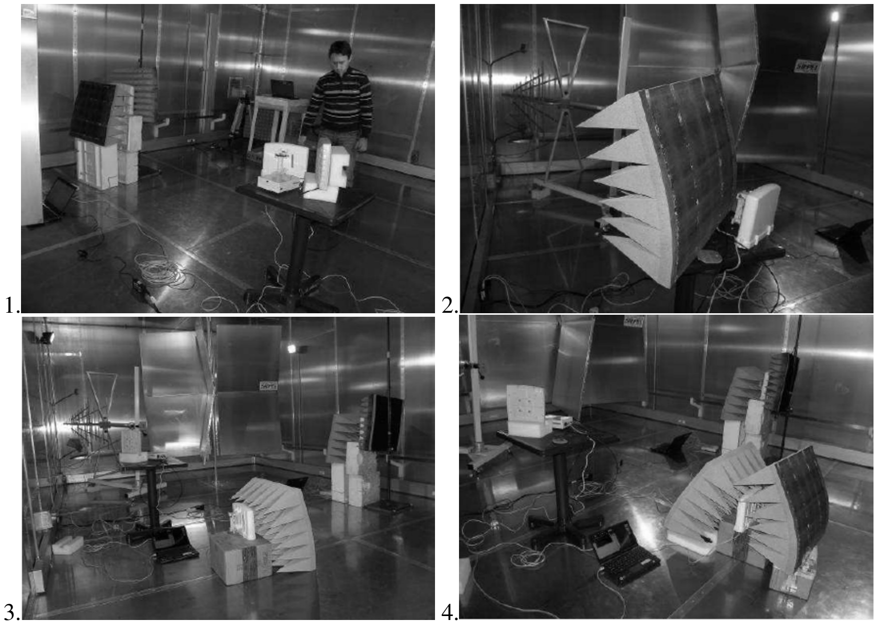


Fig. 16.6. Configurations of the testbed

16.6 Measurement Results

The study was conducted for four scenarios associated with the different placement of both devices of the systems in the chamber and with different number and placement of absorbers. The data transfer rate for each system was monitored every second at a constant slow stirrer circulation from 0 to 360 degrees [20].

16.6.1 Reference Measurements

In order to get an overview of systems performance some reference measurement were conducted. Both the placement of devices as well as the testing procedure were exactly the same as in the first scenario. However during WiMAX performance test the WLAN AP was turned off and accordingly, test of the WLAN was performed while WiMAX devices were not operating. As shown in Fig. 16.7 and Fig. 16.8 both systems were able to transmit data for almost entire stirrer rotation. The average transmission rate for WiMAX was about 0.9Mb/s whilst for WLAN it was about 9.3Mb/s. One have to bear in mind, that reverberation chamber is extremly strict environment. That is why abolute values of trasmission rates are less meaningful.

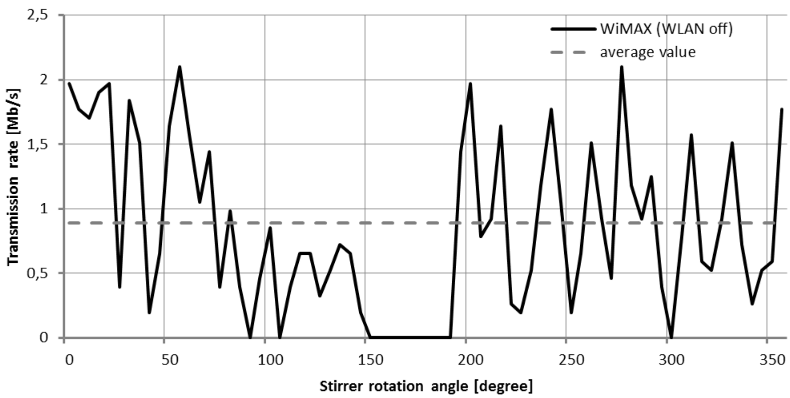


Fig. 16.7. The results of the reference measurements for WIMAX

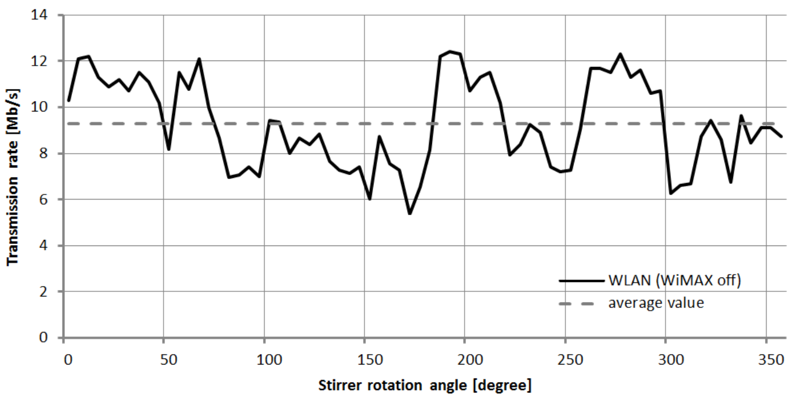


Fig. 16.8. The results of the reference measurements for WLAN

16.6.2 Measurement Results for WiMAX System

The results of average data rate for each scenario for WiMAX measurements are shown in Tab. 16.3 . The data rate for each scenario as a function of the stirrer position is shown in Fig. 16.9 and Fig. 16.10. Taking into account the reference results one can say that operation of the WiMax system was not disturbed by WLAN. The achieved average transmission rates for all configurations were very similar to each other as well as to reference value. The high variance of transmission rates was not caused by the interfering system but by the changes of EM field distribution in the chamber.

Table 16.3. Averaged measurement results for WiMAX

Average transmission rate [Mb/s]			
Configuration 1	Configuration 2	Configuration 3	Configuration 4
0.966	0.880	0.815	0.869

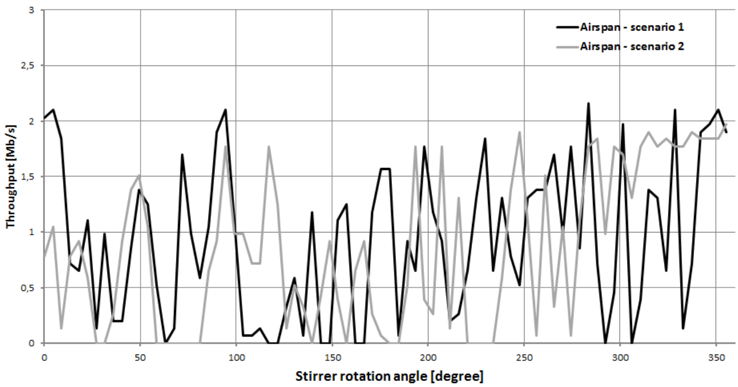


Fig. 16.9. The measurement results of WiMax for the first two scenarios

16.6.3 Measurement Results for WLAN System

The results of average data rate measurements for each scenario for WLAN are shown in Tab. 16.4. The data rate for each scenario as a function of the stirrer position is shown in Fig. 16.11 and Fig. 16.12. As in the earlier case the operation of the system was not disturbed by WiMAX and high variance of transmission rates was not caused by interfering system but by changes of EM field distribution in the chamber. The achieved average transmission rates for all configurations were similar

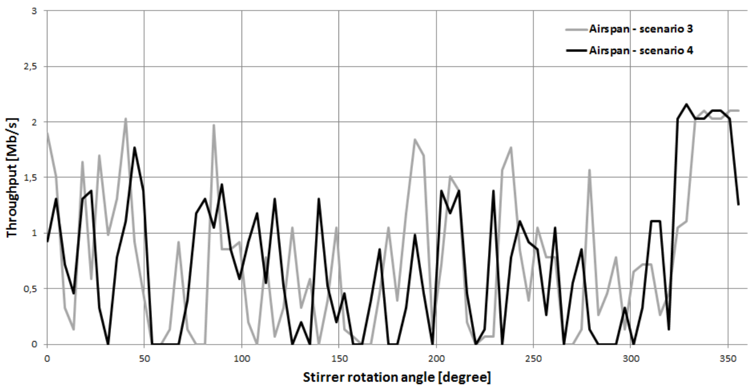


Fig. 16.10. The measurement results of WiMax for the scenarios 3 and 4

Table 16.4. Averaged measurement results for WLAN

Average transmission rate [Mb/s]			
Configuration 1	Configuration 2	Configuration 3	Configuration 4
8.45	10.60	10.71	13.11

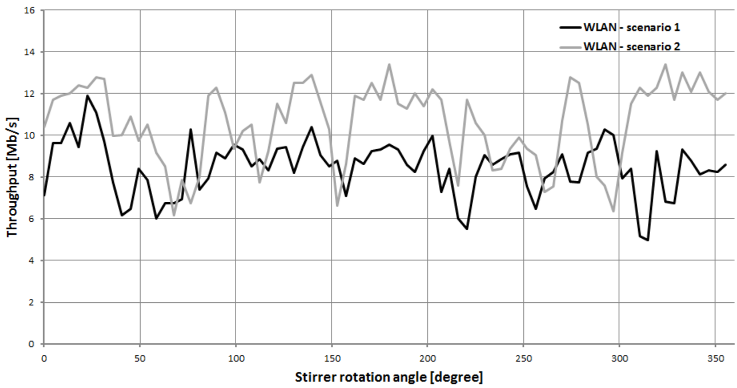


Fig. 16.11. The measurement results of WLAN for the first two scenarios

to each other as well as to reference value. A better performance for Configuration 4 could be caused by degradation of chamber's Q factor. It was a result of increasing the chamber's load by adding two additional absorbers. The detailed explanation of above mentioned phenomena can be found in [15].

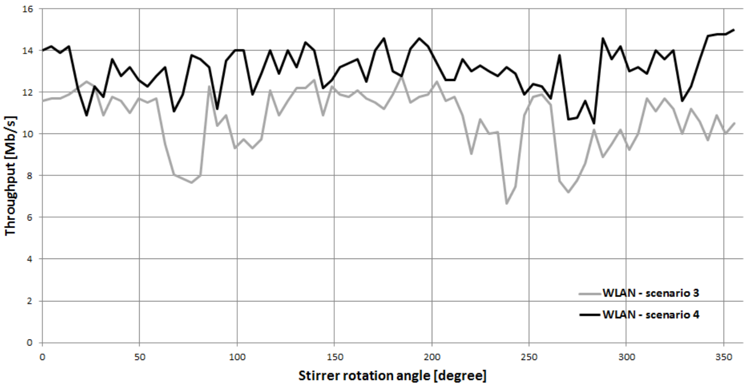


Fig. 16.12. The measurement results of WLAN for the scenarios 3 and 4

16.7 Summary

The propagation environment in the reverberation chamber is very demanding for wireless data transmission systems due to the very large number of wave reflections from the walls of the chamber. Such an extremely difficult environment makes possible to check the efficiency of transmission techniques and technical solutions of radio equipment. Only systems with above-average properties can operate in such conditions. All the tests conducted in the chamber confirmed the excellent transmission properties of the WiMAX system in the hard propagation conditions, which emerged during the test in the mine environment. Although the achieved transmission rate differ significantly from the maximum (about 11Mb/s) it is essential that the system enables transmission of the data for each configuration and each measurement scenario. The operating WLAN system had no apparent effect on the work of the WiMAX system and vice versa. In any configuration the WiMAX system achieved similar results, confirming the good electromagnetic compatibility between these systems.

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