

Report on Radio Frequency Compatibility Measurements between UWB LDC Devices and Mobile WiMAX (IEEE 802.16e-2005) BWA Systems

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Glossary

ACELP	Algebraic Code Excited Linear Prediction
AMC	Adaptive Modulation and Coding
AWG	Arbitrary Function Generator
BPSK	Binary Phase Shift Keying
BS	Base Station
CS-CELP	Conjugate Structure Code Excited Linear Prediction
CTC	Convolutional Turbo Code
DL	Downlink
DSO	Digital Storage Oscilloscope
ECC	Electronic Communications Committee
FDD	Frequency Division Duplex
FEC	Forward Error Coding
FFT	Fast Fourier Transform
FSPL	Free-Space Path Loss
FTP	File Transfer Protocol
FUSC	Fully Used Sub-Channel
IEEE	Institute of Electrical and Electronic Engineers
IPTV	Internet Protocol Television
ITU	International Telecommunication Union
LAN	Local Area Network
LDC	Low Duty Cycle
LNA	Low Noise Amplifier
MB- OFDM	Multi-Band Orthogonal Frequency Division Multiplex
MIMO	Multiple Input Multiple Output
MOS	Mean Opinion Score
MPEG	Motion Pictures Expert Group
OFDM	Orthogonal Frequency Division Multiplex
PA	Power Amplifier
PESQ	Perceptual Evaluation of Speech Quality
PPM	Pulse Position Modulation
PPoM	Pulse Polarity Modulation
PSD	Power Spectral Density
PUSC	Partially Used Sub-Channel
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
RSSI	Received Signal Strength Indication
RTP	Real-time Transport Protocol
SIR	Signal-to-Interference Ratio
SISO	Single Input Single Output
SS	Subscriber Station
TCP	Transport Control Protocol
TDD	Time Division Duplex
TFC	Time Frequency Coding
TUSC	Tile Usage of Sub-Channels
UDP	User Datagram Protocol

UL	Uplink
UWB	Ultra Wideband
VoIP	Voice over IP
VSA	Vector Signal Analyzer
WiMAX	Worldwide Interoperability for Microwave Access
WMV	Windows Media Video

Introduction

In 2006 the ECC examined the impact of pulsed Low-Duty Cycle (LDC) UWB signals on the quality of various services (FTP, VoIP, video streaming) provided via a fixed WiMAX (IEEE802.16d) link, and published its findings in ECC Report 94 [1]. The resulting spectrum regulation and standardization stipulate a maximum UWB activity (T_{on}) of 50 ms per second, with a maximum permissible pulse width of 5 ms. Report 94 showed that for activity factors of 5% there was no measurable impact on any of the victim services if a minimum distance of 4 meters (LOS) between the UWB interferer and the WiMAX terminal was maintained.

As fixed WiMAX terminals are typically mounted outdoors in elevated positions the isolation between a WiMAX terminal and LDC UWB devices will in most cases be sufficiently high to avoid interference. Mobile WiMAX (IEEE802.16e-2005) terminals, however, may be operating indoors, in close vicinity to a UWB device. On the other hand, mobile WiMAX was designed to be more robust against fading and interference than fixed WiMAX.

The objective of the measurement campaign described in this document was to determine the impact of UWB LDC signals on different types of services provided by a mobile WiMAX (IEEE802.16e-2005, further on referred to as “WiMAX”) victim system, and in particular to examine LDC pulses with a width of more than 5 ms, whilst maintaining an overall activity limit of 5%, equalling 50 ms per second.

Test description

The main elements of the test setup were a WiMAX link and a UWB interferer. The WiMAX link was realized with a commercially available base station (BS) and subscriber station (SS). Two different types of UWB interferers were employed; an MB-OFDM system and a TH-UWB system. The first round of tests was done using a WiMedia-compliant UWB evaluation kit that allows a large number of UWB parameters to be freely configured. In order to create a realistic scenario comparable to that of ECC report 94, measurements were done in a radiated manner. For verification purposes, certain measurements were also done with a conducted setup. In the second round an additional set of measurements was done with a TH-UWB system. To avoid interference from external sources during the radiated measurements, the WiMAX BS, SS, and the UWB antenna were placed inside a shielded anechoic chamber. WiMAX and UWB signal characteristics are given in Table 1 - Table 3.

BS max. Tx power [dBm]	27
SS max. Tx power [dBm]	25.5
Centre frequency [MHz]	3500
Duplexing method	TDD
Channel bandwidth [MHz]	10
FFT size	1024
Frame length [ms]	5
DL:UL TDD ratio	29:18 (60%)
Modulation	Adaptive
Antenna diversity	No (SISO)

Table 1: WiMAX system and signal characteristics

UWB TFC	5
Frequency [MHz]	3168 – 3696
UWB Tx PSD [dBm/MHz]	-41.3
Superframe duration [ms]	62
Tx/(Rx-TX) ratio	100%

Table 2: MB-OFDM UWB transmitter characteristics

Pulse width [ns]	0.45
PRI [ns]	72
Modulation	PPM, PPOM
UWB Tx PSD [dBm/MHz]	-41.3

Table 3: TH-UWB transmitter characteristics

Measurement setups

In the radiated measurement setup the WiMAX BS and SS were placed at a distance of 12 m of each other (Figure 1). At 3.5 GHz the free-space path loss (FSPL) at this distance is approximately 65 dB. The transmit power of the WiMAX BS can be adjusted between 13 and 27 dBm, in steps of 1 dB, so that the minimum signal strength at the location of the SS was about -52 dBm. In accordance with ECC Report 94 the SS had to be operated at the sensitivity limit which in this case was determined to be -90.5 dBm. Consequently the BS transmit signal had to be attenuated by another 38 dB which was achieved through the use of a 30 dB attenuator at the BS antenna output and the insertion of a movable RF absorber in between BS and SS (see Figure 19).

Between WiMAX antenna and SS a RF splitter was inserted so that the received signal could be monitored using a digital storage oscilloscope (DSO) which could also operate as a spectrum analyzer. The LNA amplified the very low-power signals arriving from the BS and the UWB interferer. As the reverse attenuation of the RF splitter was only about 25 dB the SS UL signal overpowered the weak signal received from the WiMAX BS.

Appendix 3: UWB LDC test signals.

Activity factor	T_{On} [ms]	T_{Off_mean} [ms]	f_{Pulse} [Hz]
5%	1	19	50
5%	2	38	25
5%	5	95	10
5%	10	190	5
5%	25	475	2
5%	50	950	1

Table 4: LDC pulse parameters

The LDC pulses were generated by an Arbitrary Function Generator (AWG) that drove a solid-state RF switch. The UWB Tx antenna was placed at a distance of 0.5 m from the SS antenna. To reduce reflections and glitches that could falsify the measurement results fixed attenuators were inserted between UWB transmitter and PA, and between the RF switch and the UWB Tx antenna. The UWB Tx path had been calibrated to produce an RF signal with a maximum mean power spectral density (PSD) of -41.3 dBm/MHz at 3.5 GHz.

Victim services were emulated with PCs 1-3 and various software packages for assessing data throughput, and VoIP and video quality.

In the conducted setup the victim and interfering signals were superimposed through RF combiners. Power levels and path loss were adjusted with variable and/or programmable attenuators (Figure 2).

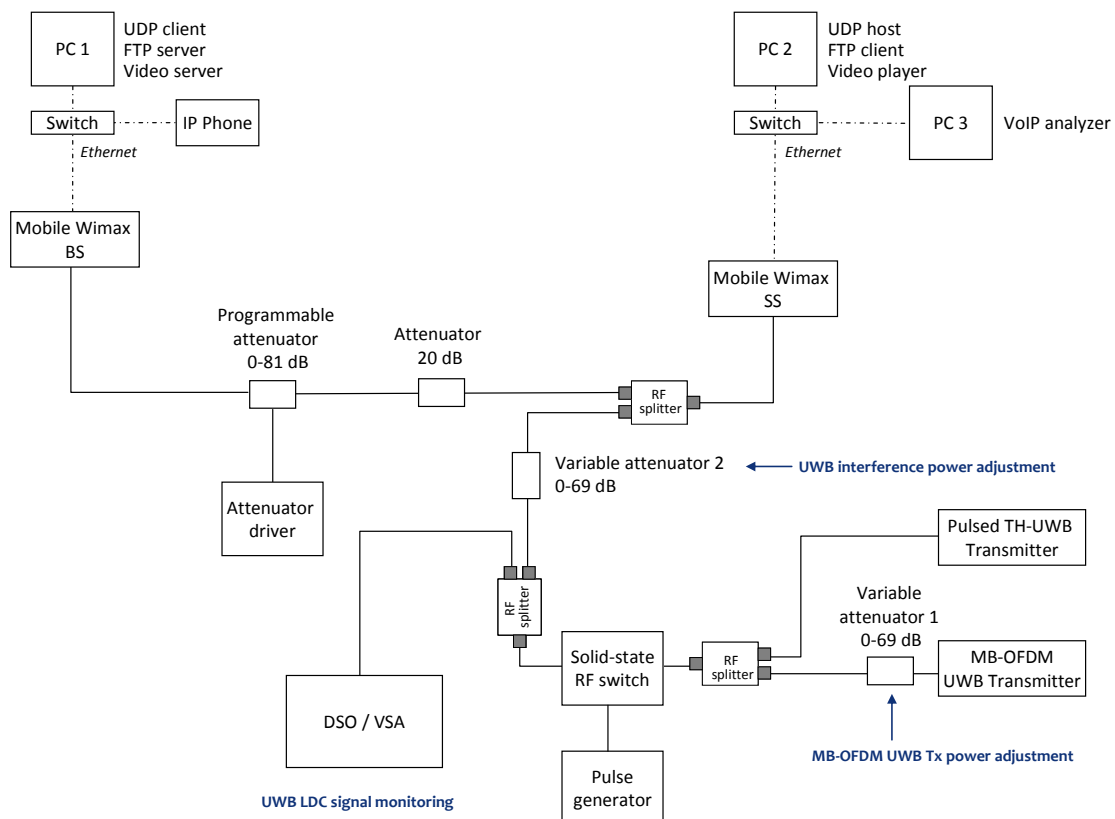


Figure 2: Conducted measurement setup

Test equipment

The following equipment was used in the measurements:

- WiMAX Base Station (BS): Hopling HopMax 3000
- WiMAX Subscriber Station (SS): Hopling HopMax 600
- MB-OFDM UWB transmitter: Wisair DV9110 UWB evaluation kit
- TH-UWB transmitter: ST UWB TX Pulse Generator
- RF power amplifier (PA): B&Z Technologies BZ4-P518-502032
- RF low-noise amplifier (LNA) : B&Z Technologies BZP112UC1
- Solid state RF switch: Agilent Technologies 9404C
- Programmable attenuator: Agilent 84904K + 84907K
- Attenuator driver: Agilent 1173B
- Pulse generator: Tektronix AFG3251
- Oscilloscope/Spectrum analyzer (DSO/VSA): Agilent Technologies Infiniium DSO81304A
- Spectrum analyzer: Tektronix RSA6114A (110 MHz acq. BW)
- UWB antenna: Wisair 3 - 4.8 GHz UWB Omni antenna
- WiMAX antennas: Hopling (provided with BS and SS)
- Variable attenuator: Narda East 4745-69
- RF splitter: Narda East 4456-2
- IP phone: Linksys SPA941
- UDP test software: iperf/jperf v2.0
- FTP client/server: FileZilla v3.3.2 / v0.9.34
- Video server/player: Videolan v1.0.5
- VoIP analysis software: Anacise Testnology WatchVoIP v2.5.0
- Packet analyzer: Wireshark v1.2.10

Test preparation

In the first step the WiMAX link was characterized in order to determine the SS sensitivity limit. The UWB interferer was switched off. Starting from an RSSI of -60 dBm which is well above the sensitivity limit for 64QAM the link attenuation was increased and the RSSI value at which a change of modulation occurred was noted. At each of these points the maximum UDP throughput across the WiMAX link that could be achieved with a packet loss of 0% was determined. The WiMAX RSSI could be retrieved directly through the management interface of the SS which continuously updated its value. The accuracy of the RSSI indication had previously been verified.

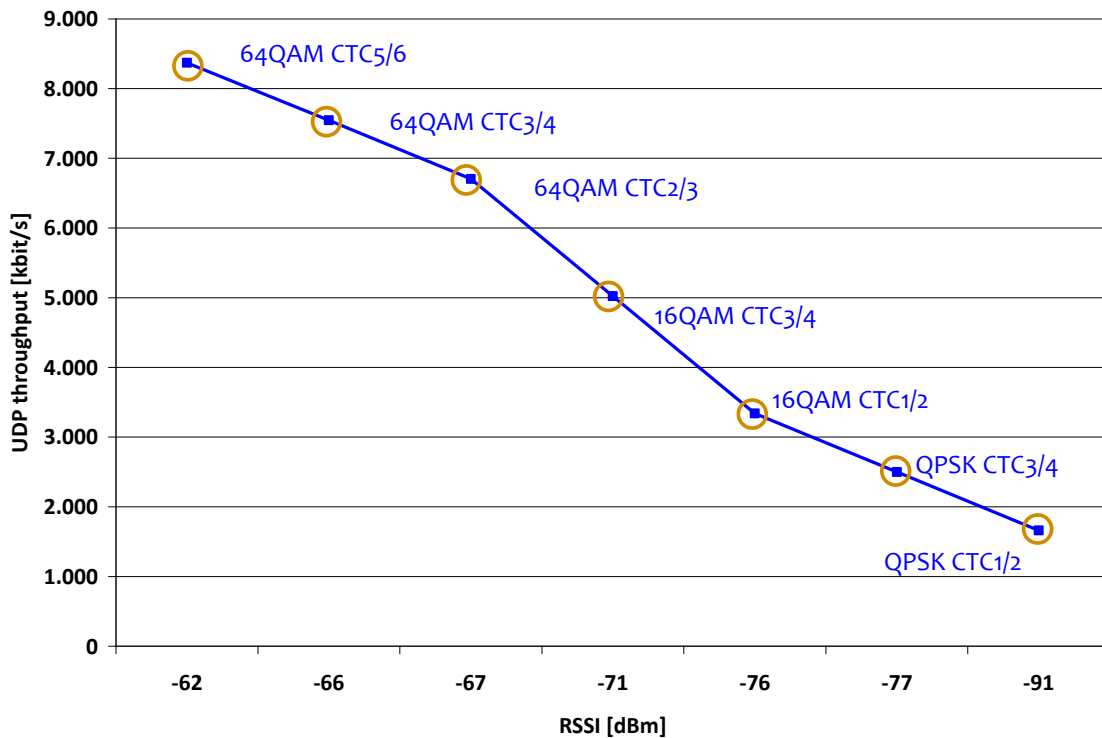


Figure 3: WiMAX UDP throughput vs. RSSI (without UWB interference)

The minimum RSSI at which a stable WiMAX link without CRC errors was maintained was -90.6 dBm. At this RSSI the maximum UDP data rate that could be achieved with a packet error rate of 0% was 1660 Kbits per second (Kbits/s), and the FTP throughput was 1638 Kbits/s. The UDP data rate was measured using the *iperf* software¹. The maximum achievable UDP data rate is determined by the downlink-to-uplink (DL:UL) TDD ratio. The default BS setting of the DL:UL ratio was 60%, so that the maximum achievable DL rate would be approx. 2.8 Mbits/s (for a DL:UL ratio of 100%) which comes close to the maximum reference DL rate of 3.07 Mbits/s [2]. The BS firmware allows DL:UL ratios between 35% and 75% so that the maximum achievable DL rate is about 2.1 Mbits/s.

In accordance with ECC Report 94 the FTP throughput was determined by measuring the transfer time of a file of random content and a size of 4 MB.

¹ In all measurements the default UDP packet size of 1470 bytes was used.

RSSI [dBm]	DL modulation/FEC	UDP Throughput [Kbits/s]	FTP throughput [Kbits/s]
-91.2	QPSK-CTC-1/2	1660	643
-90.6	QPSK-CTC-1/2	1660	1638
-76.5	QPSK-CTC-3/4	2500	2341
-75.7	QAM16-CTC-1/2	3340	2979
-71.1	QAM16-CTC-3/4	5022	4681
-67.1	QAM64-CTC-2/3	6705	4681
-66.4	QAM64-CTC-3/4	7546	4681
-62.0	QAM64-CTC-5/6	8372	5461

Table 5: WiMAX UDP and FTP throughput vs. RSSI (without UWB interference)

Unsurprisingly, FTP throughput was poor at an RSSI of -91.2 dBm which is where WiMAX CRC errors started to occur. At data rates above 5 Mbits/s the FTP throughput started lagging behind the UDP throughput, probably because of the protocol overhead.

Considering that in a real-world deployment a certain fading margin would be applied measurements were made at an RSSI level of -84.6 dBm, corresponding to a fading margin of 6 dB. In reality, operators work with even higher RSSI levels in order to guarantee a certain quality of service. One of the mobile WiMAX coverage criteria of Korea Telecom, for instance, is a minimum RSSI of -75 dBm [3].

Data transfer / throughput test

In the next step the performance of the WiMAX link in the presence of an UWB LDC signal was measured. As performance metrics UDP throughput and packet loss, and FTP transfer time were chosen.

1. UDP

For the first test the UWB interferer was placed at a distance of 0.5 m from the WiMAX SS. For each of the LDC signals shown in Table 4 UDP throughput and packet loss were measured over a period of 20 seconds.

It is important to note that in the previous version of this report (v1.0) measurements had been made with LDC pulses of constant duration. For this reason the temporal position of the interfering UWB pulse in relation to the WiMAX DL and UL bursts remained more or less constant at all times, due to the fact that for all LDC pulsing schemes the pulse duration ($T_{ON} + T_{OFF}$) was an integer multiple of the WiMAX frame rate of 5 ms. As a consequence, the impact of the interfering signal on the victim signal varied, particularly for small pulse widths, depending on the amount of overlap between UWB pulse and WiMAX DL burst. For the current revision of the report we did three additional sets of UDP measurements, for the following cases:

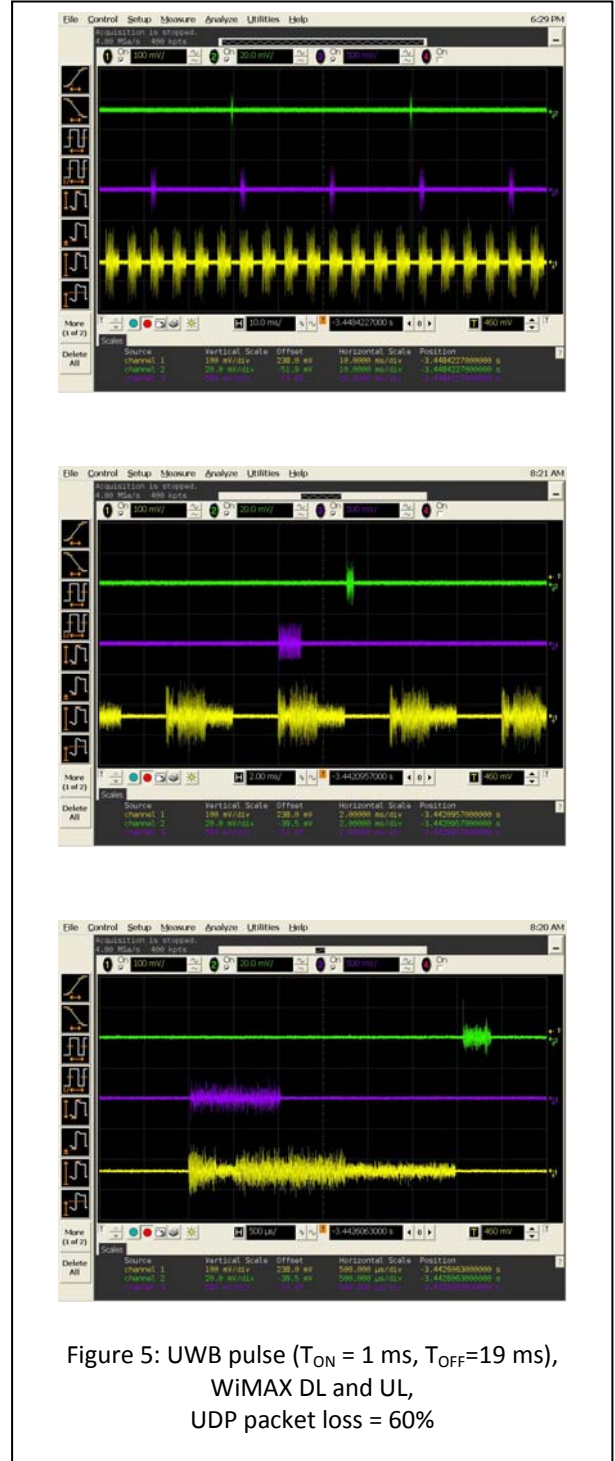
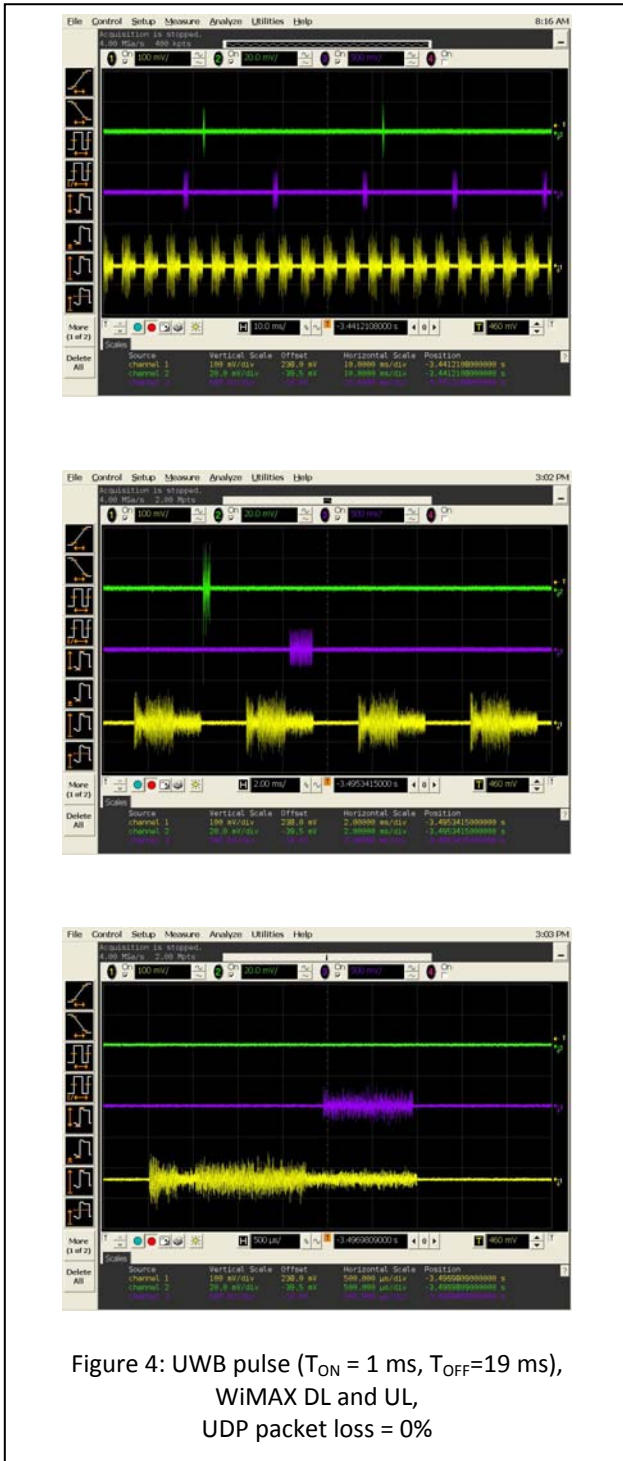
1. Worst case (constant LDC pulse duration, maximum WiMAX overlap = maximum interference).
2. Best case (constant LDC pulse duration, minimum WiMAX overlap = minimum interference).
3. Realistic case (randomized LDC pulse duration, random WiMAX overlap). In this case T_{ON} remained constant, and T_{OFF} was randomized whilst maintaining the conditions $T_{OFFmin} \geq 38$ ms and $T_{OFF_Total} \geq 950$ ms/s.

In the first step, we did measurements with constant LDC pulse durations. WiMAX DL, WiMAX UL, and UWB signals were monitored with a digital oscilloscope. The position of the UWB pulse relative to the position of the WiMAX DL subframe was then modified until the UDP packet loss rate reached either a minimum or maximum.

An overview of the WiMAX OFDMA frame structure can be found in Appendix 2: Mobile WiMAX frame structure.

The measured length of the WiMAX DL subframe is 3 ms, corresponding to approx. 29 OFDM symbols. Maximum interference occurs when the first part of the subframe containing the Preamble, the DL signaling information and data destined for the interfered WiMAX SS (PUSC zone #1) coincides with a UWB LDC pulse. Minimum interference occurs when the LDC pulse coincides with the part of the DL subframe which does not carry data destined for the interfered WiMAX SS (in this case PUSC zone #2)

Figure and Figure show oscilloscope screenshots of the pulse positions that resulted in minimum and maximum interference (pulse parameters: $T_{ON} = 1$ ms, $T_{OFF} = 19$ ms) taken with different temporal resolutions. The WiMAX DL signal is shown at the bottom (yellow graph), the WiMAX UL signal is shown at the top (green graph), and the UWB signal is shown in the middle (purple graph).



In the second step we modified the LDC pulsing schemes in a way that the pulse duration would vary randomly in order to avoid a synchronisation of the UWB pulse and the WiMAX burst. As expected the measured UDP packet loss rates were in between the minimum and maximum values determined previously (Figure 4). These results confirmed the previous finding that short pulses with high PRFs have a stronger negative impact on UDP throughput than longer pulses with lower PRFs.

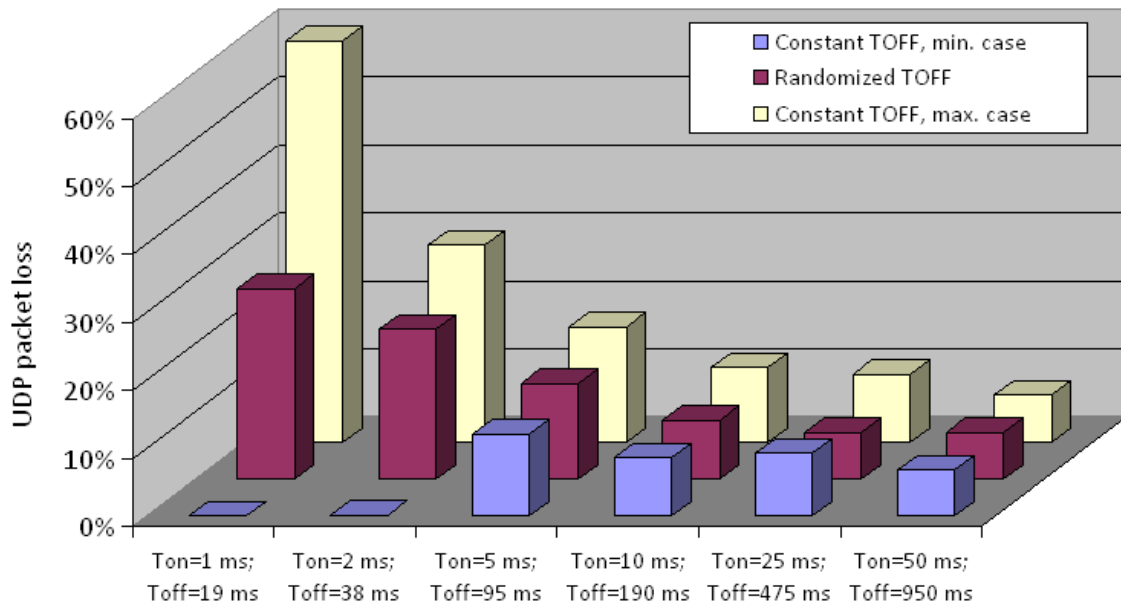


Figure 4: UDP packet loss for different LDC pulsing schemes, equivalent UWB distance = 0.5 m, SS RSSI = -84.6 dBm

The results of the UDP throughput measurements that were presented in the previous revision of this report reflected the worst cases, i.e. maximum overlap between LDC pulse and WiMAX burst (Figure 5).

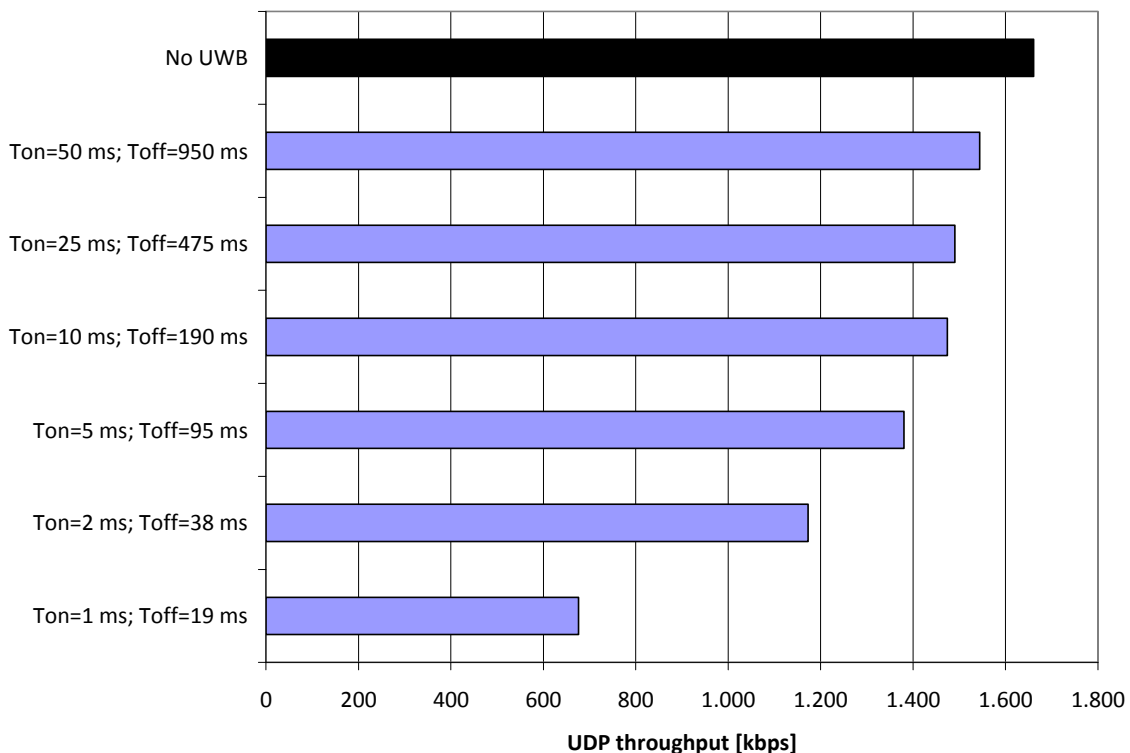


Figure 5: WiMAX UDP throughput for different UWB LDC schemes (constant PRF, worst case), equivalent UWB distance = 0.5 m, SS RSSI = -84.6 dBm

The next test focused on the effect of pulse widths ≥ 5 ms on UDP throughput and packet error rates for various distances between UWB interferer and WiMAX.

For a WiMAX RSSI of -90.6 dBm, i.e. at the very edge of the victim's coverage area, UDP throughput was affected up to a distance of 8 meters. Beyond 10 meters the impact of the UWB interference on UDP throughput and packet loss was negligible.

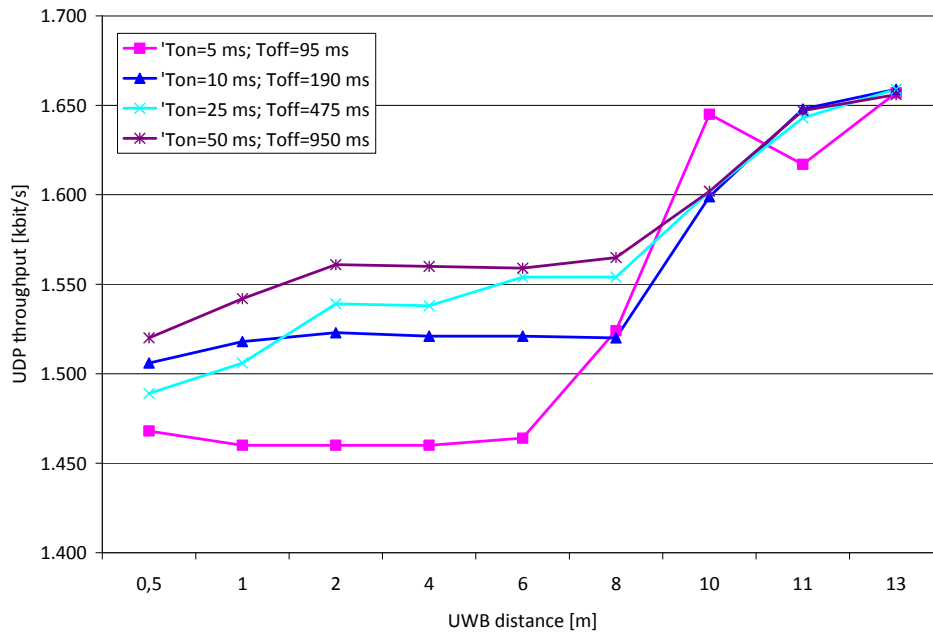


Figure 6: WiMAX UDP throughput for different UWB LDC schemes and distances, SS RSSI = -90.6 dBm

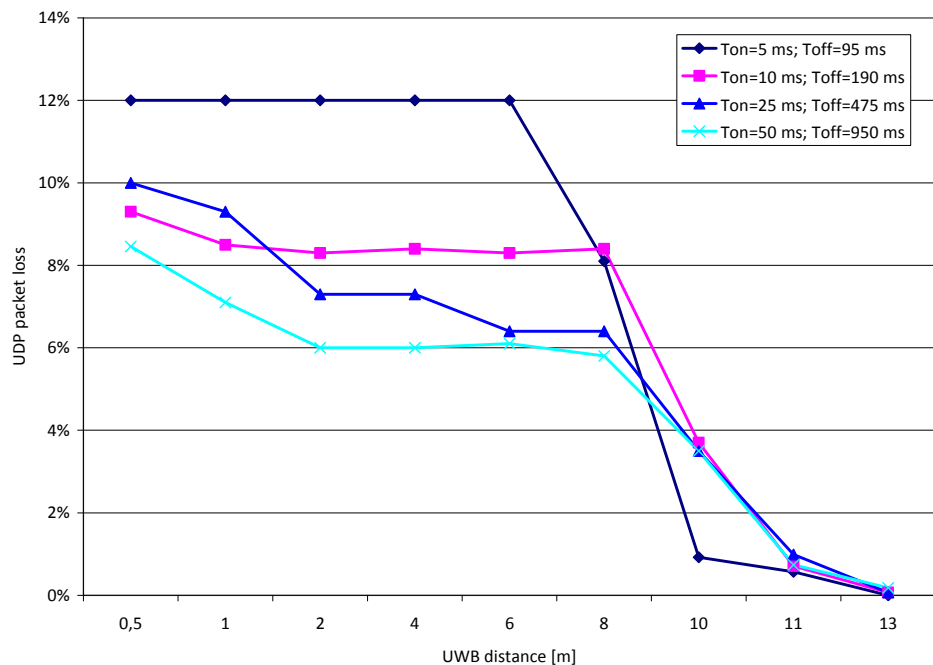


Figure 7: WiMAX UDP packet loss for different UWB LDC schemes and distances, SS RSSI = -90.6 dBm

For a WiMAX RSSI of -84.6 dBm the impact of the UWB interferer on the UDP throughput remained more or less unchanged up to a distance of 2 meters; at a distance of 4 meters, however, there was no measurable impact (Figure 8).

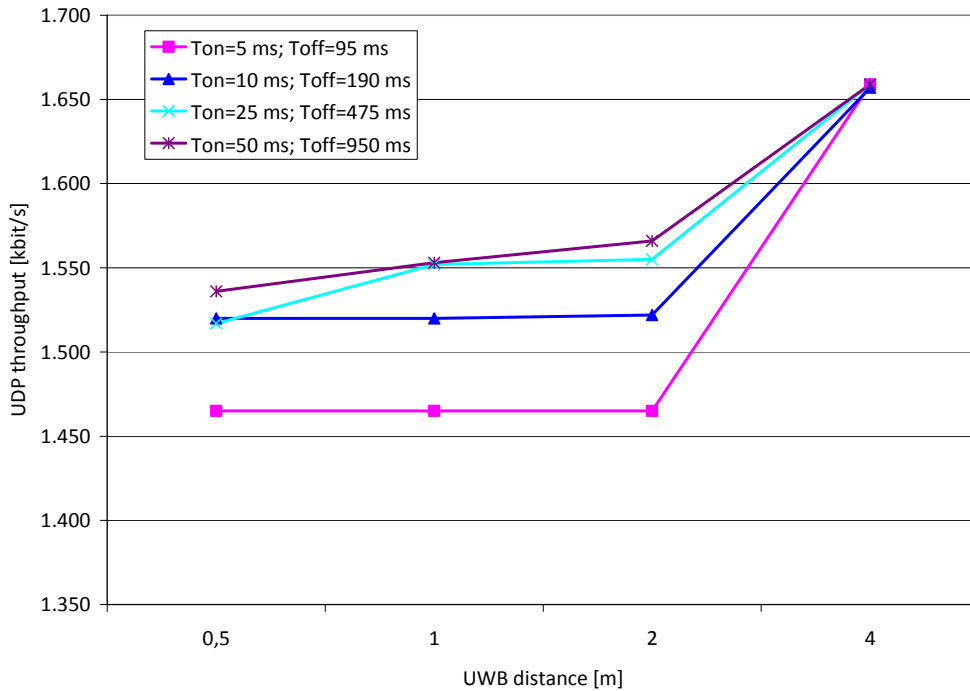


Figure 8: WiMAX UDP throughput for different UWB LDC schemes and distances, SS RSSI = -84.6 dBm

Conducted measurements made at an RSSI of -84.6 dBm confirmed the observation that UDP traffic is adversely affected by signals with a high pulse frequency. Interestingly, the maximum UDP packet loss occurs for a pulse width of 100 μ s which corresponds more or less to the WiMAX useful symbol time of 91.4 μ s. For pulse widths < 100 μ s UDP packet loss decreases again (Figure 9).

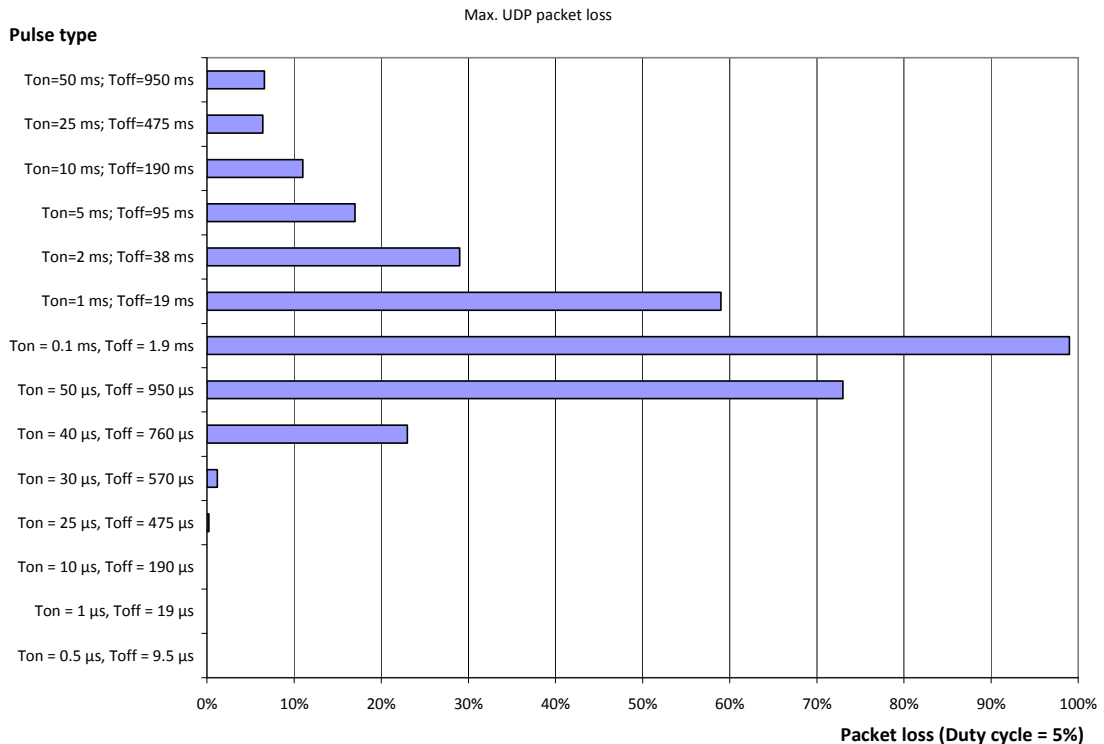


Figure 9: WiMAX UDP packet loss for different UWB LDC schemes (5% activity level), equivalent UWB distance = 0.5 m (LOS), SS RSSI = -84.6 dBm

A comparison between conducted measurements made at an RSSI of -90.6 dBm and of -84.6 dBm revealed that the WiMAX link was significantly more susceptible to interference when operated close to the sensitivity limit. When operated at an RSSI of -90.6 dBm, UDP throughput started being affected at a signal-to-interference ratio (SIR²) of 8 dB; at a SIR of 5 dB UDP packet loss had increased to 98%. When operated at an RSSI of -84.6 dBm, however, UDP throughput started decreasing only from a SIR of 3 dB on.

As seen in Figure 6 and Figure 7, the transition from the non-interference to the interference region is very sharp. Within 1 m (equivalent LOS distance at 3.5 GHz, corresponding to a change in SIR of 2 dB) UDP packet loss increases drastically once the SIR threshold of 3dB is reached. Figure 10 shows this transition for LDC pulses of various durations, and for a continuous UWB signal.

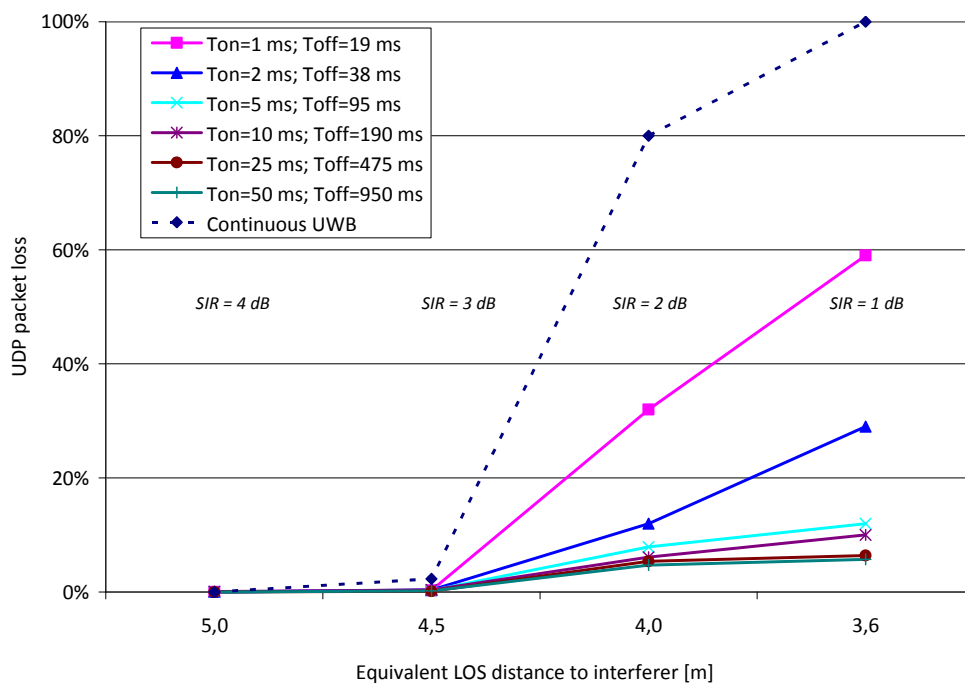


Figure 10: UDP packet loss vs. equivalent distance to interferer (LOS), SS RSSI = -84.6 dBm

Once the 3 dB threshold was passed, packet loss rates remained relatively constant, even when the UWB Tx power was increased above the maximum level of -41.3 dBm/MHz permitted by the current spectrum regulation.

Figure 11 shows the UDP packet loss rates in relation to the WiMAX SIR for the various pulses types. Down to a SIR of -24 dB, packet loss rates remain more or less constant for all pulse types. When the UWB signal level was increased further, the WiMAX link started breaking down. We observed that the smaller the pulse width, the lower was the SIR at which the link broke down:

- T_{on}=50 ms; T_{off}=950 ms: SIR_{min}³ = -24 dB
- T_{on}=25 ms; T_{off}=475 ms: SIR_{min} = -28 dB
- T_{on}=10 ms; T_{off}=190 ms: SIR_{min} = -29 dB

² For the SIR calculation the maximum mean power of the UWB pulse in the WiMAX bandwidth, in this case 10 MHz, is considered

³ SIR_{min} is the lowest SIR value at which the WiMAX link was still operational

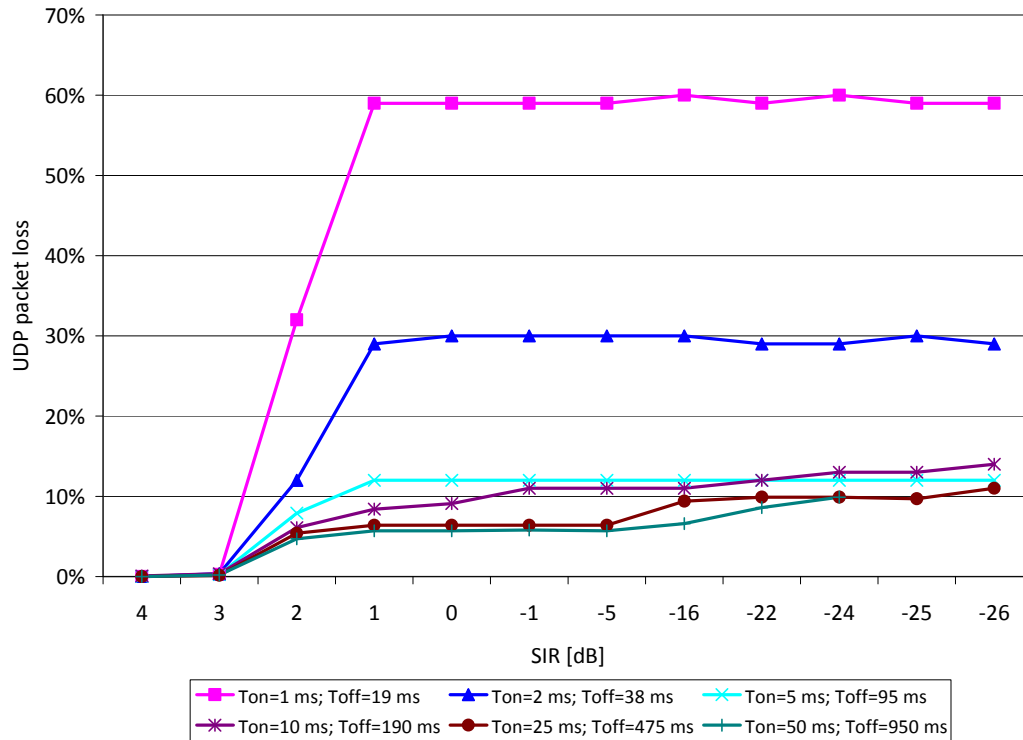


Figure 11: UDP packet loss rates vs. WiMAX Signal-to-Interference Ratio (SIR) for various LDC pulse durations, RSSI = -84.6 dBm

For this test the UWB interferer had been placed in a distance of 0.5 m from the WiMAX SS. Then, the UWB Tx power was gradually increased, starting from -62 dBm/MHz. Up to a UWB PSD of -34 dBm/MHz, which corresponds to a WiMAX SIR of -24 dB, the WiMAX link operated robustly and UDP packet loss remained more or less unchanged, as described above.

A further UDP throughput test was performed with the WiMAX BS and SS operating in MIMO (Matrix B) mode. The Hopling system supports SISO, and MIMO Matrix A and Matrix B modes. Matrix A uses two downlink transmit antennas but only one receive antenna at the SS; Matrix B mode requires two downlink transmit antennas and two SS receive antennas. When operated in Matrix B mode, the SS RSSI increased by 3 dB; other than that we could not observe any change in the behaviour of the WiMAX link. The impact of UWB LDC interference on UDP throughput for a given RSSI remained unchanged.

The nature of the interfering UWB signal was found not to have an impact on the victim's UDP performance. Adjusted to the same average power levels, both MB-OFDM and TH-UWB signals created almost identical levels of impairment (Figure 12).

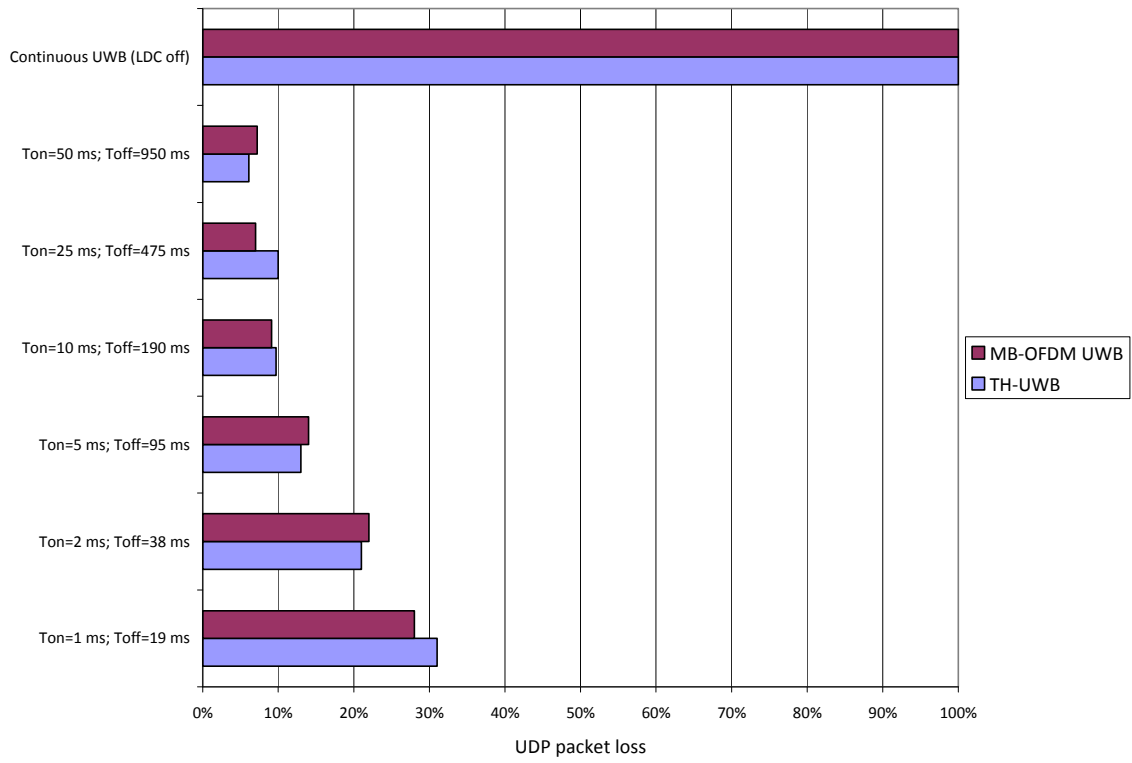


Figure 12: Comparison of pulsed TH-UWB and MB-OFDM UWB impact on WiMAX UDP throughput

2. FTP

For the FTP test a file of random content and a size of 4 MB was downloaded from an FTP server located on the WiMAX BS side. As FTP runs over TCP which is a connection-oriented protocol, transmission errors result in an exchange of protocol messages and re-transmissions which affect the throughput much more than in the case of a connection-less protocol such as UDP.

Pulse type	Activity factor	TOn [ms]	TOff [ms]	Pulse frequency [Hz]	UWB distance [m]	FTP transfer time [s]
No UWB	-	-	-	-	-	21
Periodic	2%	0.78	38	25.8	0.5	90
Periodic	5%	1	19	50	0.5	FTP not possible
Periodic	5%	2	38	25	0.5	FTP not possible
Periodic	5%	5	95	10	0.5	FTP not possible
Periodic	5%	10	190	5	0.5	70
Periodic	5%	25	475	2	0.5	50
Periodic	5%	50	950	1	0.5	44

Table 6: FTP transfer times for different UWB LDC schemes, UWB distance 0.5 m, SS RSSI = -90.6 dBm

Without UWB interference, the 4 MB file was downloaded in about 21 s which corresponds to a data rate of 1.6 Mbits/s which was the maximum bit rate for this WiMAX configuration.

With UWB LDC switched on, we found once again that data throughput was highly affected by signals with high pulse frequencies, even if pulse widths were small. In three cases an FTP transfer was not possible at all because transmission errors prompted the FTP program to continuously stop and re-start the file transfer. A reference measurement made with a low activity signal (2%) with a very short pulse width of 0.78 ms and a relatively high pulse frequency of 25.8 Hz showed that even in this case the FTP transfer time increased significantly.

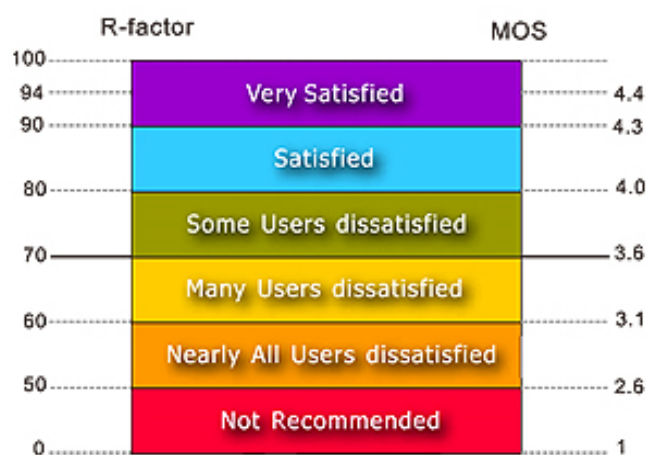
VoIP quality test

In this test the impact of UWB LDC interference on the quality of a VoIP link was examined. For this purpose a VoIP connection was established via the WiMAX link, using a Linksys IP phone on the BS side and a PC emulating a VoIP phone on the SS side. For analyzing the VoIP quality the WatchVoIP software from Anacise Testnology was used. WatchVoIP is a relatively simple but comprehensive software package that can handle call setup, soft phone functions, and voice quality measurement for both called and calling parties. WatchVoIP supports four different voice codecs three of which were tested in this measurement campaign.

A common benchmark used to determine the quality of sound produced by specific codecs is the mean opinion score (MOS). In order to determine the MOS of a particular voice codec, a wide range of listeners judge the quality of a voice sample on a scale of 1 (bad) to 5 (excellent). The results are then averaged to provide an overall score. An alternative method of assessing call quality is the R-Factor. Its scaling from 0 to 100 as opposed to the limited scale of 1 to 5 makes the R-Factor a somewhat more precise tool for measuring voice quality. The R-Factor is calculated by evaluating user perceptions as well as objective factors that affect the overall quality of a VoIP system, such as packet loss, jitter and other network factors.

Various types of MOS exist, such as MOS-LQ, MOS-CQ, and MOS-PQ .

- LQ = Listening Quality. Refers to how users rate the quality of what they hear during a call.
- CQ = Conversational Quality. Refers to how users rate the quality of the conversational experience. This differs from listening quality as it also takes any delay or echo-related problems into account,
- PQ = PESQ (Perceptual Evaluation of Speech Quality). Maps the R-factors to the ITU-T standard P.862 (PESQ) end-to-end measure of voice quality using a test signal.



*The Estimation of R-factor and MOS values.
The opinion of human listeners is shown in the middle.*

Figure 13: Voice quality metrics MOS and R-factor (source: Anacise Testnology)

WatchVoIP calculates all of the above parameters. For reasons of simplicity we only refer to the MOS-PQ value in our analysis.

We examined three voice codecs with distinctively different characteristics in terms of bit rate/compression and voice quality.

Voice codec:	G.711u	G.723.1	G.729a
Compression scheme	None	ACELP	CS-CELP
Packet duration [ms]	20	60	20
Packets/s	50	16,67	50
Bit rate [Kbits/s]	64	5,3	8
Bits/packet	1280	318	160
Bandwidth [Kbits/s]	80	11	24
Reference MOS ⁴	4.3	3.74	3.76

Table 7: Characteristics of the examined voice codecs

All three codecs were first tested without UWB interference in order to determine the basic MOS achievable over the WiMAX link. It showed that all values were in line with the reference values. We then applied the interfering UWB LDC signals and measured the resulting MOS. In contrast to version 1.0 of this report we used LDC signals with randomized T_{OFF} in order to avoid synchronisation with the WiMAX frame.

The MOS results obtained under these more realistic conditions confirmed the observation made in the UDP throughput tests, i. e. short pulses with a high PRF impair service quality more than longer pulses with a lower PRF do.

Depending on the type of codec, voice quality was affected in different ways. The uncompressed high-bit rate G.711u codec showed a significant decrease in MOS for high PRFs. The high-compression G.723.1 codec maintained good performance for all PRFs ≤ 10 Hz, the G.729a performed well for PRFs ≤ 25 Hz. Throughput decreased by a maximum of 10% to 13% for all codecs.

Activity Factor	T_{On}/T_{Off} [ms]	Pulse frequency [Hz]	MOS PQ	Mean throughput [kbit/s]
0% (no UWB)	-	-	4.45	84.2
5%	1 / 19	50	2.83	74.5
5%	2 / 38	25	2.98	75.9
5%	5 / 95	10	3.16	77.0
5%	10 / 190	5	3.18	78.3
5%	25 / 475	2	3.44	78.3
5%	50 / 950	1	3.46	81.4

Table 8: G.711u MOS values for different UWB LDC schemes.
equivalent UWB distance = 0.5 m. SS RSSI = -84.6 dBm

⁴ Ideal Conditions: No Network Load with Both Gender Voice.
Source: http://www.vocal.com/speech_coders/psqm_data.html

Activity Factor	T _{on} /T _{off} [ms]	Pulse frequency [Hz]	MOS PQ	Mean throughput [kbit/s]
0% (no UWB)	-	-	3.66	27.9
5%	1 / 19	50	3.01	18.0
5%	2 / 38	25	3.15	18.7
5%	5 / 95	10	3.28	19.3
5%	10 / 190	5	3.36	19.3
5%	25 / 475	2	3.33	19.4
5%	50 / 950	1	3.45	19.8

**Table 9: G.723.1 MOS values for different UWB LDC schemes.
equivalent UWB distance = 0.5 m. SS RSSI = -84.6 dBm**

Activity Factor	T _{on} /T _{off} [ms]	Pulse frequency [Hz]	MOS PQ	Mean throughput [kbit/s]
0% (no UWB)	-	-	3.80	29.6
5%	1 / 19	50	2.97	25.7
5%	2 / 38	25	3.20	26.7
5%	5 / 95	10	3.22	26.9
5%	10 / 190	5	3.42	27.3
5%	25 / 475	2	3.38	27.7
5%	50 / 950	1	3.48	27.9

**Table 10: G.729a MOS values for different UWB LDC schemes,
equivalent UWB distance = 0.5 m, SS RSSI = -84.6 dBm**

Comparative measurements made at different distances between UWB interferer and Wimax SS yielded the same result as for the UDP throughput test, namely that at a distance of the UWB interferer of 4 meters from the WiMAX SS there was no impact on the MOS of any of the three voice codecs.

Video test

For the video quality measurements a VoD server was set up on the PC connected to the WiMAX BS. Three videos with a content bit rate of 1 Mbits/s were streamed from BS to SS and subjected to interference from the UWB LDC signal. All videos had been generated from the same source, a 2-minute HD video clip in WMV format with a resolution of 1440 x 1080 pixels. File no. 1 was coded in MPEG-2 with a resolution of 640 x 480 File, no. 2 was coded in MPEG-4 with a resolution of 640 x 480, and file no. 3 was coded in MPEG-2 with a resolution of 352 x 264. Videolan was used for both video server and player. Video streaming makes use of RTP, a connection-less protocol running on top of UDP. A schematic of the video network topology, adapted from [4] , is shown in Figure 14.

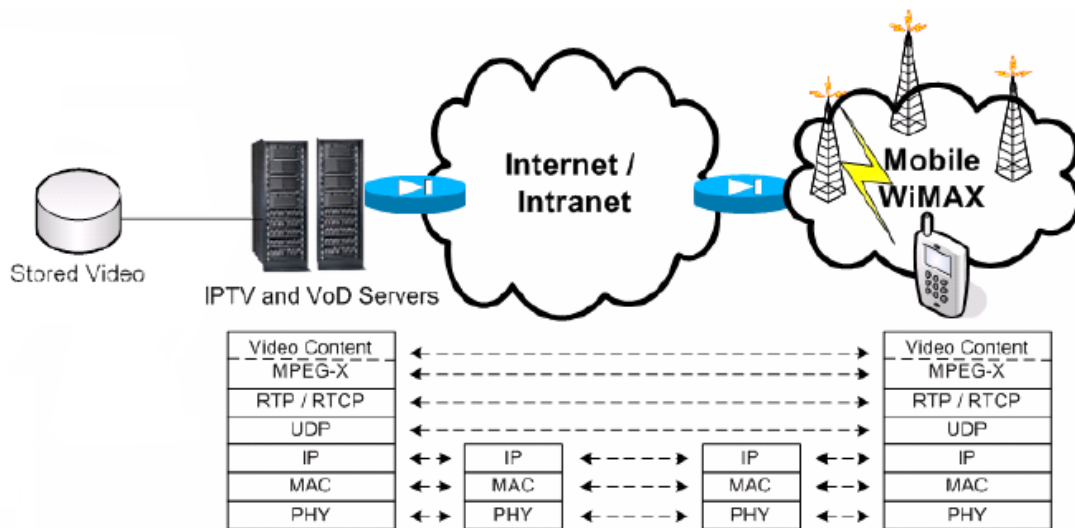


Figure 14: Video streaming network topology

The first test was performed with video no. 1 at three different distances of the UWB interferer from the WiMAX SS (0.5 m, 4 m, and 10 m).

It has to be noted that the video quality measurement results were retrieved using LDC pulses of constant duration only, without control of the temporal position of the LDC pulse. For the reasons described in section 1, the impact of short LDC pulses on the victim's QoS varies depending on this position. Due to availability constraints of our lab facilities these test could not be redone with randomized LDC pulses. The measurement results that were retrieved during this first round and that are presented below are therefore not conclusive. We do believe, however, that due to the similarities of the transport mechanisms the conclusions drawn from the UDP and VoIP measurements can be applied to video streaming, as well.

At a distance of 0.5 meters the video signal was heavily disrupted for all pulse types. Although an increase of the RSSI of 9 dB (which was the maximum possible due to the configuration of the BS) to -81.6 dBm improved the quality of the transmission, errors remained. At a distance of 4 meters the video signal was still impaired for all pulse types. At 10 meters pulses with widths of 10 ms and more caused blockiness of the video.

Pulse type	Activity factor	T _{On} [ms]	T _{Off} [ms]	Pulse frequency [Hz]	UWB distance [m]	Required RSSI increase [dB]
Periodic	5%	5	95	10	0,5	>9
Periodic	5%	10	190	5	0,5	>9
Periodic	5%	25	475	2	0,5	>9
Periodic	5%	50	950	1	0,5	>9
Periodic	5%	2	38	25	4	Blocks
Periodic	5%	5	95	10	4	Blocks
Periodic	5%	10	190	5	4	Blocks
Periodic	5%	25	475	2	4	Blocks
Periodic	5%	50	950	1	4	Blocks
Periodic	5%	2	38	25	10	No impact
Periodic	5%	5	95	10	10	No impact
Periodic	5%	10	190	5	10	Blocks
Periodic	5%	25	475	2	10	Blocks
Periodic	5%	50	950	1	10	Blocks

Table 11: Impact on WiMAX streaming video quality for different UWB LDC schemes and distances

In the second test the video was streamed from BS to SS as before, and the RTP packets received by the SS were analyzed using Wireshark. The UWB interferer was placed at a distance of 0.5 meters from the SS. With no UWB signal present the packet loss rate was 1.9%. With interference, the packet loss rate increased significantly. For pulse widths of 5 ms and above, the loss rate remained relatively stable in the low-10% range.

Pulse type	Activity factor	T _{On} [ms]	T _{Off} [ms]	Pulse frequency [Hz]	UWB distance [m]	Lost RTP packets
No UWB	-	-	-	-	-	1,9%
Periodic	5%	2	38	25	0,5	26,0%
Periodic	5%	5	95	10	0,5	11,1%
Periodic	5%	10	190	5	0,5	9,7%
Periodic	5%	25	475	2	0,5	10,4%
Periodic	5%	50	950	1	0,5	13,5%

Table 12: Video (RTP) packet loss for different UWB LDC schemes (UWB distance: 0.5 m)

An analysis of the received RTP packets showed that with all pulses packet loss occurred more or less exactly at the pulse rate or multiples thereof. An example showing the number of packet loss occurrences vs. the time between occurrences for the pulse T_{on} = 25 ms, T_{off} = 475 ms is given in Figure 15.

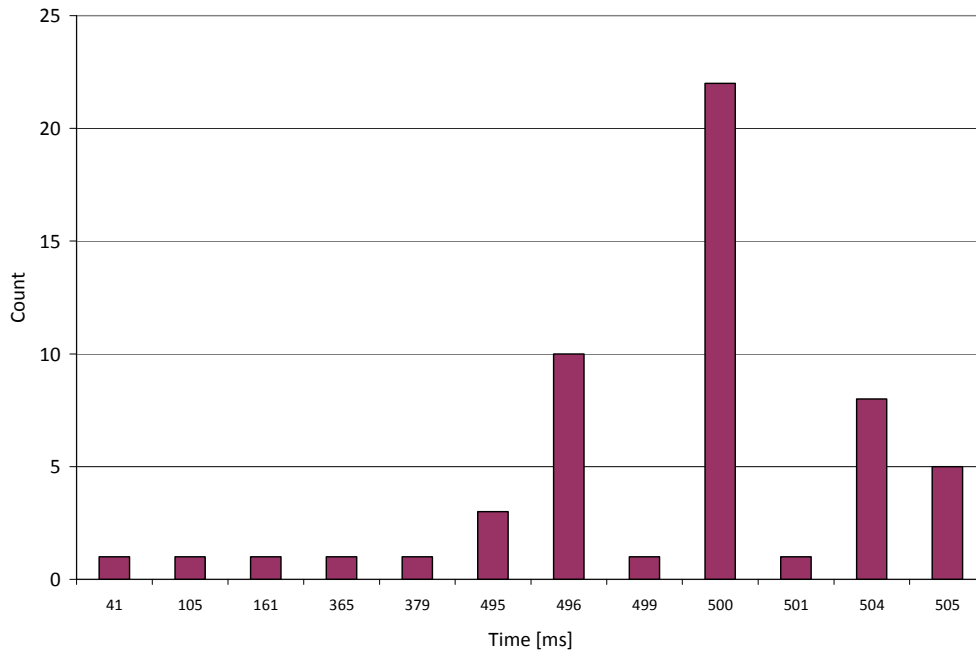


Figure 15: Time between packet loss occurrences ($T_{on}=25$ ms, $T_{off} = 475$ ms)

The number of packets lost at each occurrence depends on the width of the interfering pulse. For pulse widths of 2 and 5 ms, on average two packets were lost. The 10 ms pulse took out three RTP packets, the 25 ms pulse six packets, and the 50 ms pulse thirteen packets. These figures may be explained by the mapping of the RTP data onto the WiMAX MAC and PHY layers. The average size of an RTP packet was 1367 bytes.

In addition, conducted measurements were made with videos no. 2 and 3 at an RSSI of -84.6 dBm. While the picture quality of the MPEG-2 video was suffering less than that of the highly compressed MPEG-4 video, both showed blockiness and image freezes up to a UWB distance of 5 meters (corresponding to a PL of approx. 57 dB), for all pulse types. This result is in line with the findings of the UDP tests. Depending on the type of pulse, the effects on the picture were different. High frequency pulses caused a constant degradation of the picture quality while low-frequency pulses frequently caused the picture to freeze.

Summary and conclusion

The measurement results obtained so far show that the impact of UWB LDC signals on victim services depends very much on the characteristics of the service and on the network setup. At short distances, i.e. up to 4 meters (LOS), the effect of interference from LDC UWB on mobile WiMAX services is not negligible, except probably for UDP data transfers. Several results indicate that in terms of interference potential LDC pulse width may be less critical than pulse frequency.

The relevance of testing Mobile WiMAX performance at the subscriber station sensitivity limit, i.e. at signal levels 15 dB below those used in actual deployments, may be questioned. At this level, the WiMAX SS is significantly more susceptible to interference (in terms of SIR) than it is at higher RSSIs so that variations in signal strength of less than 1 dB can have a strong impact on the measurement results.

Compared to ECC Report 94, this study found a much stronger impact of UWB interference on the different types of victim services, particularly for short distances and independent of the type of UWB signal (MB-OFDM or TH-UWB). Due to the lack of detailed information on the configuration of the WiMAX system and on the UWB signal parameters in ECC Report 94, however, it is very difficult to compare the findings of Report 94 and this study.

Based on the measurement results obtained in this study we see no particular benefit in limiting the LDC pulse width to 5 ms, provided that an overall activity factor of 5% per second is maintained. Pulses of longer widths (> 2 ms) were actually found to produce a more graceful degradation of victim service quality in the transition zone (SIR = 3 to 0 dB). In order to protect mobile WiMAX services, however, a minimum SIR of 3 dB should be observed.

We also found that as far as UDP throughput and packet loss is concerned, the impact of UWB interference on the WiMAX link remained stable below a SIR of 3 dB, down to -24 dB. This means that at a distance of 0.5 m between UWB interferer and the WiMAX SS the UWB maximum mean PSD could be increased up to 8 dB above the currently permitted level of -41.3 dBm/MHz without creating any further impairment of the WiMAX service.

Appendix 1: Test setup



Figure 16: Hopling HopMax 3000 base station



Figure 17: HopMax 3000 BS and attenuator

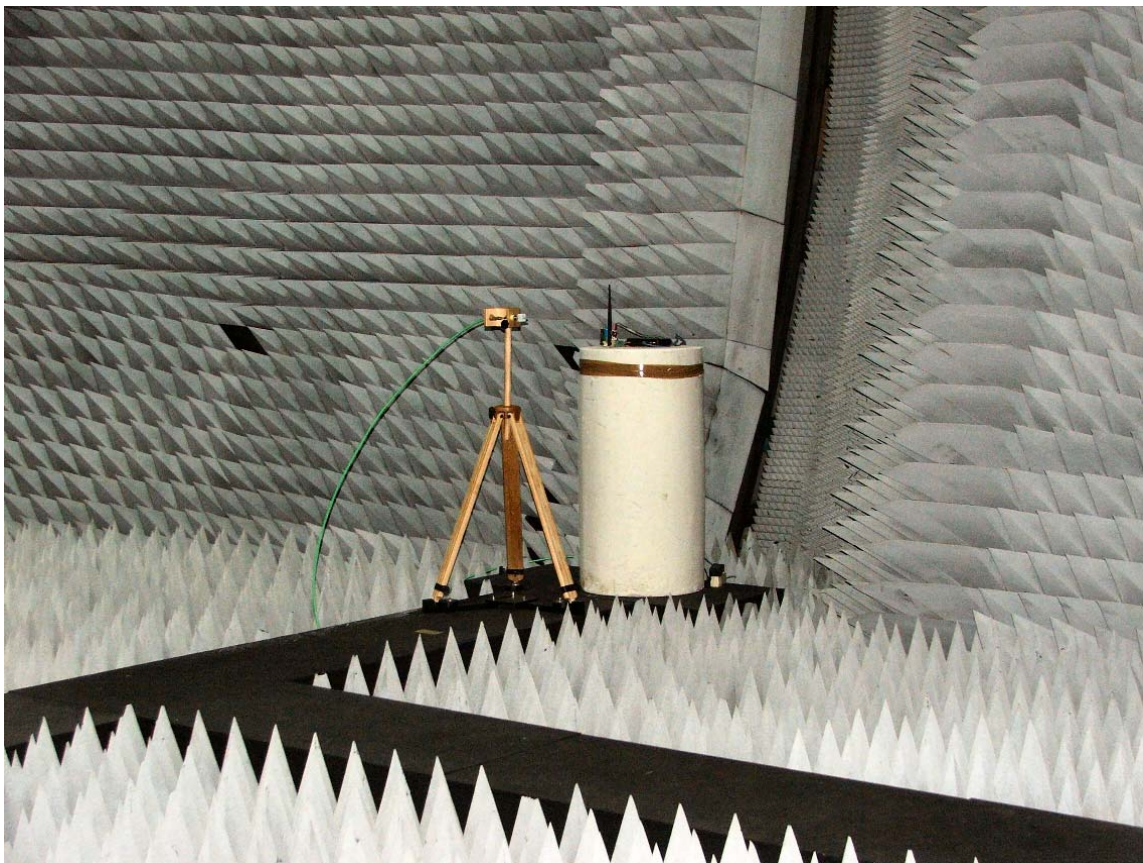


Figure 18: Mobile WiMAX subscriber station and UWB interferer

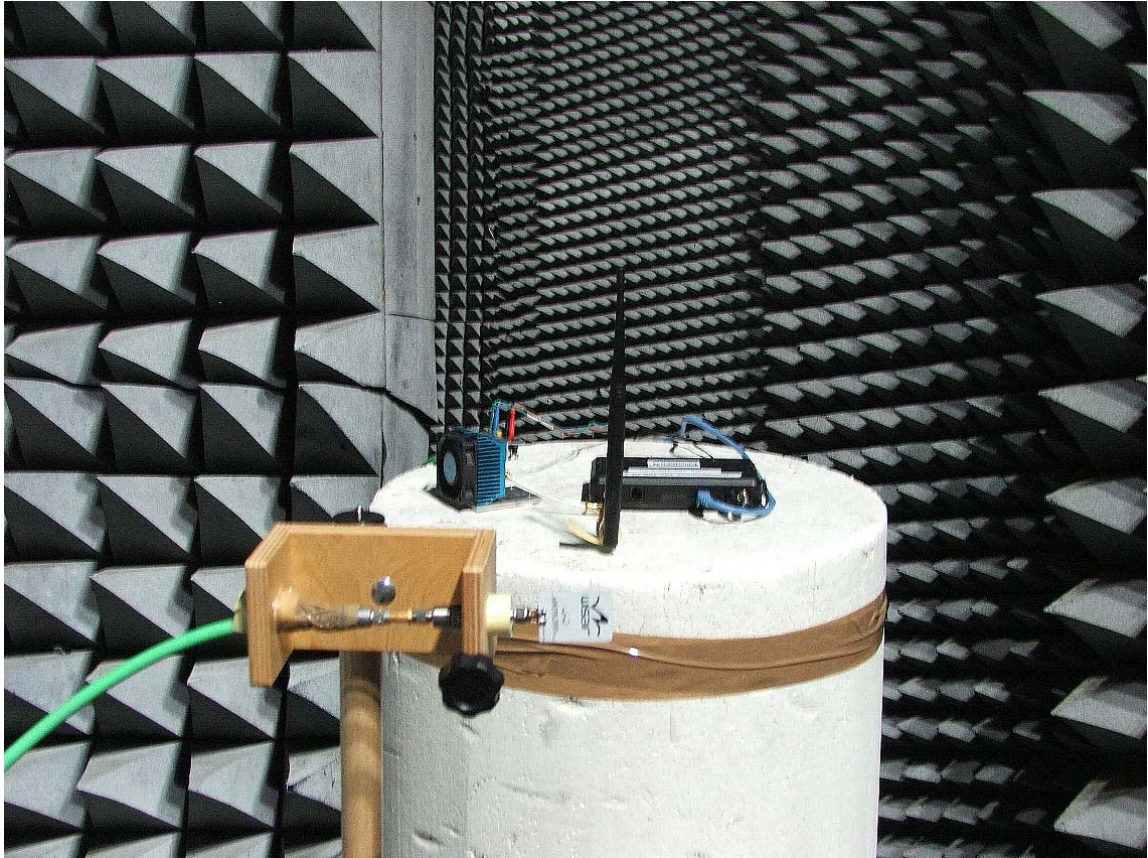


Figure 19: Mobile WiMAX subscriber station and UWB interferer (close view)

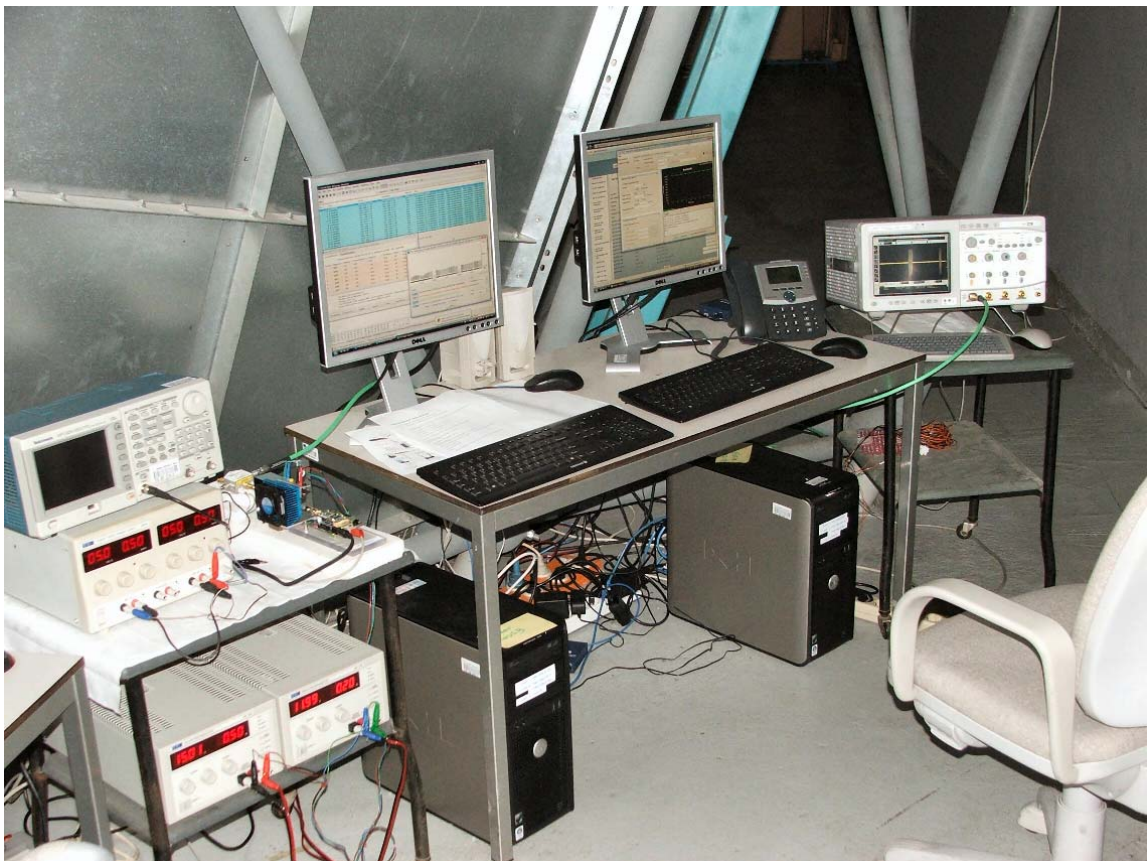


Figure 20: Interfering signal generation, and victim service generation and analysis

Appendix 2: Mobile WiMAX frame structure

In IEEE 802.16e-2005 (Mobile WiMAX), both frequency division duplexing (FDD) and time division duplexing (TDD) are allowed. In the case of TDD which is the most preferred method in mobile WiMAX deployments and the only one our test system supports, the uplink (UL) and downlink (DL) subframes are transmitted on the same carrier frequency at different times.

Each DL subframe and UL subframe is divided into various zones, each of which uses a different subcarrier permutation scheme. Some of the zones, such as DL PUSC, are mandatory; other zones, such as FUSC, AMC, UL PUSC, and TUSC, are optional. The relevant information about the starting position and the duration of the various zones being used in a UL and DL subframe is provided by control messages in the beginning of each DL subframe.

Each segment (sector), as defined in the PUSC subcarrier permutation section, uses a preamble composed of only one of three allowed carrier sets, thus modulating every third subcarrier. A cell-ID-specific pseudonoise sequence is modulated, using BPSK to create the preamble in the frequency domain. The power of the subcarriers belonging to the carrier set of the preamble is boosted by $2\sqrt{2}$. The frame length, which is defined by the interval between two consecutive DL frame preambles, is variable in WiMAX and can be anywhere between 2 ms and 20 ms. In our case the only frame length supported by both BS and SS was 5 ms.

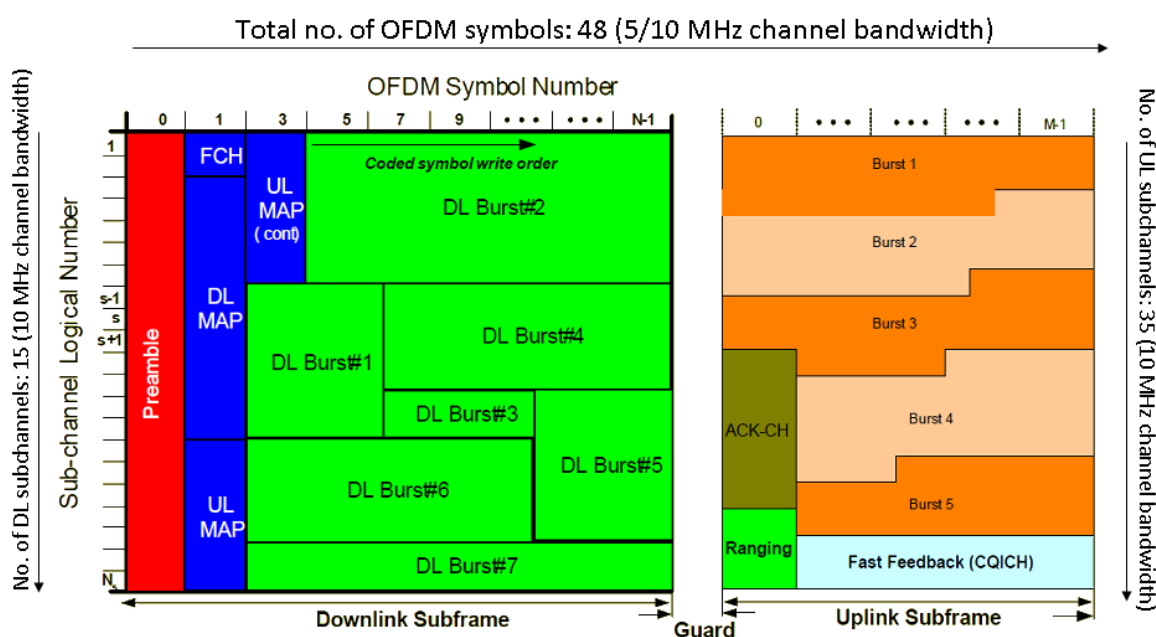


Figure 21: Mobile WiMAX OFDMA frame structure (adapted from WiMAX Forum specification)

In a 10 MHz system each frame consists of 48 OFDMA symbols of which 44 are data symbols that can be flexibly allocated to DL or UL. Each symbol has a length of $102.9 \mu\text{s}$.

The first OFDM symbol in the downlink subframe is used for transmitting the DL preamble. The preamble can be used for a variety of PHY layer procedures, such as time

and frequency synchronization, initial channel estimation, and noise and interference estimation.

In the OFDM symbol following the DL frame preamble, the initial subchannels are allocated for the frame correction header. The FCH is used for carrying system control information, such as the subcarriers used (in case of segmentation), the ranging subchannels, and the length of the DL-MAP message. The FCH is BPSK-coded to ensure maximum robustness and reliable performance, even at the cell edge.

Following the FCH are the DL-MAP and the UL-MAP messages, respectively, which specify the data regions of the various users in the DL and UL subframes of the current frame. By listening to these messages, each MS can identify the subchannels and the OFDM symbols allocated in the DL and UL for its use.

Appendix 3: UWB LDC test signals

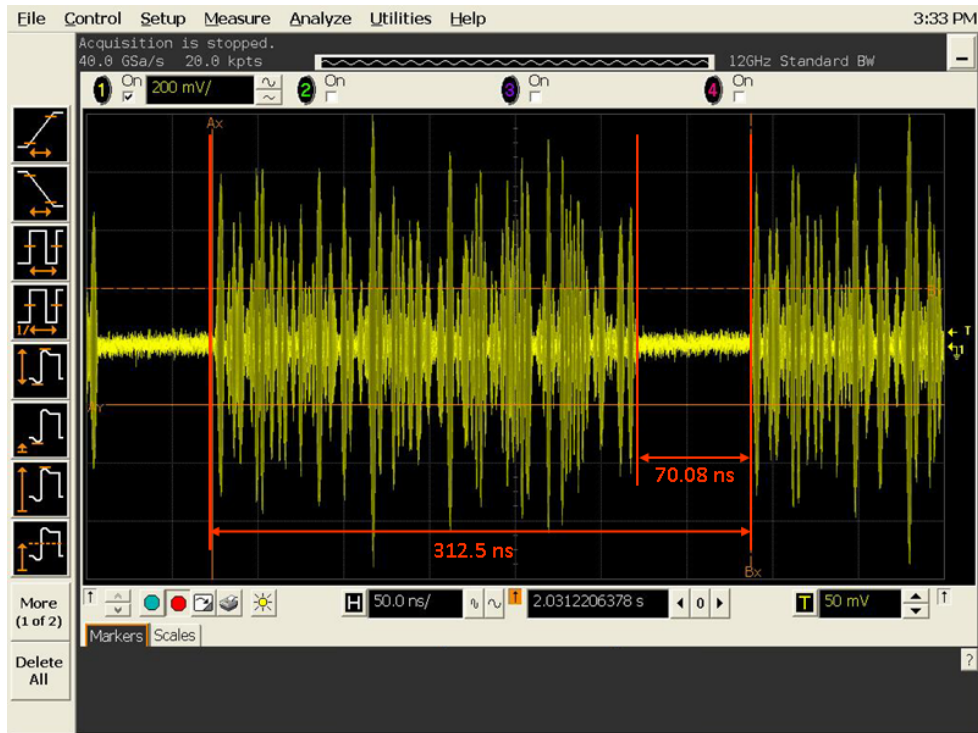


Figure 22: MB-OFDM UWB test signal (symbol)



Figure 23: MB-OFDM UWB test signal spectrum

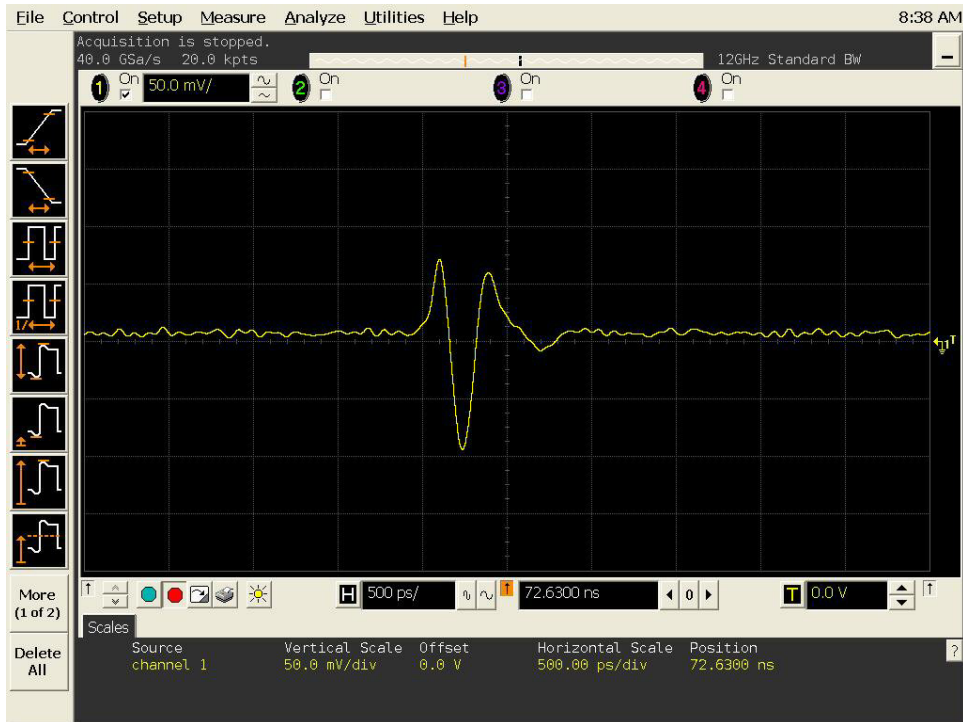


Figure 24: TH-UWB test signal (pulse width = 450 ps)

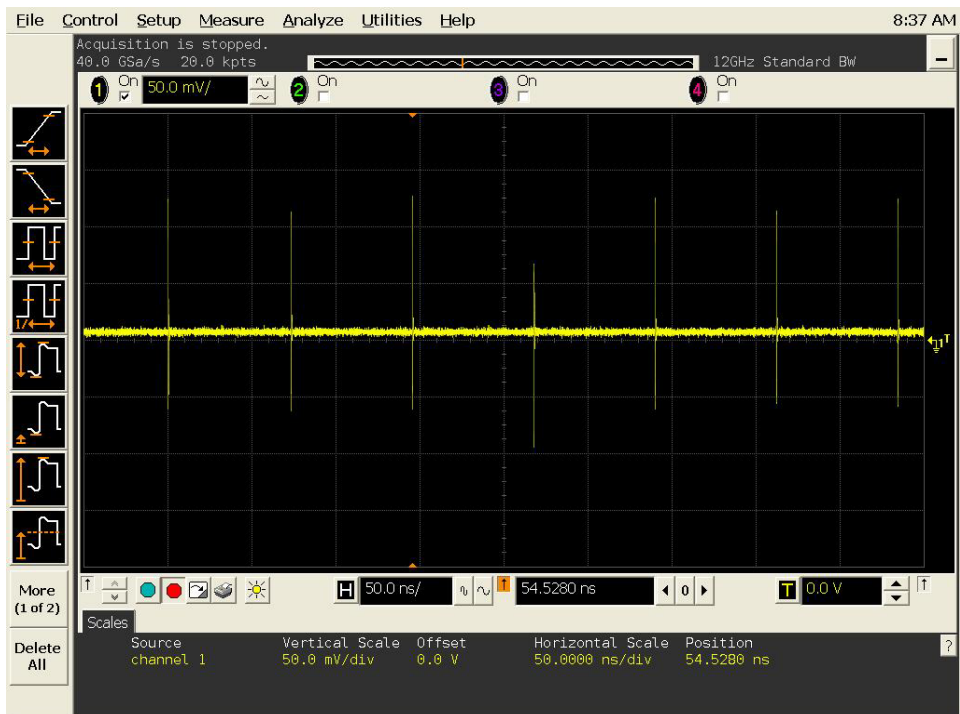


Figure 25: TH-UWB test pulse train (pulse width=450 ps, PRI = 72 ns)

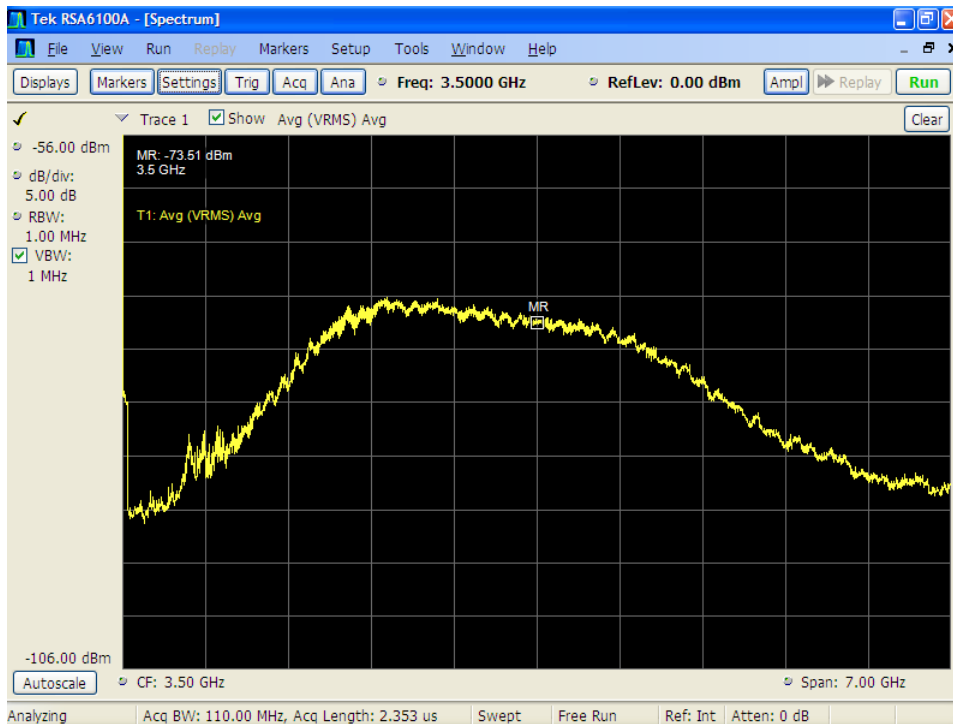


Figure 26: TH-UWB test signal spectrum



Figure 27: MB-OFDM UWB LDC signal (Duty cycle: 5%, $T_{on} = 10$ ms, $T_{off} = 190$ ms)

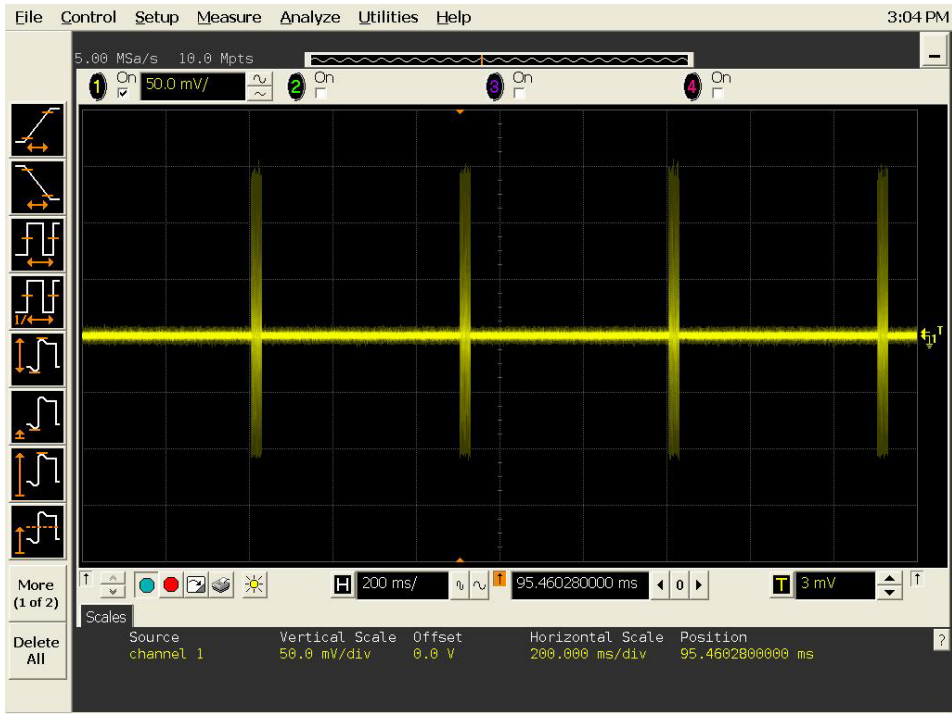


Figure 28: MB-OFDM UWB LDC signal (Duty cycle: 5%, $T_{on} = 25$ ms, $T_{off} = 475$ ms)



Figure 29: MB-OFDM UWB LDC signal (Duty cycle: 5%, $T_{on} = 50$ ms, $T_{off} = 950$ ms)

Appendix 4: Antenna gain

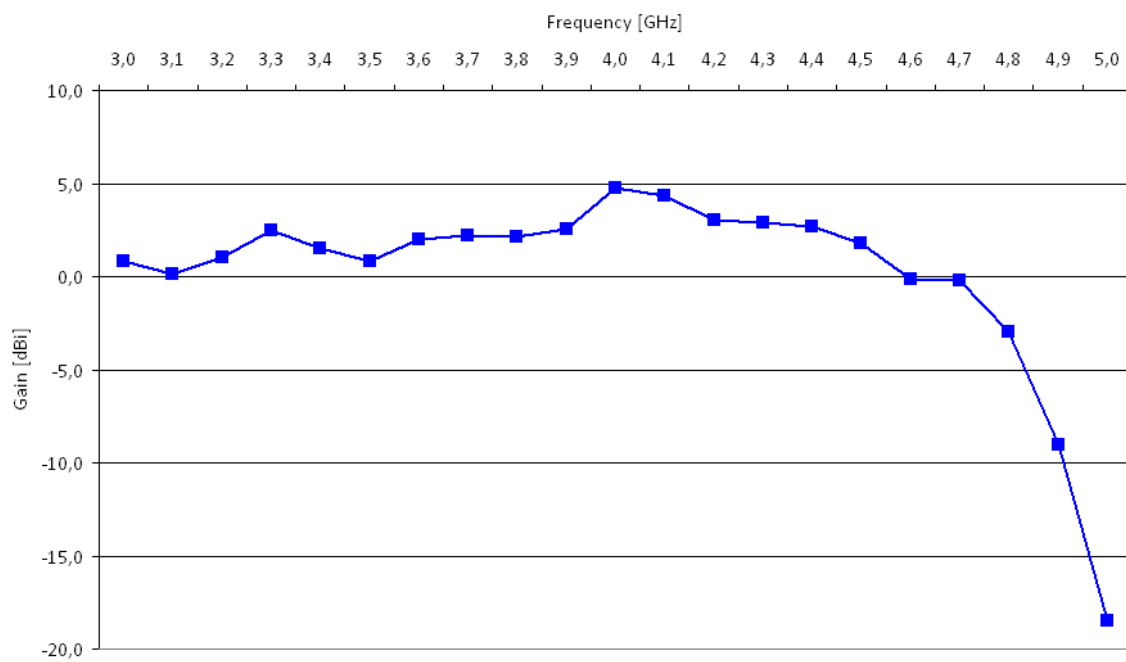


Figure 30: Wisair UWB transmit antenna gain vs. frequency

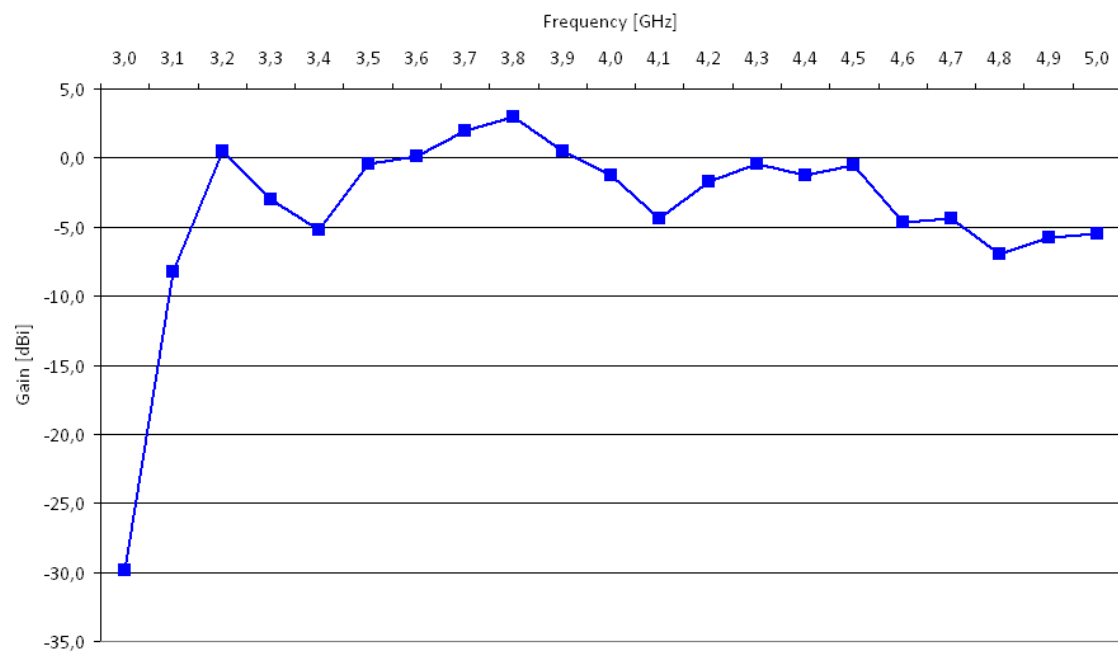


Figure 31: Hopling mobile WiMAX SS antenna gain vs. frequency

References

- [1] ECC Report 94 “Technical Requirements for UWB LDC Devices to Ensure the Protection of FWA Systems”, Nicosia, December 2006
- [2] Rohde & Schwarz “Mobile WiMAX™ Throughput Measurements using R&S®CMW270 Application Note”
- [3] “Business Experience in Implementation of WiMAX”, Do-Young, Kwak, KT Corporation, ITU-T Workshop on Bridging the Standardization Gap and Interactive Training Session, Cyberjaya, Malaysia, 29 June – 1 July 2010
- [4] “Streaming Video and Audio Content over Mobile WiMAX Networks”, William Hruday, Simon Fraser University, 2009

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Abstract

In 2006 the ECC examined the impact of pulsed Low-Duty Cycle (LDC) UWB signals on the quality of various services (FTP, VoIP, video streaming) provided via a fixed WiMAX (IEEE802.16d) link, and published its findings in ECC Report 94 [1]. The resulting spectrum regulation and standardization stipulate a maximum UWB activity (Ton) of 50 ms per second, with a maximum permissible pulse width of 5 ms. Report 94 showed that for activity factors of 5% there was no measurable impact on any of the victim services if a minimum distance of 4 meters (LOS) between the UWB interferer and the WiMAX terminal was maintained.

As fixed WiMAX terminals are typically mounted outdoors in elevated positions the isolation between a WiMAX terminal and LDC UWB devices will in most cases be sufficiently high to avoid interference. Mobile WiMAX (IEEE802.16e-2005) terminals, however, may be operating indoors, in close vicinity to a UWB device. On the other hand, mobile WiMAX was designed to be more robust against fading and interference than fixed WiMAX.

The objective of the measurement campaign described in this document was to determine the impact of UWB LDC signals on different types of services provided by a mobile WiMAX (IEEE802.16e-2005, further on referred to as “WiMAX”) victim system, and in particular to examine LDC pulses with a width of more than 5 ms, whilst maintaining an overall activity limit of 5%, equalling 50 ms per second.

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