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Experimental analysis of the interference between WiMAX and Ultra WideBand technologies

Experimental analysis of the interference from WiMAX 802.16d and WiMAX 802.16e to WiMedia Ultra WideBand wireless communication

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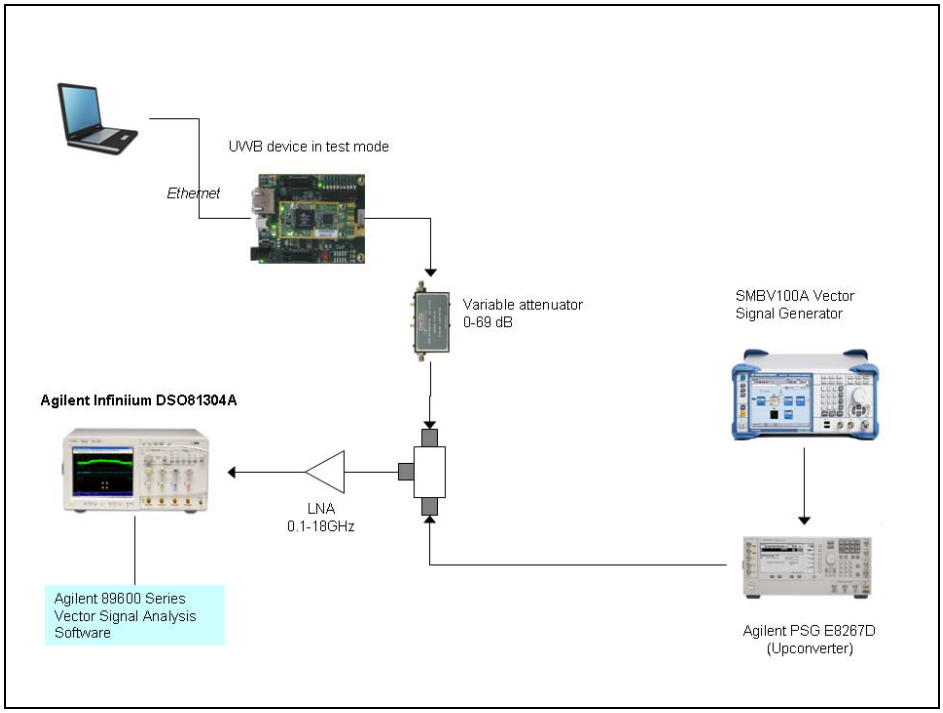

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I. INTRODUCTION

Ultra Wideband (UWB) is a term used to describe the nature of an RF signal which occupies a large bandwidth and which is intended for very-high-speed data transmission. Definitions of the minimum bandwidth of an UWB signal vary; while the European Telecommunication Standards Institute (ETSI) defines a minimum bandwidth of 50 MHz [1], the Federal Communications Commission (FCC) specifies a minimum absolute bandwidth of 500 MHz or 500 MHz or 20% of the center frequency [2]. There are different technical implementations, such as MB-OFDM (MultiBand-Orthogonal Frequency Division Multiplexing) which has been adopted by the WiMedia®[1] Alliance, or pulse-based implementations such as DS-UWB (Direct Sequence Ultra Wideband), which had been the technology of choice of the defunct UWB Forum.
The MB-OFDM implementation by WiMedia is examined in this technical report. In the WiMedia standard, the UWB signal may use bands with a width of 528 MHz distributed in band groups with center frequencies from 3.432 GHz to 10.296 GHz (from [3]).
Because of its wide spectrum occupancy, UWB MB-OFDM signals coexist with other wireless communication systems.
Regulators have defined emissions masks for UWB transmission to avoid harmful interference to existing or planned wireless communication services. These constraints are in line with the planned commercial use of UWB for short range, high data rate communication in Wireless Personal Area Networks (WPAN).
One significant example of coexistence is with the WiMAX (Worldwide Inter-operability for Microwave Access) communication systems, which are or will be operating in a number of bands in the 2.3 GHz, 2.5 GHz, 3.5 GHz or 5.8 GHz frequency ranges.
WiMAX provides medium to long range communications for a number of applications with the primary objective to provide broadband wireless access (BWA). WiMAX specifications were developed by the IEEE and WiMAX standards are currently maintained and promoted by the WiMAX forum [4].
There are currently two main sets of standards: IEEE 802.16-2004 (also called IEEE 802.16d) for fixed applications and IEEE 802.16e-2005 to support mobility.

This technical report describes the results of the experimental analysis of the impact of the transmission of both set of standards on UWB communication defined by WiMedia Alliance.
The measurement campaigns have been executed using a conducted test environment where UWB transmitters and signal generators are used to generate the UWB communication and interference signals.

This technical report is composed of five sections: Section II describes the state of the art in experimental analysis of interference between UWB and other wireless services. Section III describes the test-bed setup used to conduct the measurements campaigns. Section IV presents and discusses the results of the measurements. Section V describes future developments and conclusions.

II. BACKGROUND REFERENCES

Historically, the analysis of interference from UWB to other wireless services has been given the highest priority.
The impact of UWB on FWA (Fixed Wireless Access) has been investigated in [5]. Reference [8] has investigated the impact of UWB emitters on 5 GHz WLAN receivers. The NTIA report [9] describes laboratory measurements of Global Positioning System (GPS) receiver vulnerability to interference from pulse-based UWB. Reference [10], again an NTIA report, describes laboratory measurements (all conducted) to determine the extent and nature of interference to Public Safety radio receivers by pulse-based UWB signals.
Reference [11] provides results from tests that measured digital television (DTV) susceptibility to UWB interference. This report contains a detailed section on DTV signal quality measurements and on the impact of MB-OFDM on the video BER.
Reference [12] describes end-to-end measurements tests with special focus on coexistence with UMTS and WAN wireless systems. Reference [13] describes the impact of UWB on CDMA2000 wireless communication systems. Theoretical models were created and verified in measurements campaigns.
The coexistence of WiMedia UWB and WiMAX has been investigated in [14].

[1] WiMedia is a registered mark of the WiMedia Alliance.

A limited number of papers have investigated the impact of wireless communications systems on UWB communications.
Reference [7] provides a theoretical analysis of the performance of the Multiband Orthogonal Frequency Division Multiplexing (MB-OFDM) system for Ultra Wideband (UWB) communication in the presence of interference from a single-carrier IEEE 802.16WiMAX system operating in the 3.5 GHz band.
Reference [16] examines the impact of distortion products in MB-OFDM UWB systems operating in band group 1 (3.1 – 4.8 GHz) caused by receiver non-linearities, as a consequence of interference from wireless systems based on 802.11 b/g, Bluetooth, WIMAX, and GSM1900.

Finally [15] presents the result of test and measurements of WiMAX 802.16e on MB-OFDMA UWB. The experimental analysis is very similar to the one presented in this technical report, even if a radiated method was used in [15] and the analysis was limited to WiMAX 802.16e.

III. TEST BED CONFIGURATION

The configuration of the test bed used in the measurement campaign is described in the following picture.

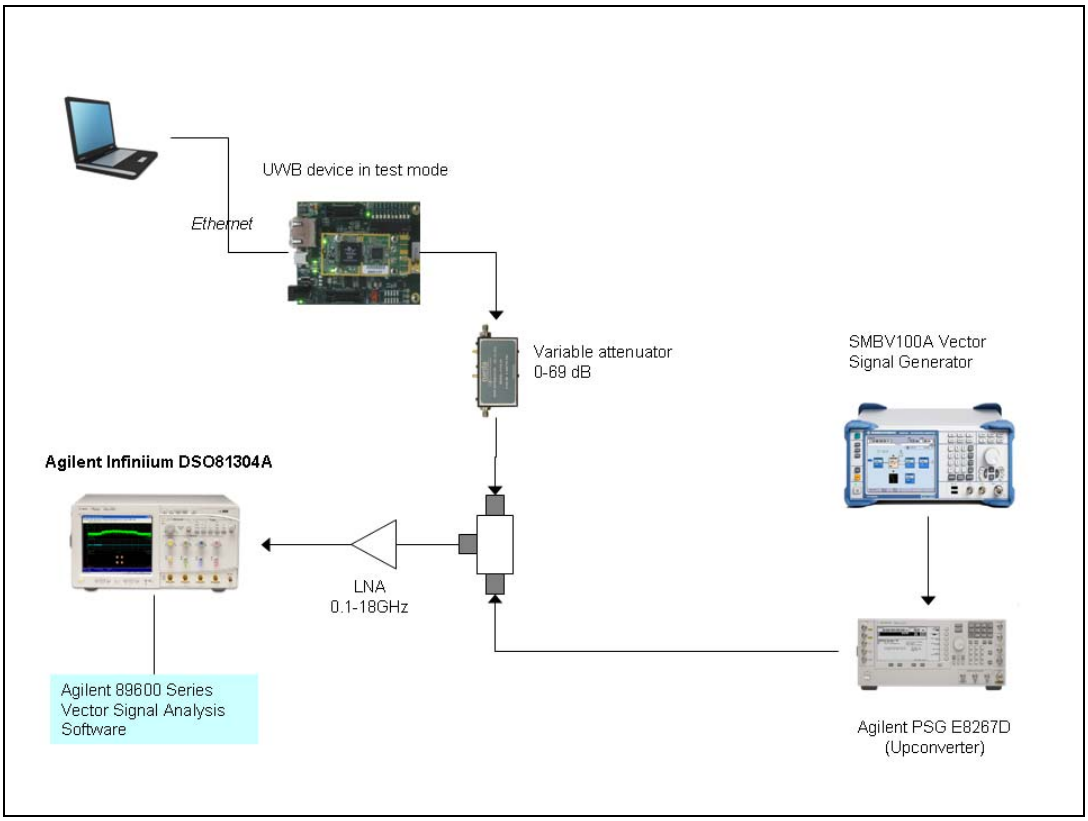

Fig. 1 Test bed configuration

The WiMedia UWB signal generator is a WISAIR DV9110 transceiver set to operate in Band Group 1, Band 1, at a center frequency of 3.432 GHz.
The WiMedia UWB signal generator provides two different UWB data rates of 200 Mbits/s and 53.3 Mbits/s with an EIRP of -41.3 dBm/MHz. The test mode with time frequency coding of TFC 5 is used. In test mode, Frequency Hopping is not used.

Test mode is intentionally used to consider the worst case scenario for interference to the UWB signal. The UWB generator is connected through a variable attenuator to a power combiner, which receives the signal from the WiMAX interference generator on its other input.
The WiMAX interference signal is generated in the baseband with a Rohde & Schwarz SMBV100A Vector Signal Generator and upconverted to 3.5 GHz using the microwave signal generator Agilent PSG E8267D. The transmit power of the WiMAX signal can be adjusted through the PSG.
The variable attenuator is used to set the attenuation of the UWB signal path, in order to simulate variations of

the distance between the UWB transmitter and the receiver.

A low noise amplifier (LNA) is used to amplify the combined UWB and WiMAX signals at the output of the RF combiner. The amplified signal is then received by an Agilent digital storage oscilloscope (DSO). The LNA is required to improve the signal to noise ratio and adjust the received UWB signal to the dynamic range of the oscilloscope.

The Agilent Infiniium Oscilloscope DSO81304A with Agilent 89600 Series Vector Signal Analysis Software (VSA) is used as UWB receiver. The UWB signal is demodulated in real-time, using the VSA software and the resulting EVM is calculated for the various measurement scenarios.

The RF paths (from UWB and WiMAX generators to the Oscilloscope) were calibrated using an Agilent E8358A network analyzer and the resulting frequency response was included in the measurements results.

This test bed configuration was designed with the aim to measure the impact of interference from a WiMAX Terminal Station (TS) on UWB signals for various (simulated) distances between the UWB transmitter and the UWB receiver (oscilloscope) and for various (simulated) distances between the WiMAX TS and the UWB receiver. The distances are simulated by setting the variable attenuator for UWB signals and by changing the transmit power of the PSG microwave signal generator.

The FSPL (Free Space Path Loss) is related to the distance by the following formula:

$$\text{FSPL} = 20\log_{10}(d) + 20\log_{10}(f) - 147.56$$

Where *d* is the distance in meters and *f* is the frequency in Hz.

IV. MEASUREMENTS SCENARIOS AND RESULTS

A number of measurement scenarios were identified.

For all measurement scenarios, we used a WiMAX uplink signal centered at a frequency of 3.5 GHz. The reference WiMAX signal power is 24 dBm, which conforms to what is specified in WiMAX standards [17]. The emission power of the Agilent PSG generator and the WiMAX signal power are used to simulate the distance of the WiMAX transmitter on the basis of the Free Space Path Loss formula presented above.

The measurements scenarios are:

- The EVM[2] of the WiMedia UWB communication is calculated for physical layer bit rates of 200 Mbits/s and 53.3 Mbits/s at various distances when the WiMAX interference signal is not present.
- The EVM of the WiMedia UWB communication is calculated for physical layer bit rates of 200 Mbits/s and 53.3 Mbits/s at various distances with an interference WiMAX 802.16d uplink signal with bandwidth of 3.5 MHz.
- The EVM of the WiMedia UWB communication is calculated for physical layer bit rates of 200 Mbits/s and 53.3 Mbits/s at various distances with an interference WiMAX 802.16d uplink signal with bandwidth of 7 MHz.
- The EVM of the WiMedia UWB communication is calculated for physical layer bit rates of 200 Mbits/s and 53.3 Mbits/s at various distances with an interference WiMAX 802.16e uplink signal with bandwidth of 7 MHz.
- The EVM of the WiMedia UWB communication is calculated for physical layer bit rates of 200 Mbits/s and 53.3 Mbits/s at various distances with an interference WiMAX 802.16e uplink signal with bandwidth of 10 MHz.

In all cases a QPSK 1/2 modulated Wimax signal has been used.
An OFDM FFT size of 256 is used for WiMAX 802.16d and OFDM FFT size of 1024 is used for WiMAX 802.16e.

The uplink signal was chosen because the typical use of UWB devices will put them in relatively close vicinity of a WiMAX TS. In a regular WiMAX deployment, the WiMAX base station would be located at a distance further than 100 meters so that the downlink signal would experience an attenuation in excess of 100 dB and

[2] The EVM values presented in the technical report are the results of an average of 10 samples.

therefore be much less likely to cause interference to a UWB link than the uplink signal.

The EVM (Error Vector Magnitude) is used to measure the degradation of the UWB signal caused by the propagation channel and the interference from WiMAX.

Error vector magnitude (EVM) is a common figure of merit for assessing the quality of digitally modulated telecommunication signals. EVM expresses the difference between the expected complex voltage value of a demodulated symbol and the value of the actual received symbol. While another common figure of merit, Bit Error Rate (BER) gives an estimate of the degradation of a communication link, EVM can be more useful to the microwave engineer because it contains information about both amplitude and phase errors in the signal. This additional information can allow a more complete picture of the channel distortion and is more closely related to the physics of the system.

Fig. 2 describes the concept of EVM as the error of the measured signal against the ideal signal on the I/Q plane. I and Q are the components of a modulated transmitted signal. For QAM modulations, the signal $s(t)= I(t)\mathrm{Cos}(2\pi Ft)+Q(t)\sin(2\pi Ft)$, where F is the frequency of the signal.

The circle with radius V represents the magnitude of the ideal symbol, while W represents the magnitude of the measured symbol. E is the error used to calculate the EVM.

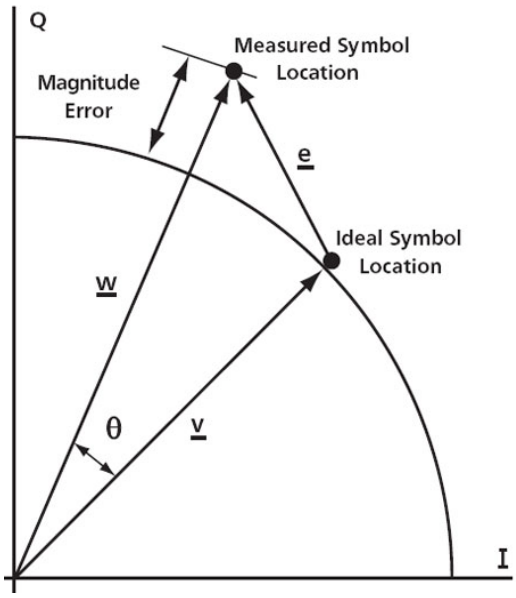

Fig. 2 EVM concept

EVM is defined as the root-mean-square (RMS) value of the difference between a collection of measured symbols and ideal symbols (also RMS quantities). These differences are averaged over a given, typically large, number of symbols and are often shown as a percent of the average power per symbol of the constellation.

Below is the image of the constellation of modulated wireless signal. The points identified to center of the black crosses are the ideal symbol location. The red and blue spots are the measured signals. The EVM is calculated from all the measured symbols.

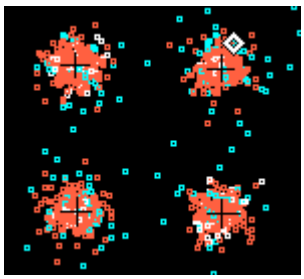

Fig. 3 Measured signals against ideal signals.

The following figure shows the EVM of the UWB signal for different distances between the UWB transmitter and receiver in the absence of WiMAX interference[3]:

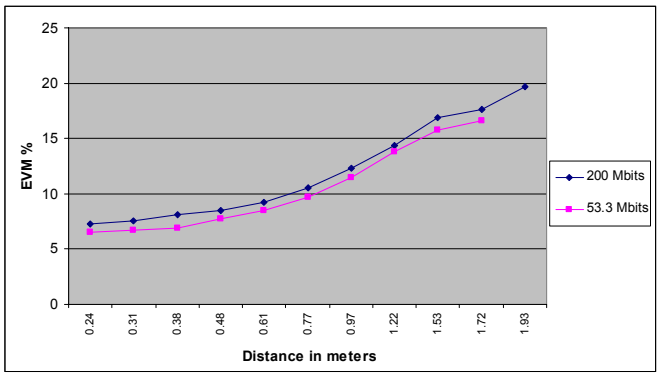

Fig. 4 EVM without WiMAX interference

A value of EVM of 19% is usually considered the threshold above which the quality of the UWB communication can degrade to unacceptable levels. In this test bed configuration, this threshold is reached at a distance of 1.93 meters between transmitter and receiver for an UWB data rate communication of 200 Mbits.
In other test bed configurations and with other types of UWB receivers and transmitters, this distance can increase, but it would be in this order of magnitude as UWB technology has been designed for Personal Area Networks with a typical range of 2-8 meters.

The following figures describe the variation of the EVM of the UWB communication in relation to the interference generated by the WiMAX transmitter at various distances.

Figure 5 and **Figure 6** describe the EVM of the UWB signal at bit rates of 200 Mbits/s and 53 Mbits/s in the presence of interference from a WiMAX 802.16d uplink signal with 7 MHz bandwidth, at various distances of UWB transmitter and receiver.

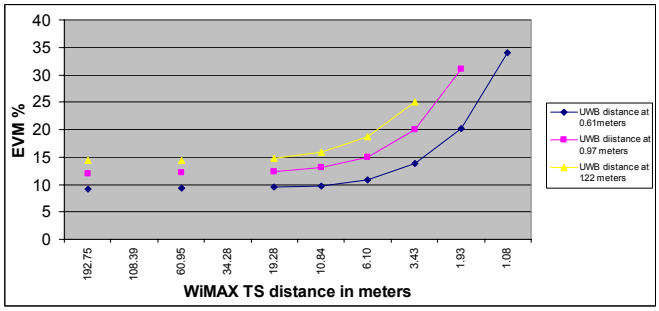

Figure 5 EVM of UWB at 200 Mbits with WiMAX Uplink 802.16d interference at 7 MHz BW

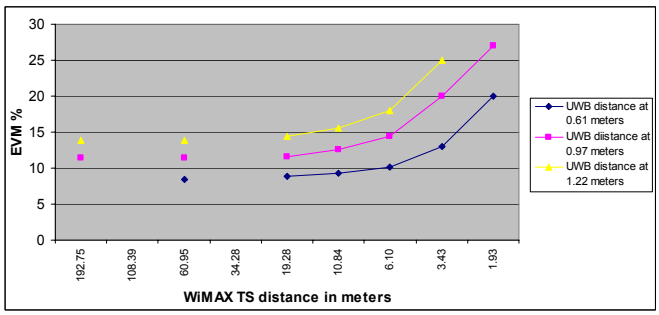

Figure 6 EVM of UWB at 53.3 Mbits with WiMAX Uplink 802.16d interference at 7 MHz BW

Figure 7 and **Figure 8** following figures describe the EVM of the UWB signal at bit rates of 200 Mbits/s and 53 Mbits/s in presence of interference from a WiMAX 802.16d uplink signal with 3.5 MHz bandwidth at various distances of the UWB transmitter and receiver.

[3] Please, note that the EVM values are related to the test bed configuration and sensitivity of the test equipment and they cannot be used as a reference to the performance of UWB commercial systems.

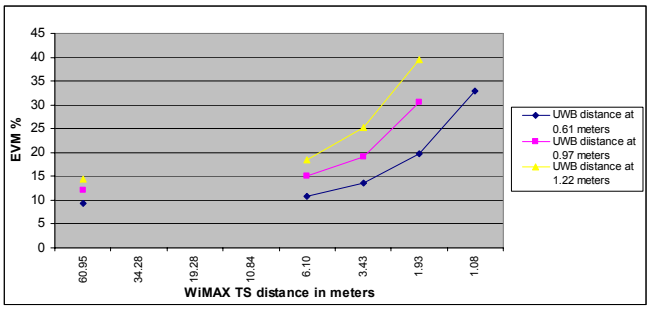

Figure 7 EVM of UWB at 200 Mbits/s with WiMAX Uplink 802.16d interference at 3.5 MHz BW

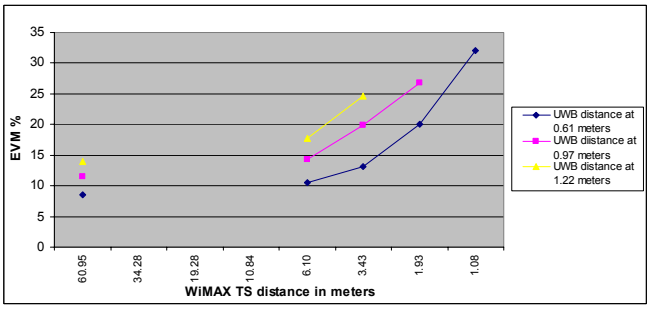

Figure 8 EVM of UWB at 53.3 Mbits/s with WiMAX Uplink 802.16d interference at 3.5 MHz BW

Figure 9 and **Figure 10** describe the EVM of the UWB signal at bit rates of 200 Mbits/s and 53 Mbits/s in presence of interference from a WiMAX 802.16e uplink signal with 10 MHz bandwidth at various distances of the UWB transmitter and receiver.

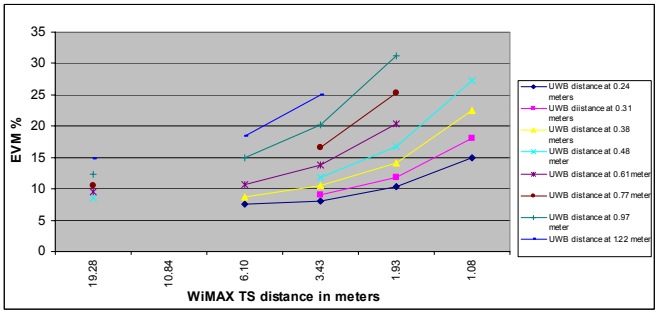

Figure 9 EVM of UWB at 200 Mbits/s with WiMAX Uplink 802.16e interference at 10 MHz BW

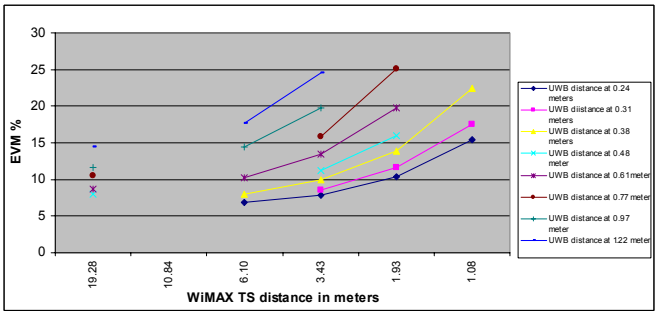

Figure 10 EVM of UWB at 200 Mbits/s with WiMAX Uplink 802.16e interference at 10 MHz BW

The following figures describe the EVM of the UWB signal at bit rates of 200 Mbits/s and 53 Mbits/s in presence of interference from WiMAX 802.16e uplink signal with 7 MHz bandwidth at various distances of the UWB transmitter and receiver.

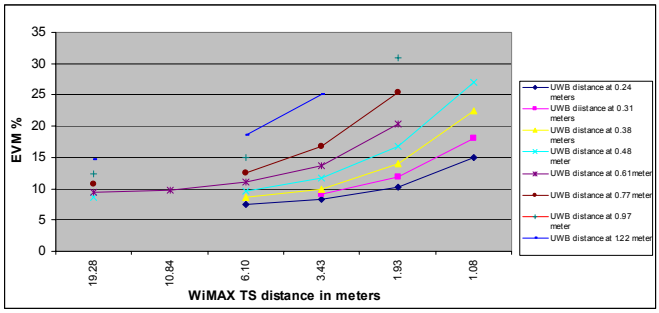

Figure 11 EVM of UWB at 200 Mbits/s with WiMAX Uplink 802.16e interference at 7 MHz BW.

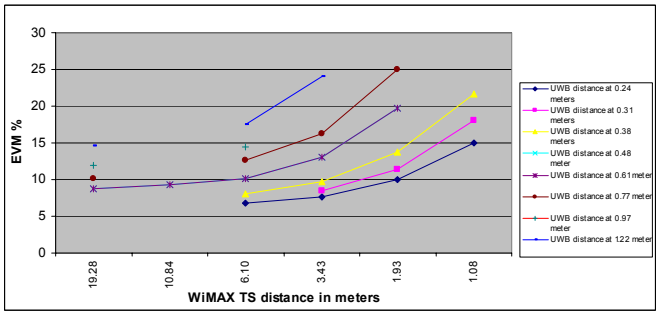

Figure 12 EVM of UWB at 53.3 Mbits/s with WiMAX Uplink 802.16e interference at 7 MHz BW.

As we can see from the graphs, the measurements are consistent with the results described in previous reference work.

The WiMAX interference has an impact on UWB transmission when the UWB devices are more than 1 meter apart and when the WiMAX distance is less than 5 meters.

We noticed that the bandwidth of the WiMAX signal does not have a significant impact on the UWB communication, as the EVM recorded values are only slightly different.

For example, the following table shows the different EVM values for WiMAX Uplink 802.16e at 10 and 7 MHz bandwidth respectively.

WiMAX Distance (meters) →	**6.10**	**3.43**	**1.93**	**1.08**
UWB distance meters ↓				
0.38	(8.7)-(8.78)	(10.44)-(10)	(14.2)-(14)	(22.55)-(22.48)
0.48	NC-(9.6)	(11.77)-(11.8)	(16.8)-(16.8)	(27.328)-(27)
0.61	(10-7)-(11)	(13.8-13.7)	(20.3)-(20.3)	

V. FUTURE DEVELOPMENTS AND CONCLUSIONS

While the EVM is a meaningful parameter to evaluate the degradation of a communication link, there are other parameters like BER, Jitter and Latency, which are more interesting to evaluate the performance of an UWB communication link. In the JRC, we are currently running measurement campaigns to evaluate the variation of these parameters in relation to WiMAX interference.

In this technical report, we only evaluated the interference at with WiMAX signals at 3.5 GHz. We plan to evaluate the interference with WiMAX signals in the 5 GHz bands.

Finally, in this technical report we used the UWB time frequency coding of TFC 5 and we would like to repeat similar measurements with other time frequency codings, which may be more robust against external interference. For example in TFC 1, the UWB signal can use more than one band to mitigate the interference from a WiMAX signal as in the following image:

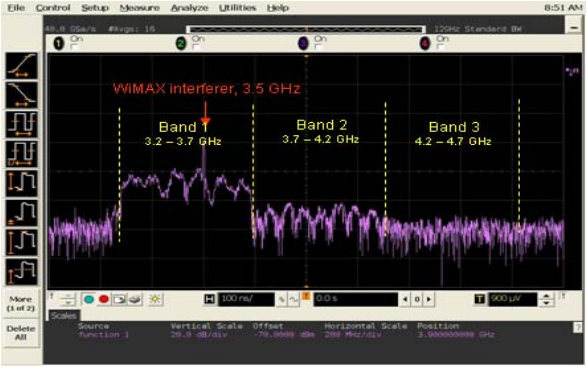

Figure 13 WiMedia TFC 1 UWB link with WiMAX interference.

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Abstract
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