Compatibility Measurement Campaign between IR-UWB and UMTS

Beatriz Quijano, Alvaro Alvarez, Manuel Lobeira, José Luis García

Abstract—**This paper describes the process and results of the measurement campaign developed to quantify the impact of impulse radio UWB transmitters on UMTS (WCDMA) receivers. Through this measurement campaign it is concluded that a ratio 'total WCDMA signal power ($\hat{I}_{OR}$) to Ultra Wideband interference power level (I_{UWB})', $\left(\hat{I}_{OR}/I_{UWB}\right)$, of –8.9dB is enough to protect the UMTS handset operation at 12.2Kbps mode, and –3.3dB at 64 Kbps operation mode, working at theoretical reference sensitivity levels and worst case conditions. Less restrict protection criteria would be required considering the low probability of worst case situations to be encountered.**

Index Terms—**IR-UWB, UMTS, Coexistence, Interference.**

I. Introduction

The current situation regarding the Ultra Wide Band (UWB) technology still requires several efforts in many fronts. Despite of its non novelty, it keeps emerging as a promising method for an efficient use of the radio spectrum, due to its low power spectral density and huge bandwidth. Some of its features such as low power consumption and low cost, make it suitable for a wide range of wireless communication applications from localisation and tracking (low data rate), while its huge bandwidth opens great possibilities for home multimedia (high data rates). Several air interfaces foreseen in the MAGNET project for Wireless Personal Area Networks (WPAN) are based on UWB concepts.

Unfortunately there is no much room for its commercialisation due to the lack of regulation in Europe or Asia. This situation is slightly better in the U.S. where some clear guidelines on UWB regulation were issued by the FCC in 2002 [1]. Europe is now facing this hot topic via relevant working groups activities within CEPT and ETSI, including the mandate of the European Commission directed to CEPT [2]. The aim of UWB regulation and standardisation is the achievement of a regulatory status for UWB on the bases of a low risk and a constructive European regulatory process, taking into account its benefits, both economically and technically, due to its multiple useful applications.

Since the spectrum occupied by UWB (initially from 3.1 GHz to 10.6 GHz) is dedicated to other radio services, it may become a potential source of interference for users in this frequency range, or some other (due to spurious emissions). Thus, in order to minimise its impact on legacy radio services, a power spectral density (PSD) mask should be conformed, both for in and out of band UWB emissions.

Nowadays, there are several theoretical studies [3-4] whose results should be compared with those extracted from measurements campaigns and field trials. This critical part of the regulatory process should include, as well, a test of the accuracy of the assumptions adopted in those studies, providing, at the end, a PSD mask proposal, based on empirical results. The current lack of experimental outcomes makes them specially valuable for regulatory bodies and national administrations.

The aim of this paper is to humbly cover some of those gaps: that referred to UMTS communications, by means of presenting the results of the measurement campaigns carried out to quantify the impact of impulse radio (IR) UWB transmitters over this legacy service. The obtained results are aimed to provide inputs to the regulatory processes.

The rest of the document is structured as follows: in section II, preliminary considerations are presented, section III deals with the equipment employed, whereas sections IV and V explain the measurement procedures and campaign, respectively. In section VI, results are summarised, whereas most relevant conclusions are presented in section VII. Finally, section VIII deals with future work.

II. Preliminary Considerations

A. Sensitivity

The measurements can be developed at measured and/or theoretical reference sensitivity levels. In order to evaluate the real impact of UWB interference, the UMTS network behaviour is characterised previously, in absence of UWB devices, to enable afterwards the quantification of the effect of a certain level of UWB interference. The characterisation in absence of interference is developed under the same conditions, same location, and average network utilisation as the measurements with interference will be. There are as many characterisations in absence of interference as different measurements scenarios.

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B. Single and multiple devices

Single interferers measurements is a must, whereas multiple interferers measurements are advisable in order to test the effects of UWB emissions aggregation on UMTS receivers, and also to verify the Gaussian assumption that presumes the addition of UWB interference power levels in the WCDMA receiver's bandwidth.

The configuration chosen for aggregated measurements consisted on 8, 4 and 2 UWB transmitters (labelled A to G), located in a circumference of different radius, of 20, 30 and 50 cm, in an indoor environment. The combinations measured are indicated in Table I.

Table I .- Aggregated case combinations measured

Aggregation (Simultaneous transmitters)		
20cm	30cm	50cm
A	A	B
B	C	F
C	E	B+F
D	G	
E	A+C	
F	A+C+E	
G	A+C+E+G	
H		
A+B		
A+B+C		
A+B+C+D		
A+B+C+D+E		
A+B+C+D+E+F		
A+B+C+D+E+F+G		
A+B+C+D+E+F+G+H		

C. UWB-UMTS distance and interference power levels

The minimum separation distance between UWB transmitters and UMTS handset proposed is 20 cm. Other separation distances are employed, such as 30 and 50cm.

UWB transmitted power depends on the final aim of the specific measurement. Any value of interference power is acceptable, as long as it is perfectly characterized.

D. Channel type

The effect of UWB emissions is measured on different channel types, 12.2 Kbps voice and 64 Kbps data channels. Both the mobile handset and the Node-B emulator support communication at higher data rates, but, unfortunately, not its monitoring.

III. EQUIPMENT

For the experimental study of the degradation introduced by impulse radio UWB transmitters in the downlink of a UMTS system, the following equipment is required :

A. Agilent Wireless Test Set (8960) Node-B

The wireless communications test set (Agilent 8960) served as an ETSI compliant Node-B with configurable parameters [5], that, generated the UMTS downlink signal, and established a communication link with a UMTS handset, using the E1963A W-CDMA Mobile Test Application. The mobile station's performance was monitored in terms of loopback bit error rate (BER), as well as other receiver's parameters such as the chip energy over noise power density (E_c/N_o), receive signal code power (RSCP) or receiver signal strength indicator (RSSI). The wireless test set was remotely controlled via GPIB with a laptop running Matlab® scripts developed for the scope of the measurement campaign.

B. UWB Transmitters

The UWB interference sources were a series of UWB Impulse Radio (IR) transmitters, that generated a UWB signal from DC to 6 GHz, including a digital control/modulation circuitry to emulate time hopping (TH) and pulse position modulation (PPM), a Digital to Analog Converter (DAC) that converts the digital pseudo-random sequence into an analog signal, which feeds a Voltage Control Oscillator (VCO), followed by a variable gain power amplifier, and a step recovery diode (SRD) based pulse generator. A UWB antenna was integrated to radiate the signal. Details on pulse shape and spectrum can be found in [6]. This is the first version of UWB transmitters developed in ACORDE.

C. Commercial UMTS handset

In order to establish a connection link, a commercial UMTS handset was employed, equipped with a test SIM card that enabled the loopback mode with the Node-B emulator.

D. Others

Additional equipment required to perform the measurements is presented in Table II:

Table II .- Equipment required

Spectrum Analyser	Agilent HPE 4408
Vector Network Analyser	Agilent N3383A
Others	Power Supply / RF Cables
	UMTS Antenna
	Laptop (Matlab® software)

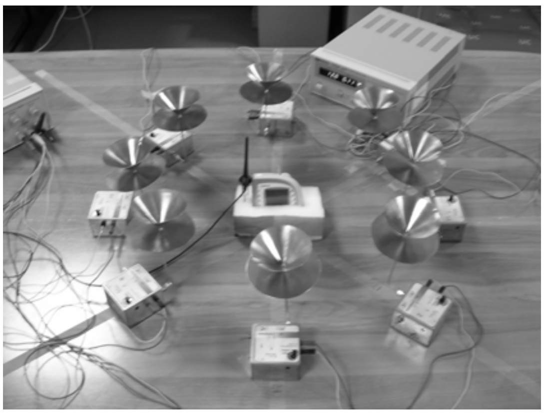

Figure 1.- Measurement Setup: UMTS Rx surrounded by IR-UWB Tx

IV. MEASUREMENT PROCEDURE

A. Interference Power measurements

A UMTS antenna was placed in the location of the victim handset, and the IR-UWB power levels in the UMTS channel chosen was measured for all possible combinations in Table I, and later on compared to the interference power level estimated through the degradation measured as a result of the activation of UWB devices.

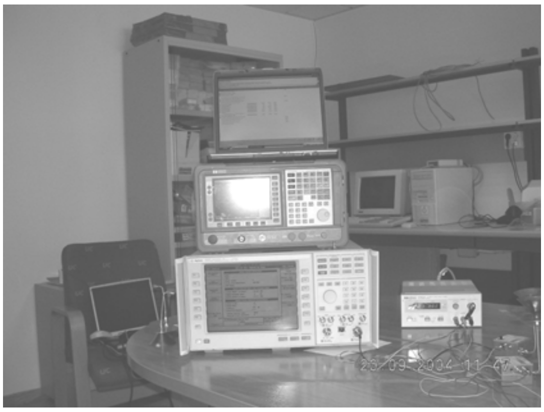

Figure 2.- Measurements test set-up equipment

B. *Degradation Measurements at high BS Power Levels*

The configuration chosen was presented in section II. The degradation introduced by each transmitter was characterised individually, and afterwards the number of active devices was increased, one by one, until the eight transmitters were active.

Measurements have to be reproducible, and taking into account the physical limitations imposed by an analog potentiometer controlling UWB output power, the UWB transmitters were calibrated at their maximum available output power, that varies slightly from one transmitter to another. This is not a shortcoming, as far as the power transmitted by each device is perfectly characterised.

The first stage was the campaign without UWB interferers. The total power of the WCDMA signal, $\hat{I}_{OR}$, was initially set at a high value, and gradually decreased in 1 dB steps until communication was lost, monitoring for each step several BER, RSCP and E_c/N_0 samples.

In a second stage, the 25 possible combinations of active UWB devices in Table I were measured. The Node-B emulator was set again at high $\hat{I}_{OR}$ level, gradually reduced in variable steps, according to the E_c/N_0 captured, until communication was lost, monitoring BER, RSCP, E_c/N_0 samples at each step. The data files generated were processed in order to calculate the $\hat{I}_{OR}$, with and without UWB interference corresponding to the 0.1% bit error rate, prescribed BER value that should not be exceeded. UWB degradation (D) was calculated as the difference between both values. I_{UWB} was calculated based on degradation, and compared to the value measured in the spectrum analyser. The almost coincident I_{UWB} value was employed to calculate the protection ratio at high $\hat{I}_{OR}$.

V. MEASUREMENT CAMPAIGN

A. *Absence of UWB Interference*

First of all a characterisation of the behaviour in absence of interference was developed for 12.2 Kbps and 64 Kbps operating modes. We must remark that it was difficult to develop measurements at UMTS sensitivity levels. At low levels, it is difficult to measure the interference power in a spectrum analyser, and it is also difficult to know whether degradation is generated by the inherent fluctuation of the UMTS network, or by UWB interference. It was therefore decided to develop the measurement campaign at higher BS transmitted levels.

The receiver operating threshold is achieved when the BER reaches the prescribed value of 0.1% BER criteria. This BER value is obtained with –1.2 dB of E_c/N_0 in the case of 12.2 Kbps and 5.4 dB of E_c/N_0 in the 64 Kbps operating mode. The corresponding $\hat{I}_{OR}$ values are referred to as 'measured sensitivity'.

Table III.- Reference and measured $\hat{I}_{OR}$: 12.2 Kbps

	$\hat{I}_{OR}$	E_c/N_0	BER
Measured Sensitivity	**-111.6 dBm**	-1.2 dB	**0.1 %**
Reference Sensitivity	**-106.0 dBm**	8.1 dB	0.0 %

The theoretical reference $\hat{I}_{OR}$ for the 12.2 Kbps channel is –106 dBm. Communication could not be established at this level in the 64 Kbps channel. Therefore, a different reference value was employed for this operating mode under the criteria of same performance conditions as the 12.2 Kbps case.

The difference in WCDMA 12.2 Kbps and 64 Kbps theoretical sensitivity is 4.3 dB. If the reference value employed for the 12.2 Kbps is –106 dBm, the reference 64Kbps $\hat{I}_{OR}$ should therefore be –101.7 dBm.

Table IV.- Reference and measured $\hat{I}_{OR}$: 64 Kbps

	$\hat{I}_{OR}$	E_c/N_0	BER
Measured Sensitivity	**-107.8 dBm**	5.4 dB	**0.1 %**
Reference Sensitivity	**-101.4 dBm**	13 dB	0.0 %

B. *Introduction of UWB Interference*

In tables V to VII, the $\hat{I}_{OR}$ threshold values in which 0.1 % BER was achieved are presented, as well as the measured UWB interference power levels, UWB power levels estimated form the degradation value and $\left(\hat{I}_{OR}/I_{UWB}\right)$ ratio for the three separation distances considered in the 12.2 Kbps operation mode. Measured sensitivity is the reference for degradation calculations. The same parameters are presented in tables VIII to X for the 64 Kbps mode.

1) Voice: 12.2 Kbps

Table V.- 12.2 Kbps results 20cm UMTS-UWB distance

	$\hat{I}_{OR}$ Threshold [dBm]	I_{UWB} Measured [dBm]	I_{UWB} Estimated [dBm]	$\left(\frac{\hat{I}_{OR}}{I_{UWB}}\right)$ [dB]
A	-92.7	-78.0	-79.6	**-14.7**
B	-92.3	-80.0	-80.2	**-12.3**
C	-97.7	-83.0	-86.2	**-14.7**
D	-94.8	-84.0	-83.5	**-10.8**
E	-81.8	-69.0	-70.4	**-10.8**
F	-91.8	-79.0	-80.3	**-12.8**
G	-82.7	-71.0	-71.5	**-11.7**
H	-86.8	-72.0	-75.2	**-14.8**
A+B	-87.8	-75.8	-76.1	**-12.0**
A+B+C	-86.4	-75.1	-74.8	**-11.4**
A+B+C+D	-86.5	-74.5	-75.2	**-12.0**
A+B+C+D+E	-81.6	-67.9	-70.0	**-13.7**
A+B+C+D+E+F	-79.9	-67.6	-68.3	**-12.3**
A+B+C+D+E+F+G	-77.0	-65.9	-66.0	**-11.0**
A+B+C+D+E+F+G+H	-77.6	-65.0	-65.9	**-12.6**

Table VI .- 12.2 Kbps results 30cm UMTS-UWB distance

	$\hat{I}_{OR}$ Threshold [dBm]	I_{UWB} Measured [dBm]	I_{UWB} Estimated [dBm]	$\left(\frac{\hat{I}_{OR}}{I_{UWB}}\right)$ [dB]
A	-95.4	-81.0	-83.9	**-12.9**
C	-97.9	-86.0	-86.5	**-11.9**
E	-82.7	-72.0	-71.0	**-10.7**
A+C	-93.5	-79.8	-81.9	**-13.7**
A+C+E	-82.0	-71.3	-72.9	**-10.7**
A+C+E+G	-81.8	-69.4	-70.1	**-12.4**

Table VII .- 12.2 Kbps results 50cm UMTS-UWB distance

	$\hat{I}_{OR}$ Threshold [dBm]	I_{UWB} Measured [dBm]	I_{UWB} Estimated [dBm]	$\left(\frac{\hat{I}_{OR}}{I_{UWB}}\right)$ [dB]
B	-106.2	-92.0	-96.0	**-14.2**
F	-100.1	-87.0	-88.8	**-11.3**
B+F	-98.2	-85.8	-86.7	**-11.5**

2) Data: 64 Kbps

Table VIII .- 64 Kbps results 20 cm UMTS-UWB distance

	$\hat{I}_{OR}$ Threshold [dBm]	I_{UWB} Measured [dBm]	I_{UWB} Estimated [dBm]	$\left(\frac{\hat{I}_{OR}}{I_{UWB}}\right)$ [dB]
A	-89.9	-78.0	-82.1	**-11.9**
B	-88.5	-80.0	-80.8	**-8.5**
C	-90.3	-83.0	-82.6	**-7.3**
D	-94.0	-84.0	-86.3	**-10.0**
E	-75.8	-69.0	-68.0	**-6.8**
F	-87.2	-79.0	-79.5	**-8.3**
G	-78.7	-71.0	-70.8	**-7.8**
H	-79.9	-72.0	-71.9	**-5.9**
A+B	NA	-75.8	NA	NA
A+B+C	NA	-75.1	NA	NA
A+B+C+D	NA	-74.5	NA	NA
A+B+C+D+E	-75.7	-67.9	-67.8	**-7.8**
A+B+C+D+E+F	-74.9	-67.6	-67.1	**-7.3**
A+B+C+D+E+F+G	-73.7	-65.9	-65.8	**-7.8**
A+B+C+D+E+F+G+H	-73.6	-65.0	-65.8	**-7.1**

Table IX .- 64 Kbps results 30 cm UMTS-UWB distance

	$\hat{I}_{OR}$ Threshold [dBm]	I_{UWB} Measured [dBm]	I_{UWB} Estimated [dBm]	$\left(\frac{\hat{I}_{OR}}{I_{UWB}}\right)$ [dB]
A	-94.1	-81.0	-86.4	**-13.1**
C	-92.7	-86.0	-85.0	**-7.7**
E	-78.5	-72.0	-70.6	**-6.5**
A+C	-80.2	-74.0	-72.4	**-6.2**
A+C+E	-89.7	-79.8	-81.0	**-8.7**
A+C+E+G	-77.9	-71.3	-70.9	**-6.6**

Table X .- 64 Kbps results 50 cm UMTS-UWB distance

	$\hat{I}_{OR}$ Threshold [dBm]	I_{UWB} Measured [dBm]	I_{UWB} Estimated [dBm]	$\left(\frac{\hat{I}_{OR}}{I_{UWB}}\right)$ [dB]
B	NA	NA	NA	NA
F	-92.5	-87.0	-84.8	**-5.6**
B+F	-91.8	-85.8	-84.1	**-7.7**

NA: Not Available

VI. RESULTS

Measurement results are summarised in Tables XI and XII, with average and works cases measured for every distance, for 12.2 Kbps and 64 Kbps respectively. The values employed for further processing and conclusions on maximum acceptable PSDs, are the absolute worst cases measured.

Table XI .- 12.2 Kbps measured $(\hat{I}_{OR}/I_{UWB})$

	$(\hat{I}_{OR}/I_{UWB})$ Average	$(\hat{I}_{OR}/I_{UWB})$ Worst Case
20 cm	-12.5 dB	-10.8 dB
30 cm	-12.0 dB	**-10.7 dB**
50 cm	-12.3 dB	-11.3 dB

Table XII .- 64 Kbps measured $(\hat{I}_{OR}/I_{UWB})$

	$(\hat{I}_{OR}/I_{UWB})$ Average	$(\hat{I}_{OR}/I_{UWB})$ Worst Case
20 cm	-8.0 dB	-5.9 dB
30 cm	-8.1 dB	-6.2 dB
50 cm	-8.7 dB	**-5.6 dB**

In order to avoid uncertainties in measurements, these were developed at high UMTS signal levels, in which all degradation imposed in the handset device is due to the UWB interference. However, conclusions regarding coexistence between UWB and UMTS should be extracted from weak UMTS signal situations.

At levels close to the sensitivity, the protection criteria should be modified. The value calculated at high levels is $\left(\hat{I}_{OR}/I_{UWB}\right)$, as far as the effect of thermal noise, N_{th}, is neglected. This value has to be introduced in order to scale results to low mobile handset receiver levels. In the following calculations, -100dBm thermal noise has been assumed. The $\left(\hat{I}_{OR}/I_{UWB}\right)$ at low handset levels is calculated, this time taking into account the contribution of thermal noise. The results are presented in tables XIII and XIV. For each $\hat{I}_{OR}$ value considered, sensitivity and values close to it, based on the ratio $\left(\hat{I}_{OR}/I_{UWB}\right)$ measured at high levels, this ratio is recalculated. As the victim receiver operates at higher levels, the ratio approaches the value measured in the campaign.

Table XIII.- 12.2 Kbps $\left(\hat{I}_{OR}/I_{UWB}\right)$ protection ratio

$\hat{I}_{OR}$	$\left(\frac{\hat{I}_{OR}}{I_{UWB}}\right)_{Measured}$	$\left(\frac{\hat{I}_{OR}}{I_{UWB}}\right) @ \hat{I}_{OR}$
-106	-10.7 dB	**-8.9 dB**
-105		-9.2 dB
-104		-9.6 dB
-103		-9.8 dB
-102		-10.1 dB
-101		-10.2 dB
-96		-10.5 dB

Table XIV.- 64 Kbps $\left(\hat{I}_{OR}/I_{UWB}\right)$ protection ratio

$\hat{I}_{OR}$	$\left(\frac{\hat{I}_{OR}}{I_{UWB}}\right)_{Measured}$	$\left(\frac{\hat{I}_{OR}}{I_{UWB}}\right) @ \hat{I}_{OR}$
-101.7	-5.6 dB	**-3.3**
-101		-3.7
-100		-4.2
-99		-4.5
-98		-4.7
-97		-4.9
-96		-5.0
-90		-5.4

VII. Conclusions

The protection ratio $\left(\hat{I}_{OR}/I_{UWB}\right)$ that assures protection of a UMTS victim handset operating at its sensitivity level are **–8.9 dB** and **–3.3 dB** for the 12.2 Kbps and 64 Kbps respectively.

These protection ratios can be relaxed on the likely case of a victim receiver operating at higher receiver signal values. For example, in the most restrictive operation channel, 64 Kbps, the protection ratio is relaxed to –4.5 dB working 3 dB above sensitivity.

These protection ratios are based on empirical results reflecting worst case operating conditions. However, in order to obtain conclusions on the maximum acceptable UWB PSD, other considerations are required.

If the aim is to protect from the extremely unlikely situation of 100% duty cycle UWB transmitters, located at 36 cm, reference distance indicated by several National Administrations, with UMTS handsets always operating at the sensitivity level, the maximum PSD derived from this ratios would be –74.2 dBm/MHz, as can easily be calculated. This value would mean that at the sensitivity level, the BER will never exceed 0.1%, even with a UWB transmitter located at 36 cm from the UMTS receiver transmitting 100% of time. However, if more reasonable conditions are taken into account, these tight limits can be relaxed, considering the low probability of a victim receiver to be working at its sensitivity level with a UWB interferer at low distances. In practical situations, higher limits might be accepted with no loss of effective protection.

VIII. Future Work

Future work is required in the definition of operating conditions under which UMTS receivers should be protected from UWB, and whether the adoption of worst case situation or more realistic solutions taking into account the probability of worst case situations to be encountered. Operation conditions include the separation distance, realistic and at the same time restrictive enough receiver signal levels at which protection must be assured, protection criteria (0.1% BER is one possibility, although others may be faced), amongst others.

Future work is also required in the scope of the regulatory bodies, such as the ECC TG3 measurements group, as well as in the development of market available UWB transceivers.

IX. Acknowledgements

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