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UWB performance assessment based on recent FCC regulation and measured radio channel characteristics

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ABSTRACT

In the framework of the European research project WHYLESS.COM recent FCC regulation on UWB is evaluated as regards power levels and achievable receiver SNR's.. The frequency band from 3.1-10.6 GHz has been evaluated based on impulse responses which were measured at IMST premises in a typical office building. Emphasis is put on the impact of strong temporal dispersion of the signal arriving at the receiver under non-line-of-sight conditions. The SNR degradation of receivers which process only part of the spectral and temporal signal features is shown for selected cases. The results, in conjunction with the UWB system specific processing gain, enable the assessment of error rates for various modulations schemes.

I. INTRODUCTION

On February 14th 2002 the United States Federal Communications Commission (FCC) adopted a „First Report and Order" that permits the marketing and operation of a new radio transmission technology. The technology referred to is Ultra Wideband (UWB) and it goes with „great promises for public safety, businesses and consumers in a variety of applications". UWB had been under public discussion in the US for less than 3 years prior to regulation which, despite existence of other competitive US wireless communications standards, demonstrates a pragmatic and particularly SME-oriented way of regulation. It is also noteworthy that the FCC limits itself to extremely generic regulation while leaving technology, embodiment, protocols and applications exclusively to industry. The explicit remark, that the current regulation is to be considered as a „first cautious step" in the process, is in line with previous FCC statements that can be interpreted as the start of an era where spectrum resources „fluently" enter the market.

II. FCC UWB Regulation

After almost a decade of hardly noticed ultra wideband technology developments of few North American companies, on May 10th 2000 the FCC released a "Notice of proposed Rulemaking" where comments were sought in response to a proposed UWB regulation. Essentially a lower frequency limit between 1 and 2 GHz, a RF mean output power limit and an actual implementation bandwidth driven peak/mean power ratio were suggested.

The public debate was fuelled by hundreds of technical and legal opinions. Soon GPS emerged as a stronghold against UWB. Several investigations on UWB interference potential were kicked off, the most prominent one conducted by NTIA. The NTIA results indicated the possibility of severe impairment of GPS receivers particularly in the area of air traffic safety. This report supposedly had a major impact on the current 'Report and Order'.

In this paper only regulation concerned with communications applications is considered. Marketing and operation of such UWB devices is permitted in the frequency range 3.1 GHz to 10.6 GHz. The mean transmit power must not exceed –41 dBm/MHz, which is equivalent to 500 uV at three meters distance, and the peak/mean power ratio is limited to less than 20 dB according to the measurement procedures of 47CFR15.35.

The maximum accumulated mean transmit power is hence limited to less than –2.2 dBm, approx. half a Milliwatt. It is obvious that considerable technical effort is required to obtain high system performance from the FCC regulation. The gravity of the problem becomes even more pronounced if the signal arriving at the receiver is considered. Even if highly concentrated energy, i.e. an impulse, is transmitted, the high geometrical resolution power of the ultra wideband

signal will cause the energy to spread in time if a non-line-of-sight radio channel is considered.
The key problem of UWB is hence the recollection of spectrally and temporally dispersed energy. In the following two basic receiver concepts under NLOS conditions and some of their implications are discussed.

A. Analouge Impulse Correlatosr

Analouge correlator performance is driven by the injection of a properly shaped and timed replica of the expected waveform (multipath component), i.e. of a minute fraction of the impulse response. A TX impulse (monocycle) centred at 6 GHz will cause an extended, exponentially decaying noise-like impulse response with typically some 10 zero crossings per nanosecond. In other words, the transmit pulse shape gets completely lost in the radio channel, except for LOS situations. Acquisition and tracking of such a multipath component requires a timer section with extremely high resolution (<10ps) and ultra-low jitter. The short correlation pulse duration causes the correlation process to cover only an extremely small fraction of the generally exploitable part of the impulse response. Already in normal size offices the ratio of the exploitable part of the impulse response and the correlation pulse width can exceed 10. A single channel pulse-correlation receiver under NLOS conditions would detect only a minute fraction of the total energy available. Next to receive power considerations a single channel pulse correlation receiver is extremely vulnerable in multi-user environments since each user 'pollutes' a major part of the delay axis (see fig. 3-5), while only a minute fraction is used for reception. Correlator banks of considerable size would be required to solve the energy- and interference rejection problem unless an information bit is coded as many subsequent pulses (e.g. 1000) with detrimental impact on the UWB radio link capacity.

B.Downconverter & Sampling Architectures

The extremely wide frequency window specified by the FCC for UWB operations may be used only in parts (e.g. the frequency band 3.1 - 4.1 GHz) in order to avoid very high frequencies and bandwidths, which leads to relatively extended (multicycle) transmit waveforms which resemble an enveloped carrier frequency. Under such conditions conventional receiver designs may be employed, involving analogue downconversion and subsequent I/Q sampling for further digital processing. For above example, the required sampling rate would be of the order of two Gigasamples per second and cause a receiver data throughput of two GByte per second if 8 bit ADCs were used. The data throughput might be reduced by processing only a fraction of the impulse response, which would still create a high data throughput and with further reduction increasingly compromise interference rejection capabilities. Processing of multiple unsynchronised users may however prevent such a strategy. Severe problems have further to be expected upstream the AD converter, e.g. in the ultra broadband I/Q conversion process.
Under FCC regulation, sacrificing on bandwidth is equivalent to sacrificing on RF power. The above example (3.1-4.1 GHz) would utilise only 0.1 mW mean transmit power, approximately 13% of the maximum power available in the FCC regulated frequency band. This is orders of magnitude less than offered for instance in ISM bands and, for economical reasons, may prevent legacy receiver architectures.

III. UWB Performance Assessment

For reference reasons the free space attenuation for signals of various bandwidths is shown in fig.(1). For further evaluation best case AWGN is assumed to be equivalent to free space attenuation and complete recovery of potentially available receive power. Three example cases are evaluated. Case A using complete bandwidth between 3.1 and 10.6 GHz, case B using 3 GHz bandwidth from 3.1 to 6.1 GHz and case C using 1 GHz bandwidth from 3.1 to 4.1 GHz. Using the wideband attenuation expression

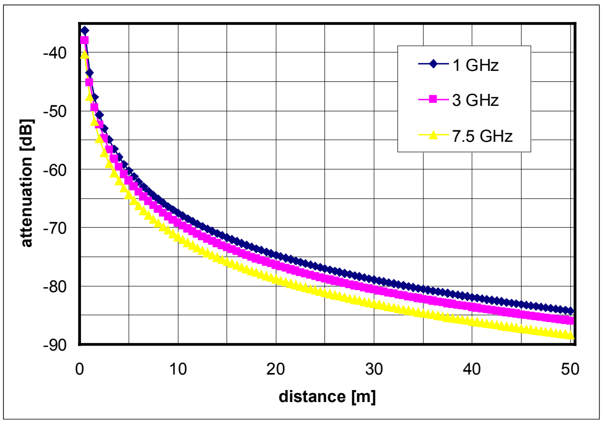

fig. (1) free space attenuation

and the allowed transmitted mean power of –41 dBm per MHz bandwidth the received power can be calculated and thus the SNR at the receiver input can be evaluated. A zero dB noise figure - better estimates need to be inserted for practical receiver considerations – and zero dB gain antennas are assumed. This is scenario depicted in **fig. (2**).

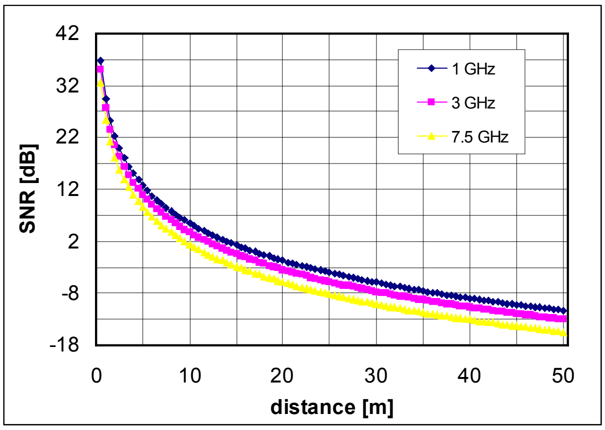

fig. (2) SNR in ideal case

According to Part 15 FCC § 15.35 the maximum permitted power is 20 dB above the average permitted power when measured with a filter bandwidth of > 1 MHz, which, depending on the transmit waveform, allows a wide range of processing gains. The SNR of fig. (2), corrected by the processing gain, can be translated into symbol error rates for a given modulation scheme.

For three scenarios within a typical office building the practical performance is evaluated in the following. Therefore ultra-wide measurement data are used. Measurements have been performed with 6 GHz center frequency and 10 GHz bandwitdh in the frequency domain. From these data subsets were derived for comparison. Three environments are considered a) line-of-sight (LOS) within one office room, b) non-line-of-sight (NLOS) within one office room and c) NLOS through wall from one to an adjacent office room. For each one a typical frequency transfer function was selected and the appropriate frequency range was selected according to the cases A, B and C mentioned above. The measurement frequency resolution was 6.25 MHz, therefore for case A a 160 point discrete Fourier transform (DFT), for case B a 480 point DFT and for case C a 1200 point DFT was used to derive the impulse response from the transfer function. The Impulse responses for case A (7.5 GHz bandwidth) are depicted in the following figures 3-5.

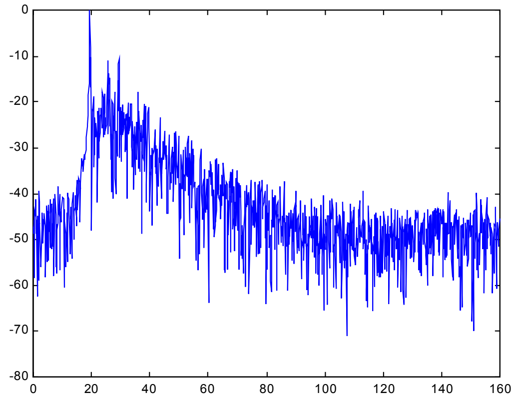

fig. (3) LOS within an office room, 3.1-10.6GHz.

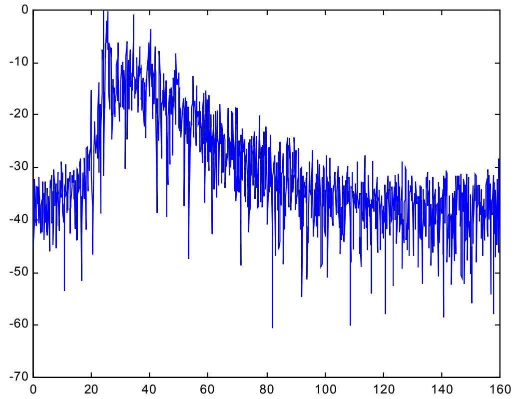

fig. (4) NLOS within an office room, 3.1-10.6GHz.

For these impulse responses the total received power in relation to the transmitted power was evaluated. As in a practical receiver the number of time bins used for signal processing is limited, the available power has been calculated for the cases of 1,8,16 and 32 time bins.

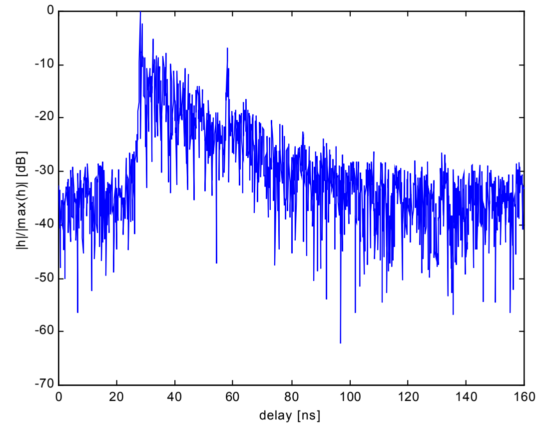

fig. (5) Q-LOS through wall between adjacent office rooms, 3.1-10.6GHz.

The receive power was analysed for i) the case of selecting the strongest N time bins of the impulse response and ii) for the case of positioning the delay window of width N such that the contained power reached a maximum. The results are shown in table (1) through table (3).

table (1) LOS within a typical office building, 4.10m distance, -41 dBm/MHz transmit power.

	select N strongest paths with maximal received power		
	1 GHz	3 GHz	7.5 GHz
P_{noise}	-84 dBm	-79.22dBm	-75.25 dBm
tx power	-11 dBm	-6.23 dBm	-2.25 dBm
rx pow(max)	*-68.71 dBm*	*-64.96 dBm*	*-63.05 dBm*
path loss	57,71 dB	58,73 dB	60,80 dB
SNR_{ideal}	15.29 dB	14.27 dB	12.2 dB
complexity	loss in dB	loss in dB	loss in dB
N=1 bin	3,46	3,04	3,98
N=8 bins	1,2	1,33	1,94
N=16 bins	0,4	0,87	1,36
N=32 bins	0,1	0,45	0,95
	select delay window of width N containing the most power		
	1 GHz	3 GHz	7.5 GHz
tx power	-11 dBm	-6.23 dBm	-2.25 dBm
rx pow(max)	*-68.71 dBm*	*-64.96 dBm*	*-63.05 dBm*
path loss	57,71 dB	58,73 dB	60,80 dB
SNR_{ideal}	15.29 dB	14.27 dB	12.2 dB
complexity	loss in dB	loss in dB	loss in dB
N=1 bin	3,46	3,04	3,98
N=8 bins	1,33	2,47	2,57
v16 bins	0,57	2,12	2,44
N=32 bins	0,12	0,79	2,32

It is shown, that for the LOS case a single bin receiver ensures utilization of approximately 50% of the received signal power for demodulation purposes. This also holds for the communication throug walls, if there is no metal object in the path causing shadowing.

table (2) NLOS within a typical office building, 4.10m distance, -41 dBm/MHz transmit power.

	select N strongest paths with maximal received power		
	1 GHz	3 GHz	7.5 GHz
P_{noise}	-84 dBm	-79.22dBm	-75.25 dBm
tx power	-11 dBm	-6.23 dBm	-2.25 dBm
rx pow(max)	*-74.03 dBm*	*-71.65 dBm*	*-70.23 dBm*
path loss	63,03 dB	65,45 dB	67,98 dB
SNR_{ideal}	9.97dB	7.57dB	5.02 dB
complexity	loss in dB	loss in dB	loss in dB
N=1 bin	6,44	9,13	10,84
N=8 bins	1,41	3,26	4,81
N=16 bins	0,72	2,19	3,44
N=32 bins	0,26	1,23	2,36
	select delay window with width N containing the most power		
	1 GHz	3 GHz	7.5 GHz
tx power	-11 dBm	-6.23 dBm	-2.25 dBm
rx pow(max)	*-74.03 dBm*	*-71.65 dBm*	*-70.23 dBm*
path loss	63,03 dB	65,45 dB	67,98 dB
SNR_{ideal}	9.97dB	7.57dB	5.02 dB
complexity	loss in dB	loss in dB	loss in dB
N=1 bin	6,4	9,13	10,84
N=8 bins	1,74	3,61	6,86
N=16 bins	1,13	2,91	4,42
N=32 bins	0,35	2,1	3,14

But in the case of NLOS, when metal objects are in the direct path, the single bin receiver suffers a loss of about 10 dB. In the NLOS case the number of bins to be used for demodulation depends strongly on the bandwidth actually used.

table (3) Q-LOS through double gypsum board wall between adjacent offices in a typical office building, 5.7 m distance, -41 dBm/MHz transmit power.

	select N strongest paths with maximal received power		
	1 GHz	3 GHz	7.5 GHz
P_{noise}	-84 dBm	-79.22dBm	-75.25 dBm
tx power	-11 dBm	-6.23 dBm	-2.25 dBm
rx pow(max)	*-75.25 dBm*	*-72.20 dBm*	*-70.40 dBm*
path loss	64,25 dB	65,97 dB	68,15 dB
SNR_{ideal}	8.75dB	7.02dB	4.85 dB
	Loss in dB	Loss in dB	Loss in dB
N=1 bin	1,89	3,43	3,12
N=8 bins	0,52	1,14	1,55
N=16 bins	0,26	0,76	1,09
N=32 bins	0,09	0,43	0,73
	select delay window with width N containing the most power		
	1 GHz	3 GHz	7.5 GHz
tx power	-11 dBm	-6.23 dBm	-2.25 dBm
rx pow(max)	*-75.25 dBm*	*-72.20 dBm*	*-70.40 dBm*
path loss	64,25 dB	65,97 dB	68,15 dB
SNR_{ideal}	8.75dB	7.02dB	4.85 dB
complexity	loss in dB	loss in dB	loss in dB
N=1 bin	1,89	3,42	3,12
N=8 bins	0,82	1,73	1,7
N=16 bins	0,43	1,24	1,64
N=32 bins	0,13	0,6	1,25

In case of 1 GHz bandwidth 8 bins are sufficient in the selection as well as in the window processing type receiver. But as the bandwidth increases to 7.5 GHz, 16 bins are required in the selection-type receiver and 32 bins are required in the window-processing type receiver.

Regarding the absolute received power it is interesting to note, that in the case of LOS and in the case of NLOS more bandwidth significantly increases power value at the receiver input by about 5 dB for the analysed examples. Comparing the NLOS and the LOS cases there is a difference of about 5-7 dB in the total received power which is increasing with bandwidth.

From the received power levels, the bandwidth used and the system specific processing gain data rates and associated error rates can be derived.

The reference SNR (SNR_{ideal}) given in above tables implies complete recovery of the received signal power for use in the demodulation process. As one can see, complete recovery is not possible with a reasonable number of signal processing branches. A loss of 1-4 dB in the LOS case (table (1)), 2-9 dB in NLOS case (table(2)) and 1-3 dB in through wall Q-LOS case (table(3)) needs to be considered depending on the receiver architecture and complexity.

IV. ACKNOWLEDGEMENT

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