COMPARED PERFORMANCE OF UWB ANTENNAS FOR TIME AND FREQUENCY DOMAIN MODULATIONS

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ABSTRACT

An analysis is carried out of the behaviour of a small selection of omnidirectional and directional UWB antennas in various time and frequency based modulation schemes. The communication system output SNR with real antennas is systematically referenced to that with ideal non dispersive frequency-independent isotropic antennas, for the same channel and the same modulation. This allows obtaining a reference scale for the performance of UWB antennas, depending on the channel characteristics expressed by the angular power spectrum and multipath temporal density, assumed to be the most important parameters.

I INTRODUCTION

I-1 Generalities

In a previous work, it has been attempted to analyse the performance of Ultra Wide Band (UWB) antennas in the case of pulse based physical layer schemes [1]. The need for such an analysis stemmed from the current belief that it is more difficult to operate UWB communications because of antenna imperfections. For pulse based modulations indeed, the antenna related distortion exhibited by the signals is a cause of performance degradation. However things are not so clear-cut, as antennas well-known for their dispersive character like log-periodic antennas, do not perform so badly. In addition, the radio channel is generally much more imperfect and dispersive than antennas, and a complex joint antenna-channel behaviour may arise as the result of their combined dispersions. Apart from pulse based systems, “frequency domain” schemes such as multiband OFDM have also been proposed, and are actively supported by a large number of companies. In this context research intended to understand and optimize antenna performance is necessary, all the more as antennas can be expected to be fairly imperfect in low-cost consumer products. Antenna performance being one of the arguments of frequency domain modulation techniques against time domain ones, it is also instructive to compare the performance of antennas when operated in either scheme. This is the purpose of the present work.

I-2 Technical Approach

The mixing of antenna and channel dispersion on one hand (pulse based systems), and the large frequency selectivity of the channel combined with antenna frequency response on the other should both be considered in order to reduce the bias on antenna performance evaluation. The approach here followed was thus to make a selection of representative scenarios, to define the UWB systems architectures of interest, and to systematically normalize the received output signal to noise ratio (SNR) in the presence of real antennas to the ideal antennas SNR. Combined antenna-channel performance is thus expressed as a SNR gain (SNRG), which gives us a simple and effective way to compare antennas given a certain channel and a certain physical layer scheme. Here we understand “ideal antennas” as isotropic dispersionless and lossless radiators.
We have investigated 4 modulation schemes, which are listed below with the corresponding SNRG definitions:

- coherent pulse detection:

$$SNRG_{IdealTempl.} = Max_t\left(S^2_{real/ideal}(t)\right) / Max_t\left(S^2_{ideal/ideal}(t)\right) \quad (1)$$

where $S_{real/ideal}$ is the correlator output for real antennas and an ideal template waveform used by the correlator, and $S_{ideal/ideal}$ idem with ideal antennas instead. The noise contribution cancels from the ratio.

- Adapted template: this is again a coherent detection scheme, where improved noise filtering can reduce the bit error rate [2]. With $S_{real/adapt}$ the correlator output for real antennas and an adapted template, SNRG writes:

$$SNRG_{AdaptTempl.} = \frac{Max_t\left(S^2_{real/adapt}(t)\right)}{Max_t\left(S^2_{ideal/ideal}(t)\right)} \times \frac{\int ref^2_{ideal}(t)dt}{\int ref^2_{adapt}(t)dt} \quad (2)$$

- On-Off keying (OOK, incoherent [3]): taking $rec_{real}(t)$ and $rec_{ideal}(t)$ are the time domain received signals at Rx antenna port output for real or ideal antennas respectively the SNR is defined as

$$SNRG_{Incoh} = \int rec_{real}^2(t)dt / \int rec_{ideal}^2(t)dt \tag{3}$$

- OFDM. Here again the numerator stands for real antennas and the denominator for ideal antennas, and the noise contribution is identical in both cases and is also removed from the ratio:

$$SNRG_{OFDM} = \sum_k \overline{rec}_{real}^2(\omega_k) / \sum_k \overline{rec}_{ideal}^2(\omega_k) \tag{4}$$

where the summation is carried out over the various OFDM tones, and an identical power is put in these tones at the transmitting antenna input port. This definition is considered to represent usefully the SNR quality, taking into account that in a real system channel coding and the strong frequency selectivity will help mitigate deep fading. From Bessel-Parseval relation expressing the identity between frequency and time domain integrations we expect no large difference between OOK and OFDM gains, which will be confirmed by the results below.

We use a cluster based discrete multipath channel model, which includes the direction of arrival (DOA) and departure (DOD) information of multipaths. Path delays are Poisson-distributed, amplitudes are Rice distributed, and DOA/DOD are gaussian-distributed. In the investigations we selected a line of sight (LOS) channel containing a dominant LOS cluster with small angular spread, and another omnidirectional and temporally spread cluster of lesser amplitude. Another channel was non line of sight (NLOS) with a single temporally and fully angularly spread cluster. We also selected a "symmetrical" LOS scenario with a fixed angular orientation of the LOS cluster, which has a particular interest for directional antennas. Such a channel may describe e.g. Rx and Tx antennas located close to opposite walls in a room. Apart from angles, it is also the multipath temporal density which is expected to have a strong effect on the output SNR, depending on pulse overlap.

The chosen antennas are shown in Fig. 1-2, together with their "time domain" radiation pattern computed with the knowledge of the transmitted pulse waveform. Most of them have been fabricated and characterized, one of them (horn) being simulated using a commercial tool. In the antenna performance under consideration, both the return loss (impedance matching to 50 Ω), the antenna directionality, and its distortion to an incoming pulse are involved. These characteristics are summarized in Table 1. More results can be found in [1].

For a relevant comparison between pulsed schemes and OFDM, it is important to use signal spectra as similar as possible. In the simulations below the transmitted direct sequence of 24 UWB pulses (compliant with FCC requirements, and with UWB forum proposal to IEEE 802.15.3a standardization group) occupy a 3 dB bandwidth from 3.7 to 5.3 GHz. In the OFDM case, we use the 2nd, 3rd and 4th consecutive sub-bands of the multiband OFDM alliance proposal, covering 3.71 to 5.28 GHz.

II RESULTS

The results presented here show statistics of the received SNRG for 100 channel realizations. For simplicity, the same antenna was used at both Tx and Rx sides (two real antennas).

Table 1: Antenna characteristics in the main lobe

Values in dB	TD gain	distortion	Gain-distortion	Incoherent gain	OFDM gain
Bicone	3.05	-0.27	3.32	3.35	2.72
Monocone	3.28	-0.09	3.37	3.37	3.44
LPDA	2.74	-1.00	3.74	3.75	3.17
F-probe	6.84	-0.27	7.11	7.16	7.30
Horn	11.10	-0.62	11.72	11.40	12.25

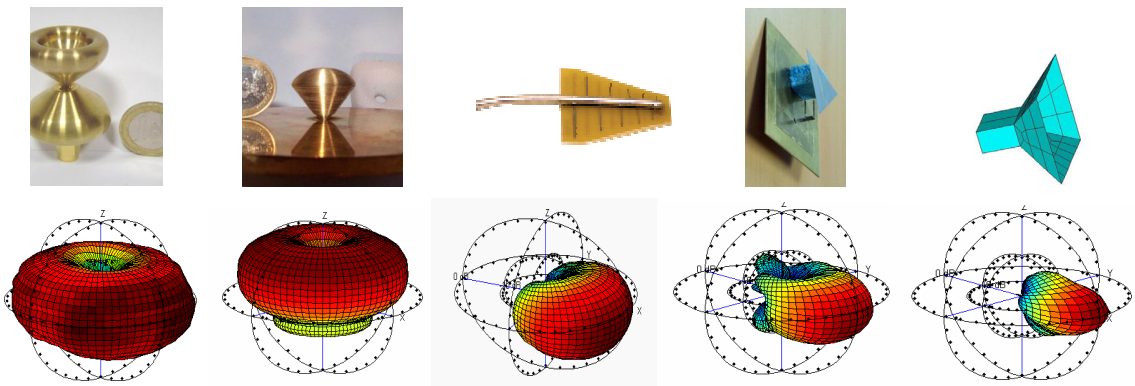

Figure 1: : up : pictures of the investigated antennas. From left to right : bicone, monocone, LPDA, F-probe, horn; down : respective time domain radiation patterns (20 dB scale)

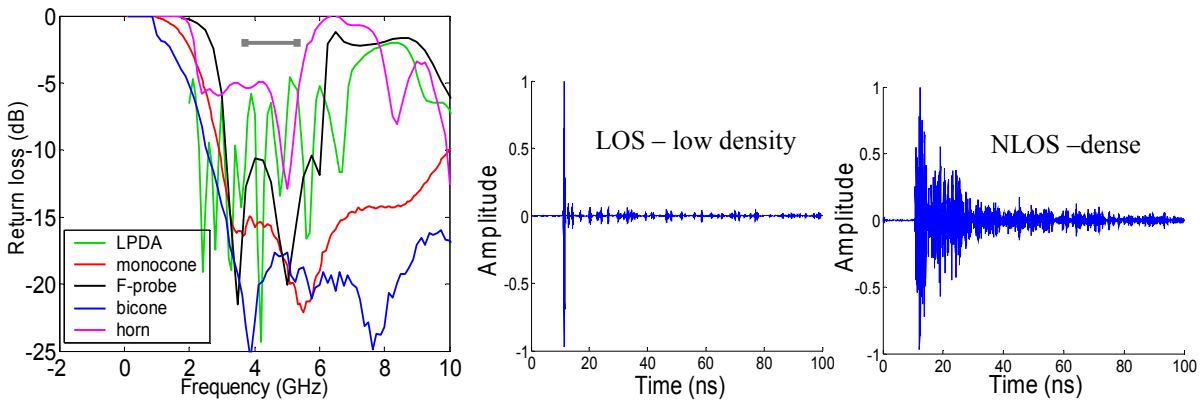

Figure 2: Left : Return loss of the investigated antennas. The grey bar depicts the used signal bandwidth. Right : temporal response of a modelled UWB channel excited by a single pulse.

The first example is shown in Fig. 3, for a low density omnidirectional LOS channel. The SNR statistics are clearly dominated by directional effects, since for directional antennas the SNR is low when the dominant (LOS) paths are outside the main lobe. This leads to widely spread statistics in e.g. both the monocone case (elevation directionality) and the horn case (azimuth directionality). In the latter, there is a rather constant gain difference between curves according to the modulation type, in favour of incoherent reception or even more of OFDM, and which is in qualitative agreement with table 1. The dense LOS channel case is interesting in that for directional antennas the gain difference is much higher between coherent pulsed modulations on one hand, and non coherent or OFDM on the other.. The explanation is rather simple and intuitive: in low density channels (take a single path as an example), the statistics are governed by the probability density of the path azimuth (which is presently uniform) and the antenna gain pattern. We do not expect a difference between the various schemes. On the other hand for the dense LOS channel, the dominant LOS cluster is accompanied by a dense time spread cluster. The coherent DS scheme basically captures a single path, with maximum amplitude. If the latter turns out to fall outside the main lobe the SNR is low. The situation is different for OOK or OFDM, which capture the energy from all paths, originating from all directions in the main lobe as well as outside it (omnidirectional cluster). The proportion of favourably oriented paths is significant if they are many, therefore there is a lesser chance to fall into a low SNR case than for a single path channel. We see here a remarkable influence of the choice of the modulation scheme on the effective antenna performance, in relation to the channel scenario.
In the symmetrical directional LOS scenario the SNR gain is very close to 5 dB for the bicone in a low multipath density (Fig. 4), which is nearly twice a single antenna gain in the horizontal plane. OFDM behaves slightly worse than the other schemes, in agreement with table 1. There is no significant improvement by using an adapted template, since in the considered bandwidth the distortion is quite small. For the other (directional) antennas, there is a rather marginal difference on SNR gain for the various schemes, except for the LPDA which has improved performance for the incoherent scheme and even more with an adapted template. Remembering that this antenna is the most distorting of the selection, such a feature is logical. For a high multipath density the SNR statistics tend to show amplified effects with respect to the low density case. In general the coherent pulsed modulation is superior, especially for distorting antennas like the LPDA. This is not a truly expected result, in that there is a popular belief for dispersive antennas to behave worse than non dispersive ones. Such a counter-intuitive observation has already been noted in our previous work [1].Clearly the interaction between antenna and channel dispersions produce complex effects that will merit further investigation.

III CONCLUSION

This work has attempted to compare the behaviour of real and ideal UWB antennas, for a small selection of time or frequency domain modulation schemes. In general but not always antenna performance is slightly worse for pulse based coherent schemes than for multi-band OFDM, due to antenna distortion. An incoherent energy capture scheme like OOK behaves similarly to OFDM as regards antenna performance. In addition it has been shown that the involvement of the channel characteristics is important and should be taken into account in choosing an antenna, for a given application or scenario.

ACKNOWLEDGEMENTS

The author thanks S.Bories and A.C. Lepage, who have provided some of the antenna data used in this work. This work was partly supported by the European Commission within the integrated project PULSERS (FP6).

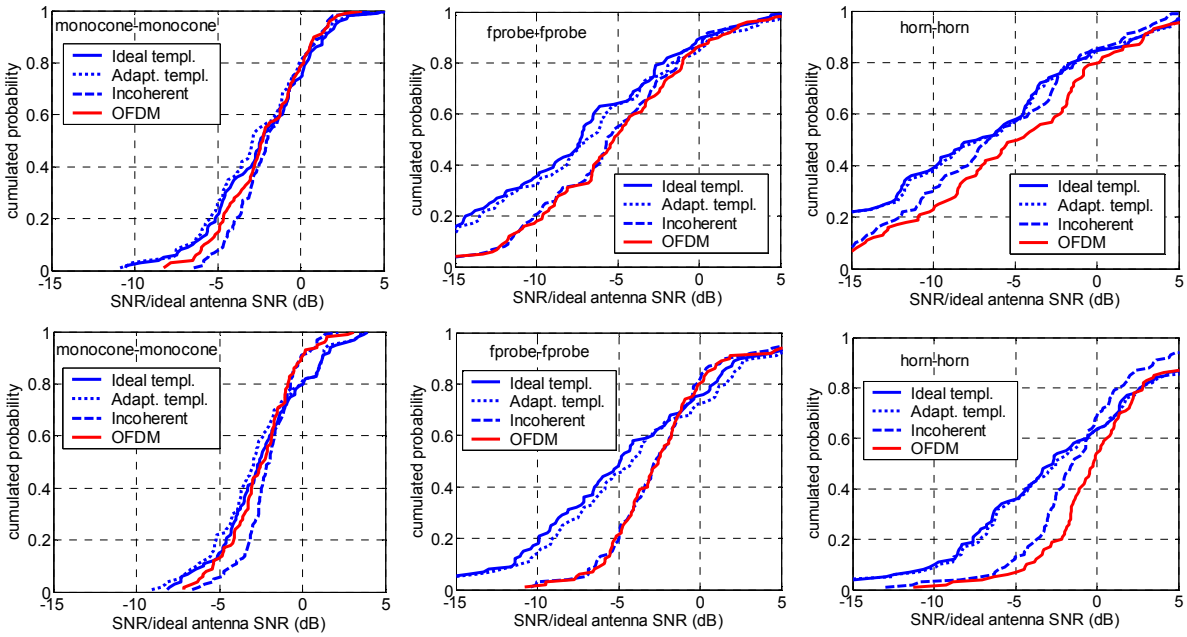

Figure 3: SNR statistics for an omnidirectional LOS channel. Up: low density; down: dense channel

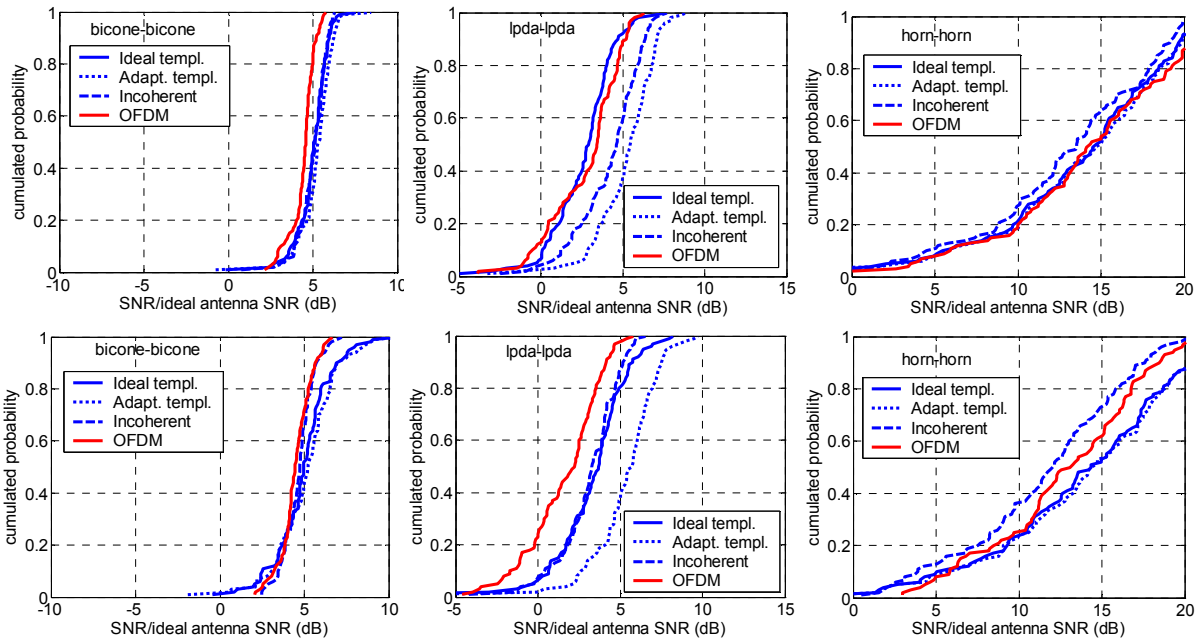

Figure 4: SNR statistics for an directional "symmetrical" LOS channel. Up: low density; down : dense channel

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