UWB Ranging Accuracy for Applications within IEEE 802.15.3a

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1 – Introduction

Ultra Wideband is a transmission technique based on the transmission of nanosecond pulses. Thanks to its MHz-bandwidth UWB can provide:

1) High transmission capacity and multiple access capability

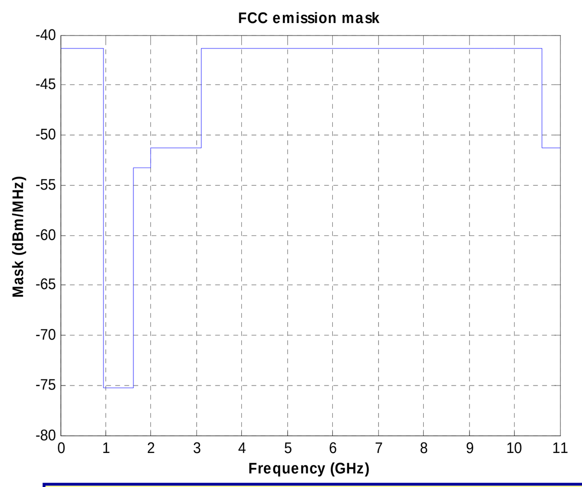
2) High precision ranging, with errors in the order of centimeters

UWB bandwidth overlaps with narrowband signals: for this reason tight emission limits are imposed to UWB emissions in order to allow coexistence.

2 – FCC emission power mask

Ultra Wide Band (UWB) radio system, thanks to its huge bandwidth, promises data transmission at very high bit rates (Gbit/s).

In order to limit the interference generated by UWB emissions to existing radio systems, the US Federal Communications Committee (FCC) released in 2002 UWB emission masks, setting tight power limitations for UWB signals.



The maximum power can be emitted in the intervals [0, 960 MHz] and [3.1 GHz, 10.6 GHz]

3 – High bit rate UWB system

Power limitations set by emission masks limit thus high bit rate UWB applications to short range scenarios (up to 10 m), suitable for Wireless Personal Area Networks (WPANs)

The interest on high bit rate applications of UWB led to the creation (2001) of IEEE 802.15.3a Task Group for the definition of a novel standard for WPANs based on a UWB physical layer capable of a bit rates in the order of 500 Mb/s

The work within the 802.15.3a TG led to two UWB PHY proposals:

Multi Band Orthogonal Frequency Division Multiplexing (MB-OFDM): based on the transmission of non-impulse OFDM signals combined with Frequency Hopping

Direct Sequence Ultra Wide Band (DS-UWB): based on impulse radio transmission of UWB DS-coded pulses

4 – Ranging in high bit rate UWB systems

- The wide band of both MB-OFDM and DS-UWB proposals suggests the possibility to use these signals for the estimation of the distance between network terminals with high accuracy.
- This aspect was only marginally addressed in the proposals, since ranging and positioning capabilities are not mandatory in the standard.
- The goal of this work is to determine and compare ranging accuracy of MB-OFDM and DS-UWB proposals in an indoor environment, by determining the Cramer-Rao Lower Bound (CRLB) for both an ideal and a real channel.

5 – MB-OFDM: signal definition (1)

An OFDM modulated signal consists in the parallel transmission of N signals that are modulated at N equally spaced frequency carrier (fm).

Sequence d_m → QPSK modulator → Frequency modulator → Pulse shaper → Signal x(t)

$c_m = a_m + jb_m$

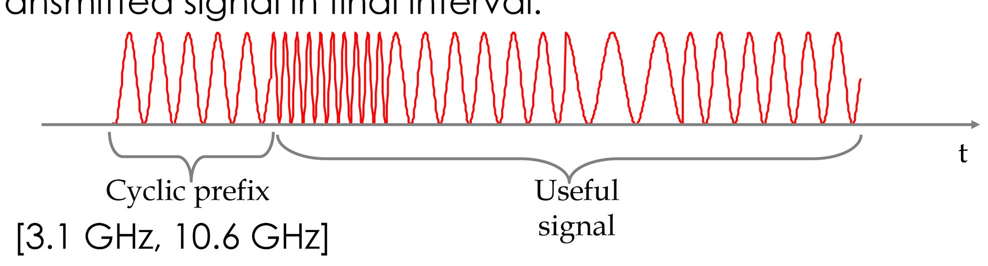
The signal expression is:

$$x(t) = g_T(t)\cdot\sum_{m=0}^{N-1}\left(a_m\cos\left(2\pi\left(f_p+f_m\right)t+\phi\right)-b_m\sin\left(2\pi\left(f_p+f_m\right)t+\phi\right)\right)$$

where f_p is the central frequency carrier, ϕ is the phase at t=0, and $g_T(t)$ is the impulse response of the pulse shaper.

6 – MB-OFDM: signal definition (2)

The signal is divided into two part: the useful signal (242.42 ns) and the cyclic prefix (70.1 ns), which is a replica of the transmitted signal in final interval.



f_p [3.1 GHz, 10.6 GHz]

[3.1 GHz, 10.6 GHz] is divided into 13 frequency sub-bands (one for each MB-OFDM band):

$$\text{Center frequency for band } n_b = \begin{cases} 2904 + 528\times n_b & n_b = 1\ldots4 \\ 3168 + 528\times n_b & n_b = 5\ldots13 \end{cases} \quad (MHz)$$

The MB-OFDM Mode 1 uses bands 1, 2, and 3, while MB-OFDM Mode 2 uses bands 1, 2, 3, 6, 7, 8, and 9.

7 – DS-UWB: signal definition (1)

Sequence b → Code Repeater → r_j → Transmission coder → d_j → PAM Modulator → d(t) → Pulse Shaper → Signal s(t)

Where:

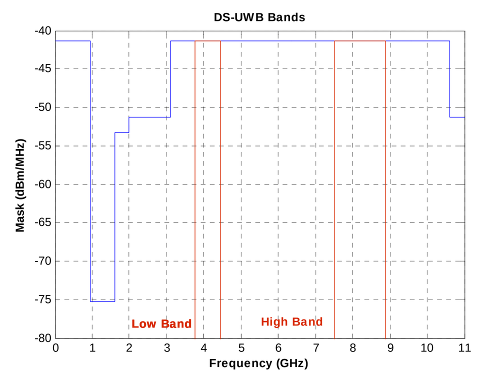
- r_j is a sequence obtained by repeating N_s times each element of sequence b;
- d_j is a binary sequence, obtained applying a binary code of period N_p at r_j (usually $N_p = N_s$);
- d(t) is a train of Dirac pulses, located at multiples of T_s;
- s(t) is the output signal, obtained from d(t) by applying a pulse shaper filter with impulse response p(t).

$$s(t) = \sum_{j=-\infty}^{\infty} d_j\, p(t - jT_s)$$

8 – DS-UWB: signal definition (2)

In the frequency interval [3.1 GHz, 10.6 GHz], DS-UWB proposal uses two different frequency carrier:

- 4.104 GHz (named Low Band), with a frequency band of 684 MHz;
- 8.208 GHz (named High Band), with a frequency band of 1368 MHz.



9 – CRLB with an ideal channel (1)

The ideal channel is characterized by an impulse response independent of frequency and dependent on distance D between the receiver and the transmitter as the inverse of the square of the distance. For an ideal channel, the CRLB (Cramer Rao Lower Bound) is:

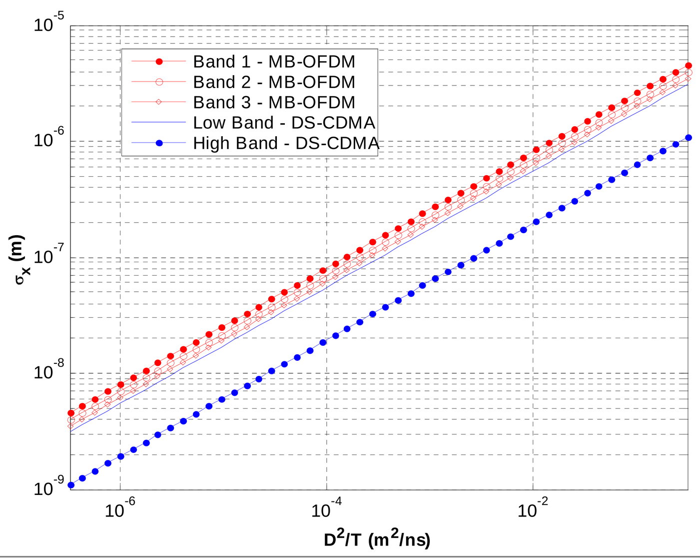
$$\sigma_t^2 = \frac{N_0 \cdot D^2}{16\pi^2 T \int f^2 PSD(f)\,\partial f}$$

where PSD(f) is the Power Spectral Density of the signal, and T is the observation interval

10 – CRLB with an ideal channel (2)

CRLB vs. D^2/T for MB-OFDM and DS-UWB

High Band DS-UWB achieves the best ranging performance thanks to a higher frequency carrier and a wider band

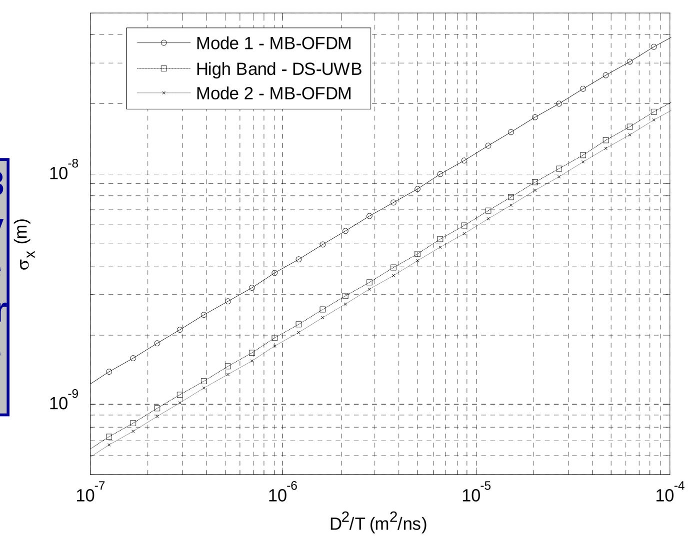


11 – CRLB with an ideal channel (3)

CRLB vs. D^2/T for Mode 1 and Mode 2 MB-OFDM and DS-UWB

Mode 1: Band 1-3
Mode 2: Band 6-9

The use of Band 1-3 only marginally improve the accuracy, the four band 6-9 leads to the best accuracy



12 – Real channel model

We selected the following UWB channel model for the indoor environment (*):

$$h(t) = \sum_{n=1}^{N}\alpha_n(D,\tau_n)\,\delta(t-\tau_n) \quad \text{with} \quad \alpha_n(D,\tau_n) = k\cdot\frac{e^{-D}}{D}e^{-\frac{\tau_n}{\tau_0}}$$

The main characteristics of this channel model are:

- the presence of N delayed replicas of the signal, modeling the presence of multipath;
- the dependence of the amplitude of the signal on distance D as both 1/D and e^{-D};

We analyzed UWB ranging accuracy for a set of realizations of the channel impulse response, obtained by varying N and t_n, while keeping constant t_0 and k

(*) Batra A., et al, Multi-band OFDM Physical Layer Proposal for IEEE.802.15 Task Group 3a. Available at www.multibandofdm.org/papers/15-03-0268-01-0034-Multi-band-CFP-Document.pdf, (September 2003).

13 – CRLB with a real channel

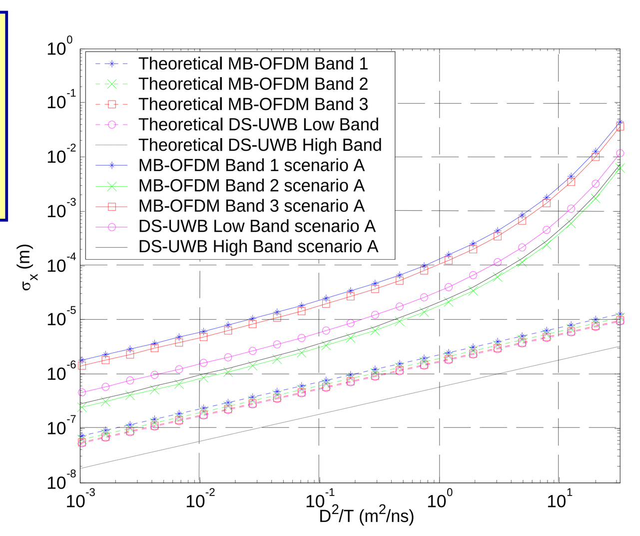
CRLB vs. D^2/T for MB-OFDM and DS-UWB

Channel Parameters (Scenario A)

- τ_n from 0 to 50 ns spaced by 1 ns
- N=50;
- k=0.1;
- τ_0 =15 ns

The signal with the minor losses is band 2 of MB-OFDM, due to the particular channel transfer function

At low distances the losses due to the multipath are limited.



14 – Impact of channel transfer function (1)

Channel Transfer function for different channel realizations for MB-OFDM Band 2

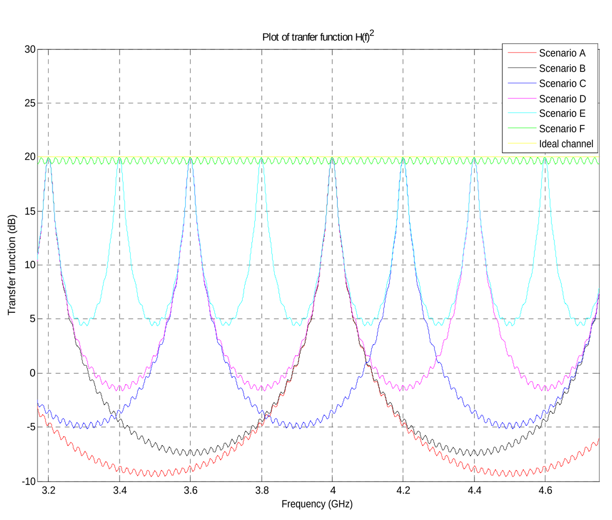
The replica number affects the positions and the number of the peaks in the transfer function.

Channel Parameters

k=0.1;

τ_0 =15 ns

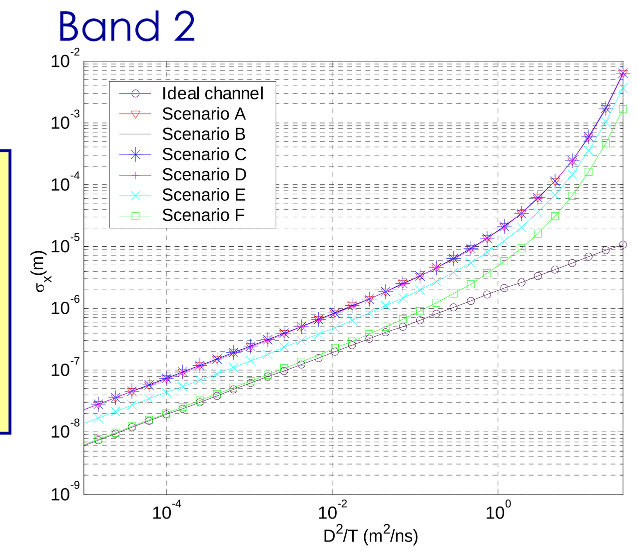
Scenario	τ_n (ns)	N
A	0 to 50 spaced 1 ns	50
B	0 to 50 spaced 1.25 ns	40
C	0 to 50 spaced 1.67 ns	30
D	0 to 50 spaced 2.5 ns	20
E	0 to 50 spaced 5 ns	10
F	0 to 50 spaced 50 ns	2



15 – Impact of channel transfer function (2)

CRLB for different channel realizations for MB-OFDM Band 2

As the number of signal replicas decreases, the CRLB with a real channel approaches the CRLB with an ideal channel



16 – Conclusions and future work

- The bandwidth used by both MB-OFDM and DS-UWB allows very high ranging accuracy.
- CRLB for an ideal channel depends on the frequency carrier and bandwidth: DS-UWB High Band shows best performance.
- The same accuracy of the DS-UWB High Band is only achievable by MB-OFDM signals if multiple bands are used at the same time.
- CRLB for a real channel depends also on the channel transfer function, and different channel transfer functions can vary the achievable performance.
- Next step: introduce multi-pulse receiver structures and analyze impact on ranging accuracy

17 – Thanks

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