# Signal processing for active and passive UWB communication

Nicolò Decarli

Supervisor: prof. ing. Marco Chiani Co-Supervisor: prof. ing. Davide Dardari

Wilab, DEIS, University of Bologna at Cesena, Italy

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## Outline



- Definition of UWB active and passive communication
- Themes addressed during the PhD

## 2 Optimization of Transmitted Reference receivers

- UWB Transmitted Reference
- Integration time optimization
- Stop-and-Go Receiver

## UWB backscatter communication

- Concept of UWB-RFID system
- Performance analysis

## Dissemination activity

## Definition of UWB active and passive communication



In particular we concentrate on *impulse radio* UWB where the emitted signal is composed of very short pulses.

In the first part of the presentation we present a demodulation technique for active UWB transmission.

In the second part we focus on UWB passive transmission, i.e. a technique that can be employed in RFID systems by using the concept of *backscatter modulation*.

#### Themes addressed during the PhD

- LOS/NLOS detection for UWB signals
- Model order selection techniques and application to UWB signal processing
- UWB backscatter modulation
- Relay techniques for localization
- Near-field electromagnetic ranging

In the context of the Europeans projects EUWB, NEWCOM++, SELECT



### **UWB demodulation**



In figure we have an example of UWB received signal, measured during an experimentation carried out in the context of Newcom++ project.

Optimal demodulation requires the availability of a filter matched to the overall received signal, composed of many multipath components, or the presence of a complex Rake receiver.

Alternative techniques to matched filtering can be adopted to perform demodulation, avoiding complex channel estimation.

#### **Transmitted Reference receiver**

The symbol is composed of a pair of pulses: the first one not modulated is used as reference template for the correlation of the (modulated) second one.



Problem: find the optimum T.

**Small** *T* leads to performance loss because a part of the useful signal energy coming from the multipath components is not correlated.

**Large** T leads to excessive noise accumulation due to the noisy template and the generic negative exponential power delay profile.

Optimum T is function of the channel PDP and noise PSD.

#### **Transmitted Reference receiver**



A solution is proposed for the optimization of the parameter T, without any *a-priori* knowledge on on the noise PSD  $N_0$  and the channel statistic (blind approach).

The circuit having in charge the T determination is composed of an energy detector and a block that, by analyzing the energy profile of the received signal, estimates the portion containing useful energy; this estimation is realized through information theoretic criteria (ITC) techniques.

## **Transmitted Reference receiver**

Example of UWB received signal, extraction of the correspondent energy profile and integration time T determination.



#### Integration time determination approach

Once ordered in decreasing order the energy bins, the integration time is estimated by deciding how many of these bins contain useful signal energy. This is done by minimizing:

$$\widehat{k} = \underset{k \in \{1, \dots, N_{\text{bin}}-1\}}{\operatorname{argmin}} \operatorname{ITC}(k)$$
(1)

with

$$ITC(k) = -2 \ln f\left(\mathbf{X}; \widehat{\Theta}^{(k)}\right) + \mathcal{L}(k),$$
(2)

where  $f(\cdot; \cdot)$  is the likelihood of observed data  $\mathbf{X}$ ,  $\widehat{\Theta}^{(k)}$  is the vector of the estimated parameters under *k*-th model order hypothesis, and  $\mathcal{L}(k)$  is a penalty factor associated to the specific model order selection rule.

Observed data **X** can be described as Chi-Squared central/non-central random variables, while the vector of the estimated parameters can be expressed as:

$$\widehat{\Theta}^{(k)} = \left(\underbrace{\widehat{\lambda}_{0}^{(k)}, \dots, \widehat{\lambda}_{k-1}^{(k)}}_{k \text{ bins with energy}}, \underbrace{0, \dots, \dots, 0}_{N_{kin}-k \text{ noise-only bins}}, \widehat{\sigma}_{(k)}^{2}\right)$$
(3)

 $\hat{\lambda}^{(k)}$ : maximum likelihood (ML) estimation of the non-centrality parameters (energy of the noise-free signal) under the hp. *k*  $\hat{\sigma}^2_{(k)}$ : noise power under the hp. *k* 

#### Performance



Figure: BEP for the TR AcR as a function of the SNR for an Exponential PDP channel model, considering different strategies for the integration time determination. Continuous lines (–) are for the receiver with proposed blind integration time determination, dashed (- -) lines are for the receiver with channel ensemble optimum integration time, and dot-dashed (– -) lines refers to fixed integration time equal to the maximum channel excess delay.

### Extention: Stop And Go Transmitted Reference Receiver

The idea is to discard, using a switching device, all the bins that do not bring useful contribution, by comparing the energy profile with a specific threshold. Different methods have been proposed to properly set this threshold with different degrees of complexity and necessary a-priori knowledge.





## (Semi-) Passive UWB RFID

This part is related to the last year activity, carried out in the context of the FP7 project SELECT. The idea is to study a new RFID communication system based on backscatter modulation adopting UWB signals.



Smart and Efficient Location, idEntification and Cooperation Techniques

The study deals with:

- System performance analysis using channel models and measurements (e.g. bit error rate (BER))
- Front-end implementation (signal processing in analog and digital parts)
- Performance analysis in presence of implementation impairments and mitigation strategies

#### **UWB Backscattering Modulation**



#### Structural Mode Scattering

It involves the antenna itself and any other structure part such as the antenna support

#### Antenna Mode Scattering

It stems from the capability of the antenna to radiate when excited at its ports

#### Tags-Reader Backscatter Communication using UWB signals



 $\{a_n\}$ : reader's code  $\{c_n\}$ : tag's code

- After the transmission of each pulse, the reader is switched in RX mode to detect the TAG response
- At the receiver the sampled signal is multiplied by the composite sequence  $a_n c_n$  which identifies the couple reader-tag

#### Equivalent scheme of the backscatter link (2-PAM case)



READER

- When switched on, the tag changes continuosly its reflection property according the sign of the code symbols (every *T<sub>ρ</sub>* seconds) and data symbols (every *T<sub>s</sub>* = *T<sub>ρ</sub>* · *N<sub>s</sub>* seconds)
- Multiple readers can access the same tag using different codes provided that they have good cross-correlation properties (e.g. Gold codes)

## Transmitted and Backscattered Signals structure

T<sub>s</sub> c<sub>n</sub> +1-1 $^{-1}$ +1+1 $^{-1}$  $^{-1}$ +177 Tp Backscattered received signal clutter +antenna structural mode scattering  $c_n d_n$ frame Ns-1 frame Ns frame 2 frame Ns-1 frame Ns frame 2 frame 1 frame 1 d<sub>n</sub> TAG data sequence

Reader trasmitted signal

## **Clutter removal**



## Symbol structure



## **Quasi-Synchronous**

- Reader and all tags code generators are synchronized at PRP level
- The Time of Arrival of the signals only depends on the reader-tag distance

#### Asynchronous

## Reader and interfering tags code generators are not synchronized

#### Code Choice for Clutter Removal and Multiple Access

- Clutter removal
  - If the TAG has zero mean, the clutter is removed after the de-spreader (if slow-varying)
- For MUI, the situation is similar to what happens in conventional code division multiple access systems
  - When the scenario is quasi-synchronous, orthogonal codes, such as Hadamard codes, represent a good choice
  - When the scenario is asynchronous, classical codes such as Gold Codes and M-sequences offer good performance.

Problem: they do not have zero mean!

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#### BER-Ns in multi-tags multipath scenario with artificial clutter

The evaluation of the system performance is obtained through Monte-Carlo simulations

Transmitter side: RRC signal compliant to the EU-UWB mask in the 3.1 - 4.8 GHz band Receiver side: a receiver noise figure of 4 dB and Single Path Matched Filter considered Simulation parameters: useful tag placed at 7 m from the reader, 59 interfering tags randomly distributed in 1 m around the useful one, 802.15.4a CM1 channel model,  $G_r = 5$  dBi,  $G_t = 1$  dBi,  $T_p = 128$  ns,  $N_c = 1024$ , artificial clutter modeled with uniform PDP with Nakagami fading



- In Quasi-synchronous scenario, when Hadamard (Orthogonal) codes are used, performance results to be not affected by MUI and clutter
- In Asynchronous scenario, extended M-sequences confirms to be a good solution

Decarli N. (University of Bologna)

Signal processing for active and passive...

## BER-Ns in multi-tags laboratory scenario (1/2)



Antennas and measurement conditions (ENSTA, Paris):

- 2 Horn Lindgren 3117 as Reader
- 1 DFMS (Dual Feed Monopole Stripline) as TAG
- 2 different load conditions: OpenL, ShortL
- 1 VNA to measure the S<sub>21</sub> parameter and to set: BW=2-12GHz Step=5MHz

- The signal from the location D is considered as that backscattered from the useful tag
- The signals from the locations A, B, C, E and F as the MUI
- *T<sub>p</sub>* = 64 ns

#### BER-Ns in multi-tags laboratory scenario (2/2)



In the asynchronous scenario, it is possible to observe the beneficial impact of extended M-sequences

#### Other themes (UWB-RFID system)

Other activities carried out, or in course of study, related to the UWB backscattering communication system:

- Non-coherent backscatter signal detection
- Low-complexity front-end structures design and performance analysis
- Analog-to-digital conversion issues (managing of the extreme near-far problem due to the presence of clutter and multi reader interference. The received signal is composed of a backscattered component, that exhibits a distance-dependent path loss with a law  $d^{-4}$ , and direct reader-reader components with a path loss dependance of  $d^{-2}$ , fact that produces very high amplitude differences in the band of interest)
- Analog partial de-spreading techniques for clutter removal
- Synchronization and code tracking in presence of tag clock drift (reduced tag oscillator accuracy)
- UHF-UWB integration (e.g. tag wake-up strategies for initial code synchronization)
- Time of Arrival estimation for network localization

#### Dissemination

Conference papers:

- Nicolò Decarli; Davide Dardari; Sinan Gezici; Antonio Alberto D'Amico, "LOS/NLOS Detection for UWB Signals: A Comparative Study Using Experimental Data", 5th IEEE International Symposium on Wireless Pervasive Computing (ISWPC), Modena, 2010.
- Francesco Guidi; **Nicolò Decarli**; Davide Dardari, Christophe Roblin; Alain Sibille, *"Performance of UWB RFID in Multi-Tag Scenario Using Experimental Data"*, IEEE International Conference on Ultrawide Band (ICUWB), Bologna, 2011.
- Nicolò Decarli; Andrea Giorgetti; Davide Dardari; Marco Chiani, "Blind Integration Time Determination for UWB Transmitted Reference Receivers", IEEE Global Communication Conference (GLOBECOM), Huston, Texas, 2011.

Journal papers:

 Andrea Conti; Matteo Guerra; Davide Dardari; Nicolò Decarli; Moe Z. Win, "Network Experimentation for Indoor Cooperative Localization", IEEE Journal on Selected Area in Communications, Special Issue on Cooperative Networking - Challenges and Applications, 2012.

## Dissemination

Demo:

 Francesco Sottile, Maurizio A. Spirito, Pau Closas, Javier Arribas, Carles Fernandez, Michel Kieffer, Montse Najar, Achraf Mallat, Pierre Gerard, Luc Vandendorpe, Davide Dardari, Nicolò Decarli, Andrea Conti: "Evaluation of Tracking Algorithms using Heterogeneous Technologies",

presented at:

Future Networks & Mobile Summit 2010 (Florence, Italy), IEEE Globecom 2010 (Miami, Florida, USA), JNCW 2011 - NEWCOM++/COST 2100 joint Workshop 2011 (Paris, France).

Project deliverables:

- EUWB D2.2.2 "Interference Identification Algorithms", 2010.
- EUWB D2.4.2 "Interference Mitigation Techniques Algorithms", 2010.
- NEWCOM DRB.4 Final Report: "Seamless Positioning Techniques in Wireless Communications", 2010.
- SELECT D2.1.1 "Backscatter propagation modeling: interim report", 2011.
- SELECT D2.2.1 "Signal Processing techniques: interim report", 2011.
- SELECT D2.3.1 "Multi-functional network design: intermediate system specification", 2011.

Thanks for the attention