Time Hopping UWB: Receiver Design and Performance of a Full-Duplex System

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Overview

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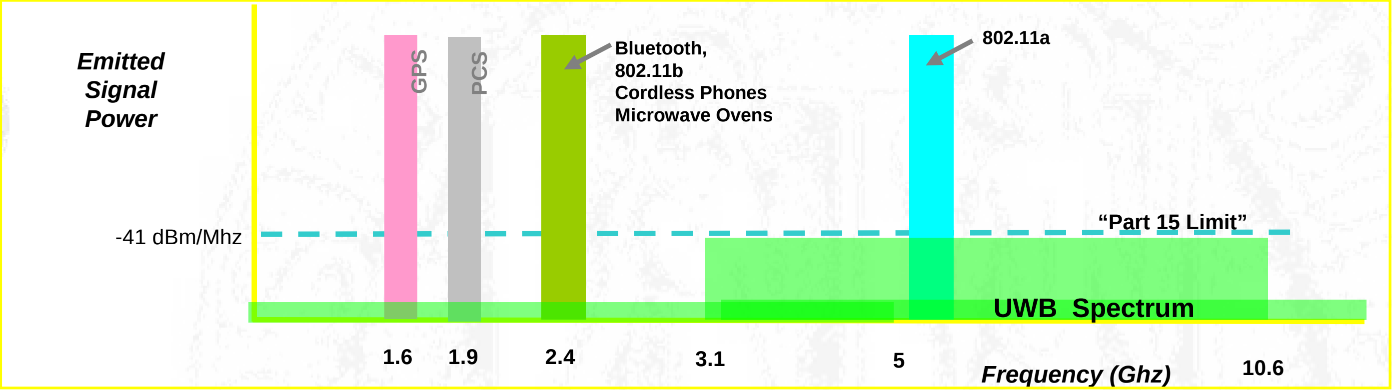
- **Introduction**
  - **What UWB?**
  - **The *full-duplex* concept in Impulse Radio**
- **System overview**
  - **System definition**
  - **Notation**
- **Receiver Design (physical layer)**
  - **Channel estimation/demodulation: *structured* versus *un-structured* approaches**
  - **Complexity**
  - **Performance (via simulations)**
- **Conclusion**

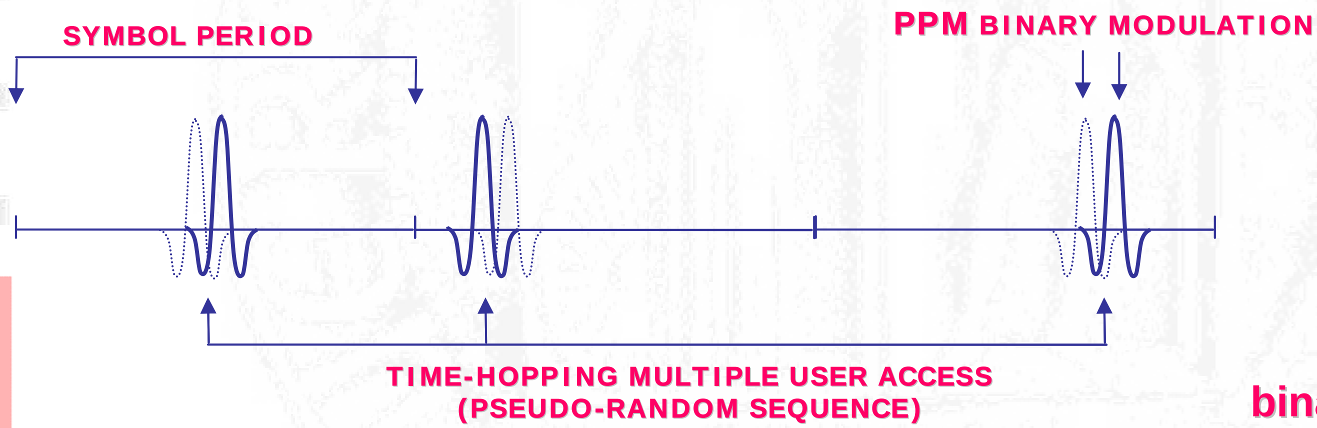
Part 1: What UWB ?



- ✓ **Multiband OFDM** *(IEEE 802.15.3 high rate alternative PHY, proposal 1)*
- ✓ **Direct sequence** *(IEEE 802.15.3 high rate alternative PHY, proposal 2)*
- ➢ **Time Hopping** *(classical Impulse Radio)*

Impulse Radio UWB

- ✓ **Impulse Radio modulation [Scholtz 1993]**
  - Pulses of sub-nanosecond duration (UWB)
  - PPM data modulation
  - Time-hopping multiple-user access



binary encoded data

PPM spacing

$$s_i(t) = \sum_{m=-\infty}^{+\infty} w\Big(t - T_{i,m} - b_{i,m}\,T\Big)$$

TH sequence
(identifying the time interval where transmission takes place)

pulse shape

The full-duplex concept [Fullerton 1997]

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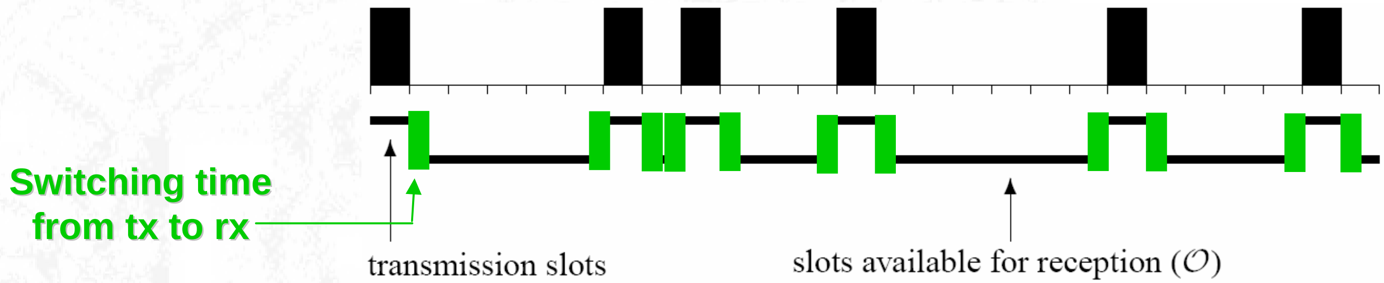

Fig. 1. slots available for transmission and reception in a TH system.

Observations:

- ✓ **In a TH system only a small portion of time is devoted to transmission (extremely low duty cycle)**
- ✓ **Reception can be accomplished in those instants where transmission is silent**

This assures that:

- ✓ **The TH format allows for the simultaneous transmission and reception of packets by exploiting the gaps in transmission (*full duplex*)**

Full-duplex consequences at MAC level

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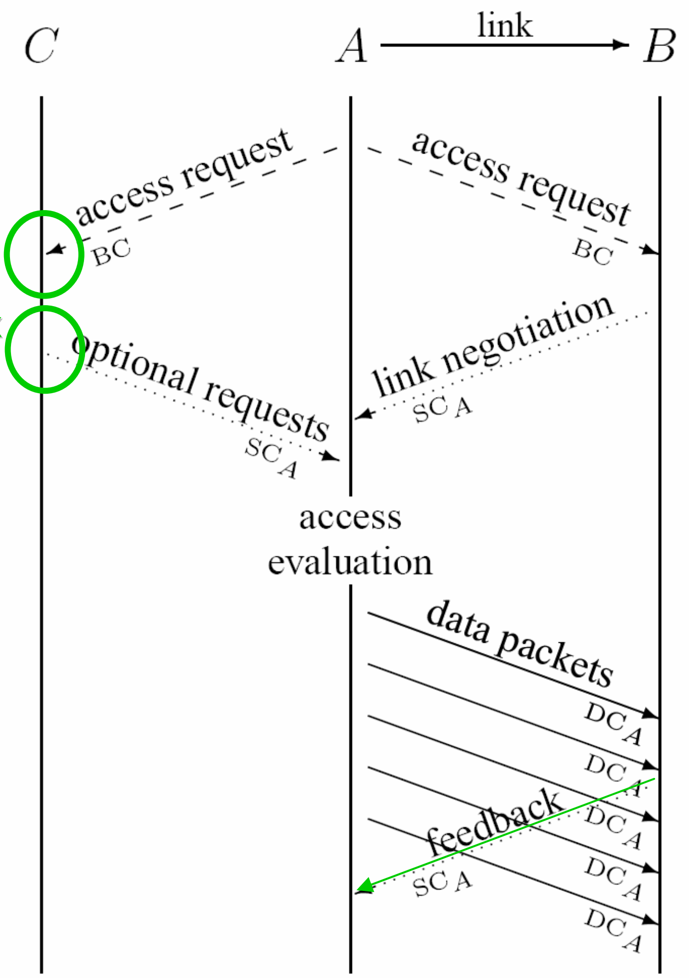

Even if already engaged in tx/rx

Full-duplex can significantly simplify link-establishment and other MAC strategies since it allows for a complete asynchronous exchange of information

Full-duplex = Impulse Radio ?

- ☺ **Multiband OFDM** ***(frequency division approach) – full duplex by frequency separation***
- ☹ **Direct sequence** ***(code division approach) – no full duplex***
- ☺ **Time Hopping** ***(time division approach) – full duplex by time separation***

Part 2: Scope of this work

Scope of this work

Full-duplex receiver

- ✓ Receiver Design at the physical layer (channel estimation, synchronization and demodulation)
- ✓ Computational complexity considerations
- ✓ Performance test / Suitability

Reference scenario

- ✓ Ad-hoc network with flat-topology
- ✓ Static, purely asynchronous network
- ✓ Distributed network (mesh topology)

Transmitter
(PAM, QAM, PSK approach)

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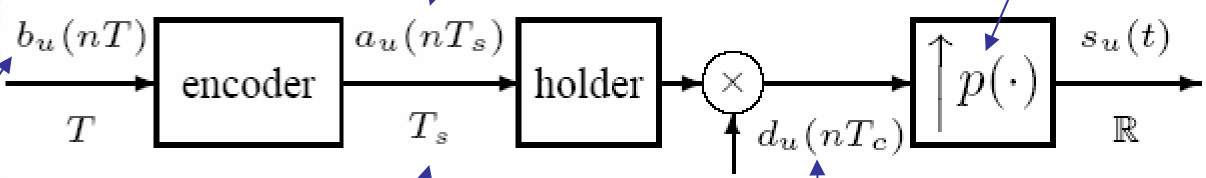
Convolutional/turbo encoder (rate ½)

Binary data

Encoded symbols (complex valued)

UWB pulse shape



Bit rate

$\sim 1.56\,\text{Mbit/s/TH-sequence}$

(and 500 TH sequences)

Symbol period

$T_s = 250\,\text{ns}$

TH signal (indicating function)

$$d_u(nT_c) = \sum_k \delta\Big(nT_c\,;\,T_{k,u}\Big)$$

Channel + digital receiver

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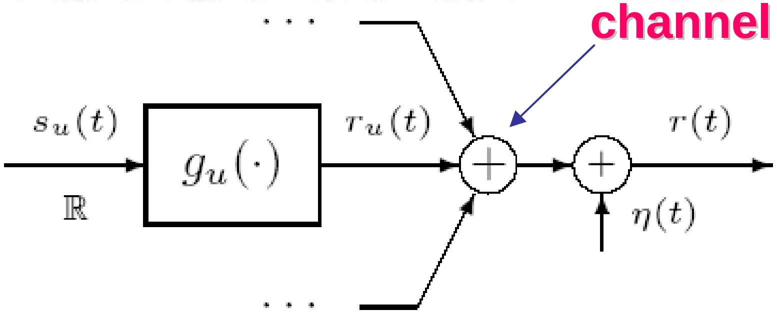
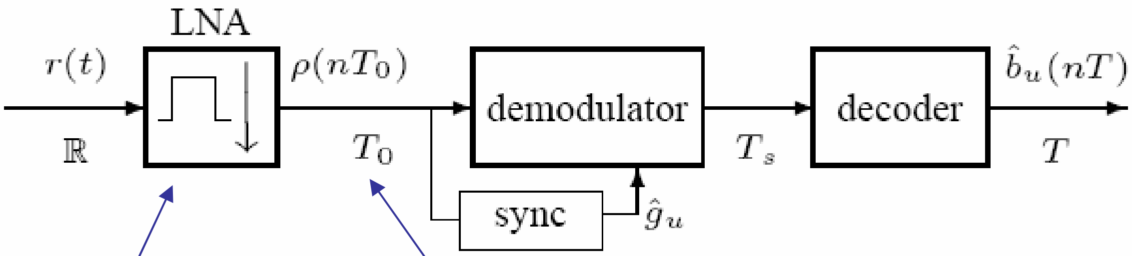
Multipath/multiuser channel [Foerster 2002]





UWB Low-noise-amplifier [Bevilacqua 2004]

Chosen accordingly to Nyquist rate

Part 3: Receiver design context

General

- Packet-based transmission (header + data)
- Absence of ISI (inter-symbol-interference) thanks to a guard interval approach

Receiver features

- Maximul likelihood approach
- Data aided (header aided) channel estimation
- Structured and un-structured approaches

$$s_u * g(nT_0) = A\, s_u(nT_0 - \tau)$$

$$\left(\sum_k A_k\, p(t - \tau_k) \right)$$

$$p * g(t)$$

Structured estimation: single path

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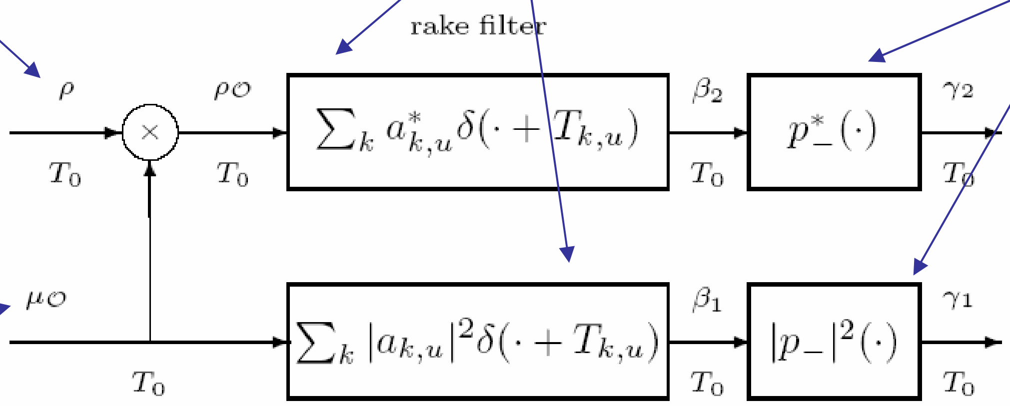

$$\mu_{\mathcal{O}}(nT_0) = \begin{cases} 1\,, & nT_0 \in \mathcal{O} \\ 0\,, & \text{otherwise} \end{cases}$$

Fig. 3. Block diagram scheme for the generation of γ_1 and γ_2 (all the operations are performed on a discrete-time domain $\mathbb{Z}(T_0)$).

$$\boxed{\hat{\tau} = \arg\max_{\tau} \frac{|\gamma_2(\tau)|^2}{\gamma_1(\tau)}\,, \qquad \hat{A} = \frac{\gamma_2(\hat{\tau})}{\gamma_1(\hat{\tau})}}$$

Structured estimation: multi-path

Successive cancellation approach.

Recursive update:

$$\Delta\gamma_2(\tau) = q * p_-^*(\tau)\,, \quad q(nT_0) = \beta_1(nT_0)\,\widehat{A}\,p(nT_0-\widehat{\tau})$$

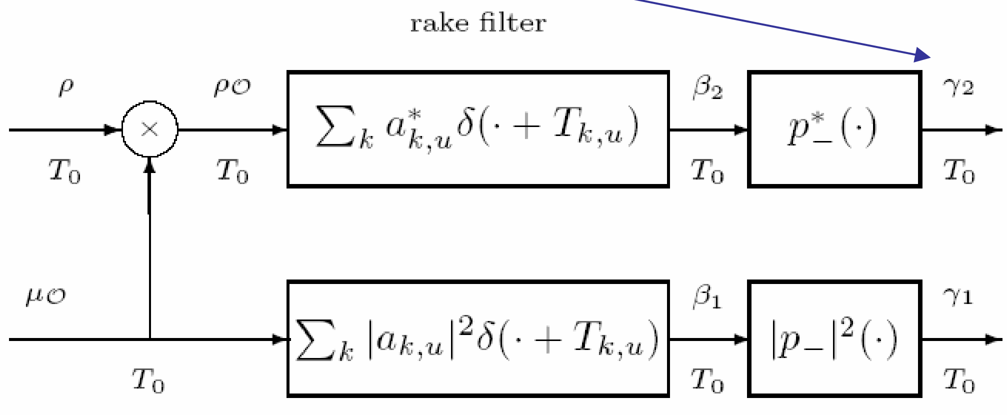

Fig. 3. Block diagram scheme for the generation of γ_1 and γ_2 (all the operations are performed on a discrete-time domain $\mathbb{Z}(T_0)$).

Unstructured estimation

No digital filters needed

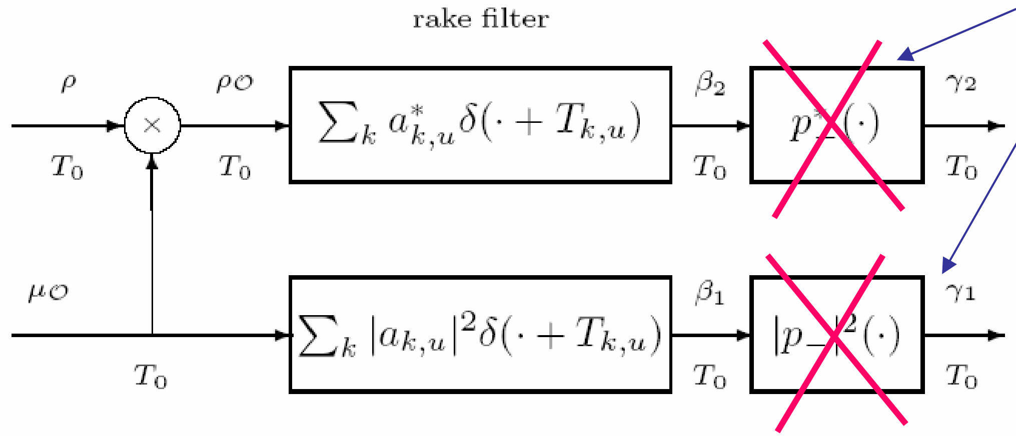

Fig. 3. Block diagram scheme for the generation of γ_1 and γ_2 (all the operations are performed on a discrete-time domain $\mathbb{Z}(T_0)$).

$$\boxed{\hat{h}_u(iT_0) = \frac{\beta_2(iT_0)}{\beta_1(iT_0)}}$$

Structured vs. unstructured (1)

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Computational complexities

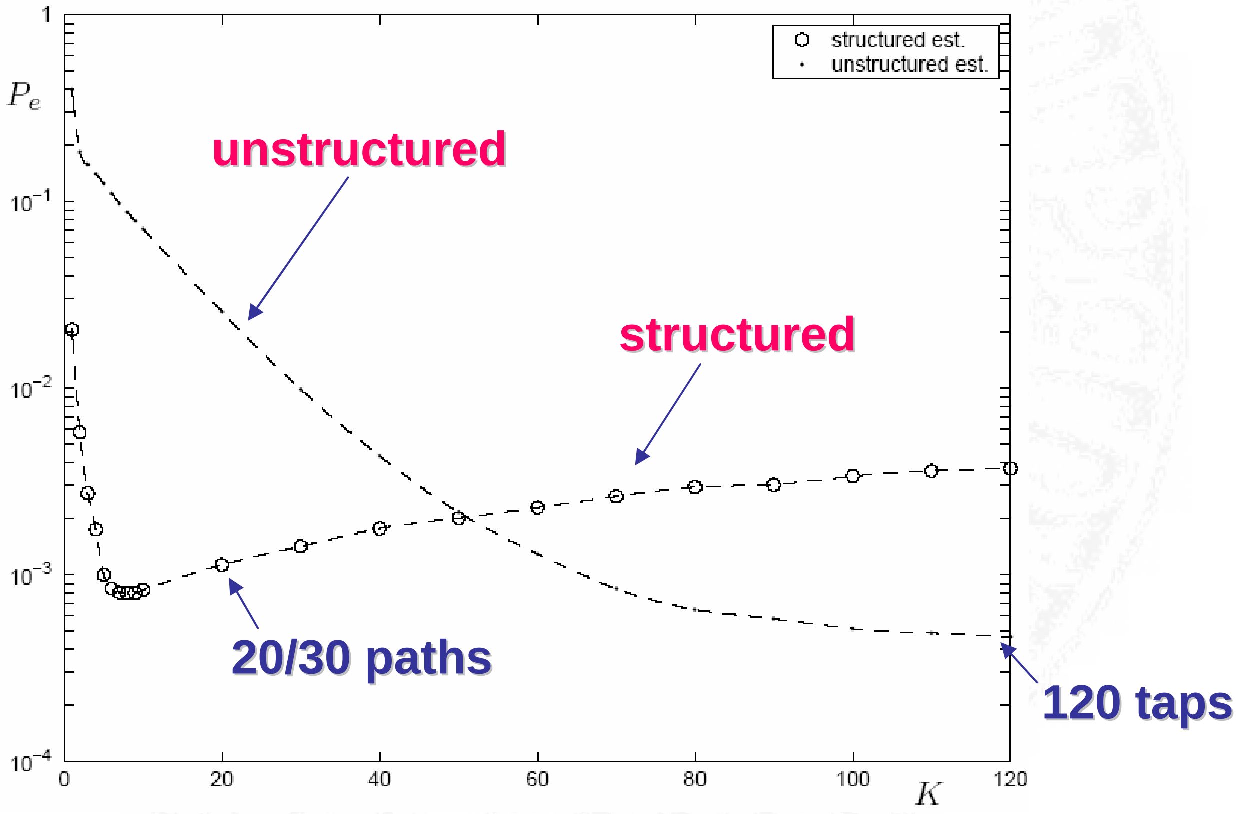
- Ordinary Gaussian unstructured : 1 x
- Windowed unstructured : 2 x
- Ordinary Gaussian structured : 1 x Int x K x
- Windowed structured : 2 x Int x K x

Interpolation factor for better accuracy in the estimation of arrivals

Number of estimated paths

Structured vs. unstructured (2)

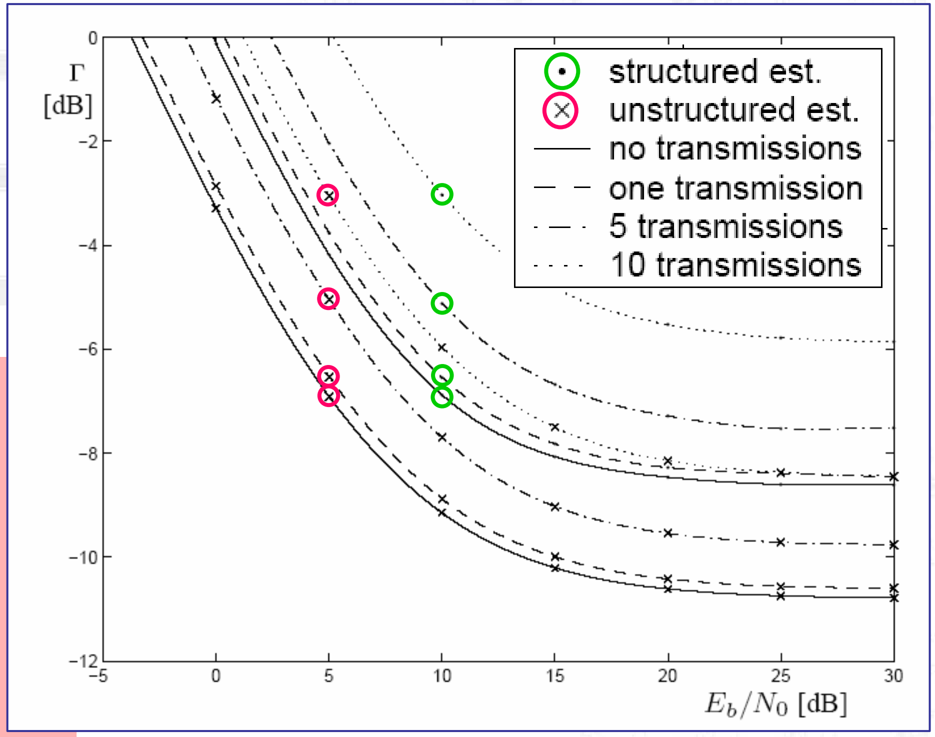
Dependence on estimated paths/channel coefficients

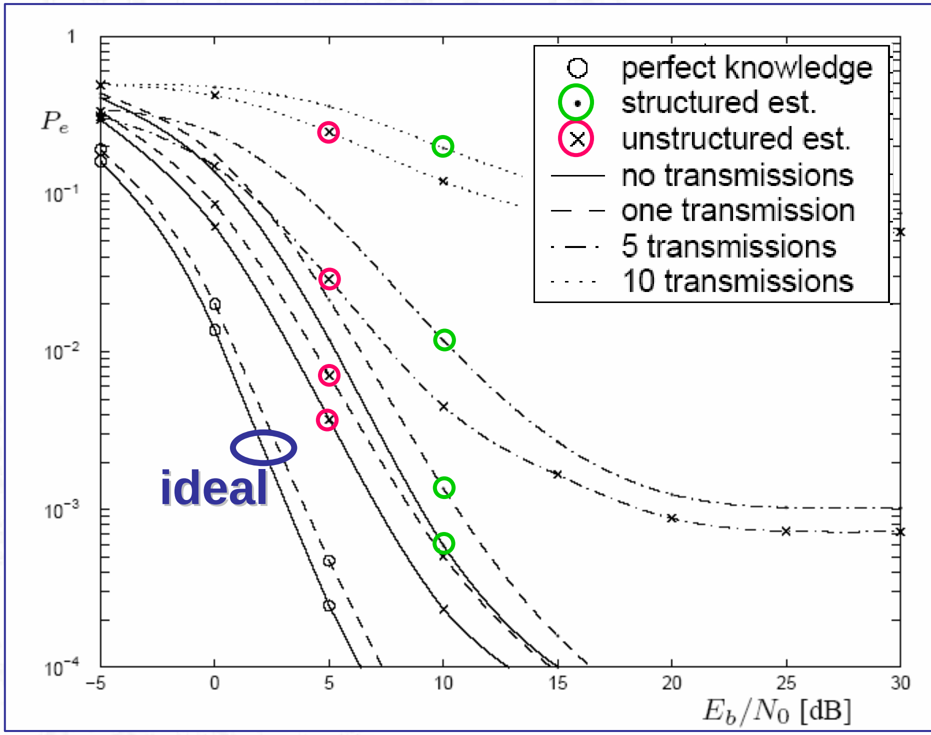


Structured vs. unstructured (3)

Performances in dependence of SNR

Normalized MSE in channel estimation $\Gamma = \dfrac{\|h_u - \widehat{h}_u\|^2}{\|h_u\|^2}$

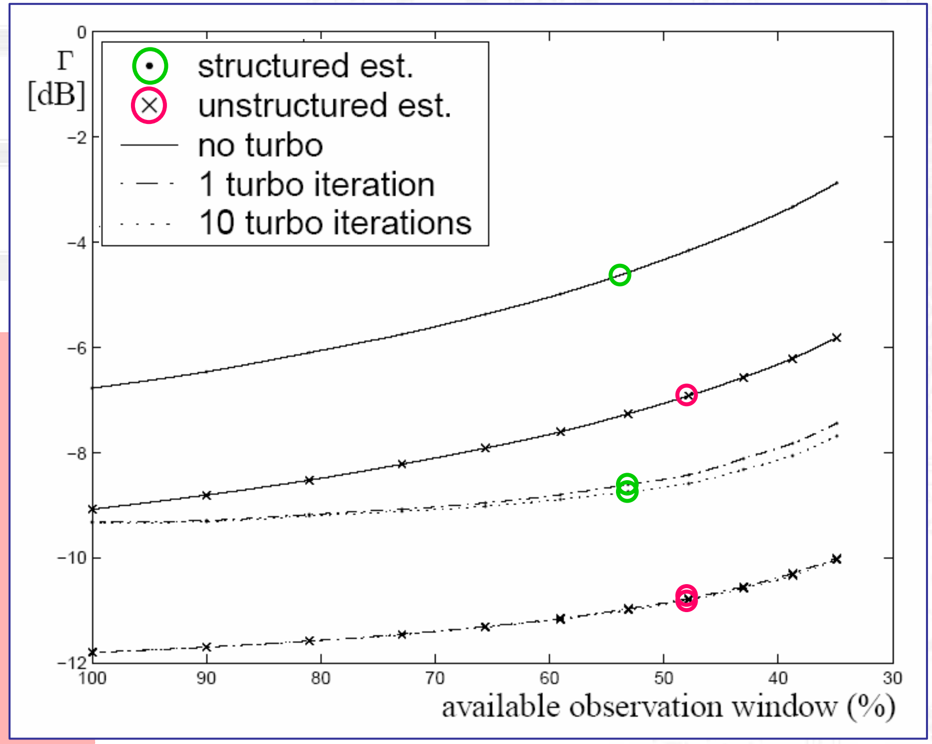


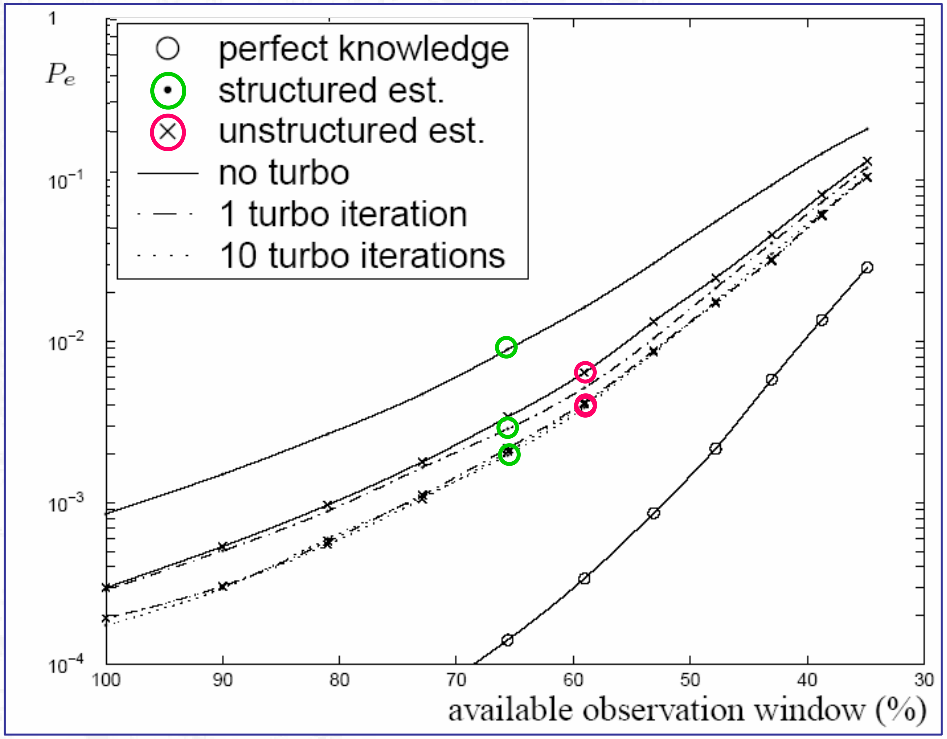


Structured vs. unstructured (4)

Performances in dependence of the observation window

Eb/No = 10dB





Conclusions

Full-duplex receiver

- ✓ Flexible design guaranteeing pure asynchronism between nodes
- ✓ Low computational complexity
- ✓ Robustness

My Suggestion: use it ! Maybe in connection with other modulation approaches (OFDM)