Coexistence of Ultra-Wideband and Other Wireless Systems: the Path Towards Cognitive Radio

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Thanks to
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Outline

- Spectrum usage considerations
- *Cognitive Radio* to increase spectrum efficiency
- *UWB* towards *Cognitive Radio*
- *Coexistence* problem
- *Narrowband* ⇔ *UWB* systems
- Example of results
- Conclusions

Traditional spectrum usage policies

Fixed spectrum allocation:
- broadcasting
- cellular..

Spectrum sharing:
Unlicensed bands (ISM):
- WiFi
- ZigBee
- Bluetooth

Drawbacks :
- *Inefficient spectrum usage*
- *Capacity limited by the allocated frequency bandwidth (data rate)*
- *Several years needed to start new wireless systems and services*

Cognitive Radio is a new radio design philosophy:
1) **First sense the spectrum**, interference, environment....
2) **Then adapt transmission**, protocol... to the spectrum available

Cognitive Radio

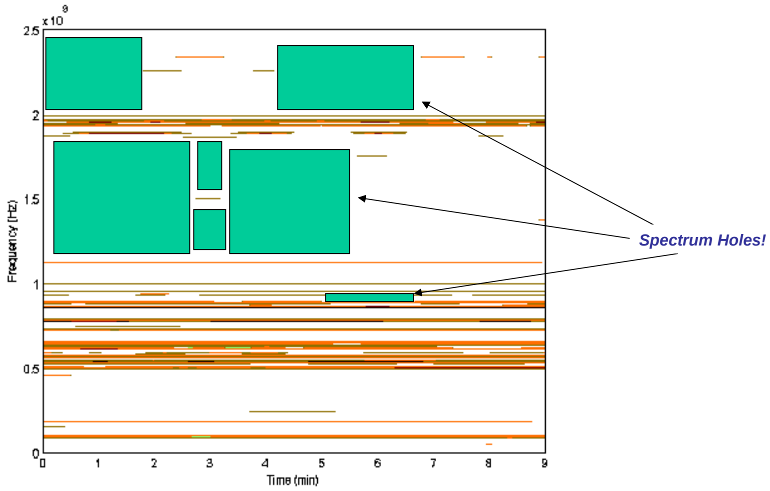
Allows secondary users to use the spectrum already licenced to primary users, without damaging the primary users' performance.

- "**interwave**" approach
  - exploits the spectrum holes (unoccupied frequency bands) opportunistically to communicate, therefore avoiding the overlapping with primary transmissions, which otherwise it would damage.
- "**underlay**" approach
  - Allows the cognitive users to operate on a certain frequency band, either unoccupied or not, provided that the interference caused to primary users remains below a fixed threshold (interference temperature). This is the case for UWB systems.
- "**overlay**" approach
  - The cognitive user employs part of its power to maintain or improve the primary users' performances, so as to compensate for deterioration due to its own transmissions (e.g. by relaying the primary user's signal).

“Interwave” approach

How much of the spectrum is actually used in space/time?

Example of usage in time in a given location



“Interwave” approach

Spectrum occupancy measurements show that licensed bands are, in many cases, significantly underutilized:

- in some geographical areas (space)

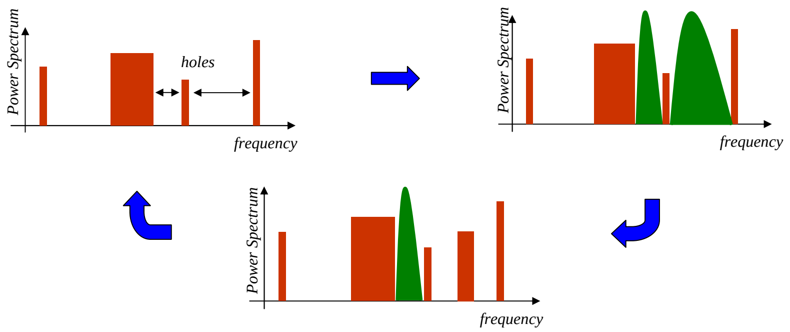
- In time

Examples: TV bands (underutilized in space), bands allocated to emergency services (underutilized in time)

“Interwave” approach

Cognitive Radio:

- ***finds free portions of the spectrum:*** *sensing*
- ***begins to transmit inside those bands****: agile spectrum usage*
- *eventually* ***being get out if needed*** *when the* ***primary users*** *show up*



“underlay” approach

Allows the cognitive users to operate on a certain frequency band, either unoccupied or not, provided that the interference caused to primary users remains below a fixed threshold.

UWB systems

USA: regulated by FCC (14/02/2002)
frequency band 3.1–10.6 GHz
power spectral density limited to -41.3 dBm/MHz

FCC definition of UWB:

- a signal with at least ***500 MHz*** bandwidth
or
- fractional bandwidth greater than ***20%***

Europe: regulated by EC (21 Feb. 2007)
frequency band 6–8.5 GHz
power spectral density limited to -41.3 dBm/MHz

EC definition of UWB:

- a signal with at least ***50 MHz*** bandwidth

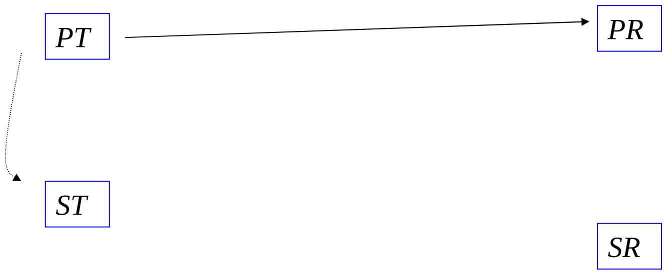
UWB:

- ✓ Time Hopping
- ✓ Direct Sequence
- ✓ OFDM/Multiband *(WiMedia)*

With the possibility of using UWB communication systems, FCC has allowed, for the first time, the use of licensed spectrum to license-exempt users (underlay licensed bands).

“overlay” approach

The cognitive user employs part of its power to maintain or improve the primary users' performances, so as to compensate for deterioration due to its own transmissions

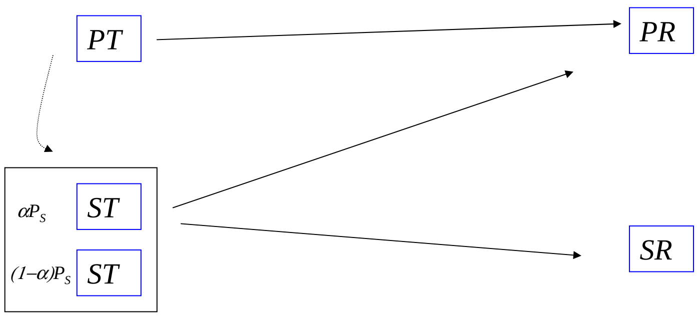


PT= Primary TX *ST= Secondary TX*

PR=Primary RX *SR=Secondary RX*

“overlay” approach

The cognitive user employs part of its power to maintain or improve the primary users' performances, so as to compensate for deterioration due to its own transmissions



For the ST-SR transmission we could use “writing on dirty paper” techniques.

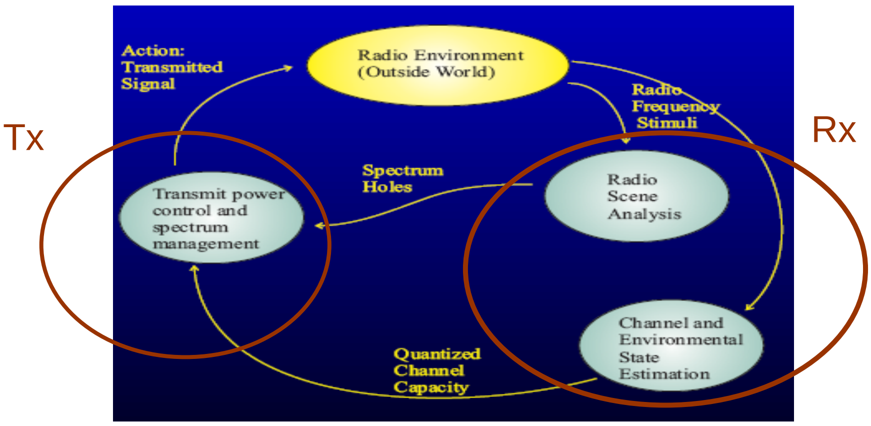
Cognitive Radio - a definition

"*Cognitive radio is an intelligent wireless communication system that is aware of its Radio Frequency (RF) environment, and uses the methodology of understanding-by-building to learn from the environment and adapt its internal states to statistical variations in the environment by making changes to adjustable parameters, namely transmit power, carrier frequency and modulation strategy, all in real Time*" [Mitola, 1999].

Aims:

- Reliable communication
- Efficient use of the frequency spectrum

Cognitive Cycle

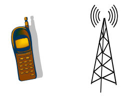


I – Radio scene analysis: interference estimation, spectrum holes detection.
II – Channel identification: estimation of the channel state and of the available capacity.
III – Transmit power control and dynamic spectrum management.

Cognitive Radio: the FCC vision

FCC, "Notice of Proposed Rulemaking and Order," Rep. ET Docket no. 03-322, Dec. 2003. → "Cognitive radio technologies can be used to improve spectrum access and efficiency of spectrum use under at least *four* possible scenarios."

- A licensee can employ cognitive radio technologies internally within its own network to increase the efficiency of use.



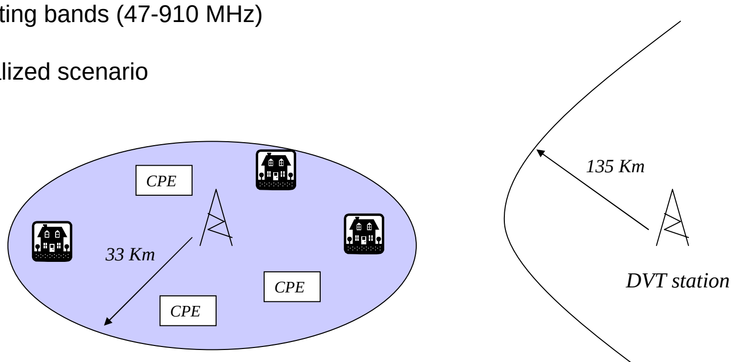
- Cognitive radio technologies can facilitate secondary markets in spectrum use, implemented by voluntary agreements between licensees and third parties. Ultimately cognitive radio devices could be developed that "negotiate" with a licensee's system and use spectrum only if agreement is reached between a device and the system.

- Cognitive radio technologies can facilitate automated frequency coordination among licensees of co-primary services.

- Cognitive radio technologies can be used to enable non-voluntary third party access to spectrum, for instance as an unlicensed device operating at times or in locations where licensed spectrum is not in use.

Some activities on CR within IEEE

- Proposal IEEE 802.22 for Wireless Regional Area Networks: CR on terrestrial TV broadcasting bands (47-910 MHz)
  - Centralized scenario



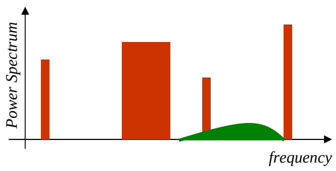
CPE= Customer Premise Equipment

- IEEE 1900 Standards Coordinating Committee 41 (SCC41), Dynamic Spectrum Access Networks (DySPAN).

UWB & CR

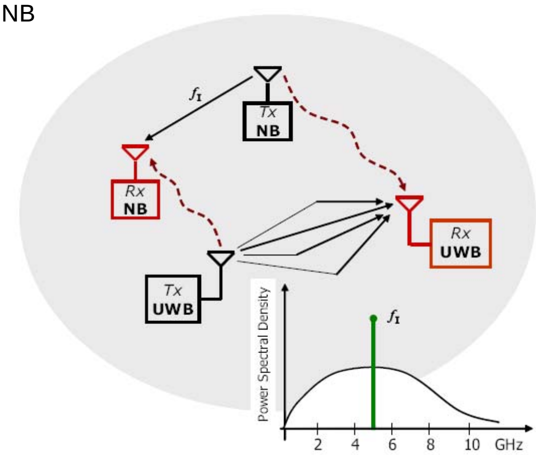
UWB represents a viable solution for CR:

- ***sensing over a large bandwidth***
- ***spectrum sculpting for interference avoidance***
- *underlay transmission with low PSD*

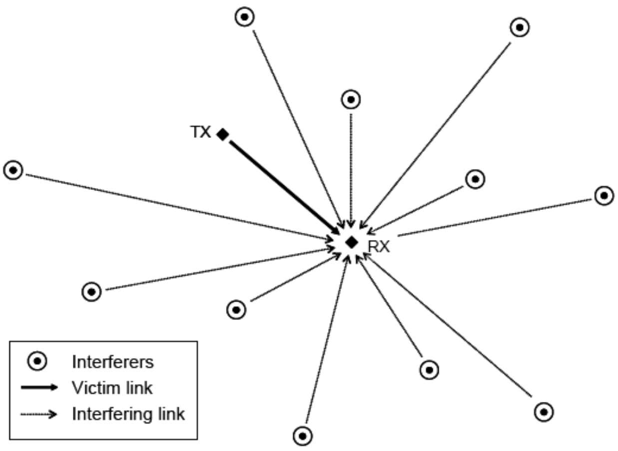


Coexistence between UWB and NB systems

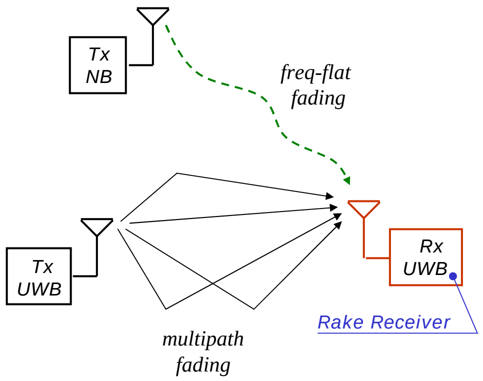
NB => UWB
UWB => NB



Multiple interferers



First scenario: NB => UWB-IR



Propagation scenario

Narrowband interference:

α_I Rayleigh distributed r.v.

Ultrawide band system:

- L paths
- α_k fading amplitude
- θ_k ~U[0,π[
- t_k path delays

$$h_D(t) = \sum_{k=1}^{L} h_k \delta(t - t_k) \quad \text{with} \quad h_k = \alpha_k \cdot e^{j\theta_k}$$

NB => UWB-IR   System Model

The Desired (UWB) Signal

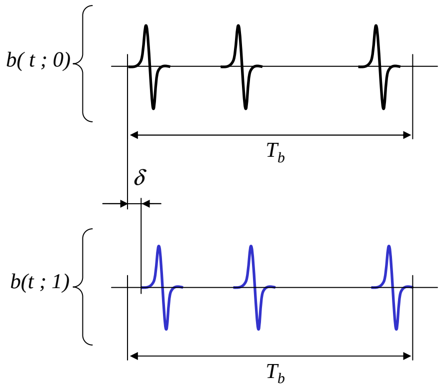
Binary **TH-PPM**

$$s(t) = \sqrt{E_\mathrm{b}} \sum_i b(t - iT_\mathrm{b}; d_i)$$

with

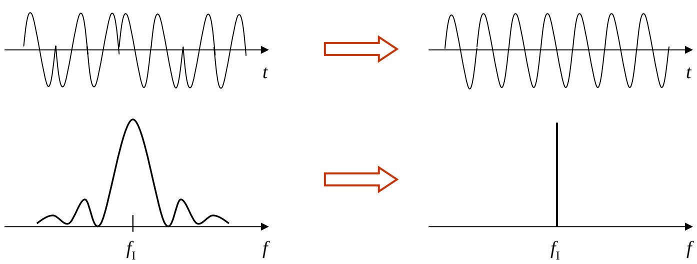
$$\rho \triangleq \int_{-\infty}^{\infty} b(t;0)b(t;1)dt$$

the correlation coeff.



First case: NB => UWB-IR
The primary user model

The **primary user** has a bandwidth of few MHz => it can be approximated as a ***TONE*** (*)



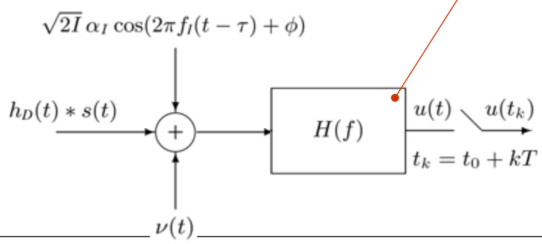
(*) Giorgetti, Chiani, Win, IEEE Trans. on Comm. Dec. 2005.

NB => UWB-IR System Model

The Rake Receiver

Conditioned on $h_D(t)$ the optimum receiver in the presence of AWGN is a MF matched to the received signal $h_D(t)*s(t)$

this MF is realized adaptively as a <u>Rake receiver</u>



NB => UWB-IR The analytical framework

Assuming perfect synchronization, the output of the MF is:

$$u(t_0) = s_0 + \sqrt{2I}\alpha_I |H(f_I)| \cos\phi + n_0$$

where:

$$s_0 = \sqrt{E_b}\int_{t_0-T_b}^{t_0} r_b(t; d_0)v(t)dt$$

$$v(t) = \sum_{k=1}^{L} h_k \left[b(t-t_k;0) - b(t-t_k;1)\right]$$

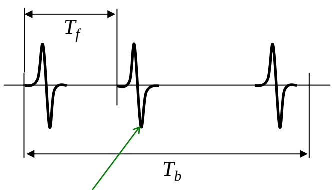
$$|H(f)| = \underbrace{|\mathcal{F}\{b(t;0)-b(t;1)\}|}_{|H_0(f_I)|} \cdot \underbrace{\left|\sum_{k=1}^{L} h_k e^{-j2\pi f t_k}\right|}_{\xi(\mathbf{h},\mathbf{t})}$$

$|H_0(f_I)|$ *signaling waveform*

$\xi(\mathbf{h},\mathbf{t})$ *multipath channel*

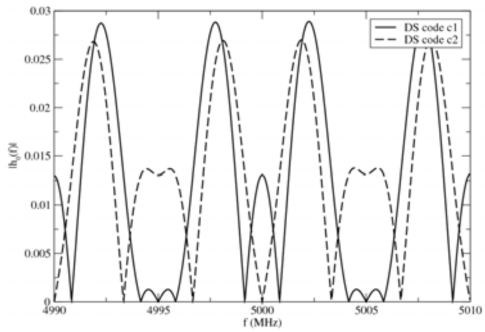
Secondary user receiver

DS-BPAM system



Assuming a 6-th derivative
Gaussian pulse with Fourier T.:

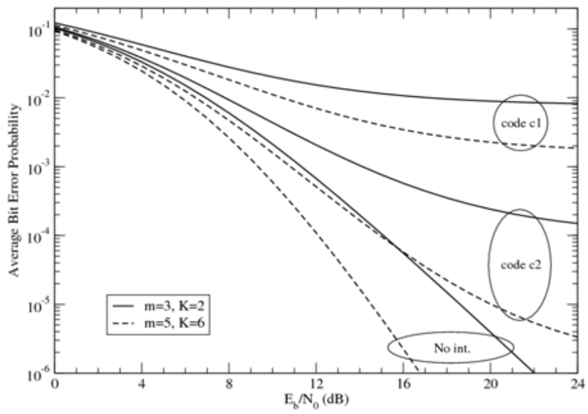
$$W(f) = \frac{8\pi^3}{3\sqrt{1155\,N_s}}\,\tau_w^{13/2}\,f^6\,e^{-\frac{\pi}{2}f^2\tau_w^2} \Rightarrow \quad |H_0(f)| = 2|W(f)|\left|\sum_{k=0}^{N_s-1} c_k e^{j2\pi f k T_f}\right|$$



Example: *performance of the SU*

System parameters

- DS-BPAM
- *pulse duration* τ_w=0.192 ns
- *frame duration* T_f=100 ns
- *pulses per bit* N_s=6
- *DS sequences*
- c_1={+1,+1,-1,-1,+1,+1}
- c_2={+1,+1,-1,-1,-1,+1}
- f_I=5.003 GHz



The spectrum of the SU

The **transmitted power spectral density** of the **secondary user** (in this case a DS-BPAM system) is

$$S(f) = \frac{E_b}{T_b} |W(f)|^2 \left| \sum_{k=0}^{N_s - 1} c_k e^{j2\pi f k T_f} \right|^2$$

Note that this is proportional to the transfer function of the matched filter **at the secondary user receiver**

$$|H_0(f)| = 2|W(f)| \left| \sum_{k=0}^{N_s - 1} c_k e^{j2\pi f k T_f} \right|$$

Therefore, we can reduce the **mutual interference!!!**

The spectrum of the SU

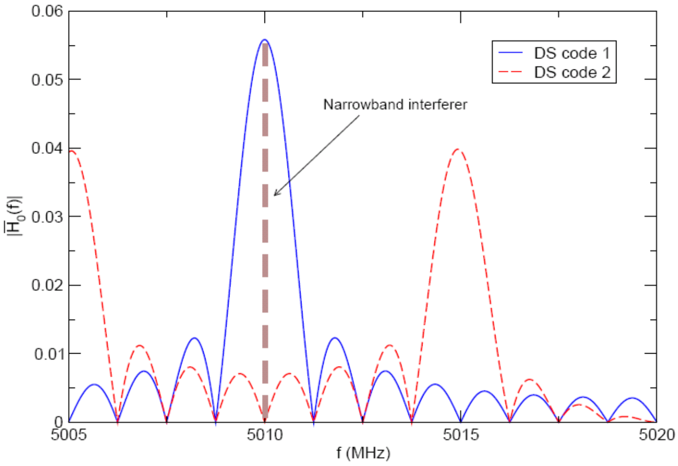


Fig. 10. The normalized transfer function of the MF around $f_I = 5.010$ GHz for two different DS codes: code 1) $\{c_j^{DS}\} = \{(-1)^j\}_{j=0}^{N_s}$, code 2) $\{c_j^{DS}\} = \{(-1)^{\lfloor j/2 \rfloor}\}_{j=0}^{N_s}$.

NB => UWB-IR: Example of results

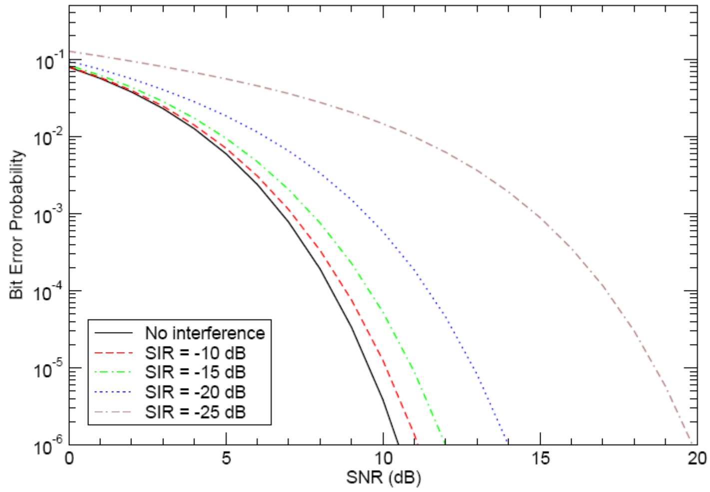


Fig. 11. BEP for the DS-BPAM system considered with a single tone interferer and AWGN.

NB => UWB-IR: Example of results

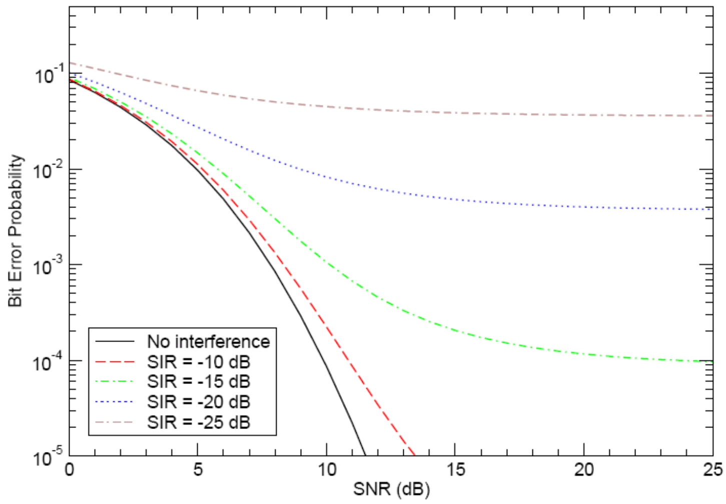


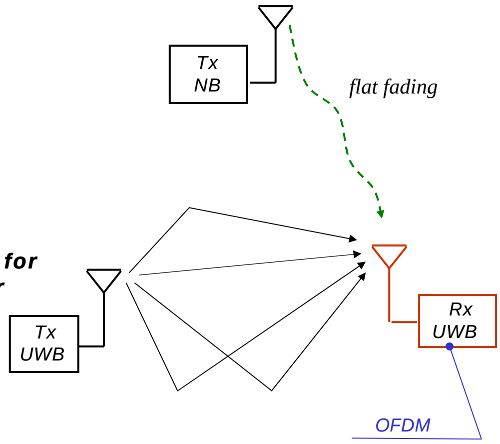
Fig. 12. BEP for the DS-BPAM system considered with Rake reception and $L = 8$ paths with a tone interferer.

Other case: NB => UWB-OFDM

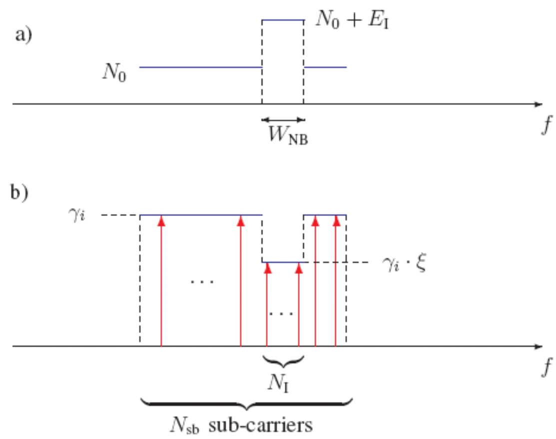
Frequency-Selective channel for the secondary user link

- ❑ block fading channel in the frequency domain
- ❑Channel coding across the subcarriers

Frequency-flat fading channel for the primary-to-secondary user link



Other case: NB => UWB-OFDM



NB => UWB-OFDM: Example of results

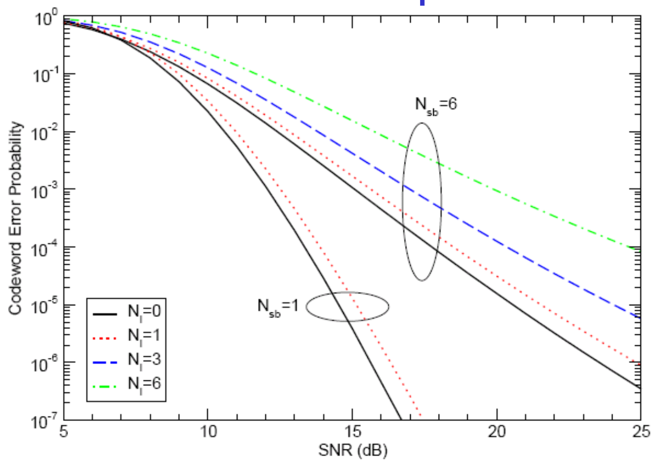
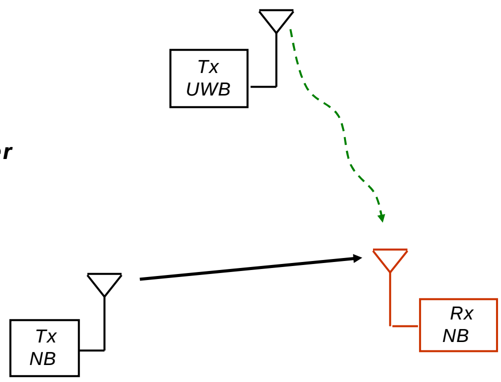


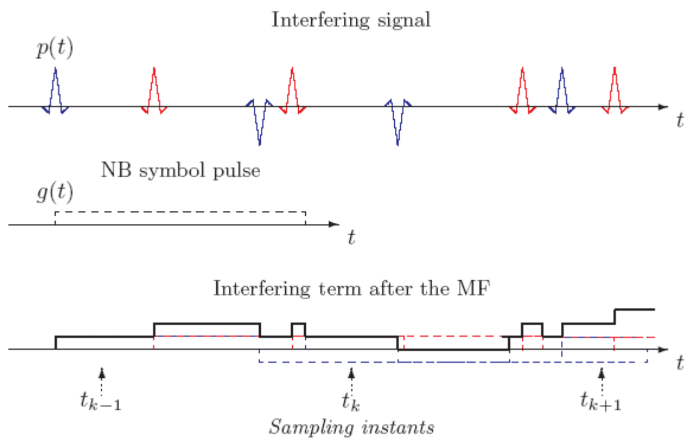
Fig. 8. Error probability per codeword, OFDM over a BFC in the frequency-domain with N_{sb} sub-carriers per block, QPSK over all useful 126 sub-carriers, BCH code with $n = 126$, $R_c = 1/2$ and $t = 10$. Narrowband interference over N_I sub-carriers, signal-to-interference ratio SIR $= 0$ dB.

UWB-IR => NB

NB receiver with matched filter receiver



UWB-IR => NB
Signal at the output of the NB MF



Gaussian approximation for the interference? Shot noise?

UWB-IR => NB: Example of results

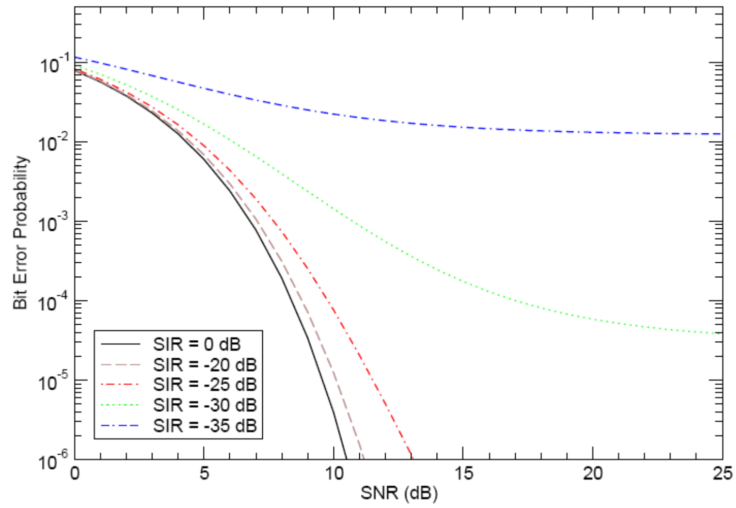


Fig. 16. BEP for the NB victim link affected by a UWB interference on AWGN.

Conclusions

➢ We addressed the **coexistence problem** by reviewing some recent results on the **impact of NB interference on UWB systems**.

➢ The analysis has shown **the great potential of UWB** in **adapting the transmitted spectrum** to counteract the NB interference and at the same time to guarantee a low spectral emission over the NB communications.

➢ By keeping low the mutual interference, **UWB can be a potential technology** for an efficient spectrum usage which represent the main goal for **Cognitive Radio**.

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EUWB
"Coexisting Short Range Radio by
AdvancEd Ultra-WideBand Radio Technology"