Combining Wireless Optical and UWB for low data rate applications

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Outline

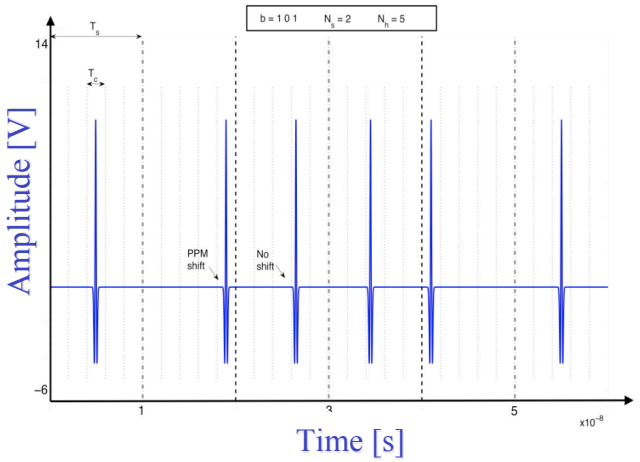
- UWB Impulse Radio features and framework of application
- Diffuse Wireless Optical features
- Optimal PHY selection at MAC layer for Impulsive wireless systems
- Simulation results
- Conclusions

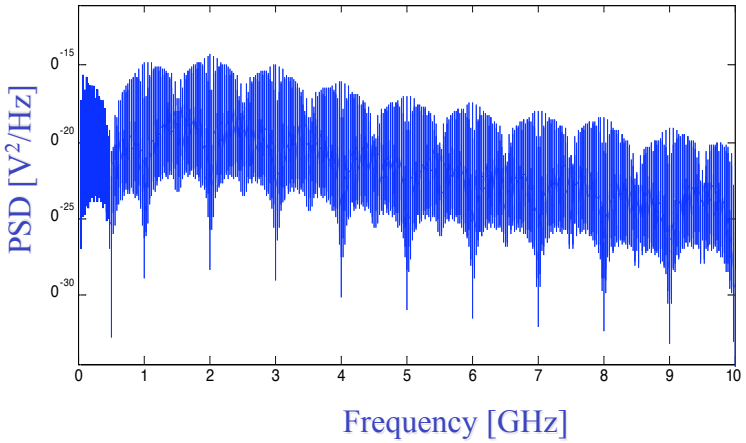
UWB Impulse Radio features

UWB signals can be obtained by transmitting **very short pulses** with typically no Radio Frequencies modulation

(In communication systems, "very short" refers to a duration of the pulse that is typically about a few hundred picoseconds)

This technique goes under the name of **Impulse Radio (IR)**





Both coherent (PSK, QAM) and non-coherent (OOK, PPM) modulation schemes can be used

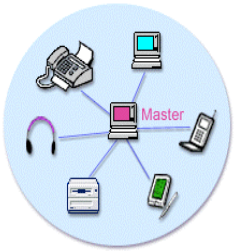
UWB scenarios of application

Increased interest towards UWB

Strong power emission constraints imposed by regulatory bodies

UWB emerged as an appealing transmission technique for applications requiring either **high bit rates over short ranges** or **low bit rates over medium-to-long ranges**

High bit rates over short ranges

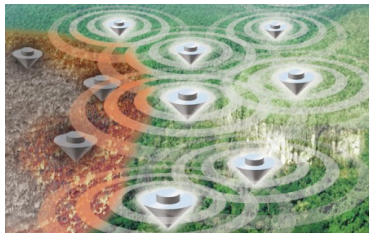


WPANs for multimedia traffic

Cable replacement for high bit rate data transfers

Wearable devices

Low bit rates over medium-to-long ranges

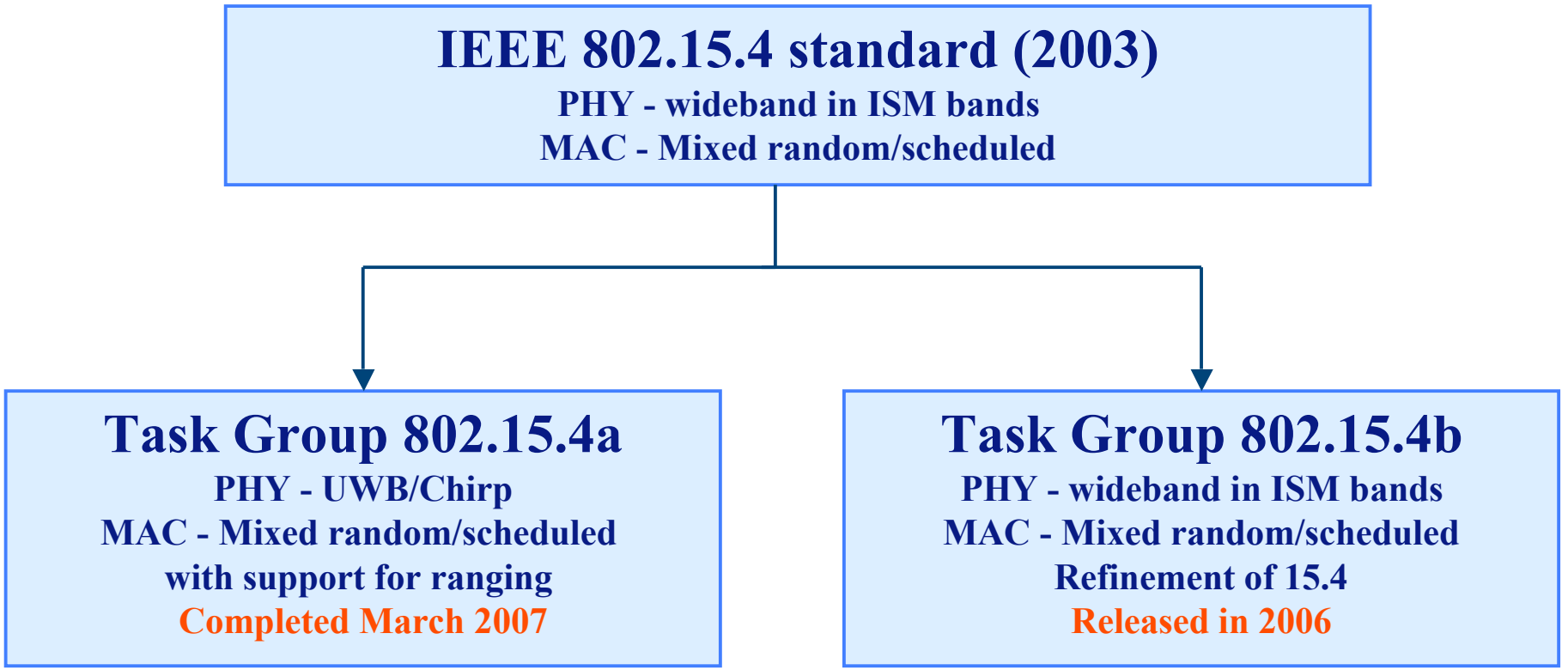


Long-range sensor networks

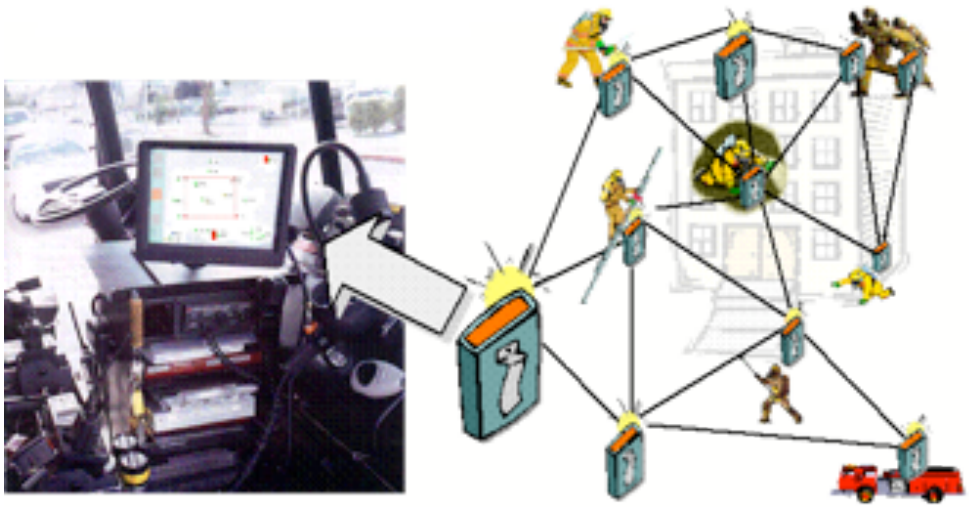
Non-real-time data applications (E-mail, instant messaging ...)

Low Bit Rate - The IEEE 802.15.4/4a standard

The main interest is in providing communications with high-precision ranging and localization, low-power emission and consumption, and a low cost



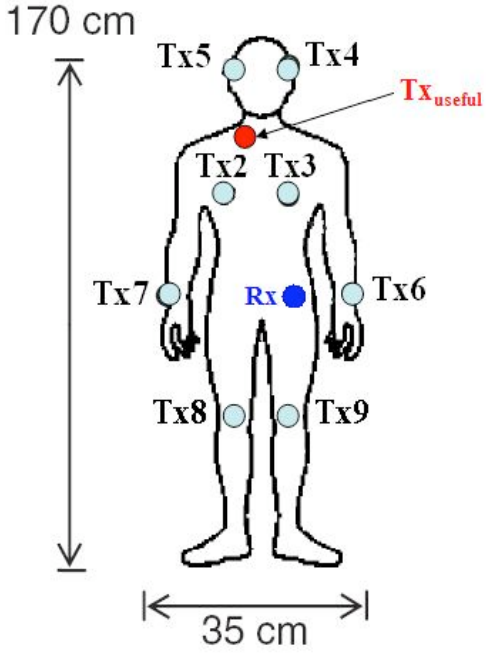
Low rate UWB: potential applications



Firefighters/Police squads positioning and tracking

Key requirements:

- Indoor accurate positioning (up to 10 cm accuracy)
- Robustness to interference

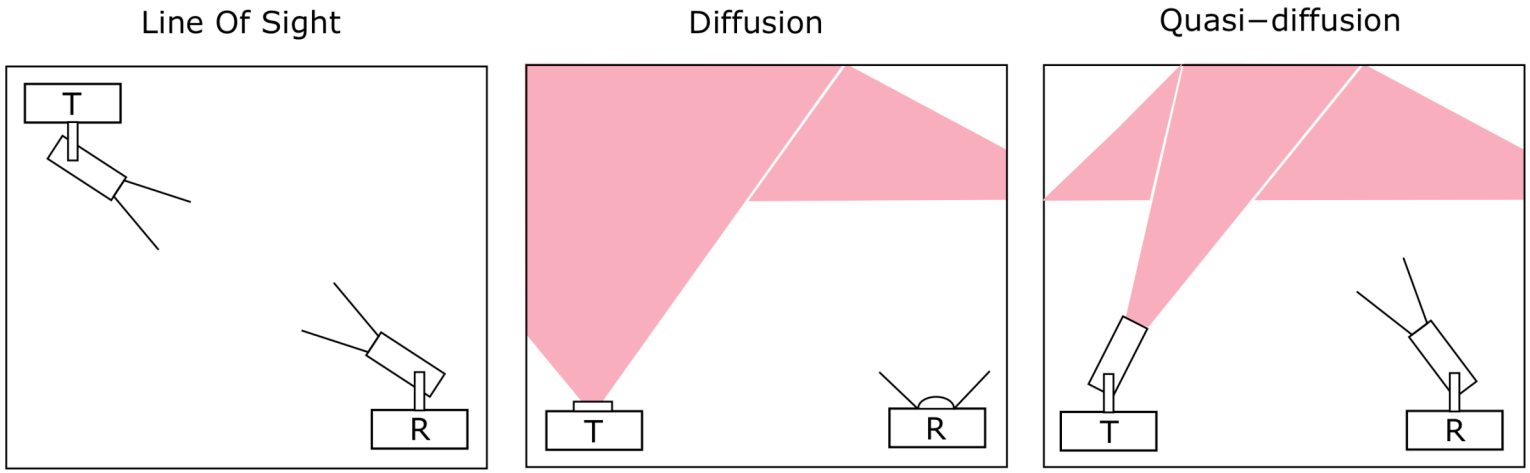


Medical applications (e.g. Body Area Networks)

Key requirements:

- Reliability/confidentiality of transferred data
- Robustness to interference
- Capability to coexist with medical equipment

Diffuse Wireless Optical



- Based on reflection on walls/ceiling
- Provides higher flexibility compared to LOS optical communications
- Often proposed as an alternative/complementary solution to RF communications systems
- Limited to low-medium data rate due to multipath propagation and Inter Symbol Interference

Diffuse Wireless Optical

- Physical layer technology
  - LED
  - PIN diode
- Modulation schemes
  - On-Off-Keying (OOK)
  - Pulse Position Modulation (PPM)
- Main sources of noise
  - Sunlight
  - Artificial light (incandescent / fluorescent)
  - Multiuser interference

Diffuse Wireless Optical: potential applications

Domotics / Home automation

Key requirements:

- Ease of use and installation
- Robustness to interference

Medical applications

Key requirements:

- Reliability/confidentiality of transferred data
- Robustness to interference
- Capability to coexist with medical equipment

UWB and DWO: analogies and differences

Signal spreading

Both systems can use sub-nanosecond pulses to achieve high processing gain

Modulation and coding

DWO and UWB share modulation schemes (OOK/PPM) and non coherent receiver schemes

Application scenarios

Indoor applications, especially involving diffuse systems for secure, low data rate communications

Sources of noise

RF interference for UWB, natural and artificial light for DWO

Coexistence issues

ISM and medical equipments for UWB, some IrDa based medical equipments for DWO

Ease of use

No blocking issue in case of UWB, care to be taken in DWO

UWB and DWO can complement one each other

Optimal PHY selection at MAC layer

- Similar PHY properties suggest the use of a common MAC layer
- Previous work on UWB MAC led to the conclusion that Aloha is a viable approach for LDR impulsive communication systems[1]
- Key idea - select the PHY according to a environment-aware cost function:

$$C = C_{UWB} \cdot BER_{UWB} - C_{DWO} \cdot BER_{DWO} \Rightarrow \begin{cases} \text{if } C > 0 & \text{select DWO} \\ \text{if } C < 0 & \text{select UWB} \end{cases}$$

Cost coefficients to be selected according to the desired performance goal (Energy, Throughput)

BER measured on the two PHYs (e.g. by means of periodic pilot packets)

[1] M.-G. Di Benedetto, L. De Nardis, G. Giancola and D. Domenicali "The Aloha access (UWB)^2 protocol revisited for IEEE 802.15.4a," ST Journal of Research, Volume 4, Issue 1, May 2007, pp. 131 - 142.

Performance analysis

- Simulation scenario: N devices deployed in a room
- Each device equipped with a dual PHY:
  - IEEE 802.15.4a-like UWB PHY
  - DWO PHY (LED transmitter and PIN receiver, $\lambda = 850$ nm)
- Common simulation settings:

Number of simulation runs	10
Number of nodes N	10
Area	12 m by 12 m (Indoor)
Network topology	Random node positions
User bit rate R	10 kb/s
Transmission rate	966 kb/s
Packet traffic model	Poisson generation process, uniform distribution for destination node
DATA packet length	1224 bits (+ 64 bits for Sync trailer)

UWB specific settings

- IR-UWB with a band of 494 MHz centered at 3952 MHz (IEEE 802.15.4a Channel 2)
- Average Pulse Repetition Frequency (PRF): 2.895 MHz
- Pulses Per Symbol (N_s): 3
- Modulation: PPM
- TX power P_{TX} = 36.6 μW (FCC indoor limit)
- Both Line Of Sight (LOS) and Non-Line Of Sight (NLOS) channel conditions
- MUI taken into account with a UWB-specific model[2]

[2] G.Giancola and M.-G. Di Benedetto, "A Novel Approach for estimating Multi User Interference in Impulse Radio UWB Networks: the Pulse Collision model", Signal Processing, Special Issue on Signal Processing in UWB Communications, Vol. 86, pp. 2185-2197

DWO specific settings

- Modulation: OOK; LOS and NLOS channel models

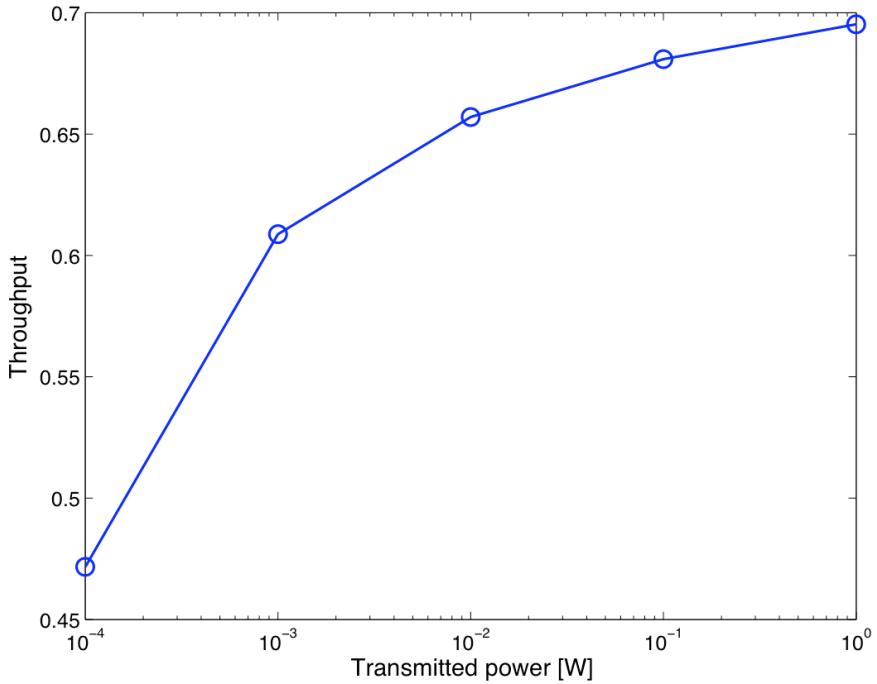
$$P_e = 0.5 \cdot p(0/1) = 0.5 \cdot e^{-\Lambda} \quad \text{with} \quad \Lambda = E_b / (hf)$$

$$P_e = 0.5 \cdot p(0/1) + 0.5 \cdot p(1/0)$$

Number of interferers

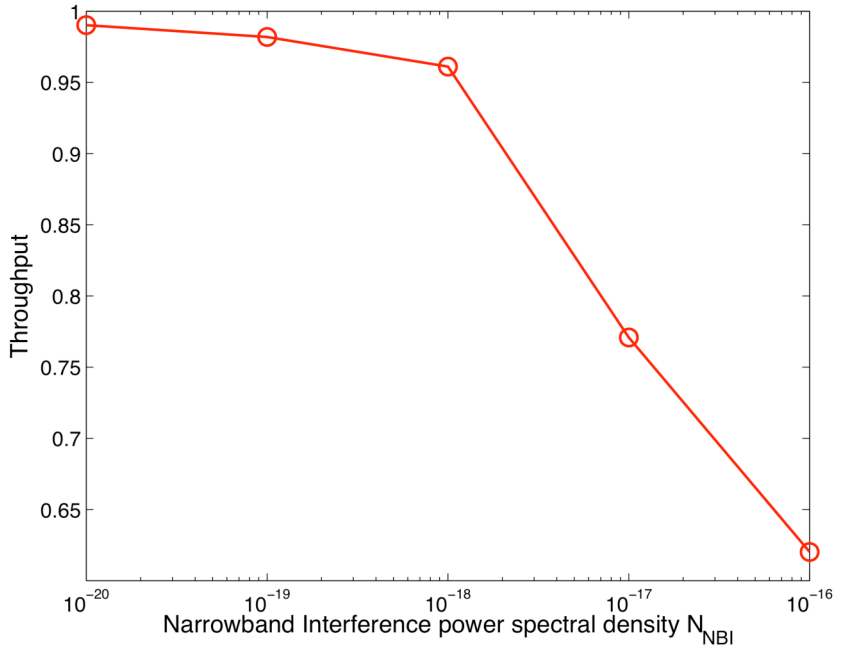
$$= 0.5 \cdot \left[e^{-\left(\frac{E_b + 0.5 \cdot \sum_{i=1}^{N_{int}} E_i}{hf} \right)} + \left(1 - e^{-\left(\frac{0.5 \cdot \sum_{i=1}^{N_{int}} E_i}{hf} \right)} \right) \right]$$

Simulation results



DWO throughput

UWB throughput



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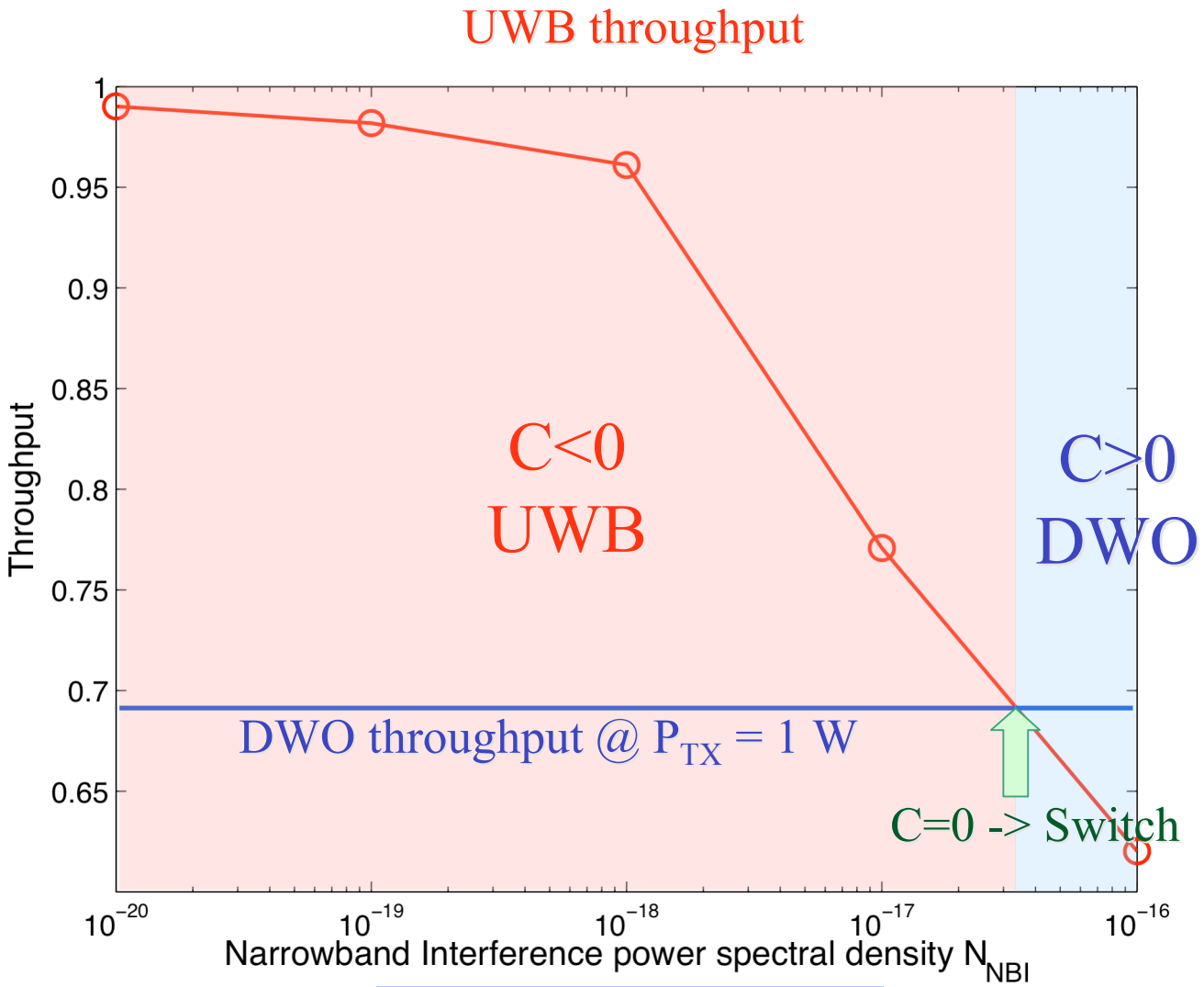

$$C_{DWO} = C_{UWB} = 1$$

Conclusions

- The combination of DWO and UWB provides a flexible solution
- The impulsive nature of both signals allows for a common MAC protocol
- A smart selection of the best PHY according to performance (BER measurement) leads to an efficient solution for addressing the issues presented by each PHY:
  - External RF interference and coexistence issues for UWB
  - Natural and artificial light for DWO