Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: [NICT's Wideband PHY Proposal Part 2: MB-IR-UWB]

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Abstract: [The presentation shows a NICT wideband PHY proposal based on MB-IR-UWB.]

Purpose: [Call for participation for a common wideband architecture for on-body BANs .]

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NICT's Wideband PHY Proposal
Part 2: MB-IR-UWB

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Motivation

IR-UWB provides advantages for BANs signaling

- Inherent low duty cycle (save battery energy)
  - *transmitter and receiver are on only when a pulse is present.*
- Inherent safety power levels exposure for human body
  - *power levels are in the order of those use for the MICS band (around -16 dBm)*
- Due to the low transmitting power and operation in the UWB band
  - *no interference to medical equipment*
- Coexistence with other wireless systems can be accomplished with DAA mechanisms combined with a multi-band approach

Motivation

BAN requirements like short range communications and data rate up to 10 Mbps

- Allows a feasible low cost, low power UWB radio implementation in the entire UWB band
  - ▷ *in contrast to other very high data rate solutions*
- Respect to the IEEE 802.15.4a standard
  - ▷ *the proposal is intended to operate with lower power consumption, higher data rate and simpler architecture*

Motivation

Call for participants to the present proposal

- We offer a generic design as much as possible and a example of design

The proposal is open for your participation in order to achieve a better solution

BAN Concept

Key requirements:

- long battery life, small form factor, short range communications:
  - *typically up to 1 m. from on-body devices to a coordinator*
  - *and up to 3 m. from coordinator (or special devices) to a gateway or base station.*
- So, BANs are highly power constrain systems

Power Consumption

Power levels set an upper limit on the number of computational operations and radio front-ends design.

Key design objective

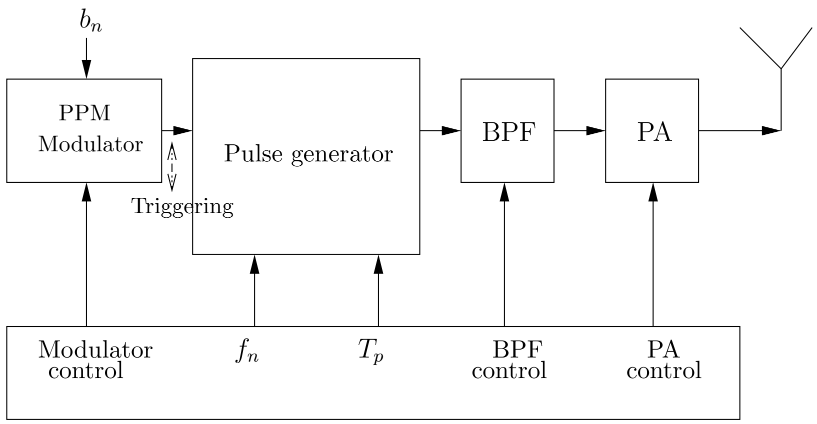
- Establishing a *reliable* communication link with the lowest power consumption as possible.
- Obviously, performance needs to be sacrificed for an architecture that allows to operate with very low power consumption.

Why UWB for BAN can be different

A key aspect of the proposal is to have analog front-ends (pulse generation and detection)

- It allows chip implementation for any point of UWB band
  - ▹ *analog technology is mature in the UWB band and it can be optimized to operate with low power consumption.*
- There are not circuits operating with high sampling rates
  - ▹ *weak point of most UWB solutions (implementation and power consumption)*
- In the proposal the fastest clock at receiver is 20 MHz
- As the maximum data rate is 10 Mbps and short range communications
  - ▹ *It is possible to compensate the penalty on performance degradation.*

UWB-BAN Transmitter



- **Information is modulated with on-off signaling (for instance 2PPM, 4PPM).**
- **The PPM modulator triggers a simple pulse generator with 500 MHz bandwidth.**
  - ▷ *it qualifies as a UWB signal, it is enough for transmission up to 10 Mbps, it allows an easy way of coexistence.*

UWB-BAN Transmitter

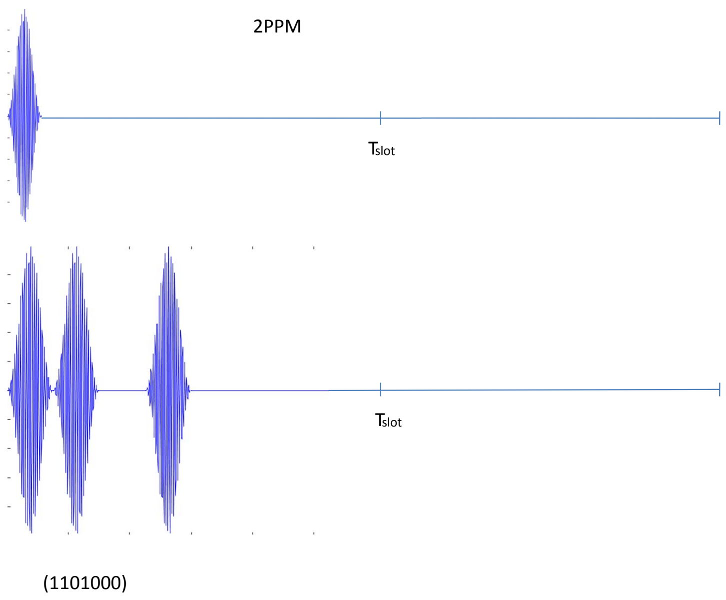
- As the signaling is on-off and the receiver is non-coherent (energy detection), the pulse shape is secondary.
- This relaxes the implementation of pulse generator (i.e. in the analog domain), so it can work in the entire UWB band with very low consumption power.
  - *Gated oscillator (oscillator modulated by a triangular waveform)*
  - *The central frequency can be changed easily*
  - *Triangular waveform (capacitor) duration (8 nsec) is set to achieve 500 MHz bandwidth*
  - *Fully implementable in a chip with very low power consumption*

UWB-BAN Transmitter

- **Example: a pulse with duration is $T_p = 8$ nsec (low duty cycle)**
- $R = 250$ **Kbps** - $T_{slot} = 2\mu$**sec**
- $R = 1$ **Mbps** - $T_{slot} = 0.5\mu$**sec**
- $R = 10$ **Mbps** - $T_{slot} = 50\mu$**sec**
- **The low duty cycle allows to introduce helpful extra characteristics:**

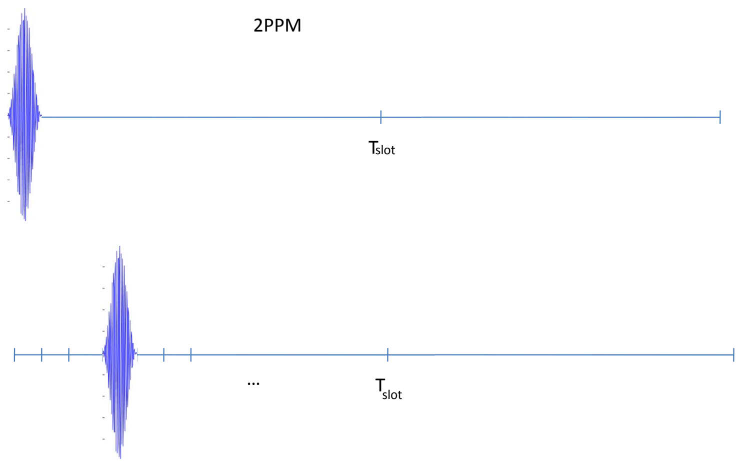
UWB-BAN Transmitter

- In order to relax the peak power limit due to a spectral mask, we introduce a short unipolar sequence of length 7 per transmitted pulse:
- $T_p' = 7 * T_p = 48$ nsec



UWB-BAN Transmitter

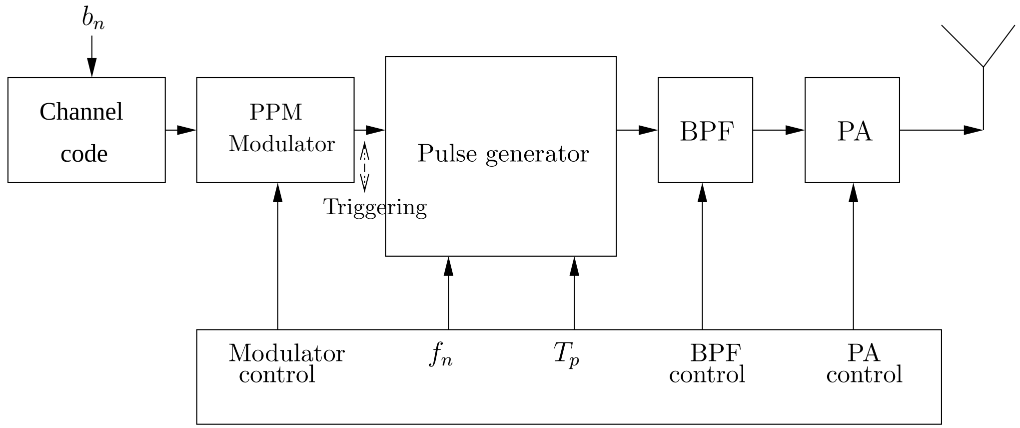
- Time hopping within T_{slot} (different TH sequence per BAN)



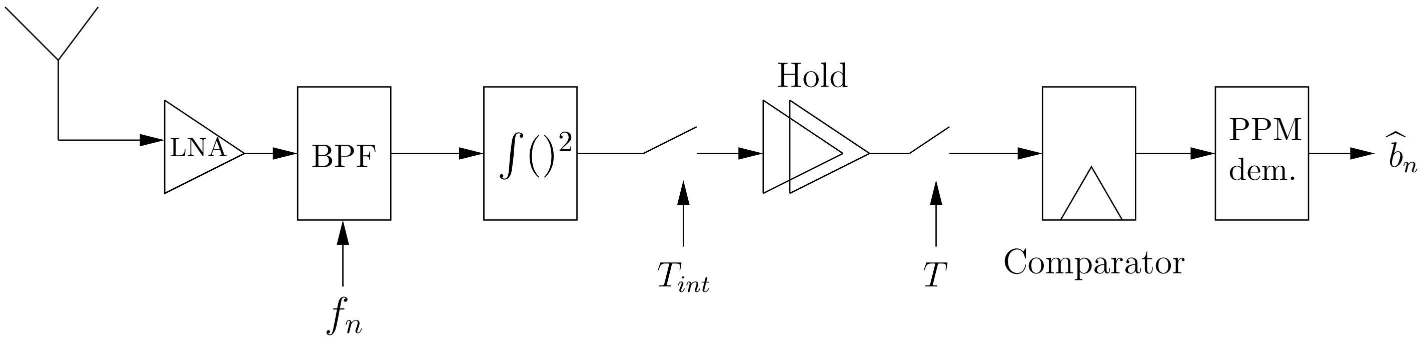
Time hopping for recognizing multiple BANs

UWB transmitter

Optional channel code

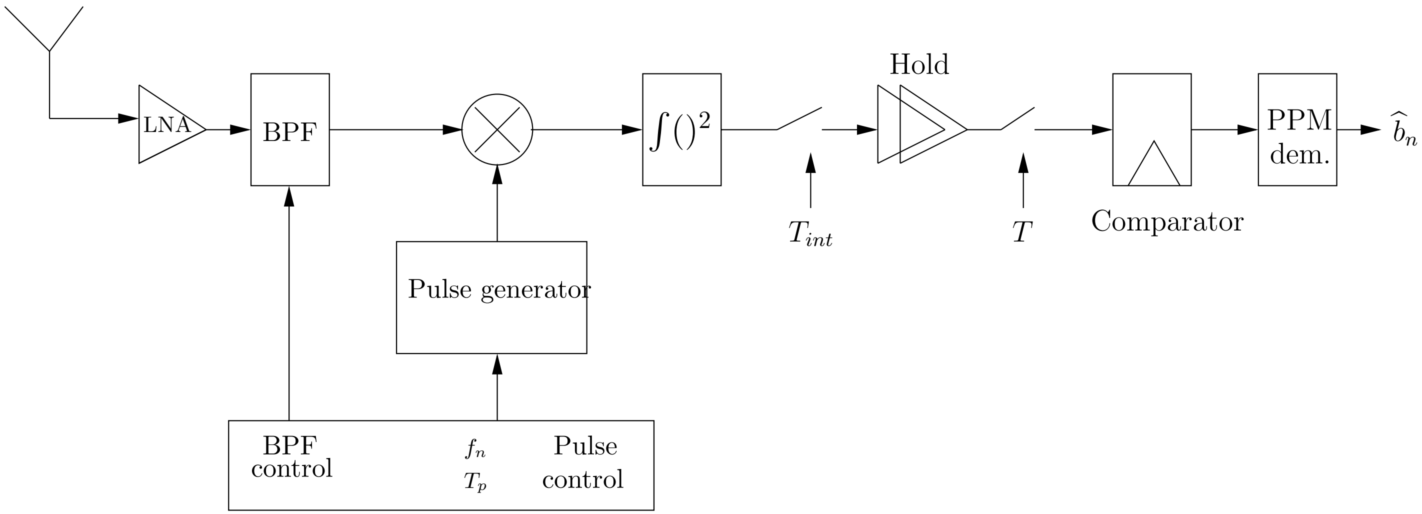


Receiver



- In order to save power consumption a non-coherent architecture is favored.
- Simple energy detection (no required PLL and ADC)
- front-end in the analog domain:
- integrator's output is sample and hold every slot time.
- After a symbol time, hold values are passed to a comparator for symbol/bit evaluation.

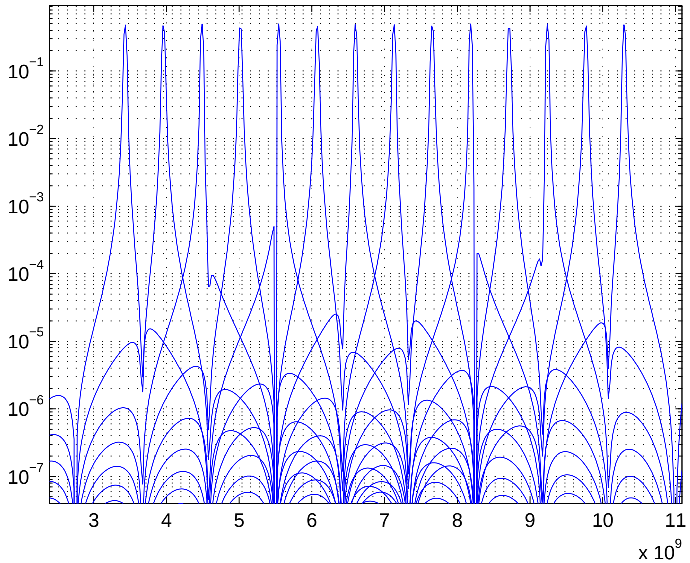
Receiver



- **Non-coherent energy detection (correlation with a locally generated pulse waveform).**
- **Still, no required PLL and ADC.**
- **Fastest clock:** $R = 10$ **Mbps -** $T_{slot} = 50$ **nsec and** $T_{int} = T_{slot}$
- **So** $f_{clk} = 1/50$ **nsec=**20 **MHz**

Multi-band Concept

- The pulse generator of 500 MHz can change the central frequency easily
- The UWB band is divided into sub-bands (for instance 15 sub-bands for IEEE802.15.4a)



Multi-band Concept

- Band frequency hopping is performed by special time frequency codes (code construction is not presented)
- Example of a codeword: [1 0 3 5 9 2 7 13 10 4 11 6 15 14 12 8] (look up table)
- A different codeword can be assigned to a different device (components are not repeated across codewords)
- frequency band = kMod15+1, for the kth codeword component
- The hopping can be done after at least a symbol time on in combination with a DAA protocol.

Multi-band Concept

- We present a general example, but do not intend to cover the entire UWB band necessarily.
- Some frequency bands can be deactivated if needed or change the time-frequency code
- The idea is to allow coexistence with other wireless systems and robustness against interference from/to other UWB systems.

Link Budget

- Simulation results are reflected in the link budget
- Modulation 4PPM over the 9th sub-band in CM4 (communication link of 3m) with non-coherent energy detection
- Data rates: 250 kbps, 1 Mbps, 10 Mbps.

Link Budget

Parameter	*Value*
Data rate (R)	250 Kbps
Average Tx power (P_{Tx})	-16 dBm
Tx antenna gain (G_t)	0 dBi
Rx antenna gain (G_r)	0 dBi
Required ($E_b/N0\|_{\text{req}}$) for BER=10^{-3}	8.2 dB
Rx noise figure (NF)	5 dB
Path loss (free space) at 3 m	59.66 dB
Implementation losses (L_o)	3 dB
Average power at receiver (P_{Rx})	-75.66 dBm
Average noise power per bit (P_N)	-115.02 dBm
Link Margin L_M	**28.15 dB**
Minimum Rx sensitivity S_r	**-103.82 dBm**

Link Budget

Parameter	*Value*
Data rate (R)	1 Mbps
Average Tx power (P_{Tx})	-16 dBm
Tx antenna gain (G_t)	0 dBi
Rx antenna gain (G_r)	0 dBi
Required ($E_b/N0\|_{\text{req}}$) for BER=10^{-3}	8.4 dB
Rx noise figure (NF)	5 dB
Path loss (free space) at 3 m	59.66 dB
Implementation losses (L_o)	3 dB
Average power at receiver (P_{Rx})	-75.66 dBm
Average noise power per bit (P_N)	-107 dBm
Link Margin L_M	**21.93 dB**
Minimum Rx sensitivity S_r	**-97.6 dBm**

Link Budget

Parameter	*Value*
Data rate (R)	10 Mbps
Average Tx power (P_{Tx})	-16 dBm
Tx antenna gain (G_t)	0 dBi
Rx antenna gain (G_r)	0 dBi
Required ($E_b/N0\|_{\text{req}}$) for BER=10^{-3}	8.8 dB
Rx noise figure (NF)	5 dB
Path loss (free space) at 3 m	59.66 dB
Implementation losses (L_o)	3 dB
Average power at receiver (P_{Rx})	-75.66 dBm
Average noise power per bit (P_N)	-97 dBm
Link Margin L_M	**11.53 dB**
Minimum Rx sensitivity S_r	**-87.2 dBm**

Conclusions

- A simple an robust UWB solution for BANs
- The analog front-ends do not require high sampling circuits
- So, this and the proposed design allows:
    - *low power consumption*
    - *low cost radios*
    - *implementation in any sub-band of the UWB band*
    - *coexistence with other wireless systems*
    - *safety power levels exposure to the human body*

Thank you for your attention.