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

Submission Title: Multi-Rate PHY Proposal for Europe - Presentation
Date Submitted: July 2009
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Re: TG4g Call for proposals
Abstract: PHY enhancements towards TG4g supporting multiple data rates
Purpose: PHY proposal for the TG4g PHY amendment
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Overview

This document guides through the proposal

15-09-0471-01-004g

PPDU

Octets: 8	1	2				4 ... 2047
Preamble	SFD	Data rate 2 bit	Frame length 11 bit	Reserved 2 bit	(Parity) 1 bit	PSDU (incl. FCS-32)
SHR		PHR				PHY payload

SHR and PHR: fixed rate of 25 kbit/s

PSDU: variable rates out of {25,50,100,200} kbit/s

Data Rate Modes

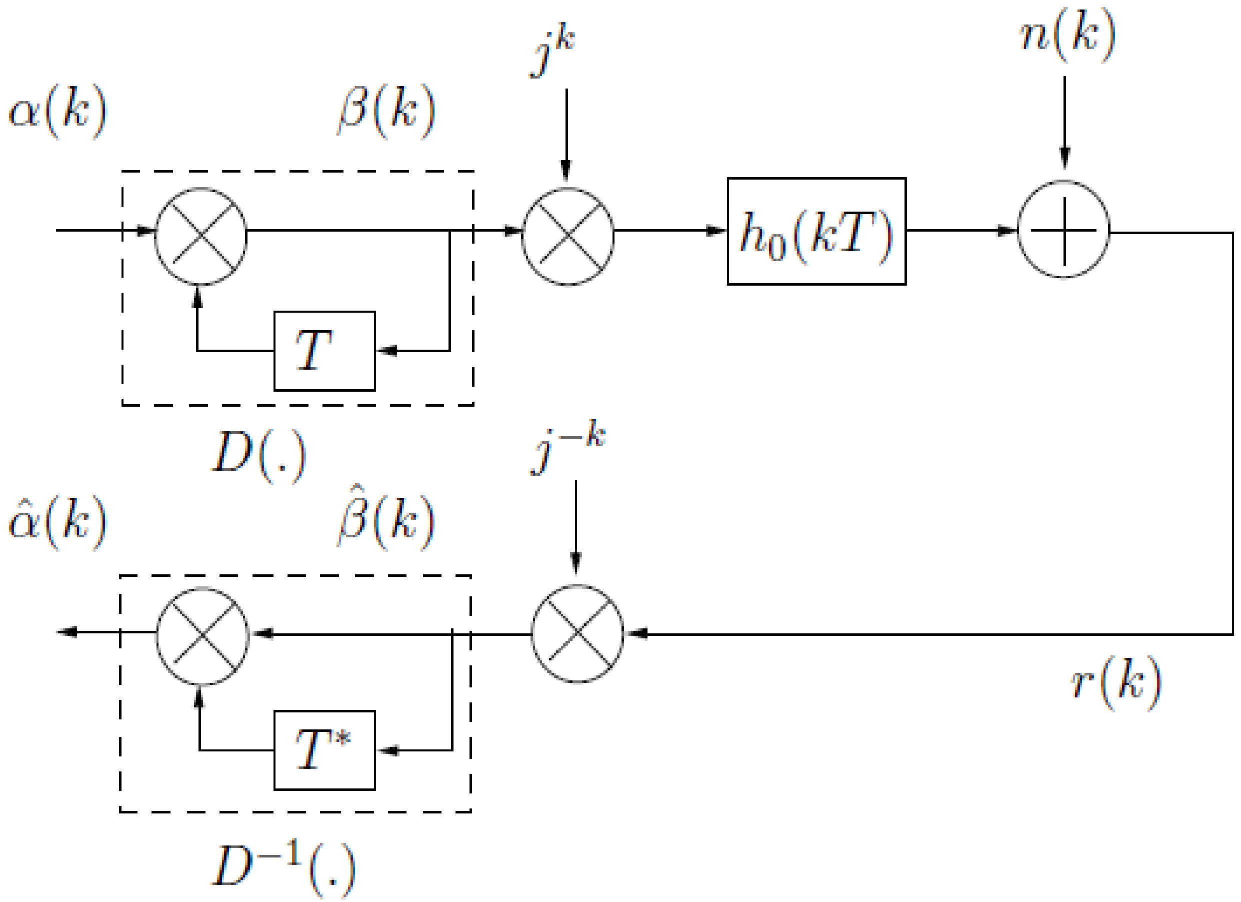
- Fixed chip rate of 200 kchip/s
- GMSK
- Different data rates are obtained by appropriate coding.

DataRateMode	Coding	PSDU Data rate [kbit/s]	Remark
1	C(32,4)	25	Mandatory Coherent, non-coherent
2	C(16,4)	50	Mandatory Coherent, non-coherent
3	C(8,4)	100	Optional, coherent
4	C(4,4) uncoded	200	Optional, coherent, (non-coherent)

Key Benefit

- Moderate RF bandwidth of 200 kHz with regard to the lowest data rate of 25 kbit/s
  - This considerably simplifies low-IF and zero-IF transceiver design w. r. t. an equivalent 25 kHz RF bandwidth of a narrow band approach.
  - Robustness against clock offset is +/- 20 ppm (+/- 40 ppm overall)

Laurent Approximation for GMSK



C(32,4) Coding

- Always used for SHR and PHR (assures reception under worst conditions).
- PSDU encoding for *DataRateMode* 1, leading to a data rate of 25 kbit/s.
- ML soft-decision decoding
- Code construction:
  - Balanced code with d_min = 14
  - Cyclic shift of a 1-extended {m=5}-sequence implying good auto-correlation properties
  - Reasonable spectral properties
- Optimal linear C(32,4) code: d_min = 16
- Coherent and non-coherent demodulation

C(16,4) Coding

- PSDU encoding for *DataRateMode* 2, leading to a data rate of 50 kbit/s.
- ML soft-decision decoding
- Code construction:
  - Balanced code with d_min = 6
  - Reasonable spectral properties
- Optimal linear C(32,4) code: d_min = 8
- Coherent and non-coherent demodulation

C(8,4) Coding

- PSDU encoding for *DataRateMode* 3, leading to a data rate of 100 kbit/s.
- GMSK pre-coding
- ML soft-decision decoding
- Code construction:
  - BCH (7,4) code extended by 1
  - Non-balanced code with d_min = 4
  - GMSK-like spectral properties due to pre-coding
- Optimal linear C(8,4) code: d_min = 4
- Coherent demodulation only

No Coding

- PSDU encoding for *DataRateMode* 4, leading to a data rate of 200 kbit/s.
- Flexible choice for additional outer coding
- Coherent demodulation recommended

Targeting Lower Data Rates?

- C(32,1)
  - Maximum receiver gain is only 3dB relative to C(32,4)
  - Influences SHR
- C(128,1)
  - Interesting option for EU band, since the output power is restricted to -4.5 dBm/ 100 kHz for some channels
  - Very low data rate of 1.562 kbit/s
  - Differential pre-coding at the chip and at the bit level
  - Requires a dedicated SHR.

Coherent Demodulation

- Phase Tracking based on decoded symbols
- Residual phase error

$$\delta\phi = N_R \cdot 2\pi \cdot \frac{f_c}{f_{chip}} \cdot \delta p$$

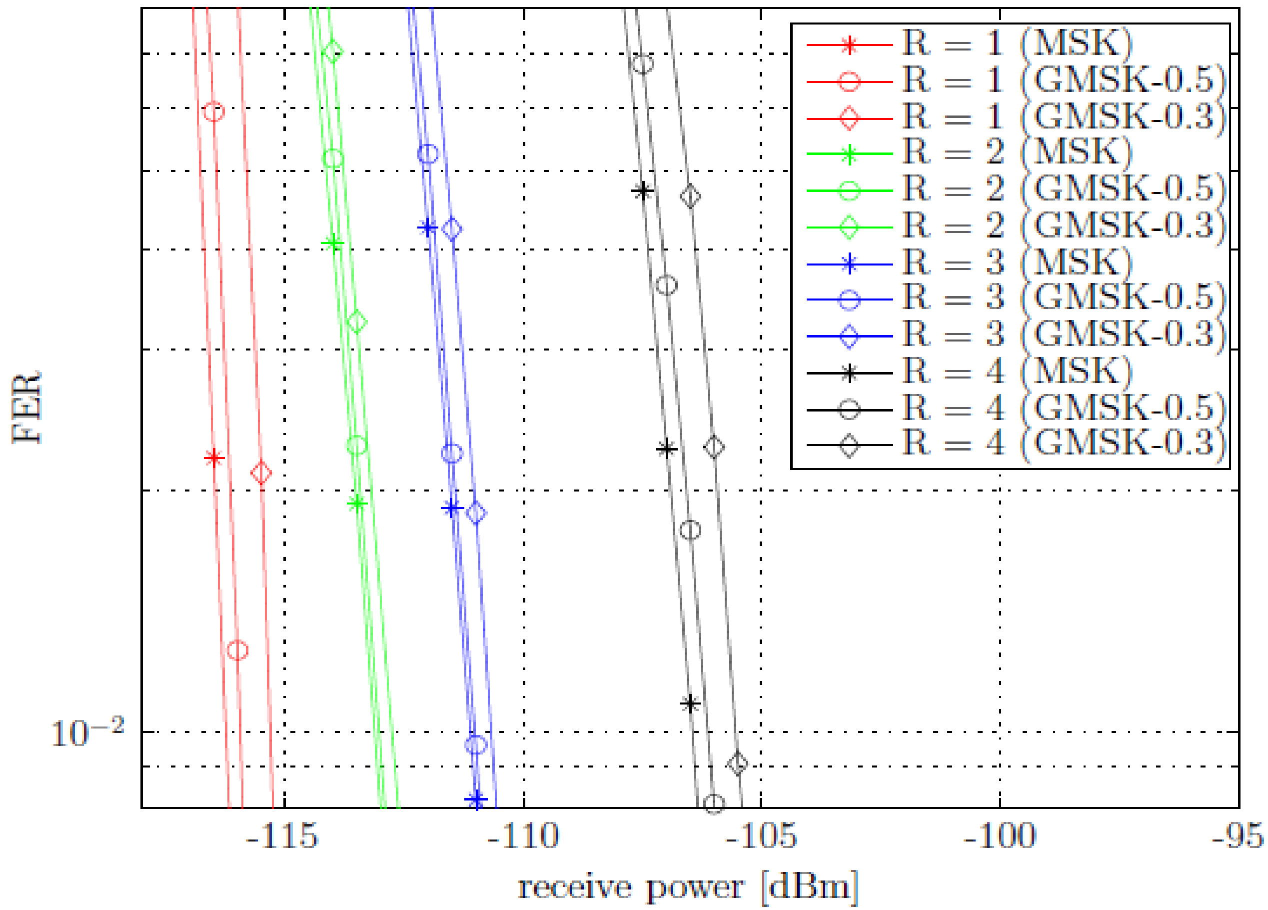
GMSK

- Modulation index h = ½ allows simple coherent detection, based on Laurent approximation.
- Unlike BPSK, problems related to I/Q images are relaxed.
- The influence of BT in {0.3,0.5} is relatively low for coded transmission (coherent and non-coherent).
- For uncoded GMSK, coherent demodulation is recommended
  - better performance
  - simpler to equalize

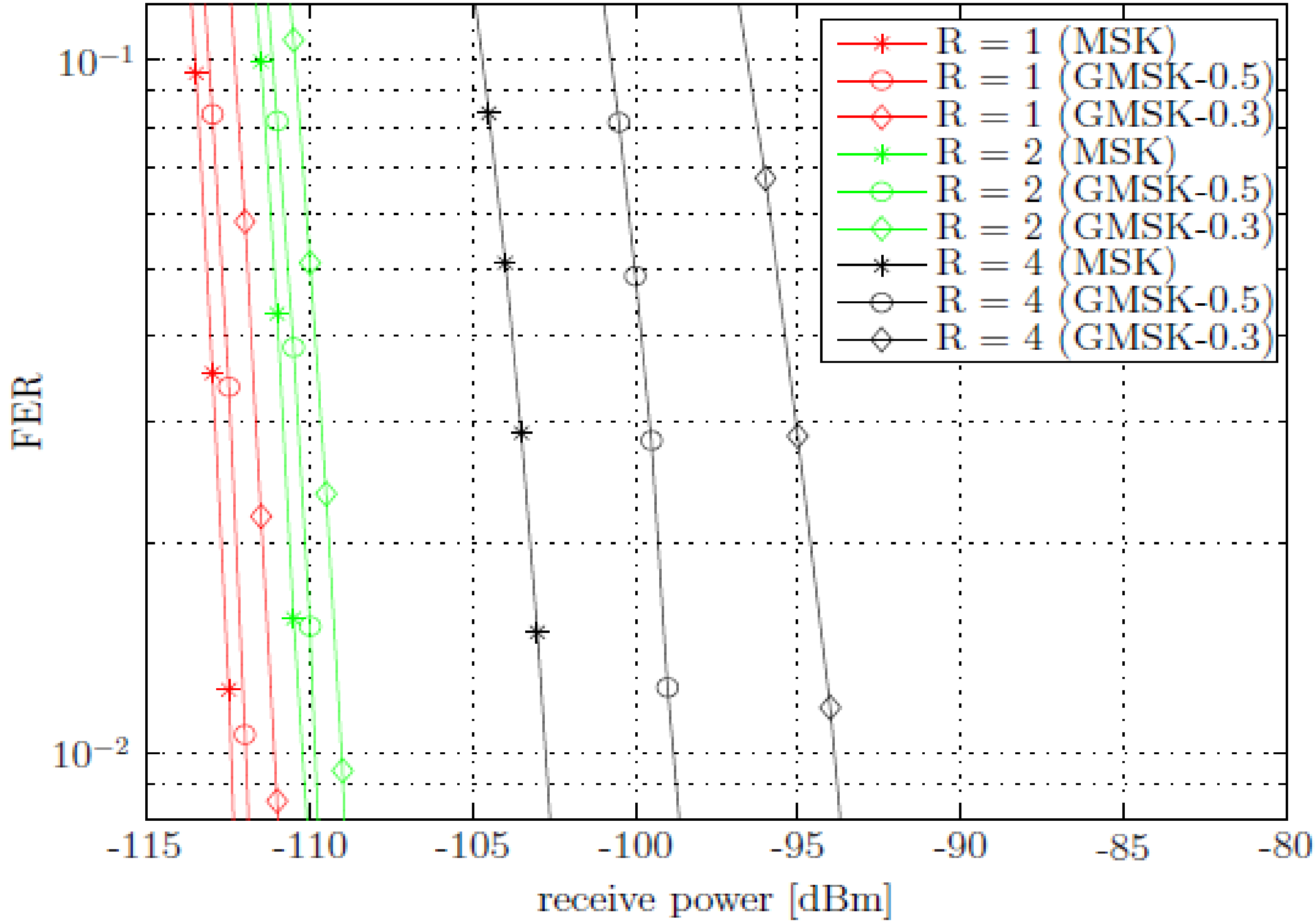
Simulation Model

- Low-IF receiver with 200 kHz IF
- 4-th order Butterworth filter of 200 kHz BW centered at IF (moderate pole-Q)
- I/Q limiter with 8 MHz oversampling + discrete-time post filtering
- LNA noise: -174 dBm/Hz + 5 dB noise figure
- I/Q mismatch: -45 dB image
- DC suppression: 50 kHz
- Clock offset tolerance: +/- 20 ppm
- Synchronisation: initial timing offset and clock offset
- Coherent detection: first-order phase decision feedback control loop
- Non-coherent detection: chip differential
- Equalization: none

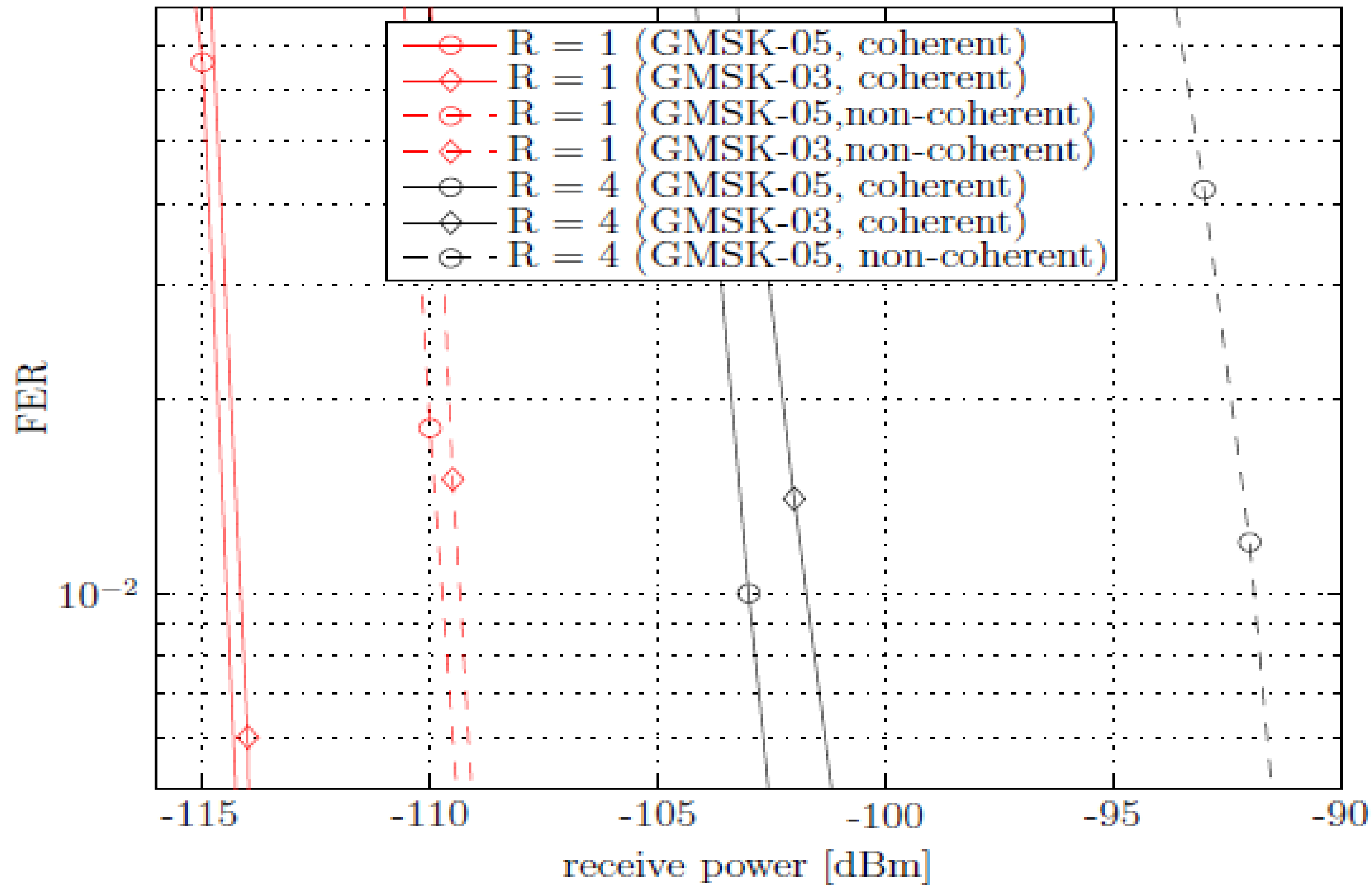
Coherent, 20 octets



Non-coherent, 20 octets



2047 octets, 40 ppm clock offset



Channel Assignment

- 12 channels within 863-870 MHz (band G)
- Avoid RFID interrogators
- Avoid alarm channels
- Use sub-bands G1 and G2

channel number	1	2	3	4	5	6
f_c [MHz]	863.4	863.8	864.2	864.6	865	865.4
channel number	7	8	9	10	11	12
f_c [MHz]	866	866.6	867.2	867.8	868.3	868.95

Outer FEC

Additional more complex outer forward error-correcting coding is useful, especially for the high rate mode when considering large PSDU lengths. The sensitivity gap to the low rate encoded header can be exploited.

- Algebraic codes (e.g. BCH codes)
  - Pragmatic approach, since it can be shifted to the upper layers.
  - However, soft decision gain is lost. Bounded Minimum Distance Decoding is not simple. So, why shifting it to other layers?

Outer FEC

- Convolutional codes
  - Since decoding usually applies soft decisions, the recursive encoder of the GMSK modulator should be taken into consideration. Interleaving may be useful too.
- LDPC codes
  - State of the art
  - Iterative decoding might be affordable due to the low data rate.

Extension to 902-928 MHz

- This PHY is mostly applicable if FH is desired anyway.
- Channel spacing could be changed to 400 kHz.
- BT = 0.5 only

Extension to 870-873 MHz

- There are rumors on the availability of this frequency band.
- This PHY might be directly applicable.

Possible Extension to 902-928 / 2400-2483.5 MHz

Targeting *digital modulation* according to FCC part 15.247

(This allows high transmit power without FH.)

Chip rate [kchip/s]:	1000 kchip/s
Modulation:	GMSK
Coding:	C(128,1), C(64,4), C(16,4), C(8,4)
PSDU data rates in [kbit/s]:	7.8125, 62.5, 250, 500
Channel spacing:	2000 kHz