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

Submission Title: [IMEC PHY Proposal]
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Source: Guido Dolmans[1], Peng Zhang[2], Li Huang[1], F. Willems[2];
[1]Holst Centre / Imec-NL, [2]TU/e Eindhoven University of Technology
High Tech Campus 31, P.O. Box 8550, 5605 KN Eindhoven, the Netherlands
Phone: +31404020436, Fax: +31404020699
E-Mail: guido.dolmans@imec-nl.nl

Abstract: [This presentation is IMEC’s proposal for IEEE 802.15.4q. It focuses on the PHY proposal.]

Purpose: [For discussion by the group in order to provide applications scenarios, develop channel models and discuss radio architectures for IEEE P802.15.4q]

802.15.4q PAR – 1/3

- **Scope of the complete standard:** This standard defines the physical layer (PHY) and medium access control (MAC)sublayer specifications for low-data-rate wireless connectivity with fixed, portable, and moving devices with **no battery or very limited battery consumption** requirements typically operating in the personal operating space (POS) of 10 m.

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802.15.4q PAR – 2/3

- Physical layers (PHYs) are defined for devices operating in the license-free 868-868.6 MHz, 902-928 MHz, and 2400-2483.5 MHz bands
- Devices operating according the Chinese regulations, Radio Management of P. R. of China doc. #6326360786867187500 or current document, for one or more of the 314-316 MHz, 430-434 MHz, and 779-787 MHz frequency bands
- Devices operating in the 950-956 MHz allocation in Japan and coexisting with passive tag systems in the band

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802.15.4q PAR – 3/3

This amendment defines an ultra low power (ULP) physical layer operating in sub 1 GHz and 2.4GHz license exempt bands supporting typical data rates **up to 1 Mbps**. This amendment also defines the necessary MAC changes required for supporting the new ULP physical layer. The desired peak power consumption for the PHY should be **typically less than 15 mW.**

Imec IEEE 802.15.4q PHY proposal

- PHY Proposal Mode A: Constant Envelope (minor modification of IEEE 802.15.4-2011 baseline)
- PHY Proposal Mode B: Non-Constant Envelope (major modification of IEEE 802.15.4-2011 baseline)

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PHY Mode A and Mode B Proposal

- Mode A: **Constant envelope** modulation: similar to baseline 802.15.4 OQPSK (2.4 GHz), BPSK and GFSK (sub-GHz)
- Mode B: **Non-constant envelope** modulation: k-bits pulse position modulation (2^k-PPM) with k=1..6. For k=1, PPM has the same duty cycle as 50% OOK.

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Proposal Mode A: keep 3 PHYs of 802.15.4-2011

- **O-QPSK PHY**: direct sequence spread spectrum (DSSS) PHY employing offset quadrature phase-shift keying (O-QPSK) modulation, operating in the 780 MHz bands, 868 MHz, 915 MHz, and 2450 MHz, as defined in Clause 10.
- **BPSK PHY**: DSSS PHY employing binary phase-shift keying (BPSK) modulation, operating in the 868 MHz, 915 MHz, and 950 MHz bands, as defined in Clause 11.
- **GFSK PHY**: Gaussian frequency-shift keying (GFSK), operating in the 950 MHz band, as defined in Clause 15.

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Proposal mode A: change the DSSS spreading in 15.4q

- **Now in 802.15.4-2011:**
  - 10.2: The O-QPSK PHY employs a 16-ary quasi-orthogonal modulation technique. During each data symbol period, four information bits are used to select 1 of 16 nearly orthogonal pseudo-random noise (PN).
- **Imec proposal:**
  - vary the bit rate by variable spreading instead of fixed spreading factor of 8: 250kbps / 2MHz in 2.4 GHz band of 802.15.4 (spreading 8). Proposal is to have spreading factors 1, 2, 4, 8,16, 32. This will result in bit rates of 2, 1, 0.25, 0.125, 0.0625 Mbps.

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Advantage of variable spreading

- **Variable sensitivity (range) can be traded against variable bit rate**
  - more spreading → lower bit rate → increased range
- **Larger spreading sequences increases the robustness**
  - Similar effect as adding error correction/coding

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Why constant-envelope PHY consumes less power

- Thanks to the constant-envelope nature of FSK/PSK-type modulations (e.g., GFSK, MSK, HS-OQPSK):
  - only modulate data on the carrier frequency or phase, so the transceiver hardware can be simplified.
  - Tx: efficiency can be enhanced by driving the circuits into a saturated mode. IF/RF analog signal can be created by ULP digital-to-phase converters instead of DAC.
  - Rx: instead of processing the signal in the complex I/Q domain, it can be demodulated in the frequency/phase domain. ULP phase-to-digital converter instead of ADC.

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Mode B: Non-constant envelope PPM proposal as ULP modulation scheme

- Non-constant ULP simple modulation schemes: examples are OOK, ASK, PPM.
- PPM detection schemes compares the energy in different positions and choose the symbol that corresponds to the peak energy.
- Advantage of PPM over OOK is avoiding a detector threshold. Implementation loss due to incorrect setting of threshold is a disadvantage of OOK.
- Another advantage of PPM is that for the same data rate, compared to OOK with direct-sequence spread spectrum (DSSS) , PPM requires no more number of pulses for transmission.
  - For the same transmission power, more energy could be allocated to one pulse in PPM and results in better receiver symbol error performance.

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Mode B: Non-constant envelope PPM proposal as ULP modulation scheme

- *Pulse-position modulation* (PPM):k message bits encoded into one of 2^k possible positions.
- *Proposal Mode B:* Bandwidth 2 MHz, Variable 2^k-PPM into 2^k positions with k=1,2,3,4,5,6,7,8. For k=8, bit rate is 62.5 kbps (same bit rate as spreading factor of 32 in mode A).

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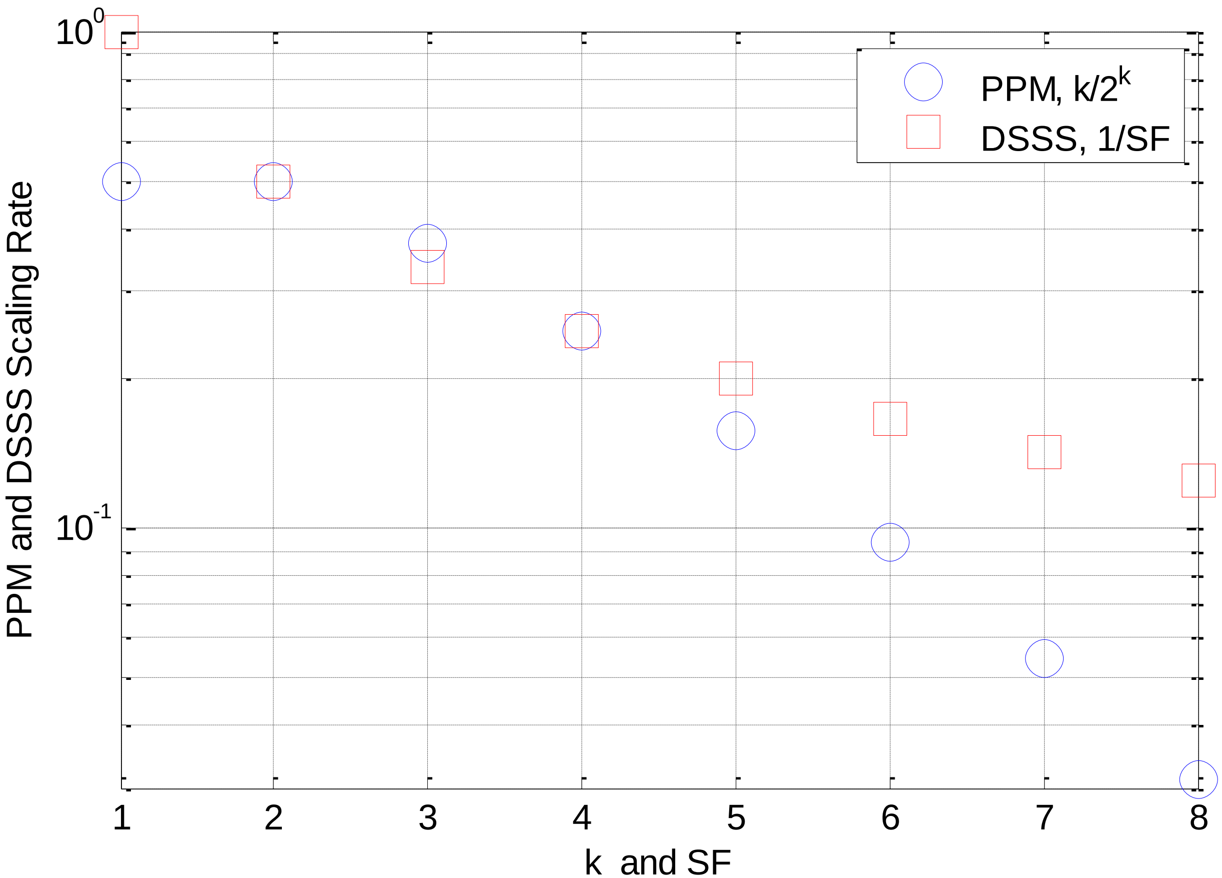
PPM and DSSS Scaling Data Rate Comparison

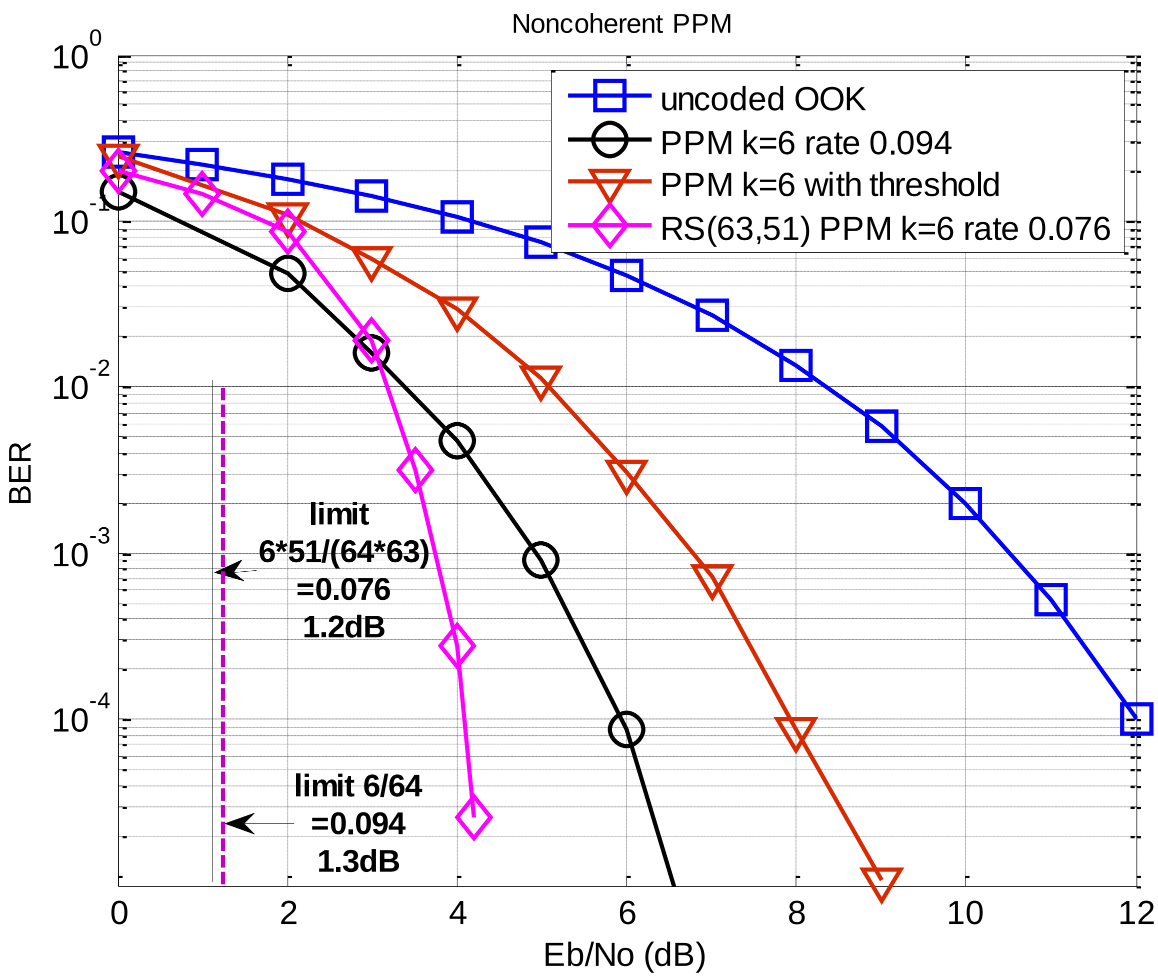


k: information bits number conveyed by 2^k-position PPM, from 1 to 8
SF: Spreading Factor= 1, 2, 3… 8.
For example: k=4 PPM results rate 1/4, which is equivalent to SF=4.

Date rate scaling by using different (2^k)- position PPM patterns.
For, x-PPM, assume k information bits is conveyed. So x=2^k, and 2^k positions are used for one PPM symbol. Then, the code rate can be expressed as r= k/2^k.

Eample:.
For example, if k=4, we have 16-position PPM and rate is 4/16=1/4. It is equivalent to using Spreading factor (SF) k equals to 4, which scales the data rate to 1/4 of the symbol rate (k in here is SF).

BER analysis



RS coded PPM has better performance than uncoded PPM in AWGN channel. RS(63,51) with PPM k=6 has a performance close to the Shannon limit

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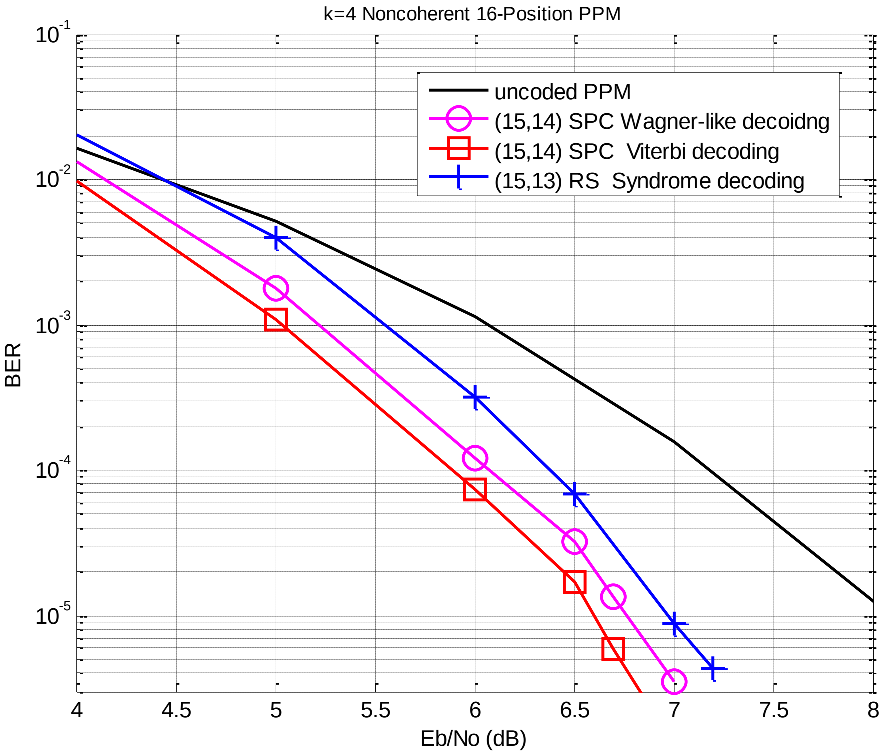
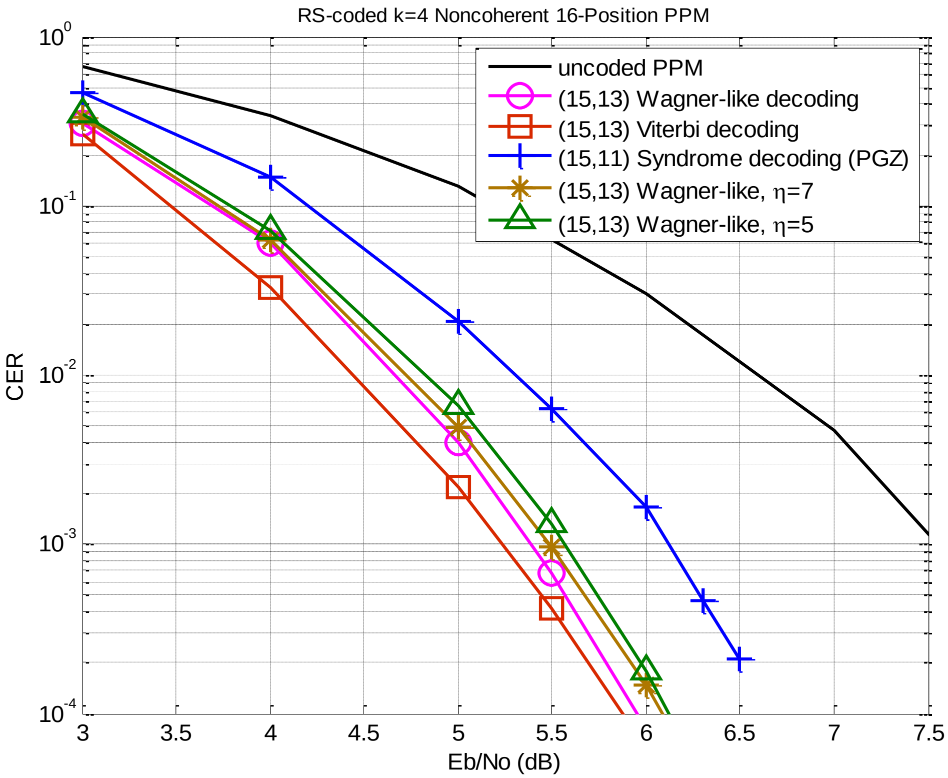
SPC-coded and RS-Coded PPM with Wagner-like Decoding





- Single-Parity-Check (SPC) coded PPM and high-rate RS-Coded PPM
- Non-coherent detection (no phase estimation is required thus low power)
- A new decoding algorithm, Wagner-like decoding (modified one specified by η), can be applied to achieve good balance between performance (BER, CER (codeword error rate)) and decoding complexity
- Wagner-like decoding approach to the ML-decoding (optimal)

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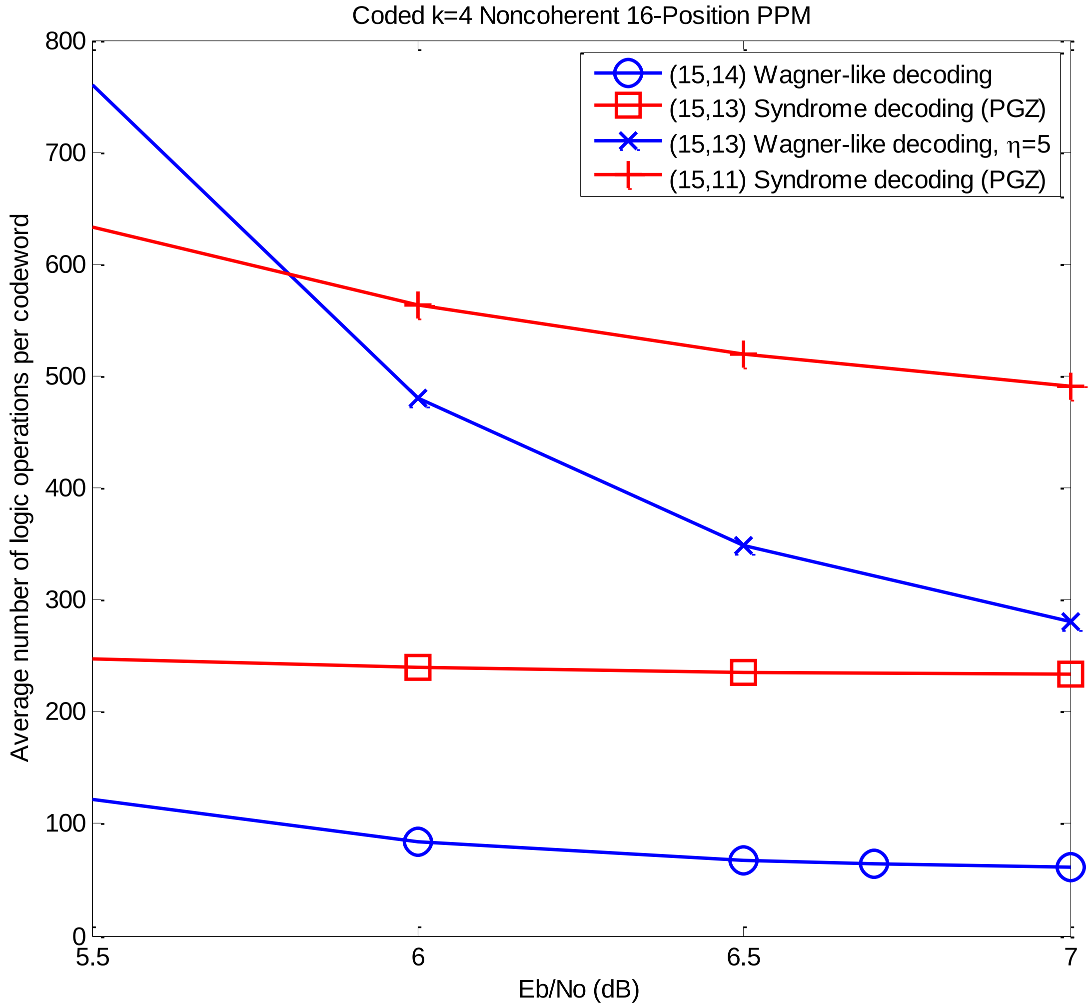
Wagner-like Decoding (WLD) Complexity



- Decoding complexity represented by logic operations (AND and XOR) required per one codeword
- (15,14) curve is SPC, other curves are RS
- For the SPC-coded PPM, WLD decoding complexity is much lower than the comparable RS-coded PPM
- For RS-coded PPM, WLD decoding has a much lower complexity for a reasonable receive SNR

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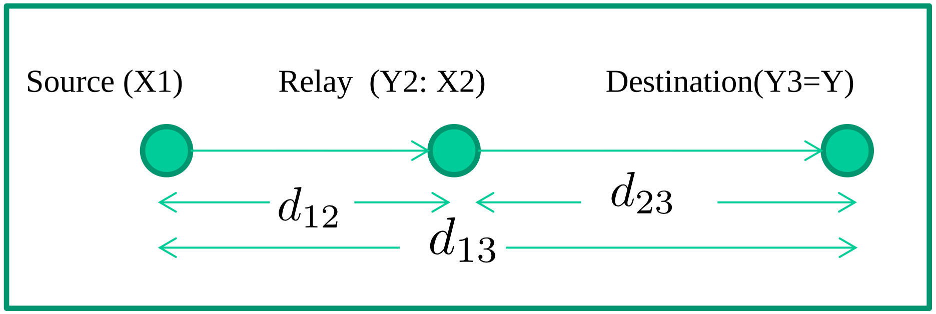
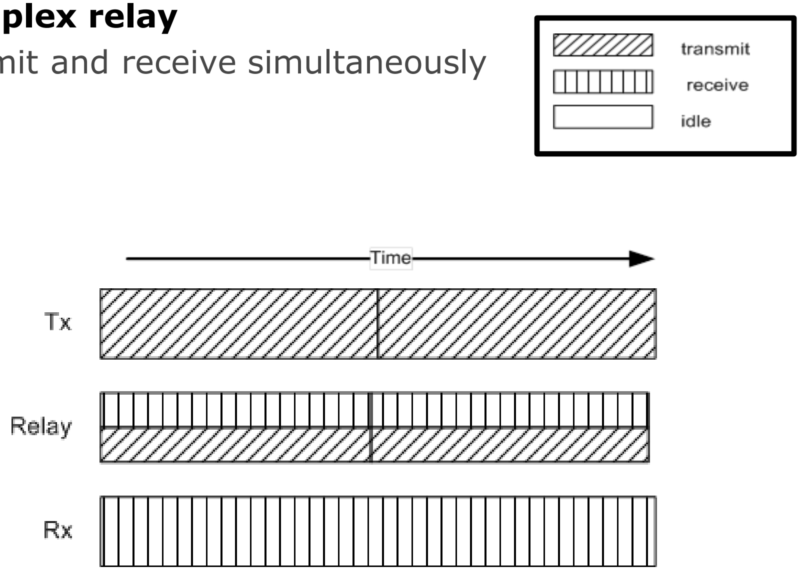
Single hop capabilities of PPM: Capacity Study of Relay Communication

- **Capacity study of relay scenarios**
  - Gaussian relay channel and PPM modulations are considered
  - Decode-and-forward strategy at relay is considered
- **Status**
  - Best scenario for best performance is a full duplex relay; as "coding strategy at the source does not need to be changed" because the source can be informed so that the output power at the source can be updated to optimize the overall output power



Scenario, full duplex relay

Relay transmit and receive simultaneously



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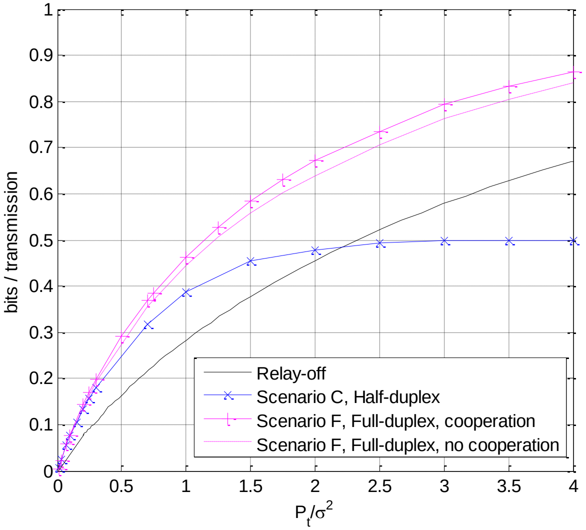
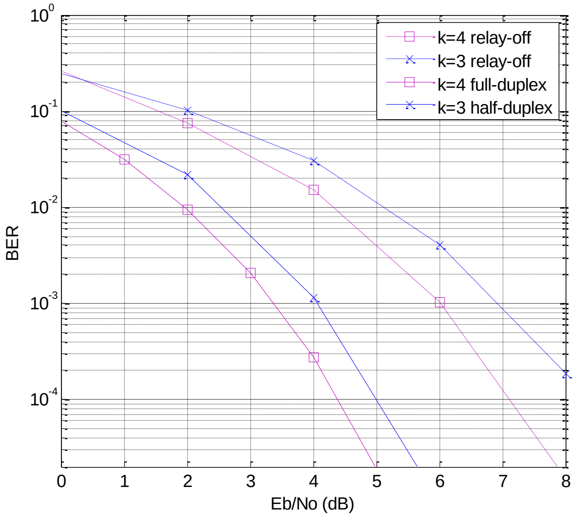
Capacity Study of Relay Communication

- **Objective**
  - Investigate capacity behavior of a relay channel based on PMM with half-duplex or full-duplex relay node.
- **Achievable-rate study in non-coherent channel**
  - Full-duplex schemes achieve higher rates which result in better energy efficiency.
  - Full-duplex scheme with cooperation is superior to the one without cooperation.
- **BER evaluation based on PPM**
  - Focusing on a BER level of 10^{-4}, about 3 to 4 dB can be saved by using duplex schemes.
  - About extra 0.7dB can be gained by using the cooperative full-duplex scheme.





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Conclusion

- PHY mode A: Minor modification to IEEE 802.15.4-2011 by keeping HS-OQPSK, BPSK, GFSK (constant envelope).
- PHY mode B: Major modification to IEEE 802.15.4-2011 by using pulse position modulation PPM (non-constant envelope). Easy relay support. Low-complexity error coding with good performance for PPM modulated signals.
- Both proposals have ULP advantages.

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