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

Submission Title: Non-coherent HRP Option for data communication
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Re: Input to the TG 4ab- May 2022 interim meeting

Abstract: PHY proposal to support low power operation for data communication applications

Purpose: Create data communication-optimized packets that can complement current ranging-focused packets

PAR Objectives Table

PAR Objective	Proposed Solution (how addressed)
Safeguards so that the high throughput data use cases will not cause significant disruption to low duty-cycle ranging use cases	Shorter preamble lengths for data centric packets reduces time-on-air and potential impact on other devices.
Interference mitigation techniques to support higher density and higher traffic use cases	
Other coexistence improvement	
Backward compatibility with enhanced ranging capable devices (ERDEVs)	Additional mode. Coexistence with legacy devices considered.
Improved link budget and/or reduced air-time	Reduced air-time
Additional channels and operating frequencies	
Improvements to accuracy / precision / reliability and interoperability for high-integrity ranging	
Reduced complexity and power consumption	Reduced complexity and power consumption via non-coherent reception
Hybrid operation with narrowband signaling to assist UWB	
Enhanced native discovery and connection setup mechanisms	
Sensing capabilities to support presence detection and environment mapping	
Low-power low-latency streaming	Enhances support for low power audio/data streaming.
Higher data-rate streaming allowing at least 50 Mbit/s of throughput	Higher data rate without increased complexity proposed.
Support for peer-to-peer, peer-to-multi-peer, and station-to-infrastructure protocols	Compatible with all these topologies.
Infrastructure synchronization mechanisms	

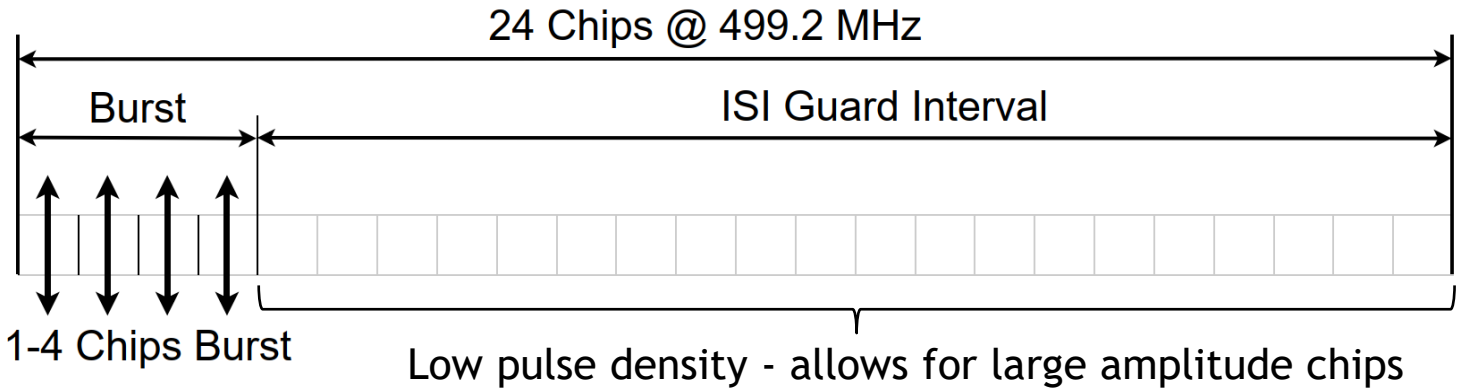
Non-Coherent Option for Data Comms

Overview

- If secure ranging is not required, non-coherent reception can be supported
- We propose an optional preamble sequence and pulse spreading ratio aimed at non-coherent data comms
  - Shorten SYNC duration to ~6 μs
  - Ensure orthogonality with secure ranging applications
  - Potential to increase energy per pulse as less energy used in SYNC field
- OOK and PPM modulations supported
- Use existing convolutional code, but use puncturing to get more effective data rate
- Power efficient, and reasonable link budgets

Simplified Symbol Structure (1)

- Minimal changes compared to current HPRF symbol to enable lower power operation
- Same symbol and rate throughout SYNC, SFD and Payload, simplifies reception processing
- Propose 20.8 MHz symbol rate, 24 chips long (leverage same peak PRF as HRP):



Simplified Symbol Structure (2)

- Proposal: up to 4 active chips in 24 chips symbol in order to minimize overlap to favor coexistence
- Possibility of 1,2, or 4 chips per burst (N_{chip}), trade off between ISI, PA peak power, and sensitivity
  - Mean PRF of 20.8, 41.6, and 83.2 MHz respectively
- Symbol duration of 3*8 chips means that there won't be any constant alignment with BPRF/HPRF symbols that have even multiples of 8 chips as lengths
- HPRF 249.6 MHz has active burst length 4 but would align for at most 1 burst in the transmission due to different symbol length

SYNC Proposal for Non-ranging data comms (2)

- Proposed preamble code: repetitions of …1/0/1/0… to
  - Active symbols separated by a guard symbols allows for OOK detection
  - Advantage that synchronisation can start every other bit
- Phase of active pulses can be freely chosen to accomplish different purposes:
  - Scrambled to whiten spectrum
  - Phase sequence to increase orthogonality with existing HRP modes
  - Include a short code (length 31 maybe) to estimate CIR for a coherent receiver
  - Invert or not invert the phase of each pulse;

    * A noncoherent detector will not know the difference, but a coherent detector can decode the phase as a binary sequence

SYNC Proposal for Non-ranging data comms (2)

- Without ranging, preambles can be shorter
  - Existing preamble sequence chosen to support channel estimation
  - Currently, minimum 16 symbols of roughly 1 μs implies SYNC length **of ~16 μs**,
  - In practice more symbols are needed to reach full RX sensitivity
  - Proposal: minimum of 16*8=128 symbols to settle AGC and do timing synchronization: 16*8/20.8 MHz = **6.1 μs**

SFD (Start of Frame Delimiter)

- Proposal:16 or 32 bits sequence.
- Can use a list of orthogonal sequences for added network separation opportunity.
- Slight change to 4a options.

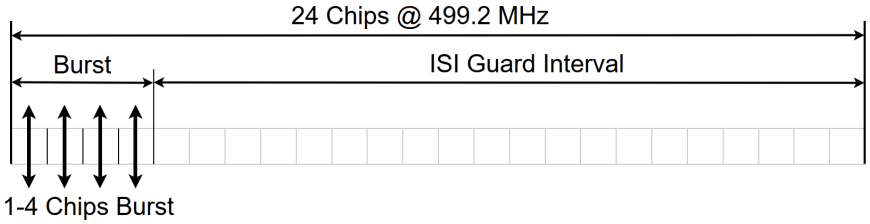
PHY header (PHR) / Payload Modulation

- Same 20.8 Mbps from preamble and SFD / SHR:
  - Constant rate throughout frame simplifies design
  - Benefits to ISI and frame pulse density

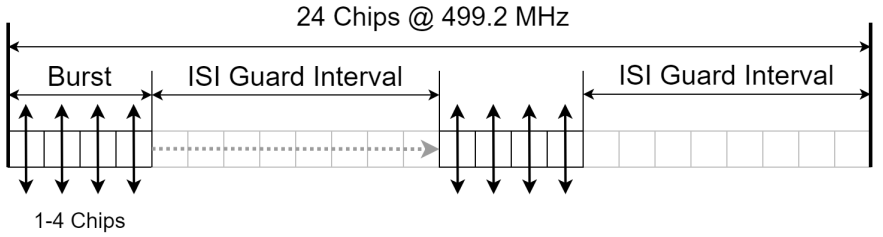
- Scramble phase with LFSR to improve spectral whitening
  - Use existing LFSR in 15.3.2, initialised with preamble sequence 1/0/1/0/... Different than existing initialisation sequences.
  - Coherent transceivers could encode an extra bit/symbol, as in 4a FEC

Payload Modulation Options

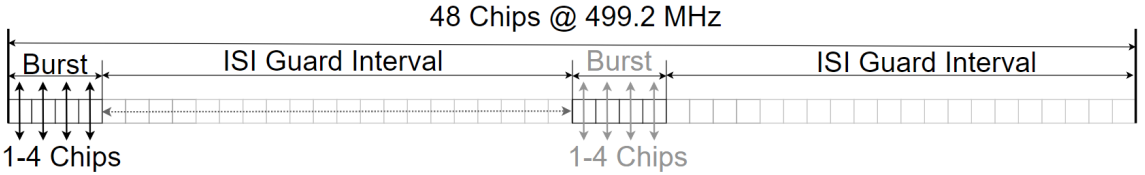
- 20.8 Mbps OOK, minimum of 20 ISI guard chips
  - Can reduce the TX power compared with BPM due to reduced PA activity
  - Slightly worst SNR compared with BPM



- 20.8 Mbps with Binary Position Modulation (BPM), minimum of 8 ISI guard chips
  - Better SNR at a cost of always transmitting maximum amount of pulses (energy)



- 10.4 Mbps Manchester OOK, minimum of 20 ISI guard chips, but same sensitivity as BPM
  - 50% pulse density but double the airtime
  - Best link budget



* Two symbol pairs possibilities - 01 or 10

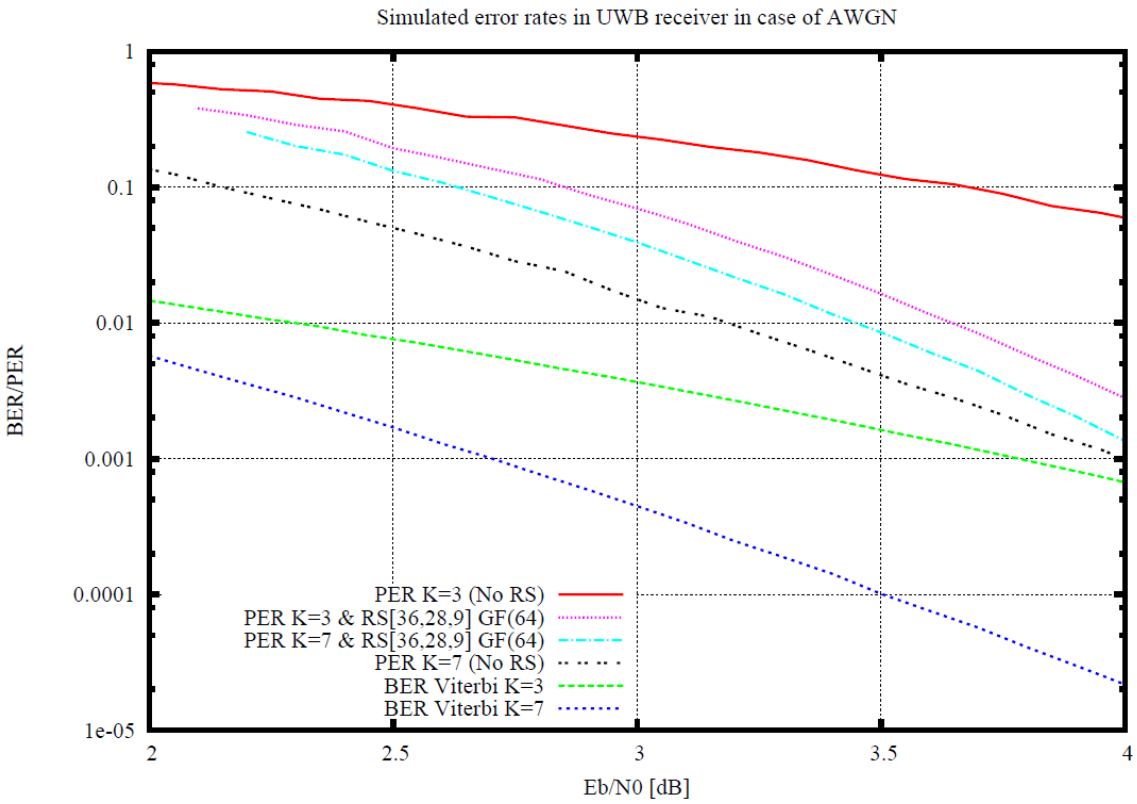
PHR Structure

Proposal

- Always modulated in Manchester OOK to enhance robustness.
- Keep current 19-bit PHR structure:
  - Bits 0-1: number of pulses per symbol. Can provide opportunity to improve payload reception.
  - Bits 2-3: payload modulation format.
  - Bits 4-12: payload length (512 bytes max payload)
  - bits 13-18: 6-bit SECDED code.
- Variant proposal could be to purpose Bits 0-1 for payload modulation format and not include pulse per symbol information.
  - Provides two more bits for payload length.

Coding (1)

- Base rate of 20.8 Mbps with a k=7 CC without RS as defined per HPRF
- Provide puncturing options
  - e.g., puncturing rates of 1.33, 1.5, or 1.66
- LDPC proposed in "15-21-0506-02-04ab-advanced-coding for data comm" could also be used. Studies of LDPC in non-coherent UWB exist (e.g. [1])



* BER curves for combinations of K=3, K=7 and RS; Frank Leong (NXP Semiconductors) et al., doc.: 15-18-0335-00-004z (mentor)

[1] Z. Liang, J. Zang, X. Yang, X. Dong and H. Song, "Low-density parity-check codes for noncoherent UWB communication systems," in *China Communications*, vol. 14, no. 7, pp. 1-11, July 2017, doi: 10.1109/CC.2017.8010966.

Link Budget*

E_b/N_0	9	9
NF	4	4
N_{chip}	1	2
RX sensitivity (dBm/Hz)	-161	-159.5

Bandwidth (MHz)	500	500
Spectral density limit (dBm/MHz)	-41.3	-41.3
Datarate (MBps)	**20.8**	**2.08**
TX Bit Energy (dBm/Hz)	-87.491	-77.49
N_{chip}	1	1
Link Budget (dB)	73.509	83.509

Notes:

- 1 chip per symbol: No penalty but requires high peak PA power (implementation choice).
- 2 chips: 1.5 dB penalty
- TX Gating gain increases link budget for duty cycled lower data rate, for example ~84 dB @ 2 Mbps, etc
- In line with other contributions on Link budget **

*For more detail, check the contribution 15-21-0585-02-04ab (Nabki, Soer et al.)
**15-22-0094-01-04ab-link budget UWB vs NB-Mc Laughlin (Qorvo)
15-22-0145-00-04ab-link budget calculator for NB and UWB-Keren et. al (Huawei)
15-22-0066-02-04ab-link budget analysis and CIR reporting for UWB RF sensing- Pakrooh et. al (Qualcomm)

Conclusions

- We propose to include an optional non-coherent mode tailored to low-power low-latency data communications with minimal impact on standard definition
- Increases the trade-off space:
  - Introduces more options for low power, higher rate communications
- Reduces the potential for disrupting ranging applications:
  - Short packet duration and symbol structure avoid disrupting other applications
- Interested to collaborate to finalize details