Project: IEEE P802.15 Working Group for Wireless Specialty Networks (WSN)

Submission Title: Low power operation for non-ranging applications
Date Submitted: 11 November 2021
Source: Michiel Soer (SPARK Microsystems), Frederic Nabki (SPARK Microsystems)
Contact: E-Mail: michiel.soer@sparkmicro.com, frederic.nabki@sparkmicro.com

Re: Technical contribution to 15.4ab

Abstract: PHY options to support low power operation for non-ranging applications

Purpose: Present a proposed technical approach to reduce energy consumption for exchange of data communication-optimized packets which complements current ranging-focused modes for applications which do not require high-precision ranging.

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. Enables use of channel access (MAC) using sensing of spectrum can reduce interference.
Interference mitigation techniques to support higher density and higher traffic use cases	
Other coexistence improvement	
Backward compatibility with enhanced ranging capable devices (ERDEVs)	Compatible with legacy devices using the BPRF mode
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	Compatible with CCA based on channel sensing
Low-power low-latency streaming	Enhances support for low power audio 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	

Aim

- PHY proposal to support low power operation for non-ranging applications
  - Create data communication-optimized packets that can complement current ranging-focused packets
- If application does not require high-precision ranging, there is no need for STS and non-coherent receivers are fully supported
- Benefit for coherent transceivers to reduce power consumption

Non-coherent Reception

- Very attractive power budget:
  - Tolerates high jitter synthesizer and/or carrier (± 100 ppm)
  - Reduced air time
  - Reduced DSP complexity (no Equalizer / Carrier Frequency Offset compensation / CIR Correlator+Accumulator)

- We will demonstrate the performance penalty

Starting from 4z STS packet config 0

Focus on data communication means there is no need for STS

- In terms of 15.4z, STS packet configuration 0
  - Can be backwards compatible with 15.4a
  - Can be compatible with non-coherent receivers if ternary SFD sequence is used

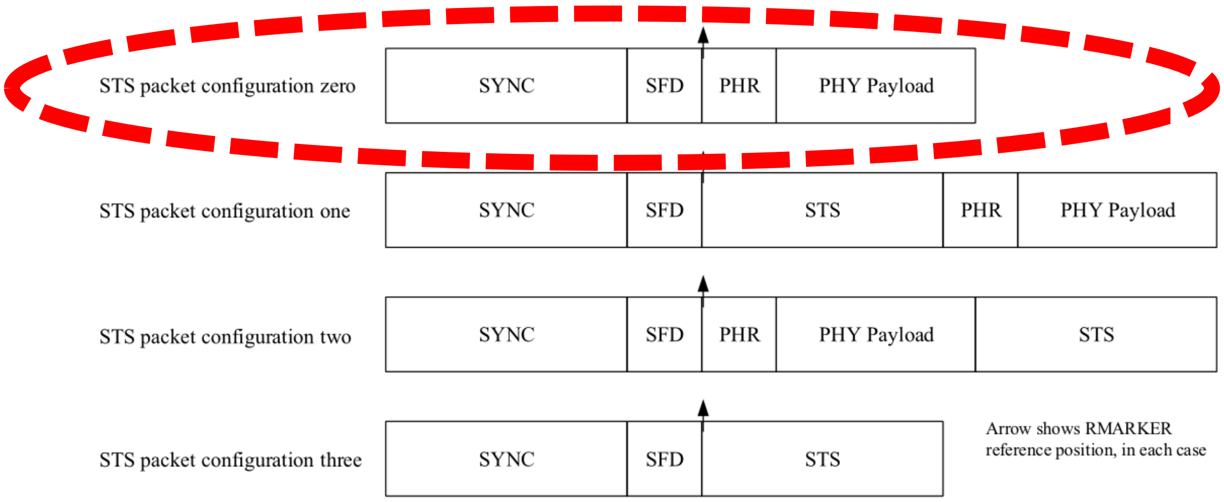
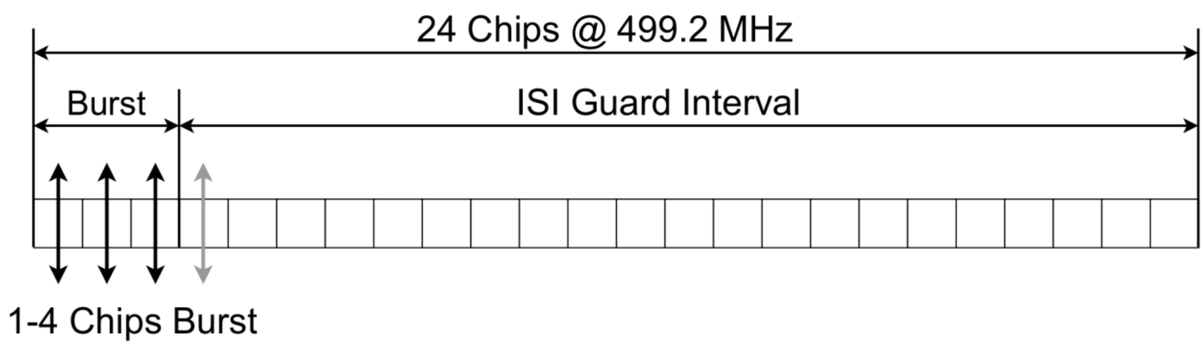


Figure 15-2a—HRP-ERDEV PPDU formats with RMARKER position

Symbol

- Same symbol rate throughout SYNC, SFD and Payload, simplifies DSP
- Propose 20.8 MHz symbol rate, 24 chips long:



- Possibility of 1,2,3 or 4 chips per burst (N_{chip}), trade off between ISI, PA peak power, and sensitivity
  - PRF of 20.8, 41.6, 62.4, and 83.2 MHz respectively

SYNC

- Existing ternary preamble codes can be detected by non-coherent receivers
- 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, although in practice more symbols are needed to reach full RX sensitivity
- To address concerns about coexistence between ‘ranging’ and ‘communications’ applications, an ‘orthogonal’ preamble format could be added
  - Proposal on next slide

SYNC Proposal for Non-ranging (data comm)

- Proposed preamble code: repetitions of …1/0/1/0…
  - 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:
  - Scrambled to whiten spectrum
  - Or increase orthogonality with existing sequences
  - Or include a short code (length 31 maybe) to estimate CIR for a coherent receiver
- The 20.8 MHz symbol rate increase orthogonality with existing ranging rates
- Propose minimum of 16*8=128 symbols to settle AGC and do timing synchronization: 16*8/20.8 MHz = 6.1 μs long

SFD

- 15.4a has ternary SFD sequences to support both coherent and non-coherent receivers
- 15.4z added binary SFD sequences to improve detection probability at the cost of excluding non-coherent receivers
- Proposal to support 15.4a sequences mapped onto 20.8 MHz symbol rate
  - 16 symbol SFD sequence @ 20.8 MHz adds 0.76 μs to preamble

PHR/Payload Modulation

- Same 20.8 Mbps from preamble:
  - Constant rate throughout packet simplifies design
  - Also gives increased ISI and orthogonality
- Scramble phase with LFSR to improve spectral whitening
  - Coherent transceivers could encode an extra bit/symbol, as in 4a FEC
- Options:
  - 20.8 Mbps OOK, minimum of 20 ISI guard chips
  - 20.8 Mbps with binary position modulation, minimum of 8 ISI guard chips
  - 10.4 Mbps Manchester OOK, minimum of 20 ISI guard chips, but same sensitivity as BPM

Coding

- Base Rate of 20.8 Mbps can be coded with either:
  - Current RS code
  - Current K=7 CC systematic code, but punctured to fractional rate
- Own experience with 4/5 rate CC:
  - 9 dB required Eb/N0
  - Yields 16.6 Mbps effective data rate
- Our estimation of Eb/N0 required for current K=3 CC+RS in a coherent receiver is 4 dB, so this non-coherent scheme incurs a 5 dB penalty
- Preference to reuse existing encoder/decoder, hence puncturing

Link Budget

- Average TX power in 500 MHz BW = -14 dBm
- Extra term in sensitivity due to non-coherent integration during integration window[1]:

$$\text{RX sensitivity} = -174 + NF + Eb/N0 + 10*\log10(\text{sqrt}(N_{chip}))$$

- No penalty if using 1 chip per symbol, but requires high peak PA power (implementation choice). Else 1.5 dB penalty for 2 chips, etc

- Example: 4 dB NF RX, 1 chip/symbol and 4/5 rate punctured FEC [1]:

  -161 dBm/Hz sensitivity -> 74 dB link budget@ full 20.8 Mbps

- TX Gating gain increases link budget for duty cycled lower data rate, for example 84 dB @ 2 Mbps, etc
  - Compare to typical 90 dB link budget for BLE 2 Mbps PHY, but with UWB requiring less fading margin

[1] For more detail, check last slides: "Extra: Non-coherent RX Sensitivity" and "Extra: Link Budget"

Power Consumption

- As an example, let's assume 50 mW RX power in a non-coherent implementation (30 mW analog + 10 mW synthesizer + 10 mW DSP)
  - Existing coherent implementations can power gate their equalizer, correlator, etc
- At 16.6 Mbps, energy efficiency is 3 nJ/bit
- To compare: BLE 2.0 Mbps PHY is typically above 7 nJ/bit
- Showcases UWB as an efficient data comm PHY

Conclusions

- If secure ranging is not required, non-coherent reception can be supported
- Alternative preamble sequence and pulse spreading ratio
  - 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
- PPM and OOK modulations supported
- Use existing convolutional code, but use puncturing to get more effective data rate
- Power efficient, and reasonable link budgets

Extra: Non-coherent RX Sensitivity

- Sensitivity expressed in power:

$$P_{sens}= N0*F*BW*SNR_{det}$$

- Integration of power into energy over bit duration Tb:
  - Coherent detector: $SNR_{det} = |Eb/N0|_{det} / (BW*Tb)$

$$P_{sens}=N0*F*|Eb/N0|_{det}* 1/Tb$$

  - Non-coherent detector: SNR_{det} = |Eb/N0|det / sqrt(BW*Tb)

$$P_{sens}=N0*F*|Eb/N0|_{det} *1/ Tb * sqrt(BW*Tb)$$

- Consider that:

$$BW*Tb = N_{chips} \text{ and } Tb*P_{sens} = \text{bit energy}$$

- Non coherent sensitivity expressed in energy:

$$E_{sens}=N0*F*|Eb/N0|_{det}*sqrt(N_{chips})$$

Extra: Link Budget

- Spectral density regulatory limit of –41.3 dBm/MHz
- In 500 MHz channel bandwidth, max average TX power of
  –41 + 10*log10(500MHz) = -14 dBm

- TX Bit energy @ 20.8 Mbps of –14 –10*log10(20.8MBps) = -87 dBm/Hz
- TX Bit energy @ 2.08 Mbps of –14 –10*log10(2.08MBps) = -77 dBm/Hz

- RX sensitivity = -174 + NF + Eb/N0 + 10*log10(sqrt(N_{chip}))
  = -174 + 4 + 9 + 10*log10(1)= -161 dBm/Hz

- Link budget @ 20.8 Mbps = -87 dBm/Hz - -161 dBm/Hz = 74 dB
- Link budget @ 2.08 Mbps = -77 dBm/Hz - -161 dBm/Hz = 84 dB