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

**Submission Title:**  MAC layer considerations for UWB data streaming
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**Re:** IEEE 802.15 IG NG-UWB Plenary Meeting

**Abstract:**      MAC layer considerations for UWB data streaming

**Purpose:**      Propose MAC layer enhancements to enhance coexistence of UWB data streaming

# 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 | Enables use of channel access (MAC) using sensing of spectrum can reduce interference and improve coexistence. |
| 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. Does not depend on a specific behavior from legacy devices. |
| Improved link budget and/or reduced air-time | Effective reduction in air-time by avoiding lost packets (better good-put). |
| Additional channels and operating frequencies | |
| Improvements to accuracy / precision / reliability and interoperability for high-integrity ranging | |
| Reduced complexity and power consumption | Potential to reduce re-transmission attempts |
| 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 latency audio streaming. |
| Higher data-rate streaming allowing at least 50 Mbit/s of throughput | Higher effective datarate through improve "good put" |
| Support for peer-to-peer, peer-to-multi-peer, and station-to-infrastructure protocols | Compatible with all these topologies. |
| Infrastructure synchronization mechanisms | |

# Quick Review of Use Case Needs

- **Audio real-time / low latency streaming**
    - headphones, hearables, speakers

- **Audio/Video real time / low latency streaming**

    - XR with multi-channel a/v (Gaming)

- **Network of objects with frequent data transport**

    – Sensors networks (Medical , Transport, Agriculture…)

    – BAN (Medical, XR, Gaming)

    – PAN (Gaming, Home office)

# Key Goals and Objectives

- Latency control

- Efficient peer to peer and small network operation

- Compatibility and coexistence with other applications

- Don't disrupt ranging and sensing applications

- Improve goodput and reduce airtime usage

# Coexistence Considerations

- Better performance through better coexistence
  - Reduced packet loss, retransmission, wasted air time and energy
  - Improved performance in presence of both UWB and non-UWB via media sensing

- Basic coexistence methods:
  - **Non-coordinated methods (with and without "cooperation")**  **Today's topic**
  - Coordinated and cooperative methods among participating devices

# Non-coordinated Access Using Modified CSMA

- Contention based channel access via sensing of the media
  - Measure medium and report idle or busy (CCA - Clear Channel Assessment)
  - Based on CCA result, make a channel access decision
- 802.15.4 CSMA
  - Simple and flexible unslotted CSMA with *or without* iterative backoff
  - Variations with prioritized access
  - Variations of slotted CSMA (e.g. TSCH - Time Slotted Channel Hopping)
  - Unslotted CSMA is a good starting point as it covers several relevant applications of IEEE 802.15.4ab

# CCA modes

- CCA Mode 1: Energy above threshold detected (ED)

- CCA Mode 2: Carrier sense only

- CCA Mode 3: Carrier sense with energy above threshold.

- CCA Mode 4: Always reports idle medium

- CCA Mode 5: HRP UWB preamble sense

- CCA Mode 6: HRP UWB preamble sense based on the packet with the multiplexed preamble
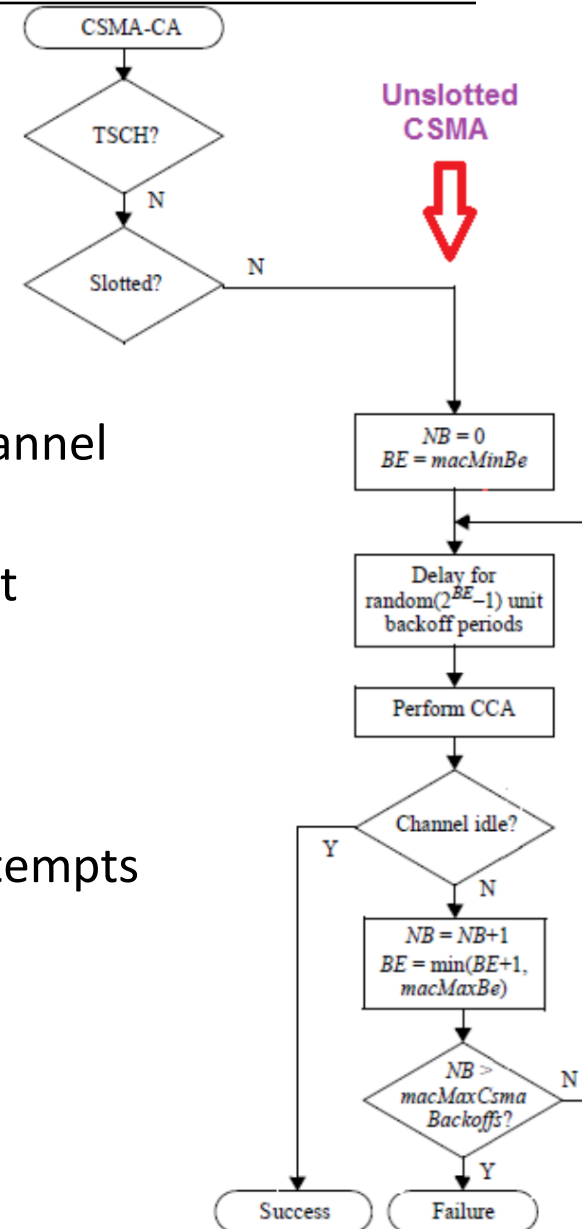
# Unslotted CSMA in a Nutshell

- Simple and flexible: Good starting point

- Can reduce to Aloha (CCA Mode 4)

- If not clear after macMaxCsmaBackoffs, returns 'channel access failure' (MPDU transmissions abandoned)

- Can reduce to simple listen before talk (LBT) without iterative backoff when macMaxCsmaBackoffs=0.

- Can bound total CSMA time with selection of macMaxCsmaBackoffs and macMaxBe

- Lacks persistence: No state carried across access attempts

- Can get "stuck" if CCA triggers w/CCA Mode 1

Note: Some CSMA PIB parameters

*macMinBe*: initial backoff exponent (minimum delay)

*macMaxBe*: upper limit of backoff exponent (maximum delay)

*macMaxCsmaBackoffs*: upper limit for backoff iterations (can be set to 0)

CSMA-CA

TSCH?

N

Slotted? — N

**Unslotted CSMA**

$NB = 0$
$BE = macMinBe$

Delay for random$(2^{BE}-1)$ unit backoff periods

Perform CCA

Channel idle?
Y
N

$NB = NB+1$
$BE = min(BE+1, macMaxBe)$

$NB > macMaxCsma Backoffs?$
N
Y

Success
Failure

# Current Standard CCA Modes (1/4)

- CCA Mode 1: Energy above threshold detected (ED)
  - Current energy threshold definition doesn't work for UWB
    - Defined as 10 dB above minimum RX sensitivity for the PHY in use
    - Will report "busy" when channel is noisy, idle and usable
  - CCA duration as defined doesn't work well in presence of non-802.15 devices
  - **But with simple changes can make it useful for UWB**
    - Threshold should be above noise floor
    - Variable threshold and duration

# Current Standard CCA Modes (2/4)

- CCA Mode 2: Carrier sense only
  - Not well defined for UWB PHYs (see mode 5 and 6 on next slides)
- CCA Mode 3: Carrier sense with energy above threshold.
  - Combined issues as modes 1 and 2
- CCA Mode 4: Always reports idle medium
  - Combined with unslotted CSMA this produces ALOHA channel access
  - Most common channel access used for UWB systems today

# Current Standard CCA Modes (3/4)

- CCA Mode 5: HRP UWB preamble sense
  - Fixed in 4z to look for a single selected preamble code locally set by *phyCurrentCode*.
  - Reasonable to implement but limited use
  - Can be useful for detecting cooperating devices if all use the same preamble code
  - Not so much for other non-coordinated devices (there's a lot of possible codes)
  - Detects preamble part of the packet
  - There is a lot more in the packet than the preamble, especially in the applications that do more than ranging

# Current Standard CCA Modes (4/4)

- CCA Mode 6: HRP UWB preamble sense based on the packet with the multiplexed preamble (superimposed preamble)
  - Intended to address the "more than preamble" issue
  - More complexity in the signal generation and receive processing
  - Not aware of a current implementation using this method

**Therefore…**

- **CCA Mode 1 (ED) is promising starting point**
  - **Low complexity**
  - **Can detect both UWB and non-UWB channel traffic**

# CCA Mode 1 Changes to Support UWB:
## Variable energy detect threshold and duration

- Currently threshold and duration are defined constants
  - There are known issues with this in the presence of non-802.15.4 devices
  - Most implementations (of any PHY) allow setting to values other than per standard
  - **Allowing these to be variables enables making ED useful**
- Energy threshold
  - Allow range of values that make sense for UWB
  - Allow for low complexity fixed threshold
  - Enables adapting to channel conditions – to be studied
- Duration
  - Currently defined as a constant for all but 2 PHYs
    - 920 MHz band and RCC PHYs defined by PIB attribute (variable)
  - Many reasons to make it variable for all PHYs including HRP and LRP
    - Easy change: use PIB attribute *phyCcaDuration* for UWB PHYs

# CSMA Enhancements to Support Bounded Latency (1/2)

Provide for more flexibility and greater resolution of CSMA parameters

- For streaming, need to bound CCA duration to achieve low latency

- Exponential growth not always desired

  – Fix duration between CCA attempts in the loop (non-random) to provide predictable timing (trade-off)

  – Option for random CCA interval range to increase linearly instead of exponentially to more tightly bound latency

- Provide additional control options (MAC PIB attributes)

  – Backoff method PIB: linear, exponential, fixed

  – Action on termination w/macMaxCsmaBackoffs exceeded

  – For Linear backoff method, increment PIB could be macMaxBi and macMinBi (can be equal for fixed Backoff)

# CSMA Enhancements to Support Bounded Latency (2/2)

- "just do it anyway" mode: TX after some number of CSMA failures (*macMaxCsmaBackoffs* exceeded)
  - Not all energy is a collision
  - Not all collisions are fatal (either way)
- Reduces to Aloha after CSMA failures
  - Potential for better collision avoidance than Aloha
  - Never worse in terms of interference probability (either way)
- Enables delivery of packets when ED is fooled by noise and sufficient separation is otherwise provided

# Use of CSMA and Legacy Devices

- A device using CSMA doesn't hurt one not using CSMA
  - Legacy devices using Aloha don't notice new devices that are using media sensing and CSMA
  - Looks like another random access
  - Devices that sense reduce aggregate traffic by the attempt
- Devices using CSMA have lower chance of disrupting legacy devices
  - Have a chance to detect and avoid colliding with legacy devices
  - Protects ranging use case
  - Protects existing 15.4z devices not using CSMA
- What if legacy device cannot be detected by ED?
  - Probability of collision never higher than Aloha
  - Probability of collision will usually be lower than Aloha with minimal added complexity

# Summary

- Channel access with ED spectrum sensing improves performance for low latency data streaming

  - Minimal complexity (power consumption, cost of implementation)

  - Improves goodput (attempt/success ratio)

  - Improves channel efficiency (less clutter)

  - Lower failed transmissions saves energy (potentially on both ends)

- CSMA flexibility (e.g., backoff settings) can enhance latency performance

- Can help ranging applications

  - Reduced probability of interference

- No impact on legacy devices

  - Either using CSMA or not, changes won't affect them

- Low complexity and power efficient