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

Submission Title: MAC layer considerations for UWB data streaming
Date Submitted: 19 January 2022
Source: Frederic Nabki (SPARK Microsystems)
Address: 1201 rue Barré Suite 201, Montréal QC, Canada
E-Mail: frederic.nabki@sparkmicro.ca

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")**
  - Coordinated and cooperative methods among participating devices

Today's topic

Non-coordinated Access Using Modified CSMA

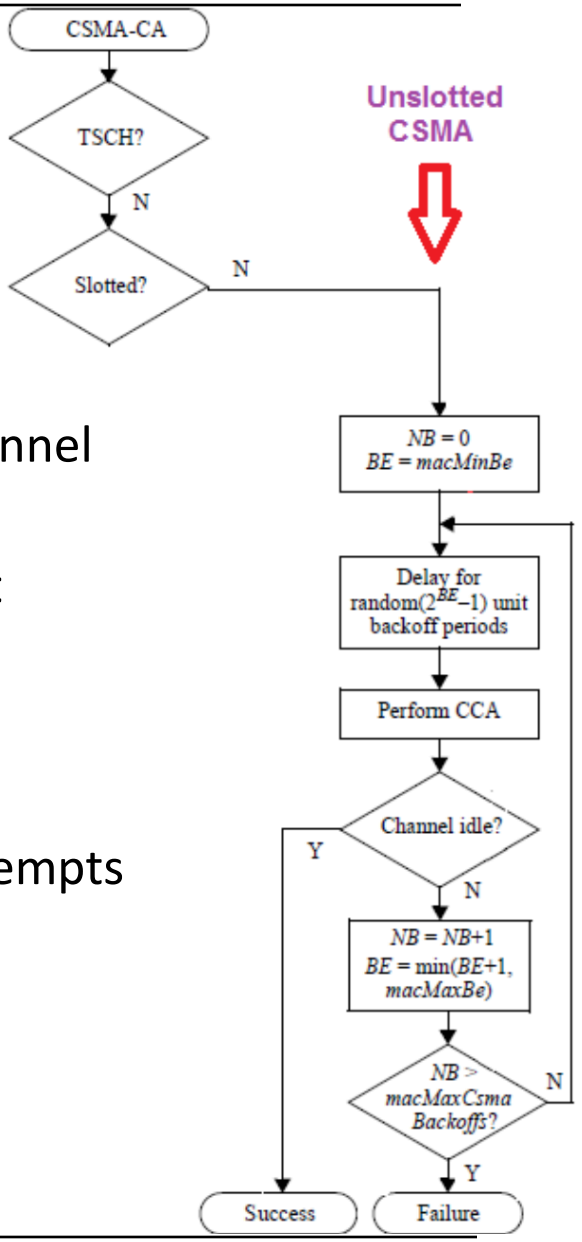
- Contention based channel access via sensing of the media
  - Measure medium and report idle or busy (CCA - Clear Channel Assessment)
  - Based on CCA result, make a channel access decision
- 802.15.4 CSMA
  - Simple and flexible unslotted CSMA with *or without* iterative backoff
  - Variations with 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)

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