by wilgengebroed

IEEE 802.11ah

sub 1GHz WLAN for IoT

What lies beneath Wi-Fi HaLow

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Purpose, scope and use cases

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IEEE 802.11ah: purpose

- Defines operation of license-exempt (ISM) IEEE 802.11 wireless networks in frequency bands below 1 GHz
  - excluding the TV White Space bands (802.11af).

- IEEE 802.11 WLAN user experience for fixed, outdoor, point to multi point applications

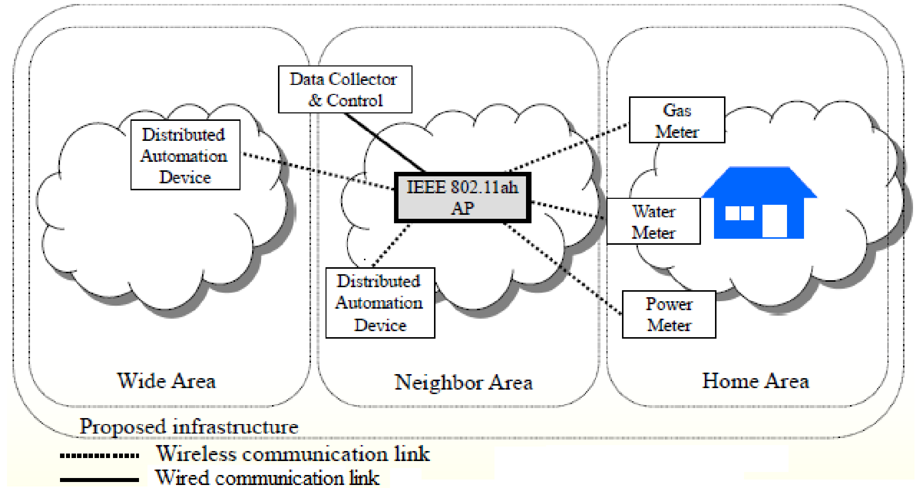
by Atmel Corp.

IEEE 802.11ah: scope

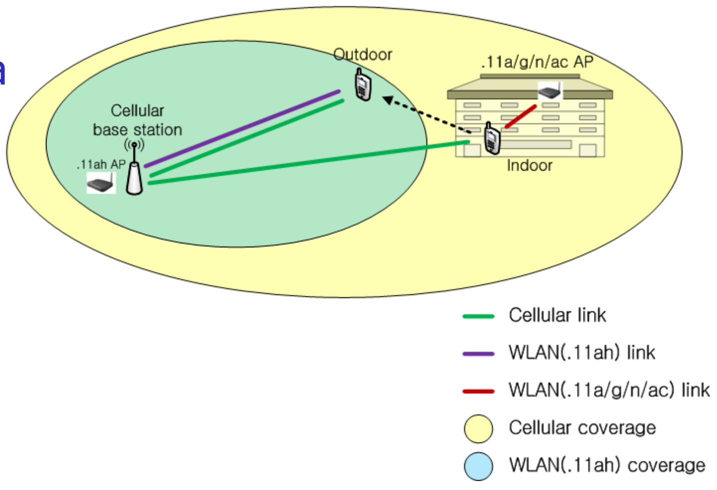
- Defines an OFDM PHY operating in the license-exempt bands below 1 GHz
    - and enhancements to the IEEE 802.11 MAC to support this PHY, and to provide mechanisms that enable coexistence with other systems in the bands (e.g. IEEE 802.15.4 P802.15.4g)
- The PHY is meant to optimize the ***rate vs. range*** performance of the specific channelization in a given band.
    - transmission range up to 1 km
    - data rates > 100 kbit/s
- The MAC is designed to support thousands of connected devices

IEEE 802.11ah: use cases

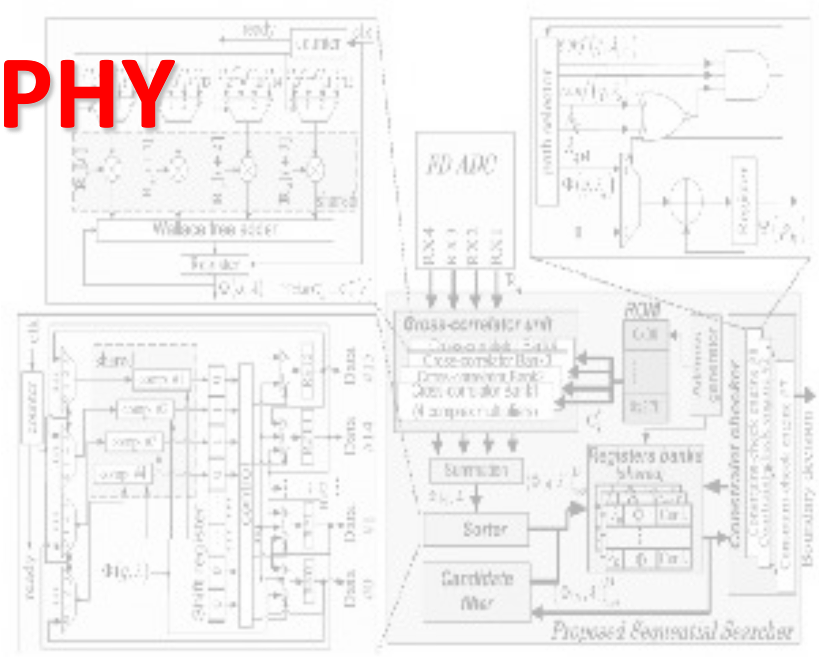
- Use Case 1 : Sensors and meters
  - Smart Grid - meter to pole
  - Environmental monitoring
  - Industrial process sensors
  - Healthcare
  - Home/Building automation
  - Smart city



- Use Case 2 : Backhaul sensor and meter data
  - Backhaul aggregation of sensor networks
  - Long point-to-point wireless links
- Use Case 3 : Extended range Wi-Fi
  - Outdoor extended range hotspot
  - Outdoor Wi-Fi for cellular traffic offloading



The PHY



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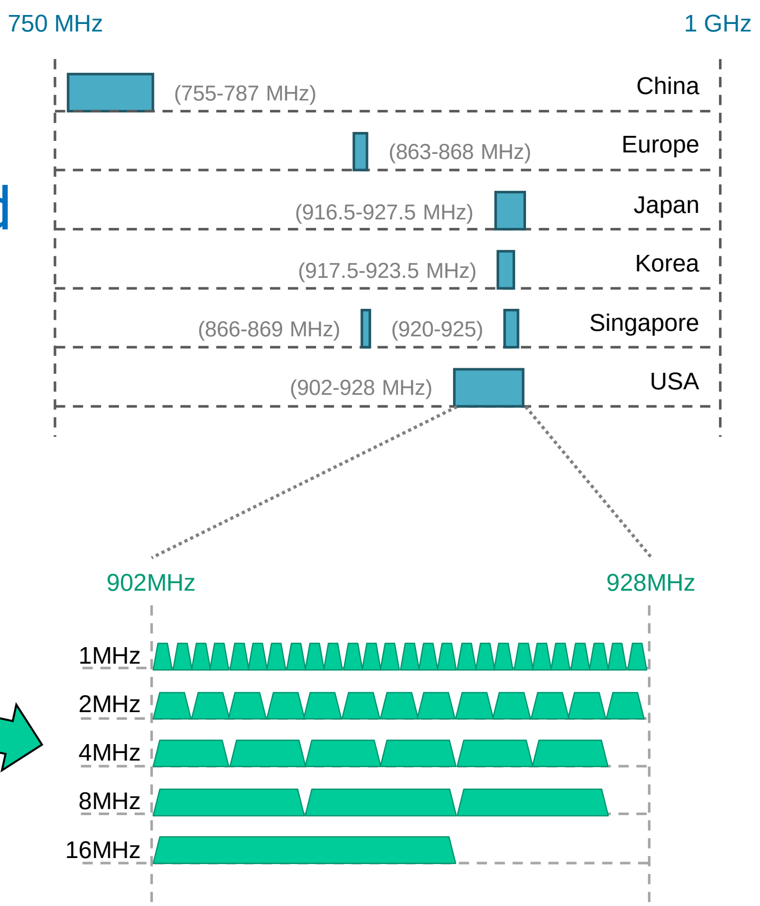
IEEE 802.11ah: PHY (1)

- Advantages of transmitting in sub 1 GHz:
  - Spectrum characteristics
    - good propagation and penetration
    - large coverage area and one-hop reach
    - license-exempt, light licensing
  - Reliability:
    - less congested frequency band
    - high sensitivity and link margin
    - available diversity – (frequency, time, space)
  - Battery operation
    - long battery life
    - short data transmissions

IEEE 802.11ah: PHY (2)

- Channelization:
  - Each regulatory domain defines a different band and different tx power limits
  - Configurable bandwidth (*channel bonding*) of: **1**, **2**, 4, 8 and 16MHz
    - Example of bandwidth options in the US

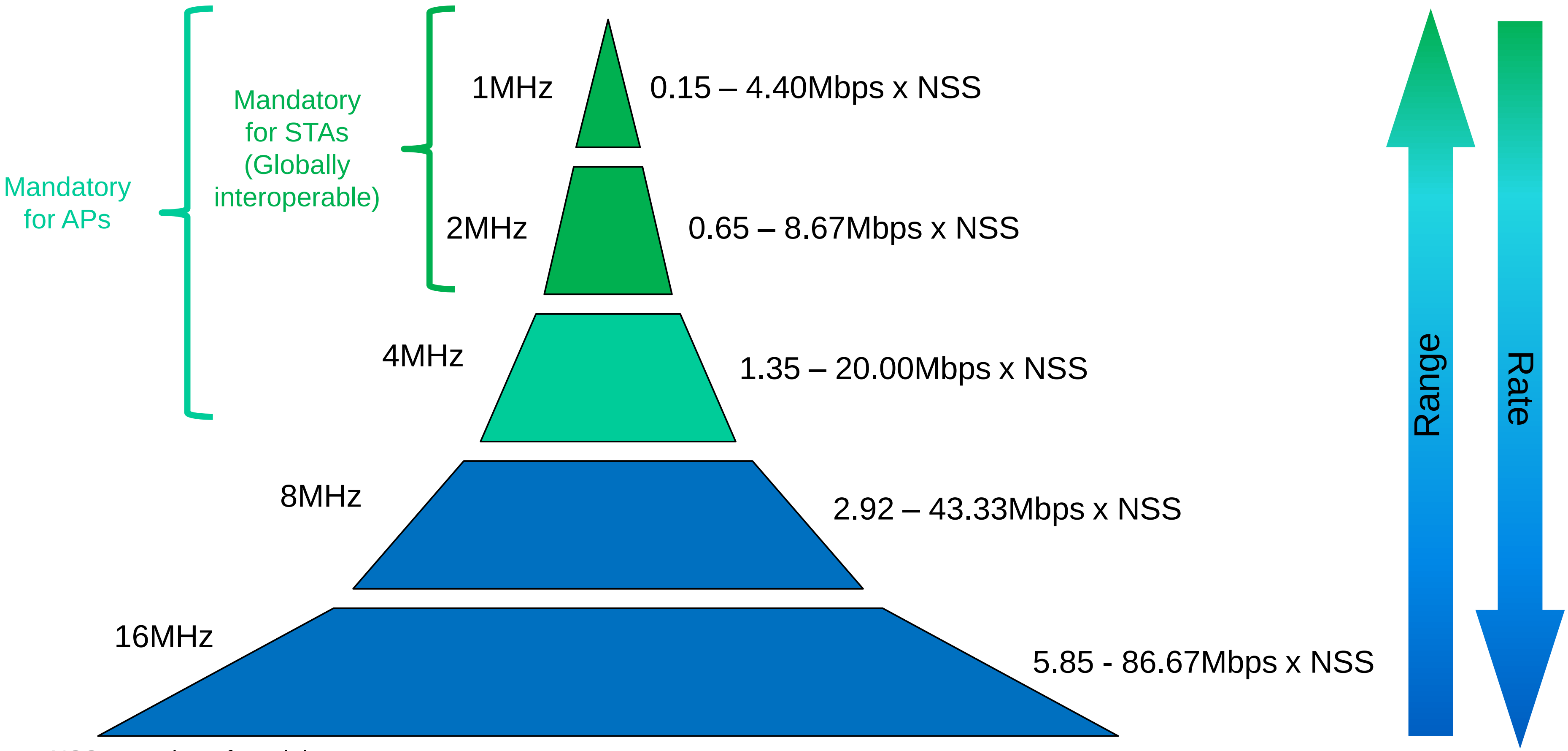


IEEE 802.11ah: PHY (3)

- Inherited from IEEE 802.11ac (adapted to S1G):
  - OFDM
    - 10 times down-clocking .11ac
      - symbol duration x 10 → 40μs
    - Same number of OFDM subcarriers: bandwidth /10
      - 20MHz → 2MHz (52/64 data subcarriers)
  - MIMO + MU-MIMO
    - Up to 4 spatial streams (NSS > 2 are optional)
  - PHY rates ranging from 150kbps to 347Mbps
    - Min: MCS10 (BPSK 1/2 with repetition) x 1 stream x 1MHz x Long Guard Interval (GI)
    - MAX: MCS9 (256-QAM 5/6) x 4 streams x 16MHz x Short GI

IEEE 802.11ah: PHY (4)

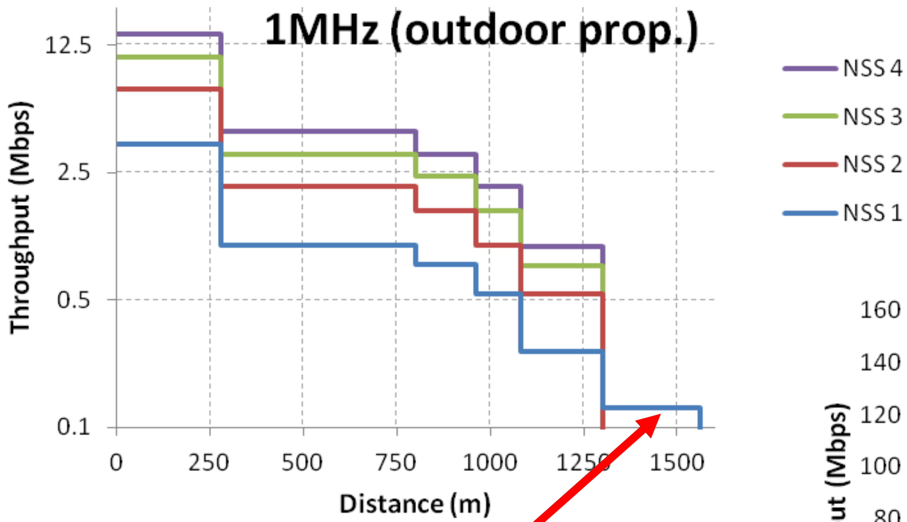
- Expected throughput vs. coverage



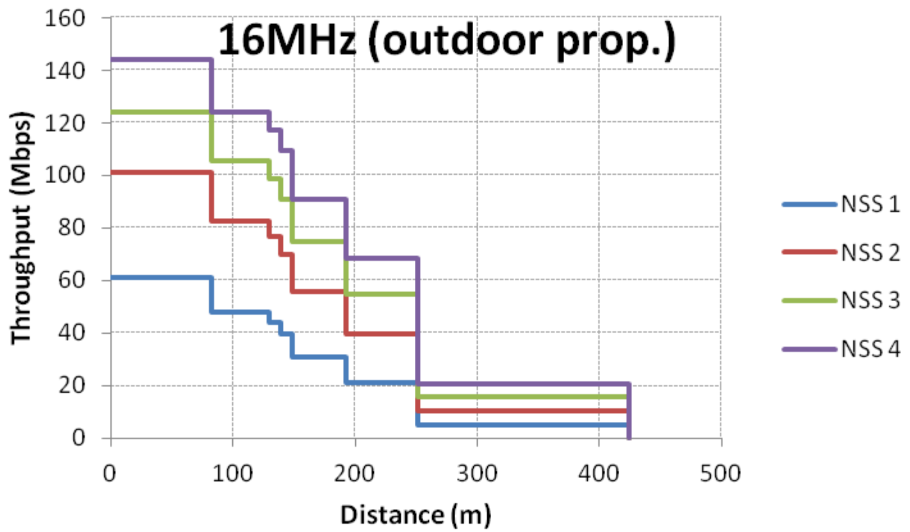
NSS = number of spatial streams

IEEE 802.11ah: PHY (5)

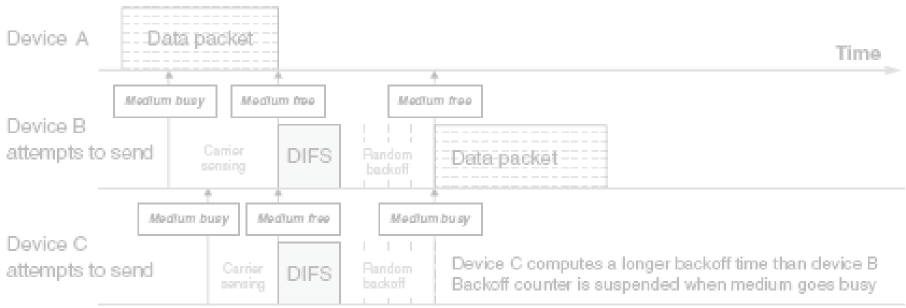
- Expected throughput vs. coverage (min and max)

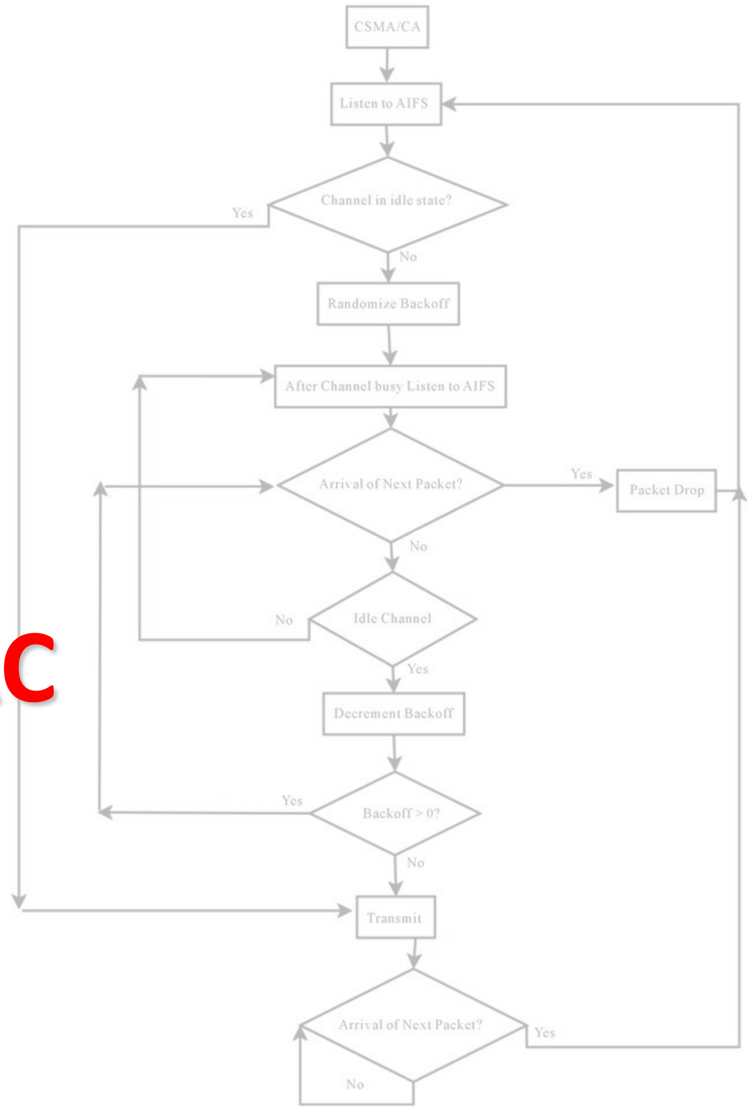


Additional step thanks to MCS10 (only available with 1MHz and NSS 1)



NSS = number of spatial streams





The MAC

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IEEE 802.11ah: MAC (1)

- Need to reduce overhead: low data rates + short frames (typical in some use cases)
  - Short MAC headers:
    - Removed fields (Duration, QoS control, HT control, optionally Sequence control)
    - Option to use only two addresses (instead of three)
      - Option to use 2B AID instead of 6B MAC address
    - Example: send frame with 100 Bytes of data
      - **Legacy**: 100B of data + 36B of header + FCS → **26%** overhead!
      - **11ah short MAC header**: 100B of data + 14B of header + FCS → 12% overhead

AID = Association ID (unique value assigned to a STA during association)

IEEE 802.11ah: MAC (2)

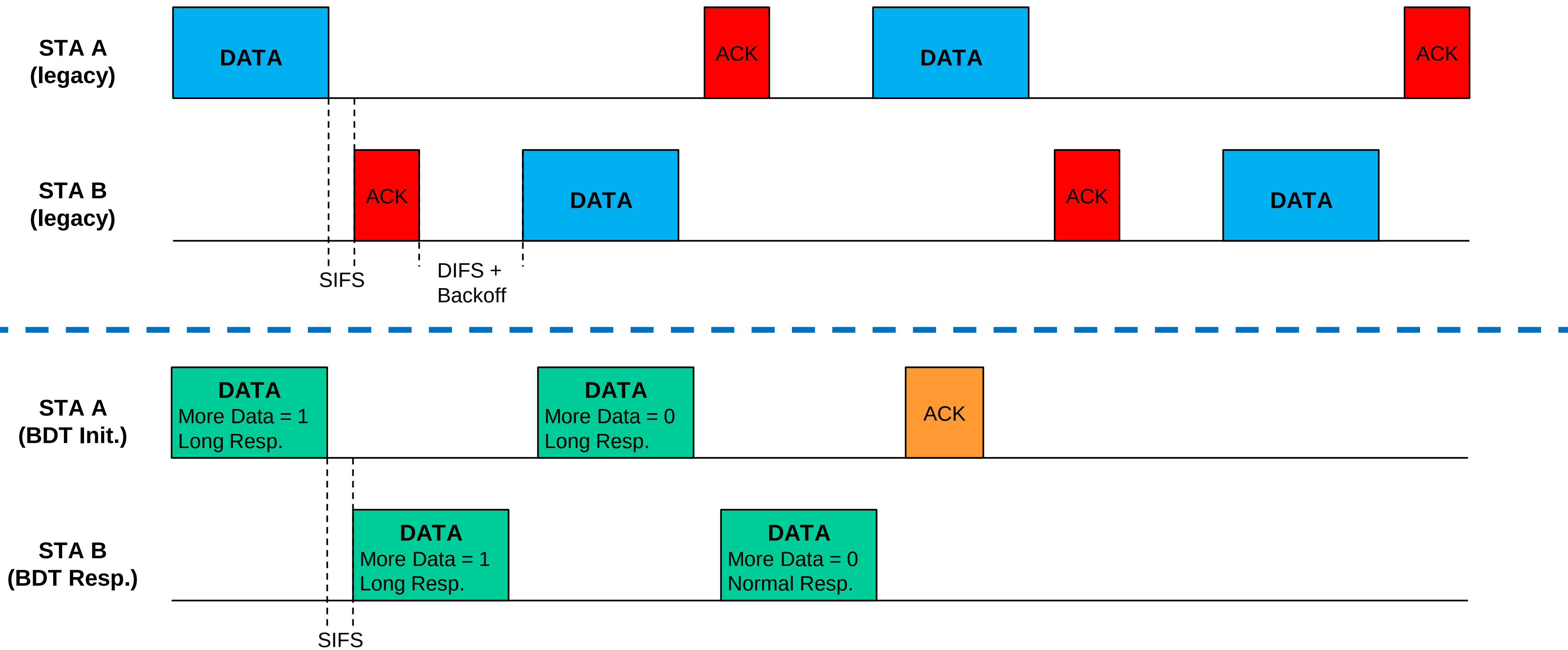
- Need to reduce overhead: low data rates + short frames (typical in some use cases)
  - NULL Data Packets (NDP)
    - Concentrate relevant information of control frames in the PHY header (avoid MAC header + payload)
    - Example:
      - 11ah transmission of 100B frame at lowest rate (1MHz x NSS 1 x MCS10) takes ~8ms
        - Legacy ACK: ~1.5ms (20% of the data frame!)
        - NDP ACK: ~0.5ms (6% of the data frame)
  - Short Beacons
    - Beacons are sent frequently at the lowest rate → short *(more frequent)* and full beacons *(less frequent)*

IEEE 802.11ah: MAC (3)

- Need to reduce overhead: low data rates + short frames (typical in some use cases)
  - Implicit acknowledgement (no ACK needed)
    - Bidirectional TXOP (BDT): extension of 802.11n’s Reverse Direction protocol (RD)
      - With **RD**: exchange of uplink and downlink frames during a single TXOP
      - With **BDT**: reception of next data frame implies that previous data was successfully received (no ACK needed).
    - Reduces channel access attempts, number of frames exchanged → Increases channel efficiency, battery lifetime

IEEE 802.11ah: MAC (4)

- Need to reduce overhead: low data rates + short frames (typical in some use cases)
  - Implicit acknowledgement (no ACK needed)



IEEE 802.11ah: MAC (5)

- Need to support thousands of associated devices (increases coverage → increases reachable STAs)
  - Legacy 802.11 limited to 2007 associated STAs → 11ah increases to >8000
    - Hierarchical Association ID (AID) assignment (uses 13bits): page/block/sub-block/STA
      - Allows grouping STAs according to different criteria
        - » Device type, power constraints, application, location, etc.
    - Increased TIM size (one bit per each associated STA)
      - 1kB each Beacon frame!?! No, it can be compressed

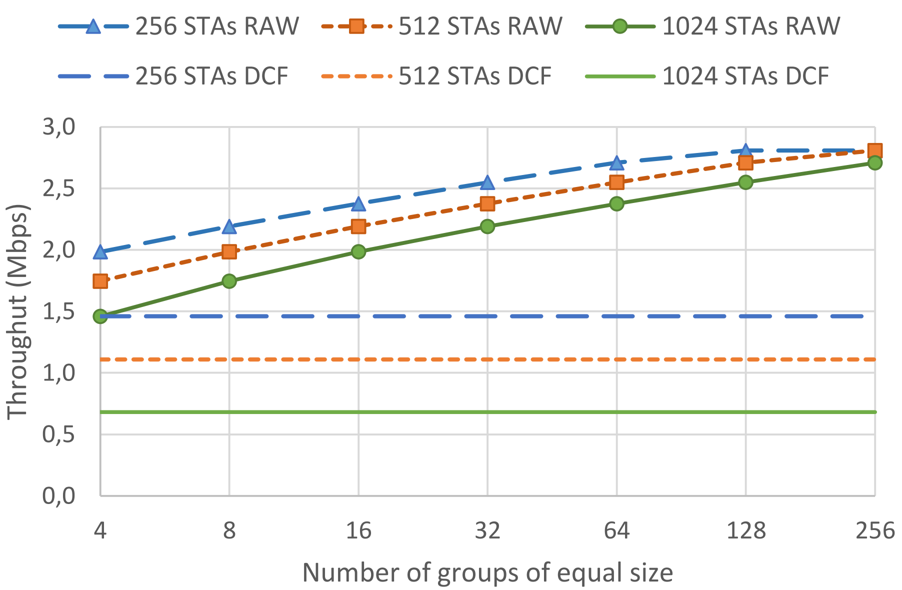
IEEE 802.11ah: MAC (6)

- Need to support thousands of associated devices
  - Thousands of STAs → huge collision probability!
  - Restricted Access Window (RAW): regular RAW
    - Divide STAs into groups (AID)
    - Split channel access into time slots
    - Assign slots to groups (AP indicates RAW allocation and slot assignments in its Beacons)
      - STAs are only allowed to transmit during its group’s slot
      - *Cross Slot Boundary* option enables STAs to cross its assigned RAW slot to complete the ongoing exchange.
      - STAs can sleep during other groups’ slots
    - Different *backoff* rules apply during RAW (due to different contention conditions)

IEEE 802.11ah: MAC (7)

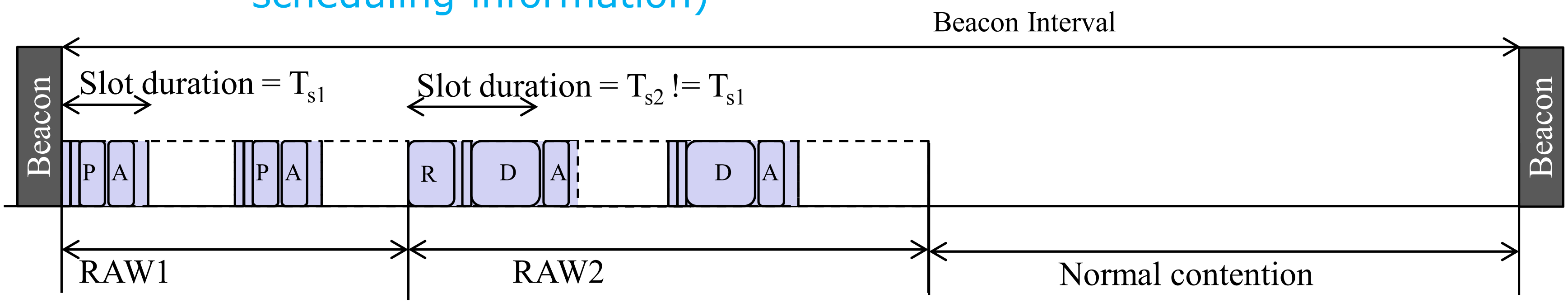
- Need to support thousands of associated devices
  - Thousands of STAs → huge collision probability!
  - Restricted Access Window (RAW): regular RAW

- Example:
  - 2MHz
  - MCS 5
  - NSS 1
  - Payload 1000B
  - Saturation



IEEE 802.11ah: MAC (8)

- Need to support thousands of associated devices
  - Thousands of STAs → huge collision probability!
  - Restricted Access Window (RAW): triggering frame RAW and resource allocation (an example)
    - RAW 1 reserved for triggering frames (e.g. PS-Poll for STAs with pending UL or DL frames)
    - AP's scheduling algorithm distributes resources among STAs
    - AP starts RAW 2 with Resource Allocation frame (contains scheduling information)



* **P**: PS-Poll/Trigger frame, **D**: DATA, **A**: ACK, **R**: Resource Allocation

Power saving

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IEEE 802.11ah: power saving (1)

- Need to reduce power consumption (battery powered devices)
  - PS mode allows STAs to remain inactive during ***max idle period*** after which, the STA is disassociated.
    - Legacy max idle period: 16 bits (units of 1024ms) → 1.024s $\cdot(2^{16} - 1) > 18$h
      - Some use cases require days/weeks of inactivity → waste of energy sending keep-alive messages.
    - IEEE 802.11ah: two first bits used as scaling factor (1, 10, 10^3 or 10^4) → $10^4 \cdot (2^{14}-1)$ > 5 years sleeping!

IEEE 802.11ah: power saving (2)

- Need to reduce power consumption (battery powered devices)
  - Beacons carry TIM bitmap (0 or 1 for each associated STA depending on whether that STAs has buffered frames) → Beacons are too big!!
    - TIM segmentation
      - Some Beacons carry bitmap at page/block level
        - Rest of the Beacons carry a partial bitmap at STA level
      - A STA calculates the moment when the Beacon with its corresponding TIM is going to be sent
        - Sleep until then!

IEEE 802.11ah: power saving (3)

- Need to reduce power consumption (battery powered devices)
  - Beacons carry TIM bitmap → even receiving and decoding Beacons consumes energy!!
    - Target Wake Time (TWT): intended for STAs rarely transmitting/receiving data (i.e. TWT STAs)
      - TWT STA and AP negotiate when, for how long and how frequently the TWT STA will be awake.
      - AP ←→ STA frame exchanges occur only during those TWT service periods.
    - Recall that Beacons are used to distribute AP's timer reference for synchronization purposes
      - Missing beacons → other synchronization mechanisms are needed for TWT STAs

Other remarkable features

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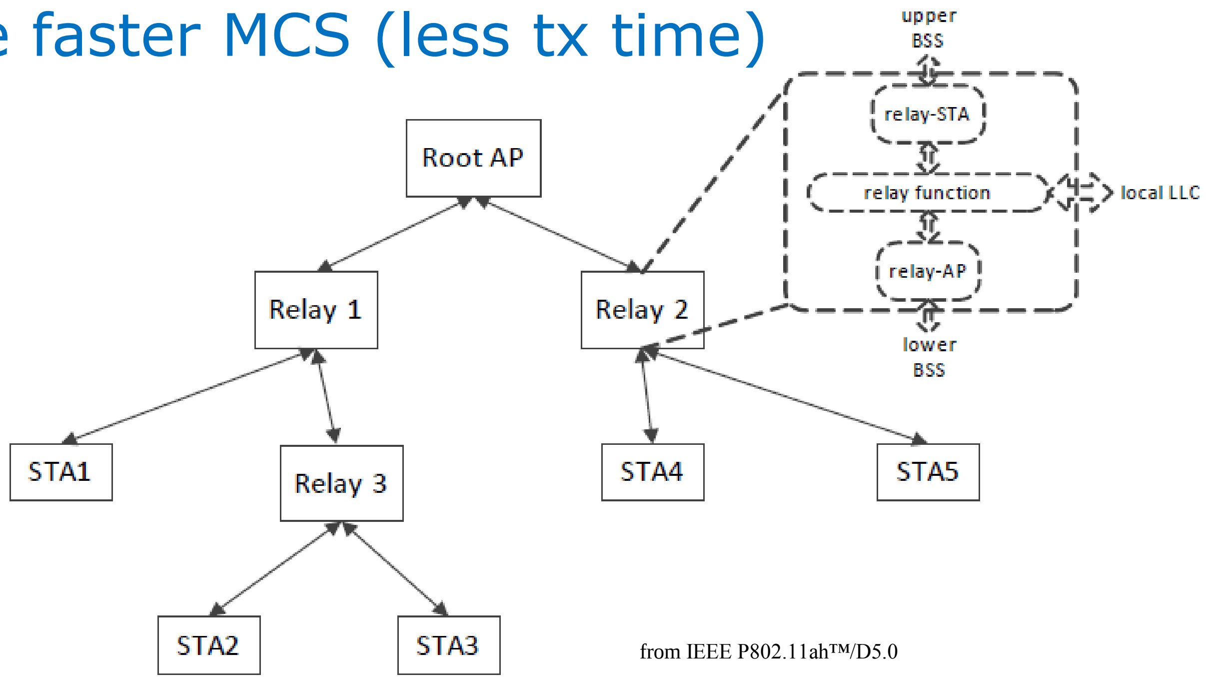
IEEE 802.11ah: other features (1)

- Multihop relay operation
  - Extend (root) AP coverage
  - STAs will require lower tx power
  - STAs may use faster MCS (less tx time)



from IEEE P802.11ah™/D5.0

IEEE 802.11ah: other features (2)

- Fast association and authentication
  - When AP (re)boots → thousands of STAs simultaneously requesting association/authentication collapse channel access!!
    - Centralized approach
      - STAs choose a number [0, 1023] at random
      - AP sets an Authentication Control Threshold (announced in Beacons)
      - STAs with random number < threshold are allowed to attempt authentication (otherwise, wait for next Beacon)
    - Distributed approach
      - STAs wait a random time (e.g. several Beacon intervals) before attempting authentication
      - Each unsuccessful attempt increases window

IEEE 802.11ah: other features (3)

- Subchannel selective transmission (SST)
  - STAs with limited capabilities (e.g. sensor nodes) may support only 1 and 2MHz (mandatory)
    - APs are likely to support wider bandwidth
  - SST APs allow the use of subchannels within a wider bandwidth
    - AP announces in Beacons which subchannels are temporarily available for SST
      - Beacons are duplicated on a set of different subchannels
    - STAs choose the best subchannel (e.g. less affected by fading)

IEEE 802.11ah: summary

LONG RANGE	SCALABILITY	EFFICIENCY
Lower frequency band	Support for >8000 nodes	Reduced frame formats
Longer OFDM symbols	Grouping	Efficient frame exchanges
Robust modulation and coding schemes	RAW access	Enhanced power saving mechanisms

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