Deterministic WLAN: A problem of scheduling and identifiers

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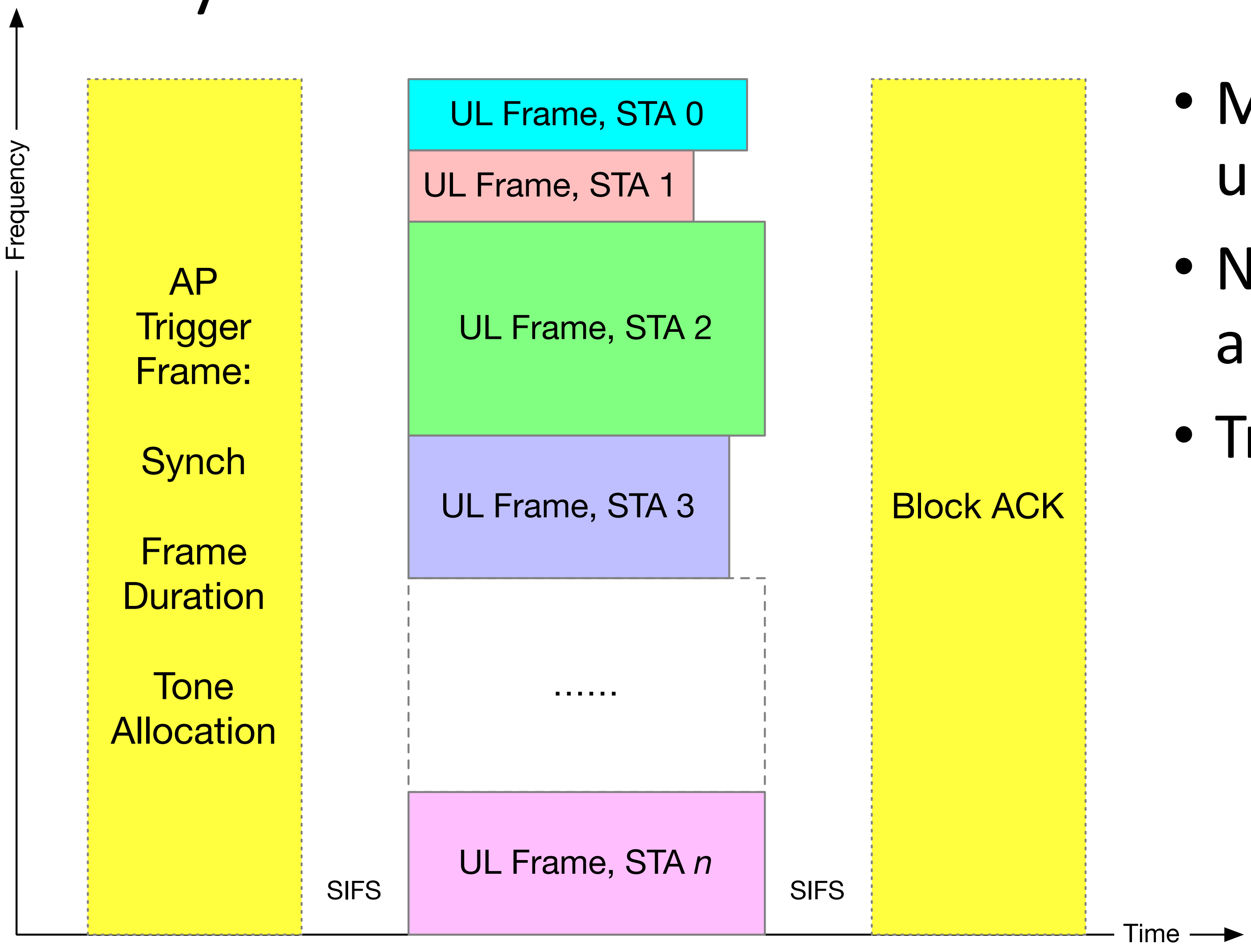
Overview

- 802.11 Working Group is developing P802.11be
  - improved wireless LAN latency is one goal
  - builds on 802.11ax
- Techniques from IEEE 802.1 Time-Sensitive Networking (TSN) are being considering for latency improvements.
- This presentation focuses on:
  - Overviewing previous deterministic wireless approaches including those considered in IEEE 802.16
  - Proposing a new mechanism to improve deterministic scheduling and effectively support a variety of traffic types, not only TSN-like streams

IEEE Project P802.11ax

- P802.11ax project began in March 2014
- Planning to complete in June 2020
- Draft is considered stable
- Key additions supporting Deterministic Wireless come from the support of uplink scheduling (multi-user uplink and OFDMA):
  - Multiple non-AP STAs transmit simultaneously
  - OFDM Orthogonality requires synchronized transmission
  - Synchronization coordinated by a trigger
  - Trigger also allocates uplink resource

Triggered OFDMA: Synchronization and Scheduling



- Multiple STAs, simultaneous uplink
- No need to have same duration and RUs can be left empty
- Transmission is triggered by AP

Enabling Trigger-based Scheduling

- Coordination is distributed, not centralized.
- Can use this central coordination to introduce time-sensitive services into 802.11
  - still assuming a single isolated BSS
- Many enabling functionalities are needed.
- AP scheduler needs to know the ongoing resource expectations, and the current/imminent resource needs.

Updating the Scheduler

- 802.11ax specifies Buffer Status Report (BSR)
- With BSR, STA informs AP of traffic queue per AC
  - Background
  - Best Effort
  - Video
  - Voice
- Only 4 classes, and no distinction of flows within them is possible
- AP scheduler allocates resources per STA
- AP can allocate some OFDMA resources for random access
  - e.g. allows a STA without a resource allocation to send a BSR

IEEE Project P802.11be

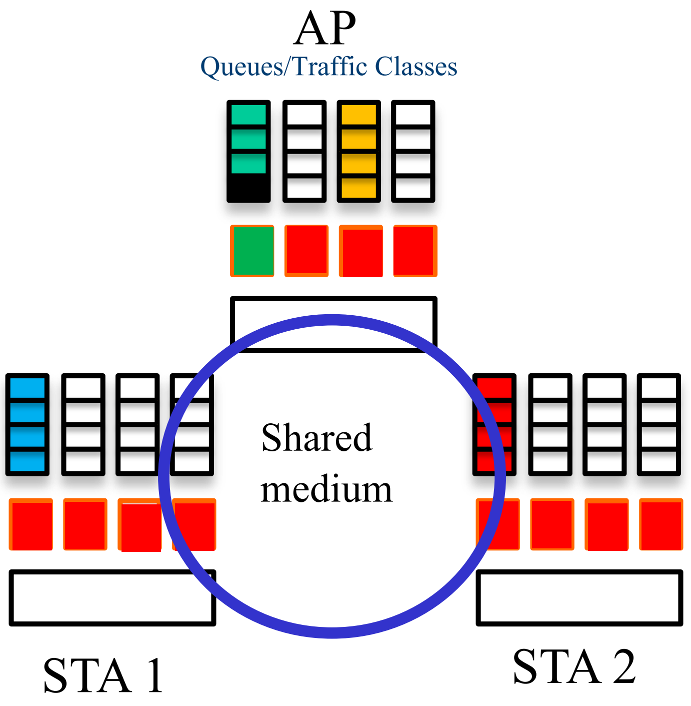
- Authorized: March 2019
  - “at least one mode of operation capable of supporting a maximum throughput of at least 30 Gbps”
  - “at least one mode of operation capable of improved worst case latency and jitter”
    - “New high-throughput, low latency applications will proliferate such as virtual reality or augmented reality, gaming, remote office and cloud computing (e.g., latency lower than 5 ms for realtime gaming).”
    - “Users expect improved integration with Time Sensitive Networks (TSN) to support applications over heterogeneous Ethernet and Wireless LANs.”
      - What is TSN?

Time Sensitivity in IEEE 802

- IEEE 802 networks were traditionally not time-sensitive
  - IEEE 802.16 was an exception
- Time-sensitivity has grown increasingly important
- In the IEEE 802.1 Working Group, time-sensitive networking has become the primary focus
  - Time-Sensitive Networking (TSN) Task Group
  - Audio-video, industrial, automotive, …
  - 5G cellular backhaul

Time-Aware Shaping (802.1Qbv) over Wireless

- **A Time-aware (Qbv) scheduler defines when gates open/close to ensure time-sensitive frames are not interfered by other traffic**



- A Qbv schedule can operate on top of one of the 802.11 MAC modes (e.g. EDCA, 802.11ax Trigger based access)
- The 802.11 network must execute the schedule and deliver frames with **bounded latency.** Support for exchanging Qbv schedules over the air is also needed.
- **Randomness in the 802.11 MAC** (e.g. due to contention) will impact achievable latency bounds and capacity/efficiency
- A **scheduled operation (e.g. based on 802.11ax triggered access)** can provide more predictable latencies/higher efficiency

We Are Interested in Deterministic Service

Traditional Service

Curves have long tail

Average latency is good

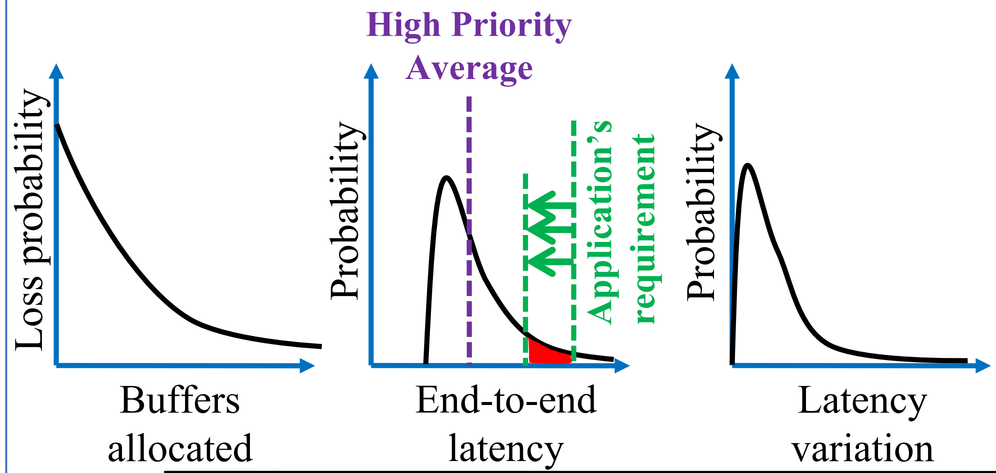
Lowering the latency means
losing packets (or overprovisioning)

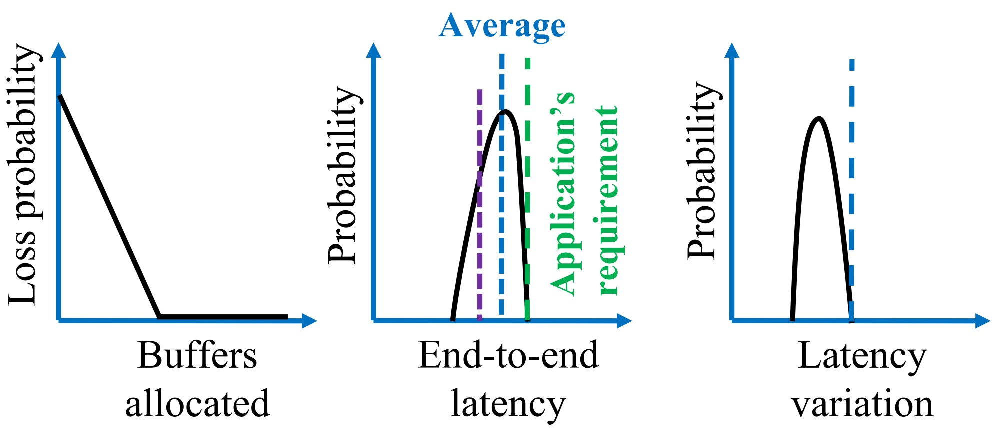
Deterministic Service

Packet loss is at most due to equipment failure
(zero congestion loss)

Bounded latency, no tails

The right packet at the right time





Bounded latency performance can be enhanced in 802.11

- **Congestion due to contention within a BSS and across OBSSs causes variations in channel access latency**
  - EDCA has been successful in resolving contention, but it cannot provide hard bounds on latency/jitter, especially under congestion
- **TSN requires a managed network approach:**
  - 802.11be can provide the tools to manage the network to address the bounded latency/jitter performance under managed OBSS operation
  - This will enable 802.11 to support wireless TSN use cases in private network environments (e.g. enterprise, factories, etc.)

Enhancements to support TSN-grade bounded latency in 802.11be

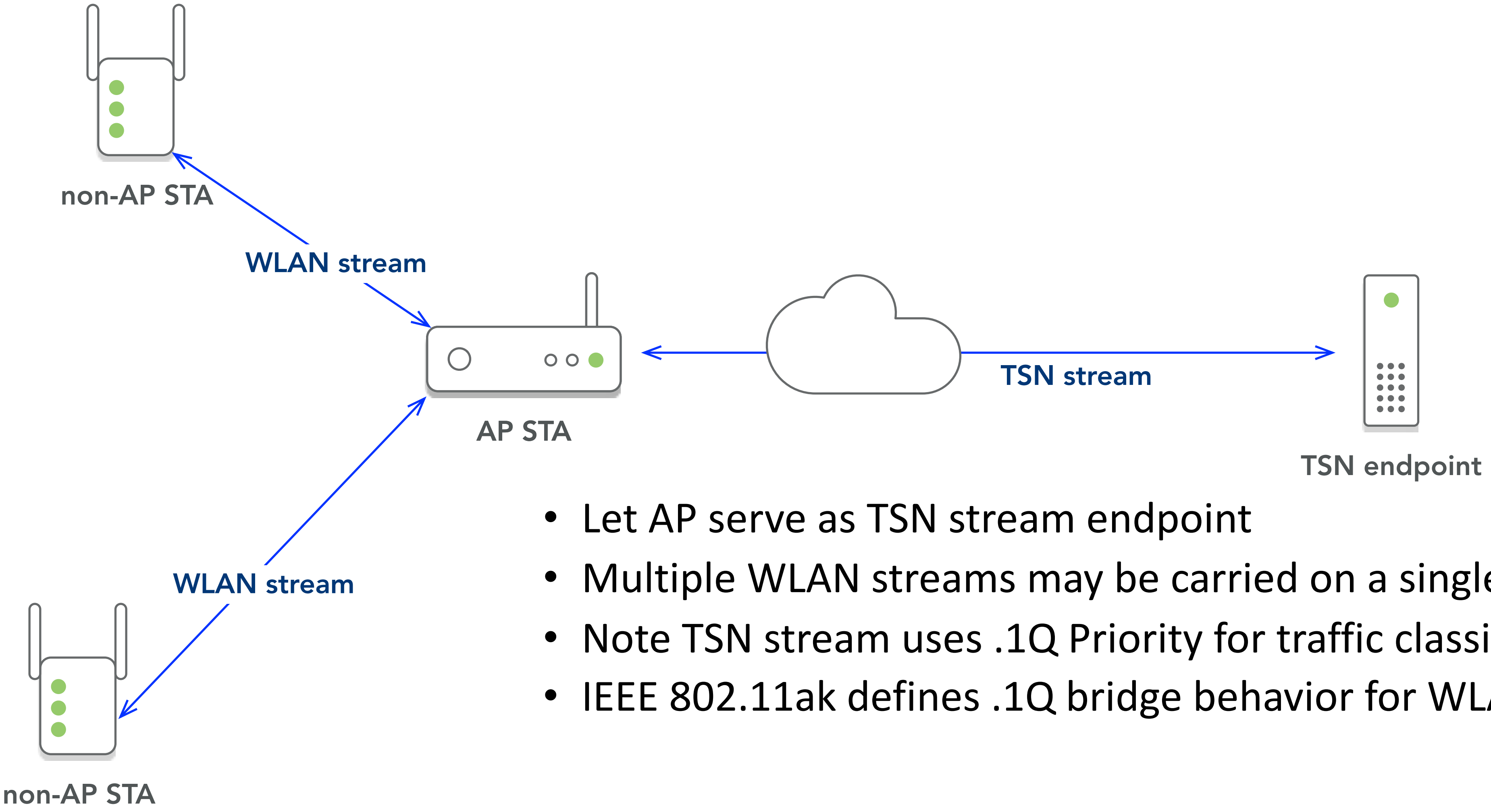
- **Time-sensitive traffic identification and requirements (within and across BSSs)**
  - Protocol enhancements to announce time-sensitive requirements and get confirmation of service
- **Efficient scheduled operation for predictable time-sensitive traffic**
  - Enable AP to control contention within the BSS with Trigger-only access and extend capability to multiple managed OBSSs
  - Mechanisms to control contention when EDCA is used (e.g. limit TXOP duration/contending STAs)
- **Traffic isolation mechanisms (time-sensitive network slicing)**
  - It is relatively easy to schedule resources to serve predictable time-sensitive traffic
  - But the network must also support a mix of predictable (time-sensitive) and unpredictable traffic (best-effort, other non-time-sensitive) efficiently
    - Need mechanisms to "protect" time-sensitive traffic from other traffic/STAs
    - Need to allow STAs (with unpredictable traffic) to indicate resource requests, traffic description updates, power save state changes, buffers reports
    - Need efficient recovery mechanisms (transmission errors, busy NAV during allocation, …)
- **Multi-AP resource coordination across managed OBSSs**

Requires fine granularity identification of flows and per-packet classification

Is the TSN model the right one for WLAN?

- TSN is about supporting a mix of contracted, continuous rate, bounded-latency flows and best-effort traffic.
- Important network traffic is not like either of these.
- Examples:
  - One-way video requires timely delivery of variable-size packets.
  - VoIP requires timely delivery, but with extensive silence.
  - Sensor data requires timely delivery but can be mostly silent.
    - Bursts may be period or unpredictable
  - Aggregated data service may be a bursty mix with latency sensitivity.
  - Some services require contracted QoS parameters but not continuous bit rate or bounded latency.
  - Services may need to be quickly initiated and quickly torn down; can't afford to dedicate unused resources.
- Should consider other QoS models.
  - Bursty traffic vs. continuous traffic over long-living streams
- TSN presumes synchronized gates, but 802.11 traffic traverses a shared medium and is transmitted after a variable delay.
- TSN presumes highly reliable transmission; 802.11 is inherently far less reliable

TSN endpoints



- Let AP serve as TSN stream endpoint
- Multiple WLAN streams may be carried on a single TSN stream
- Note TSN stream uses .1Q Priority for traffic classification
- IEEE 802.11ak defines .1Q bridge behavior for WLAN

IEEE Std 802.16

- Broadband Wireless Access
  - Wireless Metropolitan Area Networks (WirelessMAN)
- Began in 1998
- Produced many versions of IEEE Std 802.16
  - Fixed access
    - Widely deployed, but obsolete
  - Mobile (i.e. “Mobile WiMAX”, an IMT-2000 Technology)
    - The first 4G technology
    - Widely deployed
    - mainly obsolete, but used in utilities, airports (AeroMACS), etc.
  - Advanced version (an IMT-Advanced Technology)
    - Was not deployed
- Working Group entered inactive (hibernating) state in 2018
  - Nov 2019 PAR proposal for utility application amendment

IEEE Std 802.16 QoS Targets

- IEEE 802.16 designed to support multiple PHY specs
  - Single carrier (10-66 GHz in 802.16-2001)
  - Later OFDM and OFDMA
- Original target was fixed wireless access to support multi-tenant infrastructure, including IP and ATM networks
  - a kind of “network slicing”
- QoS based on service-level agreement was key requirement.
- 802.11 architecture was not suitable.
- How were the goals met?

IEEE Std 802.16 MAC Architecture

- Expecting operation in a managed (licensed) environment
- point-to-multipoint, with a central control at the Base Station (BS)
- Scheduled access, both uplink and downlink, with schedule distributed by BS frame by frame
- Connection-oriented
- All scheduling based on service flows
- Various uplink scheduling service, for various QoS needs
- Random access opportunities for devices without an allocation to make a request
- Originally based on “cable TV” technology (DOCSIS)

IEEE Std 802.16 Scheduling

- Primary scheduler is in the BS
- Secondary scheduler is in the subscriber station (SS)
  - The SS may support many connections
    - multiple tenants and multiple diverse services
    - BS schedules uplink resources to the SS as an aggregate for all the uplink connections
    - SS decides how to distribute uplink resources
- 802.16 QoS philosophy is to provide all requirement and status information to schedulers
  - Scheduling algorithms are unspecified
  - Subject of extensive research

IEEE Std 802.16 Key Service Flow Attributes

- Service Flow ID; direction; Connection ID
- PDU Classification Rules
- Payload Header Suppression Rules
- Service Class
- QoS parameter set (Provisioned, Admitted, Active)
  - Maximum Sustained Traffic Rate
  - Maximum Traffic Burst
  - Minimum Reserved Traffic Rate
  - Maximum Latency
  - Tolerated Jitter
  - Unsolicited Grant Interval
  - Unsolicited Polling Interval
  - etc.

IEEE Std 802.16 Scheduling Services/QoS Classes

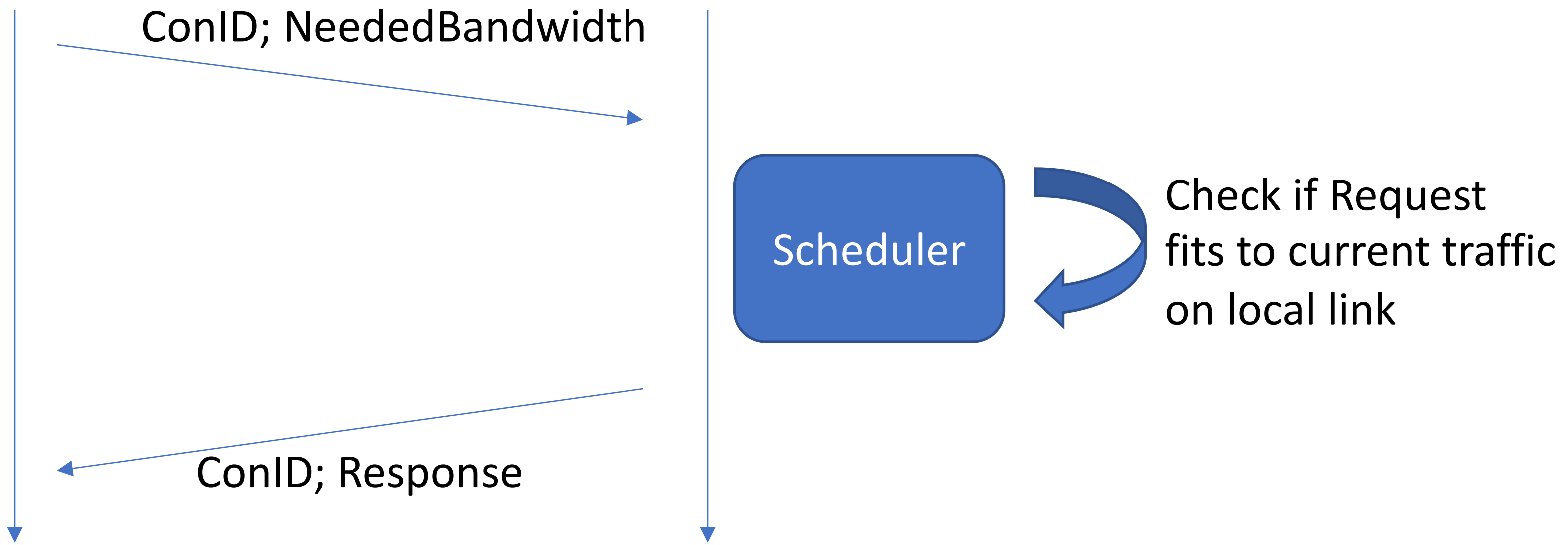
- Unsolicited Grant Service (UGS): periodic unsolicited fixed-size grants (continuous bit rate)
- Real-Time Polling Service (rtPS): periodic unsolicited variable-size grants (e.g., MPEG video)
- Extended Real-Time Polling Service (ertPS): periodic unsolicited variable-sized grants and polling
- Non-Real-Time Polling Service (nrtPS): periodic polling
- Adaptive Grant and Polling Service (aGPS): manages both primary and secondary QoS parameter sets
  - Example: toggle between VoIP active and VoIP silence
- Best Effort (BE)

QoS classes from 3GPP

QCI	Resource Type	Priority Level	Packet Delay Budget (NOTE 13)	Packet Error Loss Rate (NOTE 2)	Example Services
1 (NOTE 3)		2	100 ms (NOTE 1, NOTE 11)	10^{-2}	Conversational Voice
2 (NOTE 3)	GBR	4	150 ms (NOTE 1, NOTE 11)	10^{-3}	Conversational Video (Live Streaming)
3 (NOTE 3, NOTE 14)		3	50 ms (NOTE 1, NOTE 11)	10^{-3}	Real Time Gaming, V2X messages Electricity distribution - medium voltage (e.g. TS 22.261 [51] clause 7.2.2) Process automation - monitoring (e.g. TS 22.261 [51] clause 7.2.2)
4 (NOTE 3)		5	300 ms (NOTE 1, NOTE 11)	10^{-6}	Non-Conversational Video (Buffered Streaming)
65 (NOTE 3, NOTE 9, NOTE 12)		0.7	75 ms (NOTE 7, NOTE 8)	10^{-2}	Mission Critical user plane Push To Talk voice (e.g., MCPTT)
66 (NOTE 3, NOTE 12)		2	100 ms (NOTE 1, NOTE 10)	10^{-2}	Non-Mission-Critical user plane Push To Talk voice
67 (NOTE 3, NOTE 12)		1.5	100 ms (NOTE 1, NOTE 10)	10^{-3}	Mission Critical Video user plane
75 (NOTE 14)		2.5	50 ms (NOTE 1)	10^{-2}	V2X messages
71		5.6	150ms (NOTE 1, NOTE 16)	10^{-6}	"Live" Uplink Streaming (e.g. TS 26.238 [53])
72		5.6	300ms (NOTE 1, NOTE 16)	10^{-4}	"Live" Uplink Streaming (e.g. TS 26.238 [53])
73		5.6	300ms (NOTE 1, NOTE 16)	10^{-8}	"Live" Uplink Streaming (e.g. TS 26.238 [53])
74		5.6	500ms (NOTE 1, NOTE 16)	10^{-8}	"Live" Uplink Streaming (e.g. TS 26.238 [53])
76		5.6	500ms (NOTE 1, NOTE 16)	10^{-4}	"Live" Uplink Streaming (e.g. TS 26.238 [53])
5 (NOTE 3)		1	100 ms (NOTE 1, NOTE 10)	10^{-6}	IMS Signalling
6 (NOTE 4)		6	300 ms (NOTE 1, NOTE 10)	10^{-6}	Video (Buffered Streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
7 (NOTE 3)	Non-GBR	7	100 ms (NOTE 1, NOTE 10)	10^{-3}	Voice, Video (Live Streaming) Interactive Gaming
8 (NOTE 5)		8	300 ms (NOTE 1)	10^{-6}	Video (Buffered Streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file
9 (NOTE 6)		9			sharing, progressive video, etc.)
69 (NOTE 3, NOTE 9, NOTE 12)		0.5	60 ms (NOTE 7, NOTE 8)	10^{-6}	Mission Critical delay sensitive signalling (e.g., MC-PTT signalling, MC Video signalling)
70 (NOTE 4, NOTE 12)		5.5	200 ms (NOTE 7, NOTE 10)	10^{-6}	Mission Critical Data (e.g. example services are the same as QCI 6/8/9)
79 (NOTE 14)		6.5	50 ms (NOTE 1, NOTE 10)	10^{-2}	V2X messages
80 (NOTE 3)		6.8	10 ms (NOTE 10, NOTE 15)	10^{-6}	Low latency eMBB applications (TCP/UDP-based); Augmented Reality

- QoS Classes from 3GPP require of a finner granularity to distinguish between bearers
- Also, may need to distinguish bearers of the same class; e.g. from different tenants

Bandwidth Requests



- ConID in requests is equal to ConID in data messages
  - Either present within the packet or referenced to with combination of packet parameters
- Only if Request is Successful determinism can be achieved
- Assuming wired reservations are not changed, only added over time

Scheduling Services in 802.11

- IEEE 802.11ax supports the core elements to schedule traffic:
  - Could be implemented on top of 802.11ax, in a “managed network”
    - for a single isolated BSS (potentially multi-BSS using multi-AP coordination)
- Many algorithms in the literature can be used for deterministic scheduling per flow
- Missing point: How do we match the packet to the connection (the flow, or stream)?
  - The available 3 bits are not enough
  - Classification per packet takes time
  - Classification should be done once, at the entry point to the IEEE 802 network or at the source, and should be usable throughout the IEEE 802 network
- This problem has been tackled multiple times in previous technologies
  - **Key missing piece: Connection Identifier (ala MPLS, IEEE 802.16, DOCSIS, 3GPP…)**
- Can we add a flow classifier without disrupting the 802.11 frame format?

Connection Identifier (ConID)

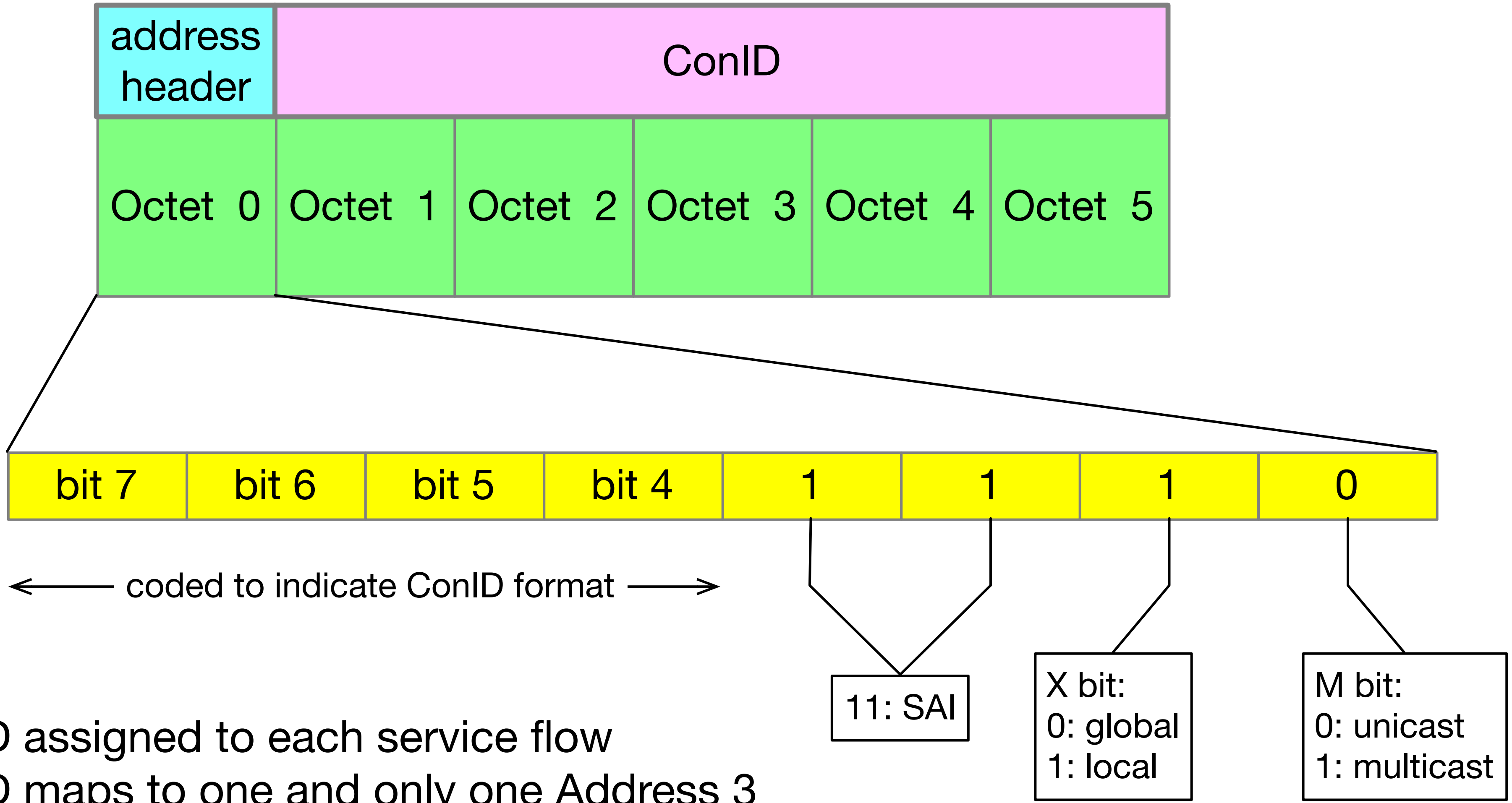
- IEEE 802.16 frame does not include the MAC SA or DA in the header.
  - This can implicitly be part of the ConID.
  - That is, the CID maps to a specific SA and DA.
- Option A: adapt this approach to 802.11
  - Greenfield scenario: With a ConID, the three MAC addresses in the 802.11 frame header are redundant.
    - We could compress the 802.11 MAC header.
    - Potential compatibility challenges.
- Option B: Backward-compatible approach
  - Without altering the 802.11 frame structure, piggyback the ConID into the MAC address.

802.11 Connection Identifier (ConID)

- ConID Option A: Address 3 (Source/Destination MAC Address) is not needed; could be repurposed as ConID
- ConID Option B: Address 1/2 (non-AP STA MAC Address) could be structured to contain the ConID

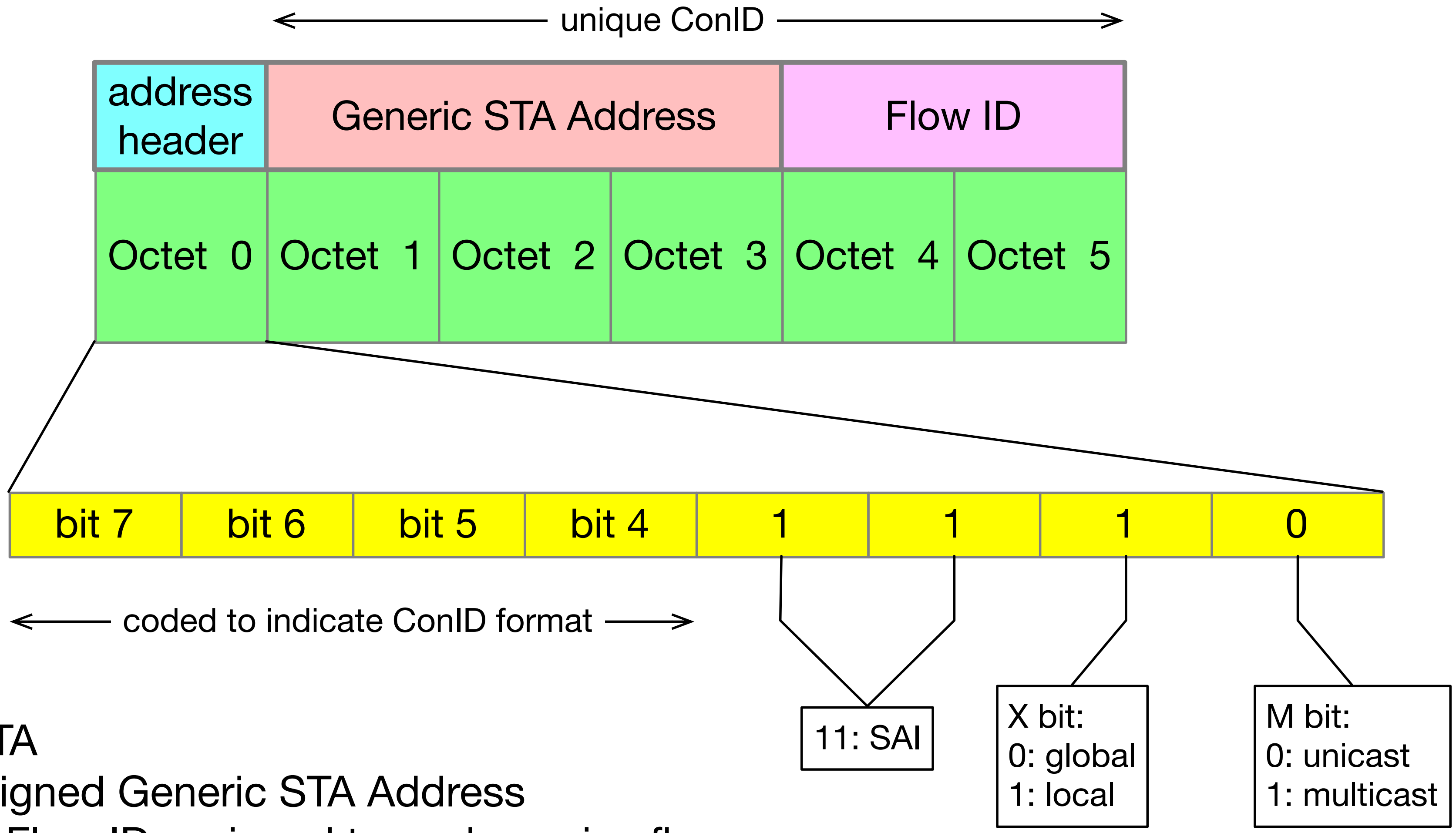
- This can exploit the structured address space per IEEE Std 802c
  - The IEEE 802 48-bit MAC Address space is half global and half local
  - Local addresses can be assigned dynamically and semantically
  - “Standard-Assigned Identifier” (SAI) usage in one-fourth of local space
    - the usage of these identifiers is subject to specification in IEEE standards
    - Local address assignment standard under development in 802.1 TSN (P802.1CQ project) can help support the necessary Connection ID.

ConID Option A: Address 3 SAI carries ConID



- ConID assigned to each service flow
- ConID maps to one and only one Address 3
- In downlink, AP needs to replace SA with the SAI
- In uplink, AP needs to replace SAI with the actual DA

ConID Option B: Non-AP STA SAI carries ConID



non-AP STA

- is assigned Generic STA Address
- has a Flow ID assigned to each service flow
- uses SAI as a MAC SA
- receives frames addressed to any SAI in block

End-to-End QoS

- Guaranteed QoS needs to be end-to-end
- Packets need to be suitably marked from end to end
- What’s an end-to-end marker of an 802 frame?
  - ➢MAC Address (DA and/or SA)
- In ConID Option A, the ConID is carried only in the WLAN
- In ConID Option B, the ConID is carried in the MAC address, and thereby end-to-end in the LAN
  - MAC/ConID address will specify WLAN QoS
  - VLAN PCP will specify Wired QoS

  => Full flexibility

Summary

- IEEE Std 802.11 has become more capable with time.
- IEEE 802.11 QoS remains unsuitable for many time-sensitive uses.
- 802.1 TSN is unsuitable for some use cases.
- IEEE 802.11ax provides an AP with BSS control.
- Deterministic WLAN could be based on QoS-sensitive scheduling services adopted from 802.16 (and similar standards).
- Local address assignment protocols under development in 802.1 TSN can support the necessary Connection ID (P802.1CQ project)

Next Steps

Potential Nendica Work Item

-explore interactions & linkages between WLAN QoS & TSN

- TSN stream identification and mapping; address assignment…

-summarize options

-summarize enabling implications for standards

- appears to require upper-MAC message specifications, not PHY/MAC operational changes

-propose to begin with a Nendica Study Item

Other options?

References

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- P802.11be (“Enhancements for Extremely High Throughput”, pre-draft) <https://standards.ieee.org/project/802_11be.html>
- IEEE 802.1 Time-Sensitive Networking (TSN) Task Group <https://1.ieee802.org/tsn/>
- P802.1CQ (“Multicast and Local Address Assignment”, draft) <https://1.ieee802.org/tsn/802-1cq/>
- IEEE Std 802c-2017 (“Local Medium Access Control (MAC) Address Usage”) <https://standards.ieee.org/standard/802c-2017.html>
- IEEE Std 802.16-2017 (“Air Interface for Broadband Wireless Access Systems”) <https://standards.ieee.org/standard/802_16-2017.html>