

IEEE 802.1 Plenary, November 2020

802.1 TSN over 802.11 with updates from developments in 802.11be

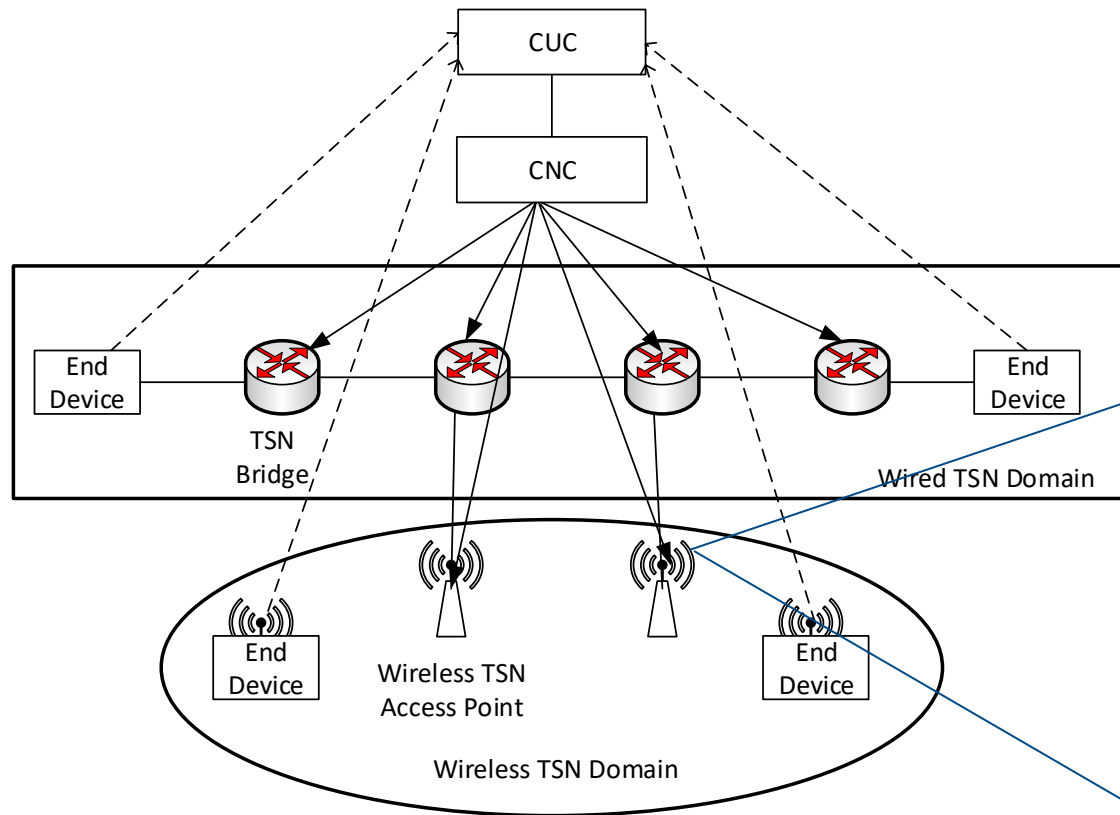
Dave Cavalcanti and Ganesh Venkatesan



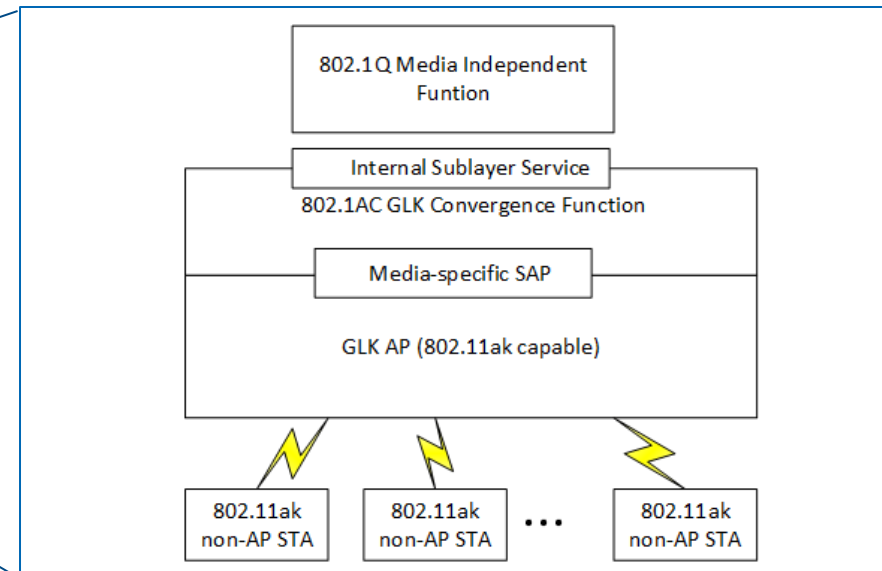
References to IEEE802.11 documents

- TSN Traffic stream classification over 802.11 (VLAN tag in TCLASS)
- Support for 802.1AS-2020 over 802.11 with Timing Measurement and Fine Timing Measurement protocols (IEEE Std. 802.11-2016)
- Support for Enhancements For Transit Links Within Bridged Networks (802.11ak features in IEEE802.11 REVm D5.0)

802.11 in an 802.1 TSN network



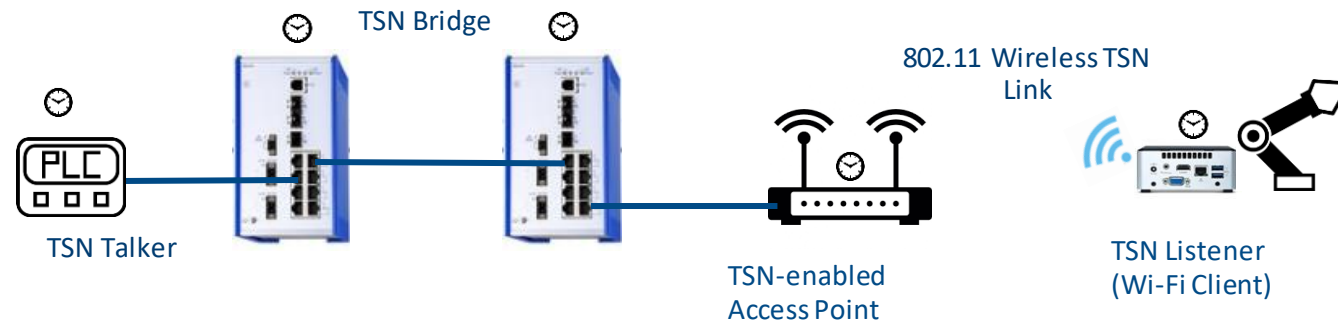
- Figure describing an end-to-end TSN network 802TSN Bridges, CNC, CUC, 802.11 AP with support for 802.11ak



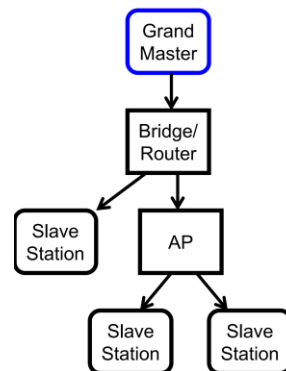
TSN features that can already operate over 802.11: 802.1AS time sync, Qbv, CB...

802.1AS Time Synchronization over 802.11

Synchronization across wired-wireless TSN



- A PLC's control cycle can be synchronized with other PLCs/Sensors/Actuators over 802.11 links
- Time-Aware traffic shaping (e.g. 802.1Qbv) operate based on the same reference clock can be applied over 802.11 links



802.11 defined MAC specific support for 802.1AS

- Timing Measurement (TM) – 802.11-2012
- Fine Timing Measurement (FTM) – 802.11-2016

802.11 modes for supporting 802.1AS

802.1AS time synch over 802.11 TM

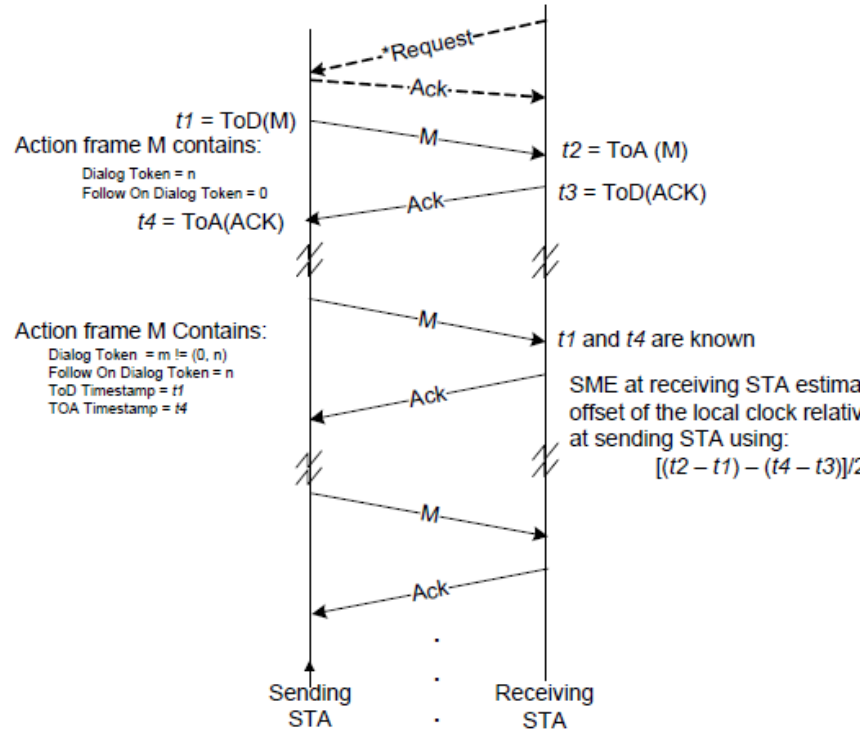


Figure 10-23—Timing measurement procedure

802.1AS time synch over 802.11 FTM

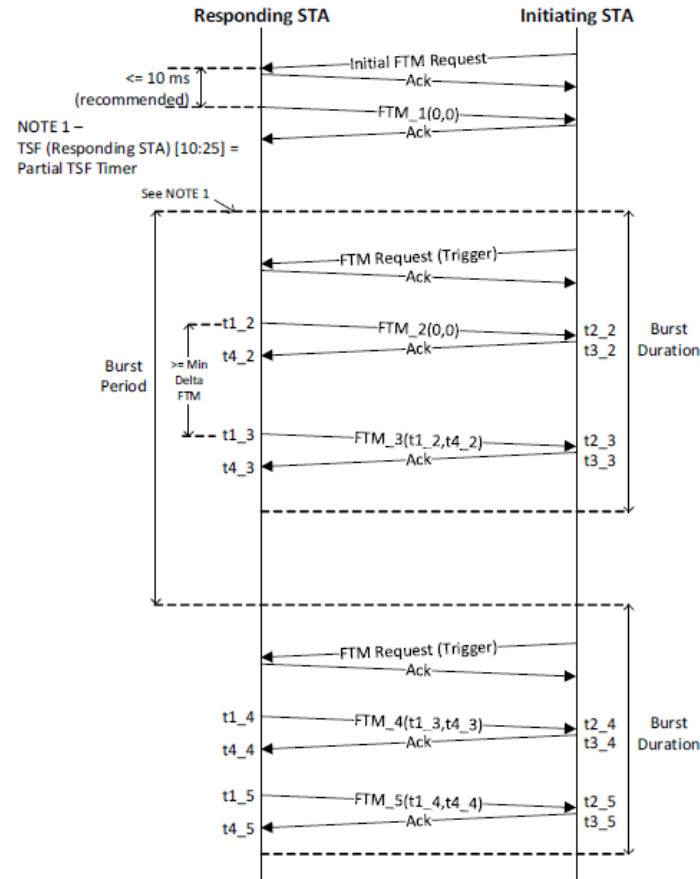


Figure 11-35—Example negotiation and measurement exchange sequence, ASAP=0, and FTMs per Burst = 2

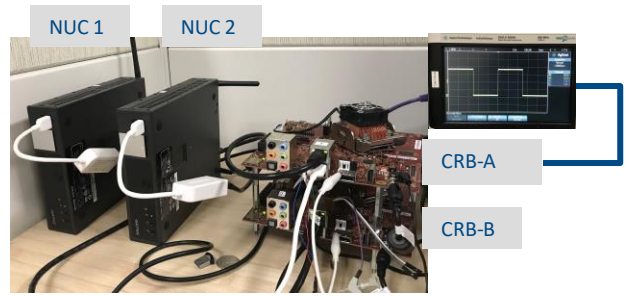
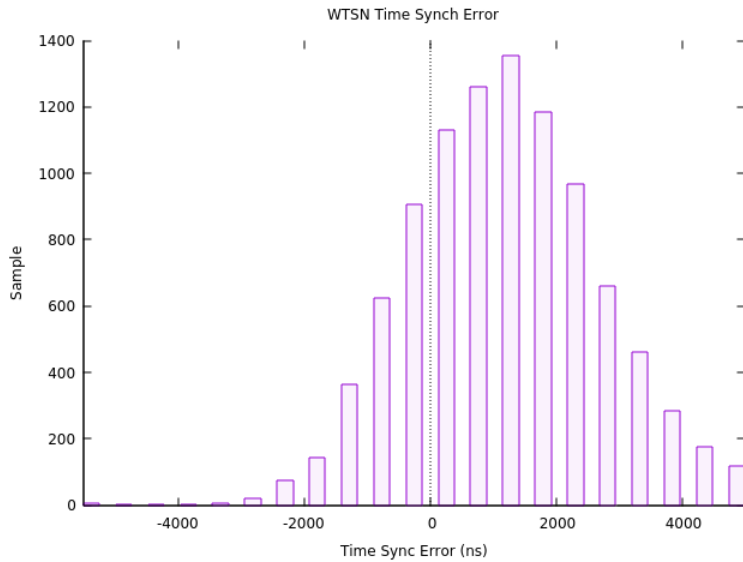
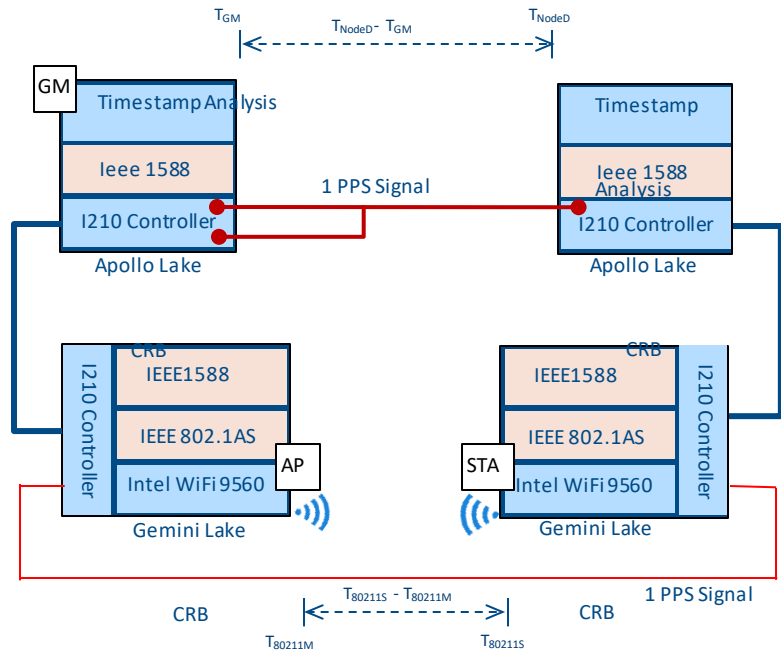
802.11 action frames are used to compute:

$$\text{LinkDelay} = [(t4 - t1) - (t3 - t2)] / 2$$

$$\text{NeighborRateRatio} = (t1' - t1) / (t2' - t2)$$

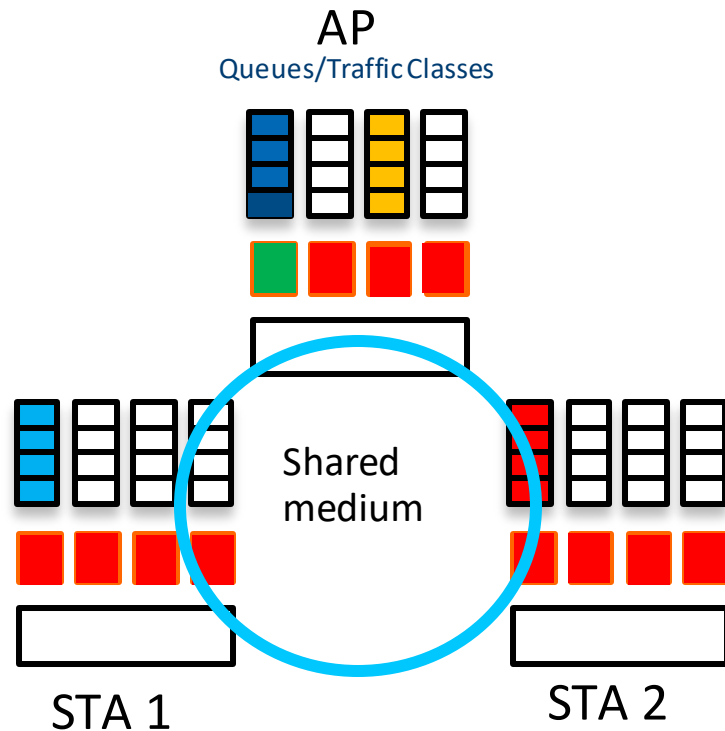
$$\text{TimeOffset} = [(t2 - t1) - (t4 - t3)] / 2$$

Experiments with 802.1AS over 802.11 TM



Time-Aware Shaping (802.1Qbv) over 802.11

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



A Qbv schedule can operate on top of one of the 802.11 MAC (e.g. EDCA or 802.11ax Trigger based access modes)

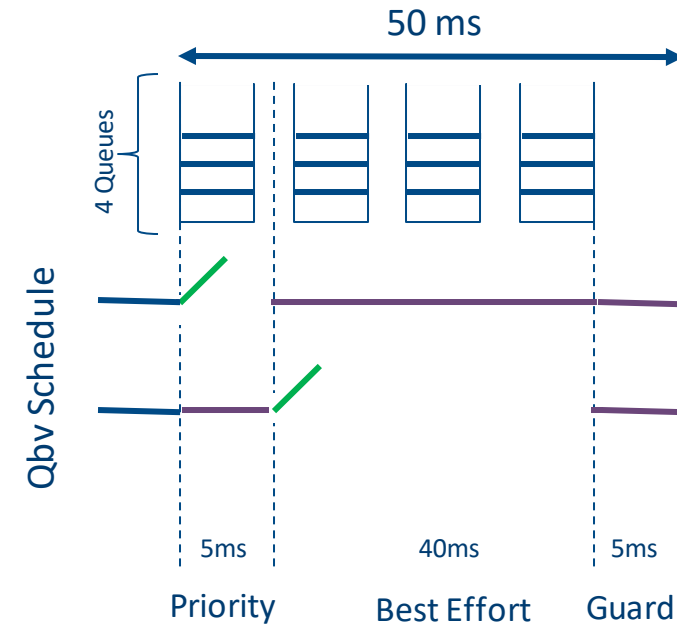
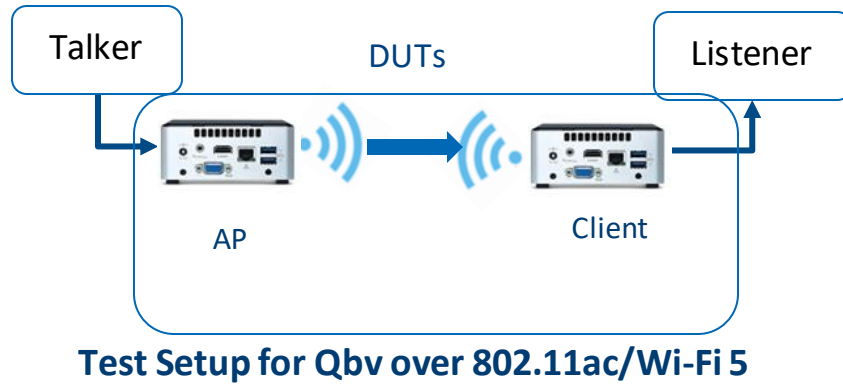
The 802.11 network must execute the schedule and deliver frames with bounded latency

The 802.11 MAC access delay will impact achievable latency bounds and capacity/efficiency

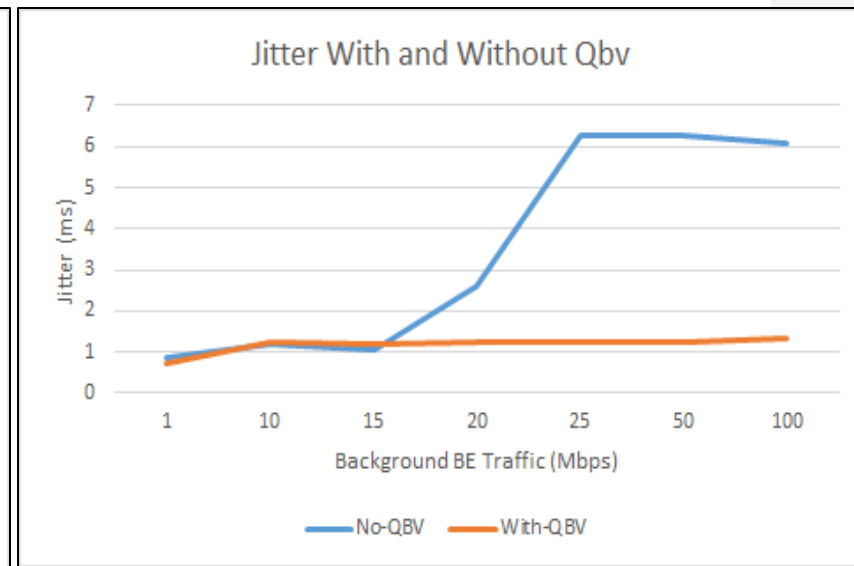
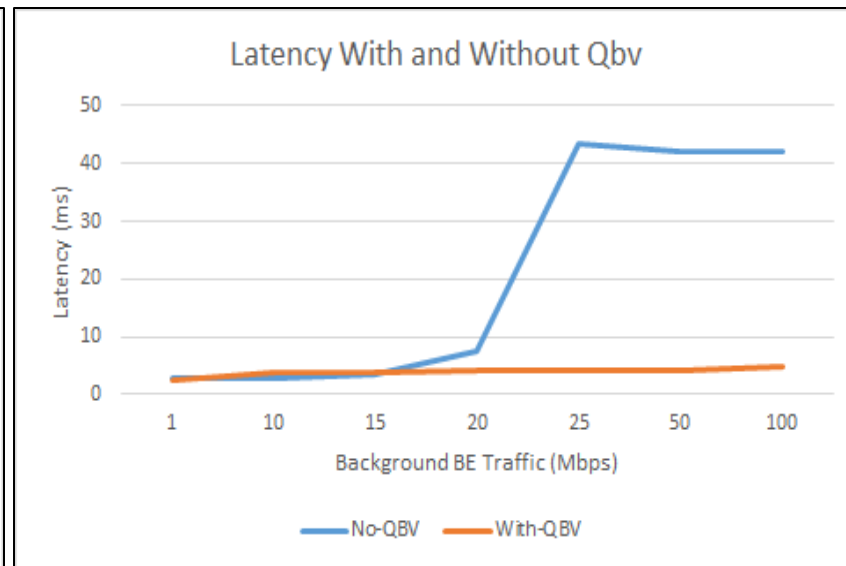
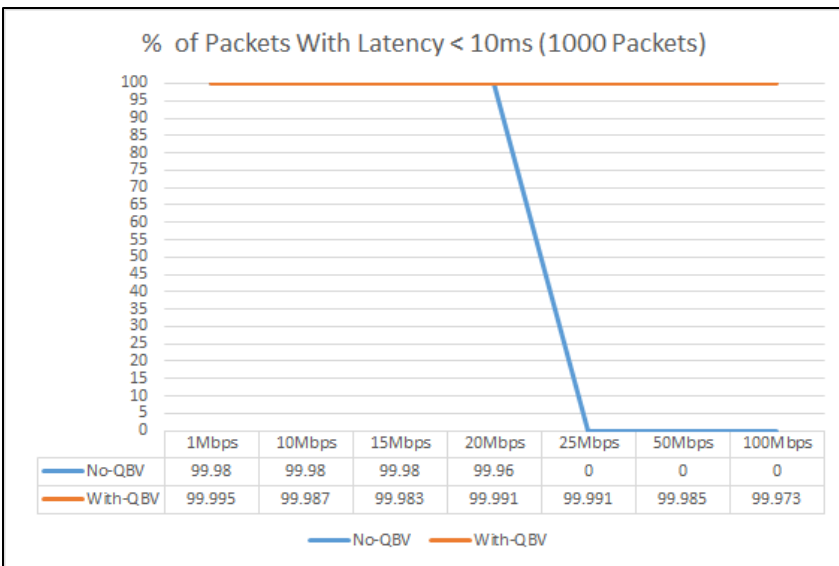
A scheduled operation (e.g. based on 802.11ax triggered access) can provide more predictable latencies/higher efficiency

Further enhancements are being developed as part of 802.11be

802.1Qbv over 802.11 (EDCA) test



Priority Traffic: **100 byte packet every 50 ms** with background BE from 1Mbps to 100 Mbps and **Qbv cycle time of 50 ms**



802.1Qbv Scheduling over 802.11ax

Schedule configuration: the CNC delivers a schedule to the 802.11ax AP (supporting TSN)

The AP uses the trigger-based mode to deliver the data according to the worst-case latency and reliability

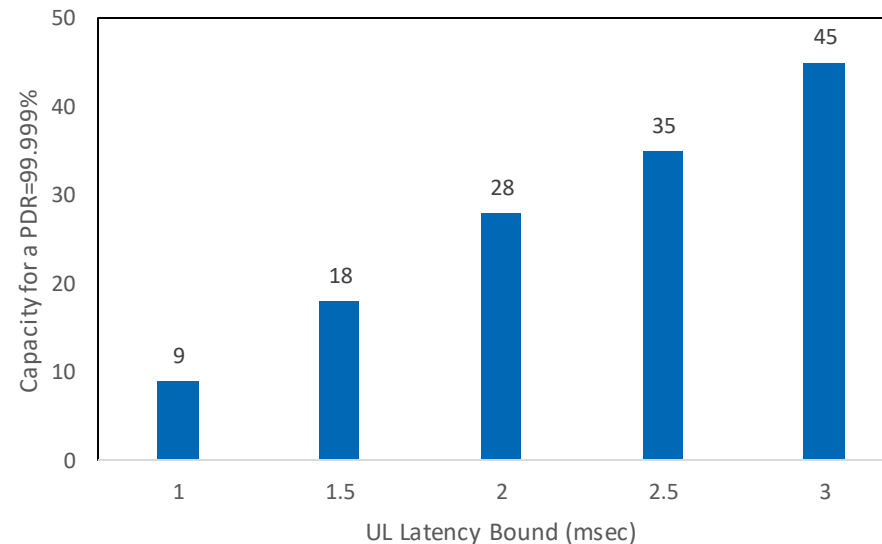
Low latency/high reliability and capacity tradeoffs can be achieved

Trigger frame figure

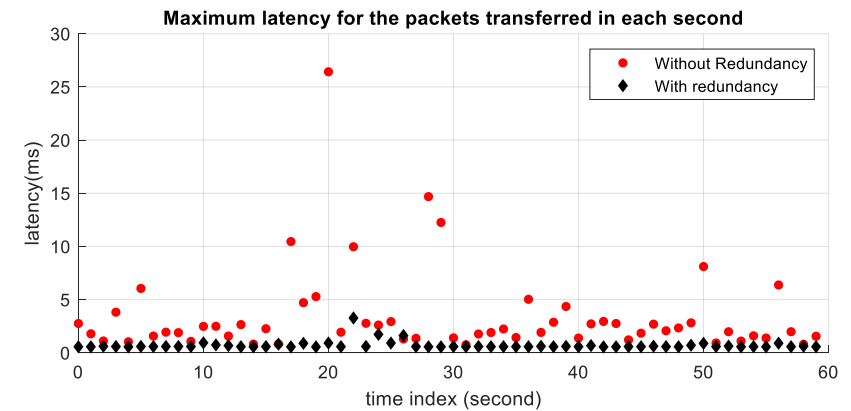
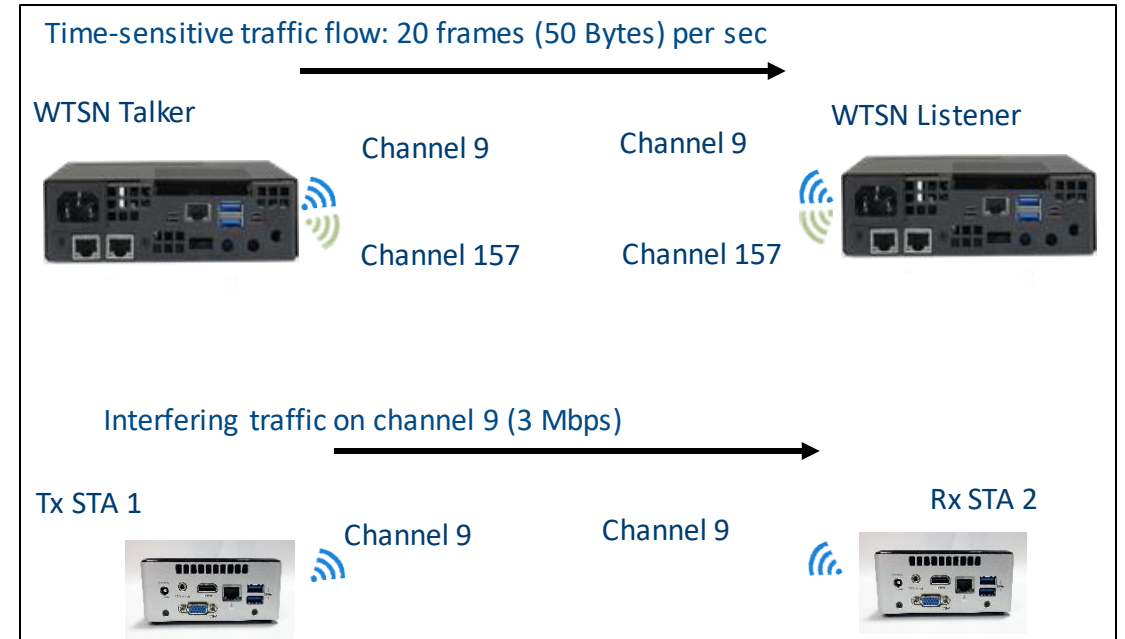
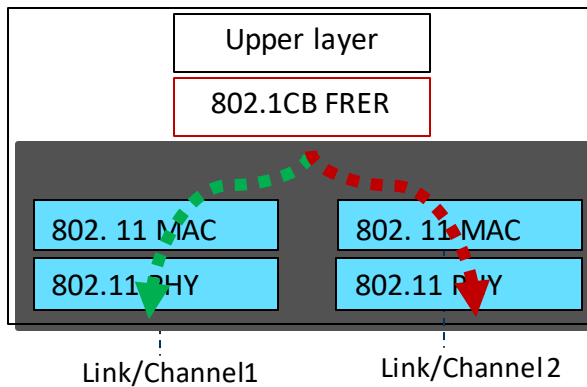
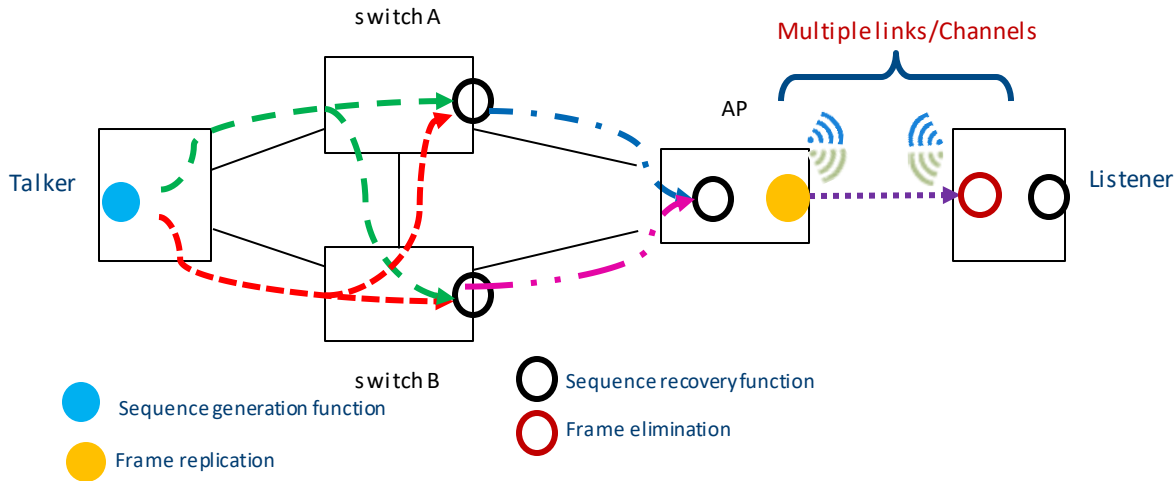
Simulation Assumptions:

20 MHz channel, SISO, 100 Bytes packets,
Channel model E, STAs randomly distributed in
a 50 m radio, latency-optimized scheduling
strategy, managed network (no OBSS).

Capacity vs. Latency bound (msec)
for Target PDR = 99.999%



802.1CB FRER over 802.11



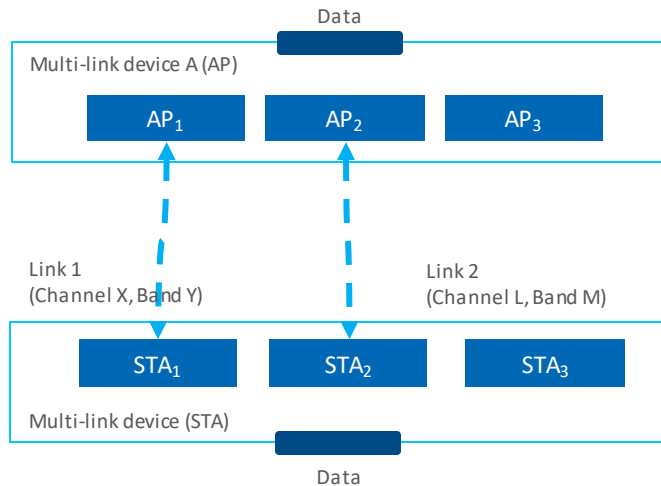
802.11be features supporting TSN

802.11be Key Enhancements

320 MHz channels
4096-QAM
16 spatial streams

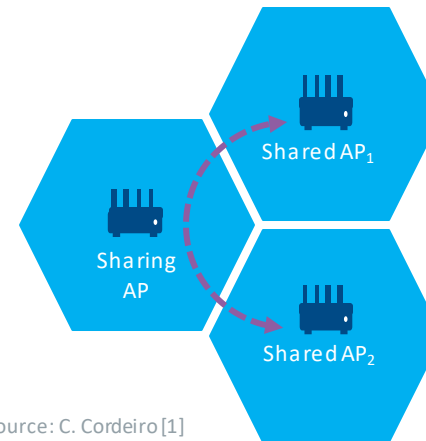
Multi-link operation
Multi-AP operation
Deterministic Low latency/TSN support

MLO (Multi-Link Operation)



Enables redundancy at the 802.11 MAC
New tools to avoid congestion delay

Multi-AP features



Source: C. Cordeiro [1]

Different flavors of multi-AP solutions are being considered (MAC-driven and PHY-driven)

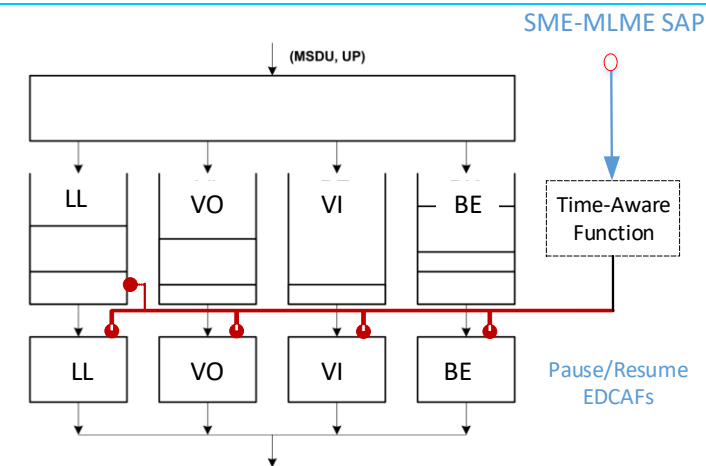
Extending coordination beyond a single BSS to provide more control over key performance metrics

Enhanced Determinism in 802.11be

- **Wi-Fi 6 can achieve single-digit millisecond** latency, but the worst-case latency may still vary under congestion
- With multi-link operation, multi-AP and 320 MHz channels in Wi-Fi 7, latency will be reduced even further
- However, to provide more predictable low latency (enhanced determinism), new protocol enhancements need to be defined

Potential features for deterministic low latency

- QoS provisioning model for low latency reliable traffic streams
- Define dedicated, low-latency (LL) and reliable access category
- Time-Aware (Qbv) scheduled access integrated in the MAC with protected service periods
- Limit TXOP duration across networks and packet preemption



<https://mentor.ieee.org/802.11/dcn/20/11-20-0418-03-00be-low-latency-service-in-802-11be.pptx>

Potential areas to extend 802.11-802.1 TSN collaboration

- Configuration and adaptation of time-aware (802.1Qbv) scheduling over wireless/802.11
 - Should 802.1Qbv be aware of wireless links (with variable capacity)?
 - Mapping of Qbv schedule to 802.11 QoS/TSPEC and admission control (ongoing discussions in 11be)
- 802.1CB over 802.11be MLD
 - the MLD enables frame duplication and elimination within the 802.11 MAC (part of 802.1CB functionality)
 - How to leverage the 802.11be MLD for optimized FRER with 802.1CB and 802.11be?

Next steps

- TSN support is part of the 802.11be PAR
 - Basic functionalities are being defined in 802.11be R1 (MLD, low latency/QoS features being discussed)
 - 802.11be Draft 0.1 available
 - Additional TSN support features will be discussed in R2 (starting soon)
 - Opportunities to enhance TSN support (redundancy, preemption, ...) and coordination with 802.1 TSN specifications

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