WI-FI TSN CAPABILITIES AND EVOLUTION TOWARDS DETERMINISTIC LOW LATENCY

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Reliable and Available Wireless (RAW) WG, IETF 108, July 30, 2020

Outline

New use cases and requirements for Wi-Fi

TSN over 802.11

Wi-Fi 6/6E scheduling enhancements

Wi-Fi7/802.11be lower latency, high reliability and enhanced determinism

802.11-based localization

New Time-sensitive Applications for Wi-Fi

Emerging time-sensitive applications require more accurate time synchronization and predictable low latency with higher reliability

Robotics, Autonomous Systems, Industrial controls

Immersive VR & Pro Gaming

Requirements defined in the 802.11 RTA TIG Report

Use cases		Intra BSS latency (msec)	Jitter variance (msec) [4]	Packet loss	Data rate Mbps
Real-time gaming [2]		< 5	< 2	< 0.1 %	< 1
Cloud gaming [15]		< 10	< 2	Near-lossless	<0.1 (UP) >5Mbps (DW)
Real-time video [3]		< 3 ~ 10	< 1~ 2.5	Near-lossless	100 ~ 28,000
Robotics and industrial automation [1]	Equipment control	< 1 ~ 10	< 0.2~2	Near-lossless	< 1
	Human safety	< 1~ 10	< 0.2 ~ 2	Near-lossless	< 1
	Haptic technology	<1~5	<0.2~2	Lossless	<1
	Drone control	<100	<10	Lossless	<1 >100 with video

https://mentor.ieee.org/802.11/dcn/19/11-19-0065-06-0rta-rta-tig-summary-and-recommendations.pptx

TSN support and enabling capabilities in 802.11

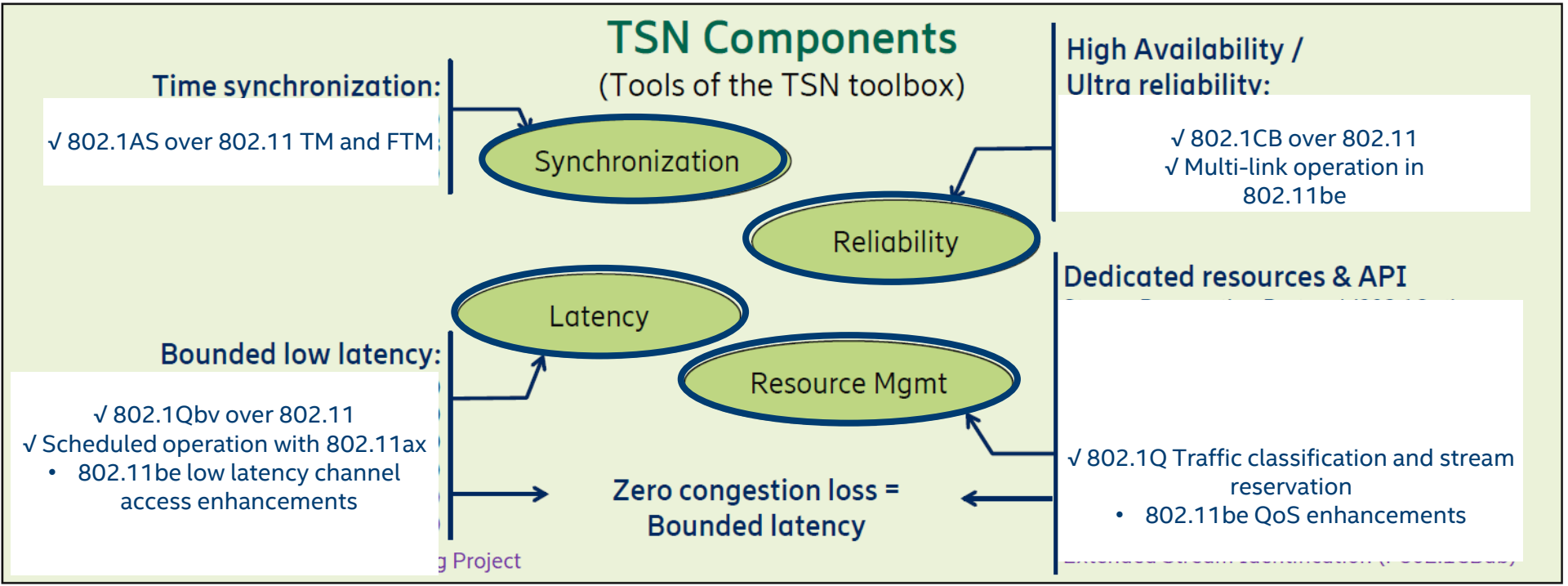


Figure from Janos Farkas, Doc#11-1298r1, July 2019 IEEE 802.11 Plenary

IEEE802.1AS-2020

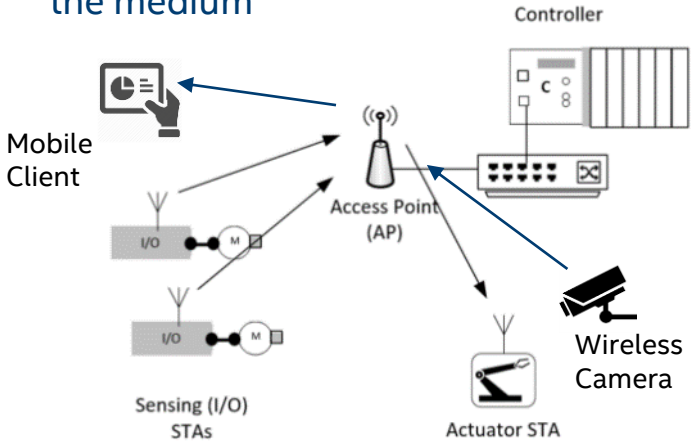
- Enables the use of IEEE802.11-2016 Timing Measurement (TM) and Fine Timing Measurement (FTM) protocols for time synchronization
- The FTM protocol enables
  - End-stations to have more control over the execution of the protocol
  - Higher resolution for timestamps (100 picosecond units)
  - 48-bit fields for timestamps (wraps around less frequently)
  - Measurement bursts to detect and account for wireless channel asymmetry (Tx path is different from the Rx path)
  - Potentially higher accuracy in time synchronization performance
  - Geolocation/positioning

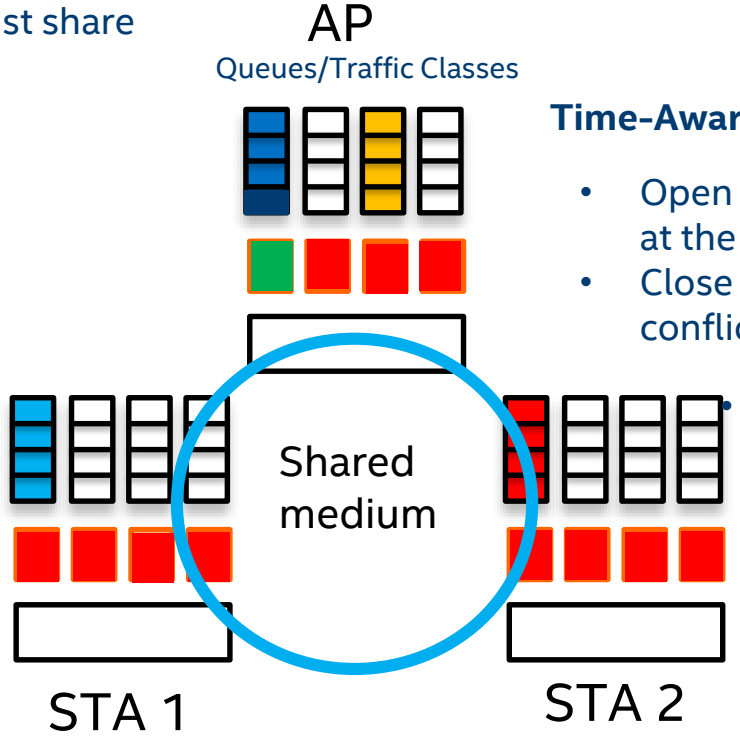
Time-Aware Scheduling (802.1Qbv) over Wireless

Time

Latency

Time-sensitive and Best-effort traffic must share the medium





Time-Aware traffic shaping

- Open a time-sensitive queue at the right time
- Close other queues to avoid conflicts

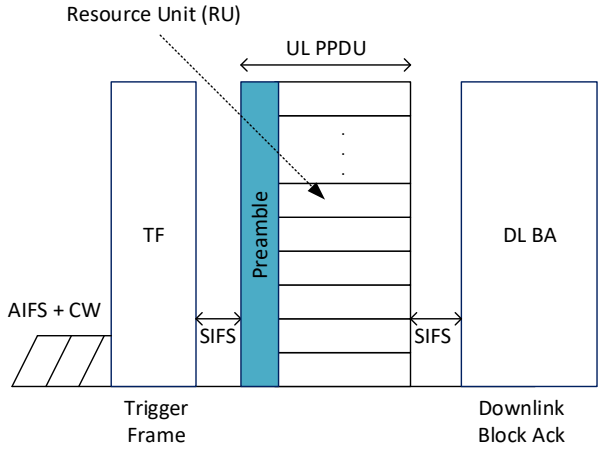
The wireless system scheduler is responsible for meeting **hard deadlines** (bounded latency) with high reliability and efficiency

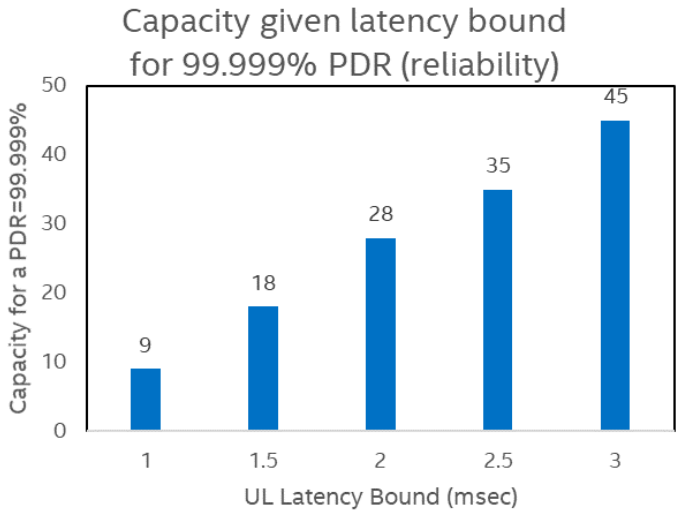
Time-Aware Scheduling with Wi-Fi6

Latency

Efficiency

802.11ax Multi-user Trigger-based with time-aware scheduling for UL





Capacity = number of STAs that can be supported with a given latency bound (1 – 3 msec) and 99.999% reliability*

802.11ax with time-aware scheduling can support low latency and high reliability in managed environments

* Assumptions: 20 MHz channel, SISO, 100 Bytes packets, Channel model E, STAs randomly distributed in a 50 m radio

PDR: Packet Delivery Ratio (fraction of packets successfully delivered within the latency bound)

Wi-Fi6E – More flexibility and spectrum

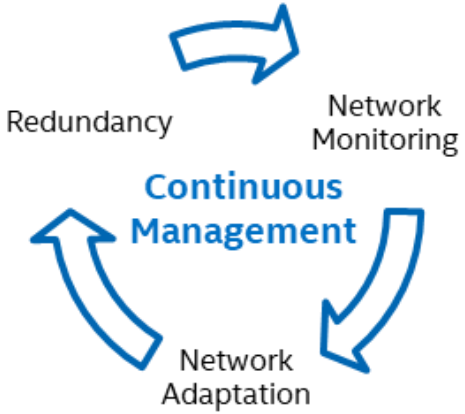
Latency

Reliability

- Extends Wi-Fi 6 with 6 GHz band operation*
- Launching Jan'21
- Key enabler for new usages that require determinism

	2.4GHz Band	5GHz Band	6GHz Band
Spectrum	85MHz	480MHz	1200MHz
20MHz Channels	3	25	59
40MHz Channels	1	12	29
80MHz Channels	0	6	14
160MHz Channels	0	2	7

More flexibility to adapt the network to interference and congestion enabling more resilience to unmanaged threats



* 6 GHz operation subject to regulatory rules in each country.

Key Wi-Fi 7 Features*

User Experience Data Rate

Spectrum Efficiency

Network Energy Efficiency

Connection Density

Key Enhancements

320 MHz channels
4096-QAM
16 spatial streams

Multi-link operation
Multi-AP operation
Deterministic low latency

Enablers of lower worst-cast latency and jitter

Multi-RU (puncturing)

Peak Data Rate

Cost Effective

Area Capacity

Low Latency

* Accurate as of June/2020. Feature set and their specification are subject to change.

Source: [1] C. Cordeiro, Next Gen Wi-Fi: Wi-Fi7 and Beyond https://pages.questexnetwork.com/IntelSenzaFili-Registration-06262020.html?source=Listing

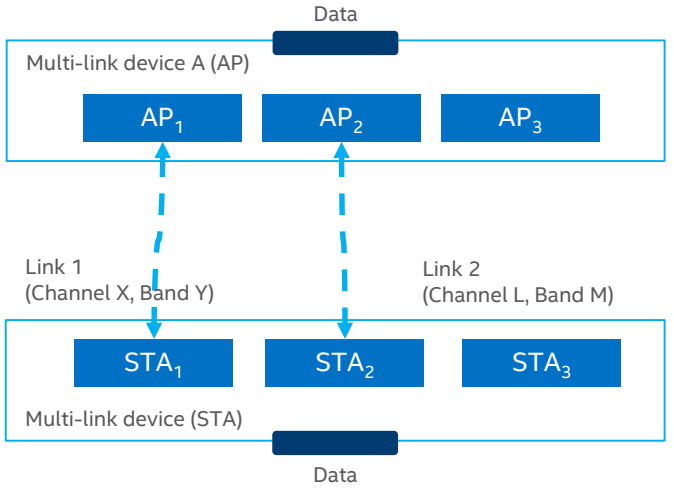
Multi-link Operation (MLO) for lower latency and reliability

MLO enables link aggregation at the MAC layer

- A link is mapped to a channel and band

MLO brings benefits in multiple dimensions:

- Additive throughput for data flows split over links
  - **For two links (e.g., 5 GHz and 6 GHz), max aggregate data rate could reach 7.2x compared to Wi-Fi 6**
- Lower latency due to access to multiple links in parallel
- High reliability by packets duplication over multiple links
- Assign data flows to specific links based on app needs



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

MLO provides higher throughput, lower latency and/or higher reliability, which are useful to a number of applications from VR/AR to industrial IoT

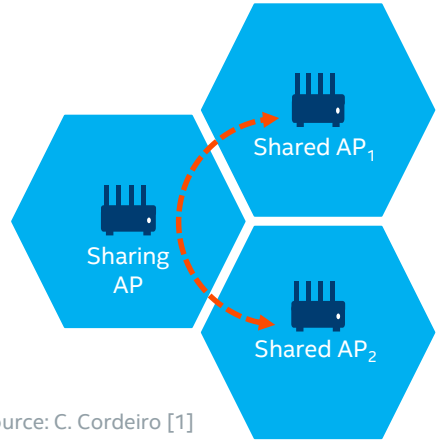
Source: C. Cordeiro [1]

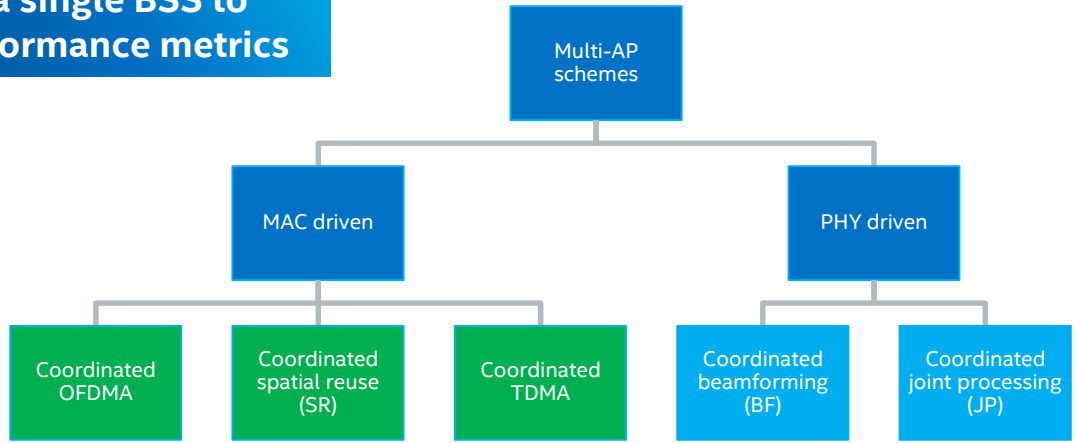
Multi-AP Features

Multi-AP refers to a collection of features that rely on direct AP coordination to achieve desired network performance goals

Different flavors of multi-AP solutions are being considered

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





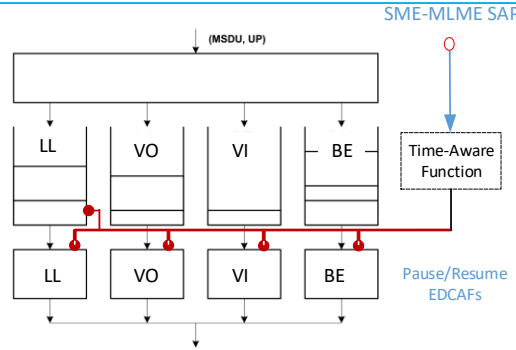
Source: C. Cordeiro [1]

Enhanced Determinism with Wi-Fi 7

- **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 low latency reliable service

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



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

FTM-enabled Localization

- In line-of-sight channel conditions, the ranging accuracy is less than 1 meter
- Positioning/ranging relative to the peer against which the protocol is executed
- Geospatial co-ordinates of a device can be determined by executing FTM from a device with 3 or more peers (whose geospatial co-ordinates are known)
- RAW use cases operating in an environment where there is no access to GPS (or GPS-like services), can leverage FTM to determine relative/absolute position
- IEEE802.11az extends ranging capabilities with security, improved accuracy and optimizes the protocol for accurate estimates with minimal protocol overhead.

Conclusions

Wi-Fi has already integrated several TSN capabilities and more enhancements are being introduced

- captured in draft-thubert-raw-technologies, but latest developments and Wi-Fi 7 features can be updated

Support for localization also enabled by the same set of core features

Wi-Fi6/6E enabled new scheduling capabilities, key for low latency and high reliability

Wi-Fi7 builds on Wi-Fi6/6E (the new 6GHz band) and introduces new innovations to achieve lower latency, higher reliability and determinism

- 320 MHz channels, MLO, Multi-AP, and low latency reliable services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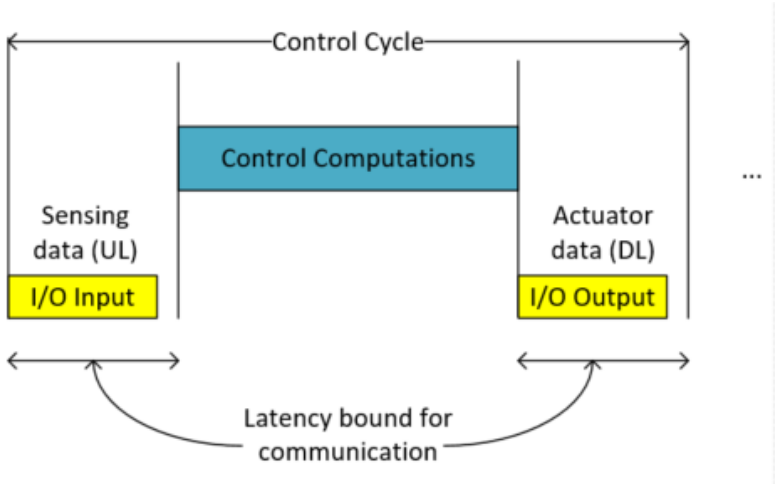
Basic model of an industrial control system

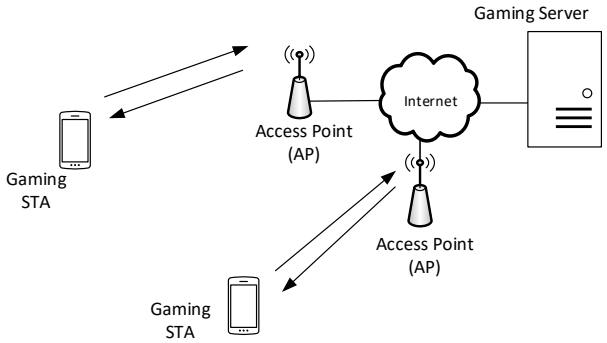
Time synchronized operation

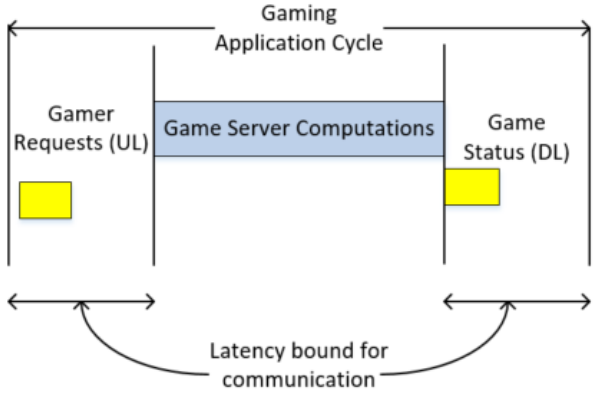


Latency/jitter may cause instability of the system

Low (worst-case) latency is also a requirement for emerging consumer applications

Real-time mobile, console and cloud gaming





Latency/jitter cause lagging/bad user experience