

## IEEE 802.11 WLAN Working Group Liaison Communication

**Date:** December 20, 2022  
**Source:** IEEE 802.11 Working Group (WG)<sup>1</sup>

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**Subject:** Liaison communication to the IEEE 802.1 Working Group

**Approval:** Approved by the IEEE 802.11 Working Group at IEEE 802.11 plenary meeting, Bangkok, Thailand 2022-11-18

Dear Glenn,

The IEEE 802.1 and 802.11 Working Groups have collaborated on enabling TSN features in 802.11 systems. The 802.1 TSN Task Group has defined a set of features, which are considered a “toolbox” to achieve bounded packet latency, low packet delay variation, and low packet loss.

There has been significant progress in enabling TSN features such as time synchronization (802.1AS) and scheduling capabilities (traffic shaping based on 802.1Qbv) over 802.11 networks. A comprehensive survey of 802.11 enhancements in support of TSN can be found in [1] and [2]. Achieving determinism over wireless links is challenging and the 802.11 standard is expected to continue evolving to increase its support of TSN capabilities.

Enhancements to provide predictable latency and jitter and better support integration with TSN are within the scope of the P802.11be project and further enhancement are expected in future projects, as currently being discussed within the Ultra High Reliability (UHR) Study Group. An overview of the EHT features that are expected to improve the performance of TSN in 802.11 networks is provided in [3], and are also summarized in this document, see Annex A.

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<sup>1</sup> This document represents the views of the IEEE 802.11 Working Group and does not necessarily represent a position of the IEEE, the IEEE Standards Association, or IEEE 802.

P802.11be enhancements and considerations to better support TSN have also been discussed in joint calls between IEEE 802.11 Task Group be and 802.1 participants in joint calls. The most recent TGbe-802.1 joint call was hosted on April 21<sup>st</sup>, 2022, and included the following technical contributions:

- [628r0](#) Wireless TSN in 802.11 and New Requirements for 802.11be and 802.1 Dave Cavalcanti
- [668r0](#) Wired-Wireless TSN Configuration and Management Malcolm Smith
- [670r0](#) Further Improve latency performance in 11be Boyce Bo Yang
- [681r0](#) 802.11be features to support TSN capabilities Liuming Lu

I hope that this summary is useful and supports ongoing collaboration between our Working Groups and members. Please contact me with any questions.

Sincerely,

Dorothy Stanley

Chair, IEEE 802.11 WLAN Working Group

## References

[1] M. K. Atiq, et al, "When IEEE 802.11 and 5G meet Time-Sensitive Networking," IEEE Open Journal of the Industrial Electronics Society, DOI 10.1109/OJIES.2021.3135524.

[2] D. Cavalcanti, C. Cordeiro, M. Smith, and A. Regev, "Wi-Fi TSN: Enabling Deterministic Wireless Connectivity over 802.11," submitted to the IEEE Communication Standards Magazine, special issue on Time-Sensitive Networking, Dec 2022, under review.

[3] <https://mentor.ieee.org/802.11/dcn/22/11-22-0634-02-00be-802-11be-enhancements-for-tsn-time-aware-scheduling-and-network-management-considerations.pptx>

[4] J. Fang, S. Sudhakaran, D. Cavalcanti, C. Cordeiro and C. Chen, "Wireless TSN with Multi-Radio Wi-Fi," *2021 IEEE Conference on Standards for Communications and Networking (CSCN)*, 2021, pp. 105-110, doi: 10.1109/CSCN53733.2021.9686180.

[5] "Wireless TSN: Market Expectations, Capabilities & Certification," Avnu Alliance White Paper, February 2022, available at: <https://avnu.org/wireless-tsn-white-paper-2-download/>

**Requested Actions:** None

## **Annex A**

### ***802.1 TSN “Toolbox” and P802.11be features in support of TSN***

The multiple features and specifications defined by the 802.1 TSN Task Group are considered part of a “toolbox”. It is expected that a sub-set of tools (features) from the toolbox may be combined to enable a given network scenario with its associated requirements.

Not all 802.1 TSN specifications may be relevant for wireless media. Currently, several standards groups are considering extensions of TSN features over wireless links, including 802.11 and 5G, as described in a recent Avnu Alliance white paper [5]. The main features under consideration for wireless media include 802.1AS (already defined for 802.11 in 802.1AS-2020 and enabled in 3GPP Rel. 16 for integration with a 5G system), 802.1Qbv, 802.1CB, and 802.1Qcc. This is not a comprehensive list, as other features may also be considered over wireless links in the future.

Wireless specific features such as time synchronization and MAC/PHY scheduling capabilities are relevant to TSN operation if they can enable better control of worst-case packet latency, jitter and increase reliability to improve the overall quality of service. That is the reason triggered access capabilities in 802.11ax and ultra-reliable low latency (URLLC) capabilities in 5G are considered relevant to TSN operation.

The goal of this Annex is to provide an overview of the features defined in the P802.11be project that are considered relevant to TSN operation because they have the potential to enhance worst case packet latency, reduce jitter and improve reliability. This Annex is not intended to prescribe how these features should be implemented in combination with TSN specifications. Further work may be required to enable such integration and optimized performance, which could be subject for further collaboration between 802.11 and 802.1 groups.

### ***Support for predictable latency***

P802.11be has specified the service for the delivery of latency sensitive traffic with predictable latency. Mechanisms, such as trigger based mechanism, restricted TWT(r-TWT) and MLO, are defined for enhanced medium access protection, resource reservation and flexible steering/scheduling over multiple links to provide predictable latency with higher reliability for latency sensitive traffic over the wireless link(s).

### ***Multi-Link Operation (MLO)***

MLO is one of the main P802.11be features and it enables STAs capable to operate over multiple links, called Multi-link Devices (MLD), to discover, authenticate, associate, and set up data communication over multiple links. MLO can help increase throughput by aggregating multiple links across different channels or bands (2.4, 5 and 6 GHz). MLO can also be leveraged to reduce latency by providing multiple channel access opportunities. The TID-to-link mapping mechanism included in MLO allows determination of how TIDs (Traffic identifiers) are mapped to the links in DL and in UL, also known as TID-to-link mechanism, which is helpful for the use of preferred link(s) for TID(s) corresponding to high-priority and latency-sensitive traffic. A TID can be used for the classification of traffic criticality, as in 802.11Qbv, selecting the most reliable link for critical traffic and improving the latency.

The MLO capability allows steering of time-sensitive traffic to links/bands that have the required capabilities to deliver the data within deadlines, which is important in a TSN-capable network. For instance, a 6 GHz link (with no legacy pre-802.11ax devices) could be preferred for time-sensitive data traffic, while other links could still be used for network management and

other traffic. Association and other management procedures (e.g., configuration and 802.1AS time synchronization messages) need only to happen on a single link, while a dedicated link for time-sensitive traffic can help meet strict scheduling deadlines and quality of service requirements.

Multi-link capabilities can also enable 802.1CB frame replication and elimination over 802.11 networks as discussed in [4]. Multiple links within a MLD can be used to implement redundancy with a single 802.11 network interface. As the MLD can enable the frame duplication and elimination required by 802.1CB through multiple affiliated STAs within the MLD. As discussed in [4], 802.1CB operation expects multiple network interfaces, where the Frame Replication and Elimination unit discards the received duplicated packets. In a similar way, the upper MLD MAC could discard such packets from its affiliated lower MLD MACs. The inverse job could be done for duplicated data transmission. Considering all these, additional work may be required to map the 802.1CB operation over 802.11be devices.

### *802.11be QoS signaling enhancements*

The Stream Classification Service (SCS) has been enhanced in P802.11be with additional QoS Characteristics for time-sensitive traffic flows, which enables a direct mapping of scheduling requirements from 802.1Qbv to the 802.11 MAC. STAs with time-sensitive flows, which may be configured based on TSN interfaces at the higher layers, can map the scheduling requirements to QoS parameters in the QoS Characteristics elements carried in the SCS Descriptor element including flow identification, minimum and maximum service interval, maximum packet size, delay bound (deadline), MSDU Delivery Ratio, and start time. The SCS Descriptor is included in the SCS Request frame sent to the AP, which is responsible for allocating resources (e.g., using triggered access) within the BSS to meet the required QoS aligned with the 802.1Qbv schedule defined for the network. These requirements could be mapped from 802.1Qcc.

### *restricted TWT Service Periods*

Enabling access to the medium with determinism is one of the main requirements to better support time-sensitive applications. It is well known that long frame transmissions occupying the channel contributes to increased worst-case latency. The triggered operation defined in IEEE Std 802.11ax-2021 provides support by centralizing channel access, which enables better control of the latency within a predefined time window.

Restricted TWT (Target Wake Time) service periods are defined in the P802.11be Draft to further increase the predictability of channel access. The TWT feature, defined in IEEE Std 802.11ah-2016 and in 802.11ax for improved power save operation, can also be used for scheduling data transmissions. The restricted TWT (rTWT) was introduced as a special type of TWT where time-sensitive traffic receives high priority, and service periods can be aligned with the corresponding 802.1Qbv gate open times. STAs can negotiate participation within rTWT service periods scheduled by the AP, which broadcasts the rTWT schedule for the BSS. 802.11be STAs that support the r-TWT feature are required to stop their transmissions before rTWT service periods and legacy STAs are quieted during rTWT service periods, thus creating the protection for time-sensitive data. The rTWT can be operated in trigger-mode where the AP is responsible for triggering the member STAs providing further latency/efficiency improvement. The rTWT is an optional feature in the P802.11be Draft, hence it is important that STAs in the BSS support the feature to ensure predictability of channel access. The rTWT feature is expected to be used in managed networks where policies and tools are in place to ensure minimal capabilities are required in alignment with the performance expectations.

Table 1 below summarizes a relevant 802.11 standard features and P802.11be enhancements in support of TSN tools in different areas.

<b>802.1 TSN toolbox</b>	<b>Relevant 802.11 features</b>	<b>P802.11be enhancements</b>
Time Synchronization	802.1AS for wireless media supported by 802.11 TM and FTM	
Bounded latency	scheduling enhancements in 802.11ax (trigger-based access).	<ul style="list-style-type: none"> <li>• QoS signaling enhancements (SCS)</li> <li>• r-TWT</li> <li>• TID-to-link mapping</li> </ul>
Reliability	802.1CB over multi-radio devices	<ul style="list-style-type: none"> <li>• Multi-Link Operation (MLO)</li> </ul>

Table 1: Relation between 802.11be and 802.1 Toolbox