A Primer on AP Power Save in Wi-Fi 8: Overview, Analysis, and Open Challenges

Roger Sanchez-Vital, Andrey Belogaev, Carles Gomez, Jeroen Famaey, and Eduard Garcia-Villegas

Abstract—**Wi-Fi facilitates the Internet connectivity of billions of devices worldwide, making it an indispensable technology for modern life. Wi-Fi networks are becoming significantly denser, making energy consumption and its effects on operational costs and environmental sustainability crucial considerations. Wi-Fi has already introduced several mechanisms to enhance the energy efficiency of non-Access Point (non-AP) stations (STAs). However, the reduction of energy consumption of APs has never been a priority. Always-on APs operating at their highest capabilities consume significant power, which affects the energy costs of the infrastructure owner, aggravates the environmental impact, and decreases the lifetime of battery-powered APs. IEEE 802.11bn, which will be the basis of Wi-Fi 8, makes a big leap forward by introducing the AP Power Save (PS) framework. In this article, we describe and analyze the main proposals discussed in the IEEE 802.11bn Task Group (TGbn), such as Scheduled Power Save, (Semi-)Dynamic Power Save, and Cross Link Power Save. We also consider other proposals that are being discussed in TGbn, namely the integration of Wake-up Radios (WuR) and STA offloading. We then showcase the potential benefits of AP PS using a public dataset collected from 470 real APs deployed in a university campus. Our numerical analysis reveals that AP power consumption could be decreased on average by at least 28%. Finally, we outline the open challenges that need to be addressed to optimally integrate AP PS in Wi-Fi and ensure its compatibility with legacy devices.**

Index Terms—**Wi-Fi 8, IEEE 802.11bn, AP Power Save, energy efficiency**

I. Introduction

Wi-Fi is everywhere, providing high-speed wireless connectivity to homes, office buildings, university campuses, airports, and industrial sites. However, maximizing the data rate is no longer the only goal of the technology, since modern applications and scenarios impose additional requirements on latency, reliability, and energy efficiency. In the upcoming Wi-Fi 8 release, the IEEE 802.11bn Task Group (TGbn) is pushing many new features, such as Multi-AP Coordination and distributed Multi-Link Operation (MLO) [1]. The focus of this paper is another key feature being considered by TGbn for standardization, the Access Point (AP) Power Save (PS), whose objective is threefold: (i) to enhance the lifetime of battery limited devices acting as AP, e.g., mobile soft APs; (ii) to cut down on the energy bills of Wi-Fi network infrastructure; and (iii) to reduce the environmental impact of dense Wi-Fi network deployments.

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The energy consumption of Wi-Fi network infrastructure is a growing concern, as the equipment is constantly turned on and works mostly at its highest capabilities to provide the best Quality of Service (QoS) to users. This behavior is not energy-efficient considering that the load of an AP typically follows predictable usage patterns, e.g., aligned with office hours, with periods of inactivity that present clear opportunities for energy savings [2]. Energy efficiency optimization has long been a primary focus in cellular networks, and many techniques have been introduced [3]. In Wi-Fi, the reduction of AP's energy consumption has never been a priority, since it has always been assumed that the AP uses wall power without any limitation. However, now it is seen as a crucial issue. WIK-Consult estimated that, if there was at least one Wi-Fi AP at every EU household, the yearly power consumption of such devices could reach 26,640 GWh, leading to 6,069 MMT of carbon emissions [4]. Since the density of APs at big venues, such as office buildings or university campuses, is much higher than at households, and the number of deployed Wi-Fi networks is steadily growing, the total power consumption related to Wi-Fi infrastructure can be, consequently, substantially higher.

The IEEE 802.11 standard has been consistently introducing STA power-saving techniques throughout its evolution. Even the first Wi-Fi standards already included basic PS mechanisms. The latter allowed an AP to indicate the buffered Downlink (DL) frames for particular stations (STAs), while the STAs can request these frames on demand and sleep in between. Since then, new amendments have significantly improved these mechanisms and introduced new features. The most notable step forward has been made by the IEEE 802.11ah amendment [5], designed for Internet of Things (IoT) devices. Target Wake Time (TWT) is the most prominent feature that appeared in IEEE 802.11ah to enhance the energy consumption of STAs. With TWT, associated STAs decide when to go to sleep and schedule individual or group wake-up times for Uplink (UL) or DL data exchange with the AP. This mechanism has been inherited by the recent IEEE 802.11ax amendment, basis of the Wi-Fi 6. Table I provides a comparison of the main STA-side PS mechanisms defined in the standard.

In contrast to the plethora of STA-side power saving mechanisms, only a few simple options are available on the AP side. Specifically, the AP can reduce the Bandwidth (BW), the number of Spatial Streams (SS), or disable links in case it supports MLO. Such changes affect all the STAs associated with the AP, and cannot be dynamically negotiated. Additionally, the AP is not normally allowed to sleep, as it should be able to reply to Probe Requests of new STAs, and regularly send Beacons. To fill the gap, TGbn is actively discussing

TABLE I: Comparison of principal IEEE 802.11 STA-side Power-Saving Mechanisms [6]

STA PS Mechanism	Functionality	Traffic direction	Power-Saving Effect	Amendment
Traffic Indication Map (TIM)	Indicates buffered unicast data in Beacon frames	DL	STAs sleep for multiple Beacon intervals, and stay awake only when there is buffered data	Legacy
Power Save Poll (PS-Poll)	Enables STAs to request for buffered frames (one per each frame)	DL	STAs poll for buffered data upon TIM indication and sleep in between	Legacy
Automatic Power Save Delivery (APSD)	Enables STAs to request for buffered frames (multiple at once, at scheduled appointments)	DL	STAs poll for buffered data upon TIM indication and sleep in between	802.11e
Power Save Multi-Poll (PSMP)	Coordinates delivery times for uplink and downlink traffic	DL & UL	Efficient scheduling of packet transmissions	802.11n (obsolete)
Spatial Multiplexing Power Save (SMPS)	Dynamic utilization of multiple antennas	DL & UL	STAs can utilize fewer antennas to save power	802.11n
Wireless Network Management (WNM) Sleep Mode	STAs can negotiate extended sleep periods	DL	Increases sleep time	802.11v
Transmission Opportunity (TXOP) Power Save	Allows STAs to go to sleep until the TXOP is completed to save power	DL & UL	Reducing idle time inside TXOP	802.11ac
Restricted Access Window (RAW)	Restricts access to the medium to specific groups of STAs	UL	Reducing idle time	802.11ah
Target Wake Time (TWT)	Schedules specific wake times for devices	DL & UL	STAs can wake up only at scheduled time slots	802.11ax (prev. 802.11ah)

several new PS mechanisms that enable APs with extended power-saving capabilities.

This paper provides an overview and analysis of AP PS mechanisms. First, we overview the main proposals that have already passed motions in TGbn and therefore most probably will be featured in the upcoming Wi-Fi 8 standard. Second, we describe other notable proposals discussed in TGbn. Then, we present a case study evaluating the performance of one of the proposed mechanisms in terms of power consumption and energy savings. Finally, we highlight several crucial open challenges.

II. AP Power Save in IEEE 802.11bn

TGbn currently distinguishes four AP PS mechanisms, namely Scheduled, Dynamic, Semi-Dynamic, and Cross-Link. Below, we describe each of the mechanisms in detail.

A. Scheduled Power Save

Scheduled PS intends to reduce the energy consumption by switching between the AP's states according to a schedule [7]. Specifically, the AP can switch between five states with different power consumption profiles.

- **Doze state:** The AP disables its radio interface. It is not able to transmit, receive, or listen.
- **Listen state:** The AP only performs Clear Channel Assessment (CCA). It can switch to receive data, but cannot transmit.
- **Interruptible listen state:** The AP performs CCA, can receive data, and can quickly switch to transmission, e.g., to respond to legacy devices.
- **Reduced capabilities:** The AP reduces its capabilities to a more basic configuration to save energy, e.g., 20 MHz BW and 1 SS. It can both transmit and receive data.
- **Full capabilities:** The AP operates using its highest-performance parameters to provide the best QoS to users. It can both transmit and receive data.

The AP elaborates its own state schedule and disseminates it via Beacons, Probe Responses, or Action Frames. The schedule consists of multiple groups of periodic time intervals, PS periods and Service Periods (SPs). Each group of such intervals is mapped to a particular state. The term SP, inherited from TWT, refers to the time interval during which the AP preferably performs data exchanges at a high data rate. Signaling frames contain schedule information, such as interval duration and periodicity; power state information; and capabilities information, e.g., BW and number of SS. The schedule information can be reused from TWT-related frames. When the STAs receive the information, they may change their states accordingly. For example, they may switch to doze state during the doze intervals of the AP. The STAs that missed the schedule due to being in doze state can request it by sending a Schedule Request.

STAs can request the AP to change its schedule by sending a Presence Request. For instance, an STA that is aware of the AP's power-saving schedule can send a request to the AP to temporarily exit doze mode at a predetermined time to meet specific QoS requirements. At any point in time, the AP can autonomously change the schedule based on network conditions, traffic volume, desired power consumption reduction, QoS requirements, etc. If the schedule is changed for any reason, the AP must disseminate the new schedule. The AP is not allowed to switch to a new schedule before all the STAs have had the opportunity to receive the updated schedule, either via Beacons or in reply to Schedule Requests.

To avoid potential issues, multiple considerations should be taken into account. First, if there are any legacy STAs associated with the AP, the AP should avoid going into doze state. Such precaution will prevent legacy STAs from losing association with the AP, as well as from severe packet losses. Second, the newly-associated and just-woken-up STAs should wait for Beacon frames or send Schedule Requests to know the latest AP schedule. Third, whenever the AP goes into doze state, the backoff counters at the AP and the STAs should be frozen. If they keep counting down, backoff may reach zero for multiple devices simultaneously once the AP wakes up again, leading to collisions. However, when multiple Wi-Fi networks coexist in the same area, neighboring networks can keep counting down the backoffs, which may lead to fairness issues. Finally, sleep patterns must consider the QoS requirements of the STAs.

B. Dynamic Power Save

Even without switching to the doze state, the AP can save energy by reducing its capabilities. More specifically, its energy consumption depends on BW, Number of Spatial Streams (NSS), Modulation and Coding Scheme (MCS), and number of active links (in case of MLO) being used during transmission, reception and listening. The current standard already allows the AP to change these parameters and announce the changes to the associated STAs. However, there are no mechanisms to dynamically change the AP's capabilities on demand, e.g., on request from an STA. Such a mechanism, called Dynamic Power Save (DPS), is introduced by TGbn [8].

DPS generally keeps the AP in Low Capability Mode (LCM), a power-saving mode that restricts the AP to a basic configuration with reduced BW, NSS and MCS. In this state, the AP is able to: (i) transmit Beacons and management frames; (ii) listen to the channel; and (iii) communicate with legacy STAs, as well as with DPS-capable STAs whose data flows can be served without increasing the AP's capabilities. Once an STA intends to perform frame exchange at higher capabilities, e.g., for higher throughput or lower latency, it sends a special control frame to trigger the AP to change its capabilities, i.e., to switch to High Capability Mode (HCM).

For signaling, DPS reuses the same approach as Enhanced Multi-Link Single-Radio (EMLSR) operation, which appeared in Wi-Fi 7 as a type of MLO. In EMLSR, an Initial Control Frame (ICF) is sent by a multi-link AP to solicit an STA to switch to its secondary link with higher capabilities. To compensate for the switching delay and allow the STA to reply with an Initial Control Reply (ICR), padding is added to the ICF. In contrast to EMLSR, DPS is triggered by an STA, which means that an STA can request an AP to switch capabilities by sending an ICF, and ICR is sent by an AP in reply. To facilitate the AP to error check ICF even before reception of the padding, an intermediate FCS before the padding field has been proposed.

The unified frame format for ICF and ICR is still under discussion. For DPS, the following parameters could be indicated in the ICF: (i) configuration (BW, NSS, MCS); (ii) HCM duration, either explicitly or via timeout, e.g., time duration without any frame exchange. The parameters of LCM can be indicated in the Capabilities Information field, recognizable by legacy devices. Besides, the transition delays to switch capabilities are manufacturer-specific and should be disseminated to STAs via an IEEE 802.11bn specific Capabilities Information field value, so that the STAs can add a suitable amount of padding.

C. Semi-Dynamic Power Save

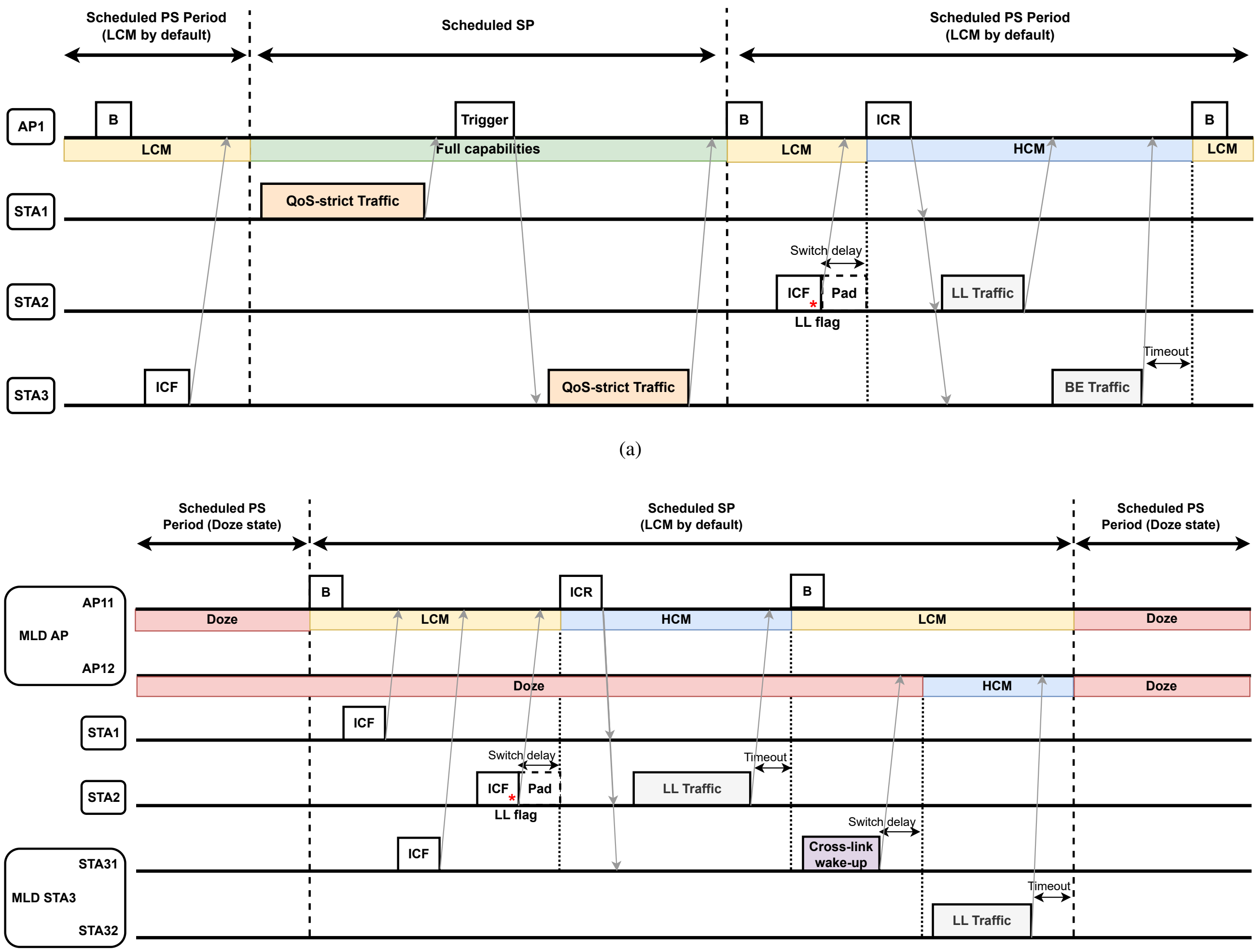
When multiple DPS-capable STAs are associated with an AP, each of them can solicit an AP to switch to HCM by sending an ICF. If an AP responds to every ICF, it cannot sustain LCM for an extended duration, which restricts the potential power-saving benefits of DPS. To address this issue, TGbn proposed Semi-Dynamic Power Save (SDPS) mechanism, which is a modified DPS mechanism where an AP can selectively react to ICFs based on traffic demands and power-saving requirements. When the AP decides not to react to an ICF immediately, it can still remember the request from the STA, and trigger the pending transmission later when it switches to HCM, e.g., by transmitting a Trigger Frame (TF). To force the switching to HCM for critical traffic, STAs can mark their ICFs with a special flag, e.g., requiring Low Latency (LL) traffic.

SDPS can be combined with Scheduled PS. TGbn distinguishes two modes of such combination: Type 1, in which the objective is to provide uninterrupted service. Therefore, in the SPs, the AP uses its full capabilities to provide maximal QoS, and transitions to SDPS in PS periods; and Type 2, in which the aim is to maximize the energy efficiency by operating in SDPS in the SPs while being in Doze state otherwise. Figs. 1a and 1b depict the frame exchange sequences for Types 1 and 2, respectively. In particular, we show Beacons (B), TFs, ICF, ICR, and different types of application data: QoS-strict, LL and Best Effort (BE). With MLO, additional PS opportunities can be leveraged via cross-link wake-up (cf., Fig. 1b). We describe the cross-link mechanism in detail in the next subsection.

D. Cross-Link Power Save

The Scheduled PS mechanism may negatively affect the performance of sporadic critical traffic, e.g., when it arrives during doze intervals. To mitigate such effects, TGbn proposes to exchange management information for other links via the active link between a pair of Multi-Link Devices (MLDs), depending on the needs of STAs [9]. In this case, an MLD AP maintains an active link that supports several functionalities, like discovery, active probing, and association for all types of STAs, including legacy STAs. Upon reception of a cross-link wake-up frame on its active link from an STA, the MLD AP can enable its other links. This way, the AP can offload this STA to another link with higher capabilities, or start serving it with multiple links.

The way this feature will be implemented is still under discussion. One possibility is to reuse the AP Assistance Request (AAR) control information field introduced in IEEE 802.11be [10]. This field contains a bitmap of link identifiers that can be used as an indication of the links that are requested to wake up. However, currently it is used only in the DL to assist the MLD STA to recover its medium synchronization.



(a)

(b)

Fig. 1: Examples of Semi-Dynamic PS operation: a) Type 1 (uninterrupted service); b) Type 2 (energy efficiency).

Hence, wake-up request implementation will require additional changes in the standard.

III. Other Proposals

Apart from the aforementioned features that have already been thoroughly discussed in TGbn and are on track to be added to the standard, some other proposals for AP-side power saving deserve attention. Those include the use of Wake-up Radios (WuRs) and the offloading of STAs to other APs.

A. Wake-up Radios

WuRs have arisen as a feasible way to maximize the energy efficiency of a device, while supporting spontaneous traffic with low-latency requirements. The IEEE 802.11ba amendment standardizes the operation of a WuR in Wi-Fi networks. The main idea is to add a secondary low-power radio to the main interface that is always active, while the more power-hungry Primary Connectivity Radio (PCR) can go into doze state when not in use. In contrast to similar ideas with MLO, a WuR has no transmission capabilities and consumes extremely low power, less than 1 mW, which allows an AP to keep it always on at a low cost, and wake up the PCR when needed for data exchange. To achieve such power-efficiency, a WuR only demodulates a simple On-Off Keying (OOK) waveform that is generated by another STAs' PCR, which offers relatively low data rates. Therefore, it is primarily considered for control data transmission, such as wake-up frames.

A proposal has been made to integrate the WuR concept into 802.11bn [11], though it presents several challenges that must be addressed. First, service of urgent traffic becomes challenging, because transmitters either have to wait before PCR becomes available, or should target the low-data-rate WuR. Although MLO can suffer from similar problems, the active link in an MLD can still be used for application data transmission. Second, WuRs use a different waveform than other Wi-Fi radios, and thus the coexistence of WuRs and legacy devices should be studied thoroughly. Besides, the device's WuR can offer a different communication range compared to its PCR.

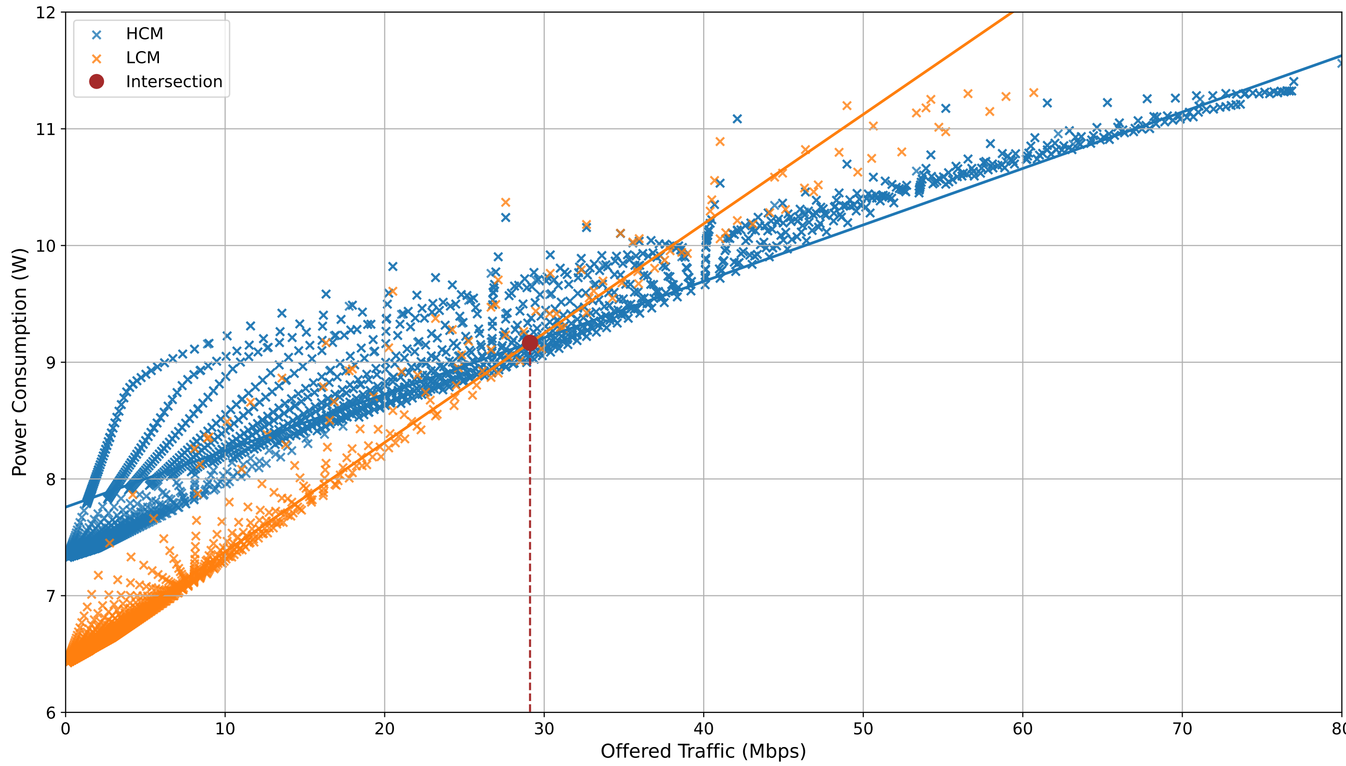


Fig. 2: Power consumption for LCM and HCM for different traffic loads.

B. STA offloading

The APs must provide fair connectivity to all STAs. However, in dense deployments, the load is non-uniformly distributed between the APs. When an AP is significantly underutilized, e.g., serving a single STA with sparse traffic, it still consumes a lot of power. The literature offers several methods for offloading STAs from underutilized APs, allowing them to save energy by temporarily transitioning to a deep doze state [12].

Before Wi-Fi 8, the standard did not offer any framework for coordination between APs. Hence, an AP can only decide to stop serving an STA, but it cannot control the rest of the handover procedure. This results in disruption in the data flows, packet loss and unnecessary packet retransmissions. For example, an STA can select a wrong AP due to incomplete RSSI measurements. With the introduction of Multi-AP Coordination to TGbn discussion, Wi-Fi APs can exchange information to facilitate a seamless roaming of the STAs.

IV. Case study: Energy Saving Analysis

In this section, we outline the potential impact of the Wi-Fi 8 AP PS mechanisms in terms of energy saving potential. It should be noted that the energy saving of Scheduled PS will be similar to that of TWT (although targeting the AP instead of STAs). The impact of TWT is already well studied in literature. For example, Yang et al. [13] recently revealed that the scheduled TWT approach can reduce the energy consumption of an STA by a factor of three. Since the AP transmits also Beacons and management frames, it is expected that energy saving for AP-side Scheduled PS in a single-STA scenario will be slightly worse, and will proportionally decrease with the number of STAs. We leave further investigation on the Scheduled and Cross-Link PS out of the scope of this study.

Let us now consider the DPS approach. Fig. 2 provides a comparison between HCM and LCM capability modes in terms of power consumption and offered traffic. The devices are configured with IEEE 802.11ac, MCS 7, short Guard Interval (GI) and 16 dBm of transmission power. The HCM utilizes 80 MHz of BW and 2 SS, while the LCM limits BW to 20 MHz and uses only 1 SS. The power consumption values for the AP's states were extracted from real device measurements [14]. The results were obtained using the NS-3 network simulator.

In Fig. 2, the lines represent the linear fit of the obtained results to showcase the trends. The results show that LCM is more beneficial for lower offered traffic values, since idle time is predominant and LCM has the lowest power consumption in this state. However, as the offered traffic increases, the idle time is reduced, and it is beneficial to switch to HCM, which provides a higher physical layer data rate and hence lowers the transmission duration, which results in a reduction in transmit power consumption, i.e., the most power-hungry state. Our results show that, approximately above 29 Mbps, HCM is more energy-efficient than LCM. The achievable power saving potential is maximal at the lower offered traffic values, reaching up to 30%. Therefore, DPS can be particularly useful at lower loads.

Additionally, to further exemplify the gains that can be obtained by applying DPS (and SDPS), we performed an

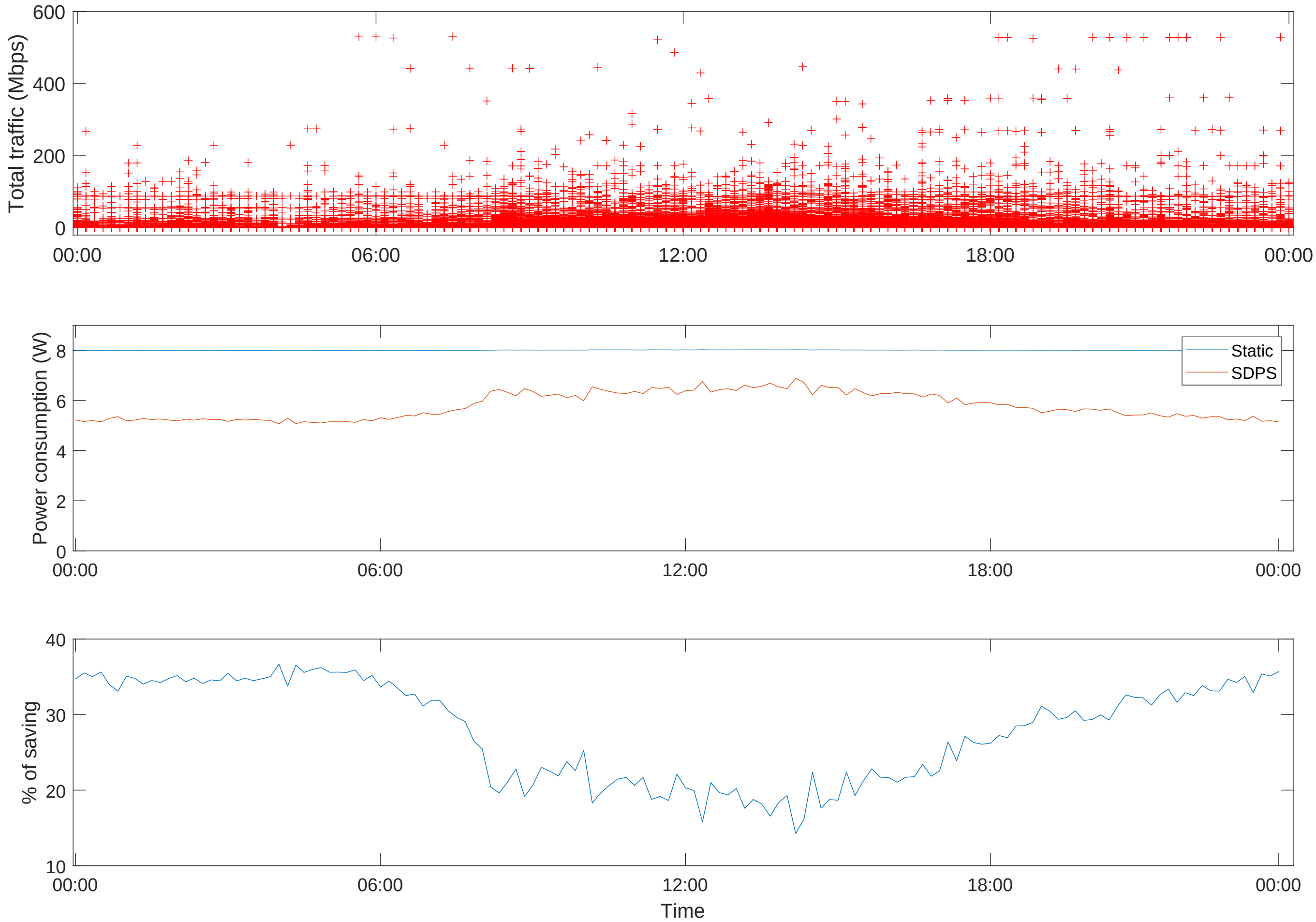


Fig. 3: Total traffic, power consumption and SDPS power savings for 470 APs on a weekday based on dataset [2].

analytical study based on real traffic measurements obtained from a public dataset [2]. Said dataset was collected from a total of 470 APs deployed in one of the campuses of University of Oulu, in Finland. The measurement period was between December 18, 2018, and February 12, 2019, and each sample provides a 10-minute observation. Fig. 3 shows the total traffic (sum of UL and DL), the average power consumption, and the percentage reduction in energy consumption achieved by SDPS over traditional static configurations for 470 APs. When SDPS is used, apart from switching the capabilities of the APs, we assume that 50% of the APs go into sleep mode and the rest remain in idle state in the periods when there is no traffic exchange. This decision is derived from [12], where authors state that around 50% of the APs in a similar scenario can be turned off in off-peak hours with a very low outage probability. The AP switches modes when the total traffic exceeds 30 Mbps, a decision based on the study depicted in Fig. 2.

In this scenario, the total traffic is noticeably higher during office hours, i.e., approximately between 8 a.m. and 8 p.m., while it is marginal at night, where the highest energy savings can be achieved. Therefore, in the latter case, the use of SDPS can result in power savings up to 35% compared to a Static configuration, while during the office hours power saving is around 15-20%, which is still a substantial amount. If we consider the average along the 24h period, there is a 28% power consumption decrease when using SDPS. Note that these results were obtained using conservative assumptions and a straightforward AP PS approach, as a detailed and complex implementation is beyond the scope of this work. Hence, we anticipate greater savings in future Wi-Fi 8 deployments.

V. Discussion and Open Challenges

In this article, we describe several AP PS mechanisms, which are highlighted in Table II. All of them manage the schedule of the AP's power states. The scheduling decisions of different PS modes can last for a few data frame exchanges (short-term), multiple Beacon intervals, or even longer (long-term). An important aspect is how the new mechanisms will perform in networks with legacy devices that are unaware of these mechanisms, i.e., their backward compatibility. In general, the greater the potential energy savings offered by the PS mechanisms, the less compatible they are with legacy devices. STA offloading can offer high backward compatibility by relying on legacy handover procedures, but such handovers

TABLE II: Summary, signaling, energy savings, schedule duration, and backward compatibility for the proposed AP Power Save mechanisms.

AP PS mechanism	**Summary**	**Signaling**	**Energy saving**	**Schedule duration**	**Backward compatibility**
Scheduled	Scheduling of SPs with different operational modes	Reuse TWT signaling, presence requests	High	Long-term	Low since legacy devices require AP to be in awake state
Dynamic (DPS)	On-demand switching of capabilities	ICF with intermediate FCS and padding, ICR	Medium	Short-term	Limited due to unfairness, because legacy devices use mostly LCM
Semi-Dynamic (SDPS)	DPS modification, when AP can defer switching. Can be combined with scheduled.	Same as for Scheduled and DPS, LL flag added to ICF	Medium to high	Both short and long-term	Limited due to unfairness and inability to for the AP to switch into doze state
Cross-Link	On-demand wake-up other links via an active link of MLD AP	Cross-Link wake-up (reuse AP assistance request)	High	Short-term	High since communication via active link is available
Wake-up Radios (WuR)	On-demand wake-up of primary radio via companion WuR	IEEE 802.11ba signaling	Very high	Short-term	Low since WuRs are not supported by legacy devices
STA offloading	Offloading of STAs to other APs to save energy	Seamless roaming signaling via Multi-AP Coordination	High	Long-term	High through legacy handover procedures (although with worse performance)

are not seamless, thus the user performance can be affected. Cross-Link PS is an exception, as it can potentially provide both high energy saving and backward compatibility. However, MLDs require more energy themselves.

The sections below overview the key challenges that need to be addressed for AP PS, namely resource allocation, backward compatibility, and signaling overhead.

A. Resource allocation

The PS mechanisms add several degrees of freedom regarding the allocation of channel resources. Specifically, the AP should schedule SPs and PS periods and assign traffic flows to specific capability modes and links. According to (S)DPS, STAs trigger the AP to switch the capabilities, but the mapping between the QoS requirements of different traffic flows and the capability modes at the STA side seems non-trivial. Moreover, for each request, the AP can decide to accept or decline it depending on many factors, such as load, requirements of ongoing flows, channel quality per STA, and others. The needed resource allocation algorithms are expected to be out of scope of the standard, and thus, contributions from the research community will be necessary.

B. Compatibility with legacy devices

In controlled environments, such as industrial deployments, the devices used for connectivity are known beforehand. Maintainers of such deployments can ensure that all Wi-Fi devices support the same features. However, in many scenarios this is not the case. In such scenarios, it is important that new features do not cause significant performance degradation for legacy devices. With respect to AP PS, the following issues should be taken into account. First, the AP cannot inform legacy devices about going into doze state. Second, legacy devices are not able to handle the PS schedule from the AP and cannot trigger the AP to switch capabilities. These issues cause several potential complications, such as: (i) the AP never going into doze state; (ii) performance unfairness between IEEE 802.11bn and legacy devices, as legacy devices are primarily limited to LCM for transmission; and (iii) the AP offloads all legacy devices to other APs to maximize the benefits from PS features, which may lead to those other, probably legacy, APs becoming overloaded.

C. Signaling overhead

Every new feature introduced in the standard requires additional signaling. Often, for backward compatibility and to limit overhead, the frames used for already existing procedures and mechanisms are reused for the new ones. For example, many control frames used in previous Wi-Fi generations have subfields that were intentionally reserved for future use. Current discussions in TGbn indicate plans to reuse TWT signaling for Scheduled PS; Buffer Status Report Poll (BSRP) or Multi-User Ready To Send (MU-RTS) for DPS; and AAR for Cross-Link PS. However, since these frames have been initially designed for other procedures, their application to AP PS will require changes both at STA and AP sides. Besides, the current Wi-Fi standard does not have a common framework for exchanging capability information for PS features. Proposals for a modular and extensible framework for capabilities exchange are currently being discussed in TGbn. In any case, new signaling would introduce overhead and, consequently, delays related to transmission of new control frames, switching between capabilities, enabling/disabling links. The effect of this overhead should be studied.

VI. Conclusion

Energy consumption is an increasing concern in the ICT sector in general and in Wi-Fi networks in particular, both due to the associated costs and carbon emissions. In this article, we outlined the new AP PS framework, under consideration for IEEE 802.11bn standardization. Specifically, we considered six different mechanisms that are being discussed in TGbn: Scheduled, Dynamic, Semi-Dynamic, Cross-Link, WuR and STA offloading. For each of the proposals we highlighted their operation flow, used signaling, potential benefits and issues. Finally, we provided a case study to quantitatively assess the potential energy savings that can be achieved in a real university campus when making use of AP PS. The results are based on conservative assumptions from a proof-of-concept AP PS approach, with greater savings expected in future Wi-Fi 8 deployments.

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VII. Biographies

Roger Sanchez-Vital Roger Sanchez-Vital received his M.Sc. in Telecommunications Engineering from La Salle–Universitat Ramon Llull in 2021 and is now pursuing a Ph.D. in Network Engineering from the Universitat Politècnica de Catalunya (UPC). He is a predoctoral researcher at the same institution. His research interests mainly include: IoT, LPWAN technologies, and the IEEE 802.11 standard.

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Carles Gomez Dr. Carles Gomez obtained his Ph.D. thesis in Network Engineering in 2007. He is a Full Professor at the Universitat Politècnica de Catalunya (UPC). He is a co-author of numerous papers published in journals and conferences, as well as IETF RFCs and Internet Drafts. He is an IETF 6Lo Working Group Chair. He serves as an editorial board member for several journals. His research interests mainly focus on the Internet of Things and deep space communication.

Jeroen Famaey Jeroen Famaey is a research professor at the IDLab research group of the University of Antwerp and imec, Belgium. At IDLab, he leads the Connected Systems research team, which focuses on signal processing, protocol design, and management of wireless communication systems. His research has led to the publication of over 180 peer-reviewed articles in journals and conference proceedings, and 8 granted patents.

Eduard Garcia-Villegas Dr. E. Garcia-Villegas is an Associate Professor at the Universitat Politècnica de Catalunya (UPC), where he specializes in radio resource optimization, network security, the IoT, and emerging 5G/6G technologies. Holding a Ph.D. in Telecommunications Engineering, Dr. Garcia-Villegas has made significant contributions to Wi-Fi technology and has actively participated in several IEEE P802.11 task groups. As a member of the Wireless Networks Group (WNG) and the i2CAT Foundation, he collaborates extensively with both industry and academia on pioneering wireless network initiatives.