Wi-Fi CERTIFIED 6 Release 2: Better Wireless Connectivity for IoT

TECHNOLOGY BRIEF

We live in a connected world. Connected appliances, intelligent home security systems, doorbell cameras, the Amazon Echo or Google Home, and wearable fitness are examples of Internet of Things (IoT) devices. Connected appliances, such as washing machines, not only allow you to operate them from an app on your smartphone they can also let you know when your laundry is done, diagnose service issues, alert you when problems occur, or notify you when its time to change the water filter on your refrigerator and if connected to other devices like Amazon Echo they can even automatically order the filter for you.

IoT devices have sensors and software to connect and exchange data over the internet. IoT devices depend on wireless internet connectivity. As Wi-Fi standards improve and provide more functionality, IoT devices that leverage the new capabilities and applications are coming to market. According to “iot-analytics.com,” the enterprise IoT market grew by 22% in 2021 to $158B.

This brief provides background on various power save mechanisms and new features introduced in the Wi-Fi CERTIFIED 6 Release 2 certified products in the market today. These advanced features improve wireless internet connectivity for IoT devices and lower device power consumption – thus driving more applications for market growth.

IoT vs. IIoT?

IoT most often refers to consumer products, as mentioned earlier. Industrial Internet of Things (IIoT) devices are IoT devices built for distributed industrial control systems. Industries such as manufacturing, healthcare, transportation and logistics, automotive and even agriculture depend on wireless internet connectivity to monitor and track devices on a network. These devices require more sophisticated features. Industrial markets need better security, reliability, redundancy, and effortless mass deployment.

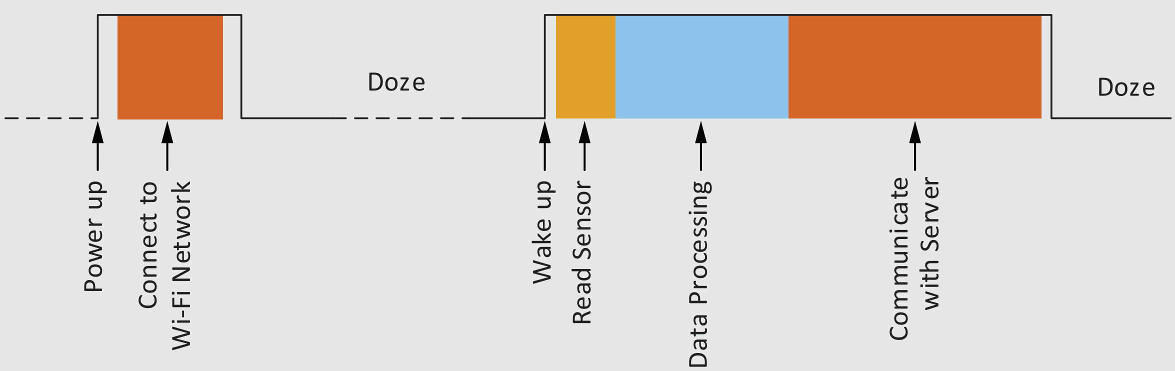
The Need for Low Power – Improvement in Battery Life

Whether for home or industrial, power efficient IoT devices offer longer battery life and should be the focus of innovative green design.

Edge computing brings computation and data storage close to the data collection point. These edge network devices run machine learning algorithms to make complex decisions. Taking decisions to the network's edge where the information is collected reduces decision-taking time and communication bandwidth. IoT devices on the network edge are known as IoT Edge devices and work with systems such as Microsoft Azure IoT Edge and Amazon AWS IoT for the Edge. Edge computing deployments are increasing because of lower overall power consumption and fast responses.

Wireless security cameras like Arlo, Ring, Blink, and Nest wake when triggered and are designed to extend battery life.

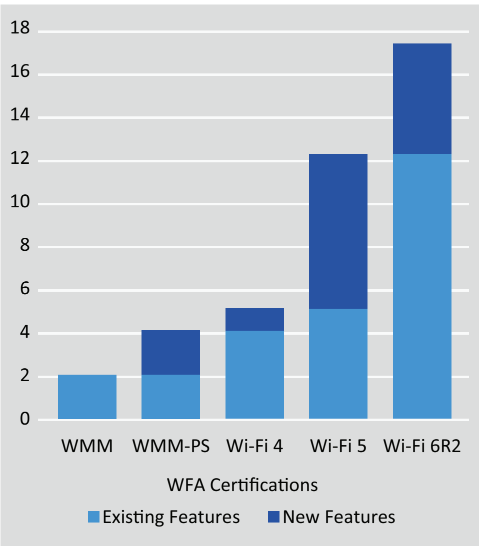
Power Consumption Profile of a Typical IoT Device



Wi-Fi is the most convenient way for IoT devices to connect to the internet. The diagram shows that the bulk of time a device consumes power from the battery is when communicating with the server. The newer Wi-Fi standard reduces the time an IoT device spends awake for communication.

The IEEE 802.11–1997 standard introduced power management in Wi-Fi. Additional power-saving features have been added with each new standard to improve the power consumption of the Wi-Fi sub-system.

Wi-Fi Standards / Power Save Features



Power Save Feature List

IEEE Standard	Power Save Feature	WFA Certification: WMM	WMM-PS	Wi-Fi 4	Wi-Fi 5	Wi-Fi 6 R2
802.11	PS-Poll (Legacy)	■	■	■	■	■
802.11e	WMM-Power Save /U-APSD		■	■	■	■
802.11i	Directed Multicast Service (DMS)		■	■	■	■
802.11n	Power Save Multi-Poll (PSMP)	■	■	■	■	■
	SMPS					
	Static SMPS			■	■	■
	Dynamic SMPS					■
802.11v	WNM-Sleep Mode				■	■
802.11ac	VHT TXOP PS				■	■
802.11ai	OPS				■	■
	FILS				■	■
802.11m	Proxy ARP				■	■
802.11me	Proxy Neighbor Discovery (ND)				■	■
802.11ax	Intra-PPDU PS				■	■
	20 MHz STA					■
	TWT					
	Individual TWT					■
	Broadcast TWT					■
	BSS Max Idle Period					■

Power Management Mechanisms

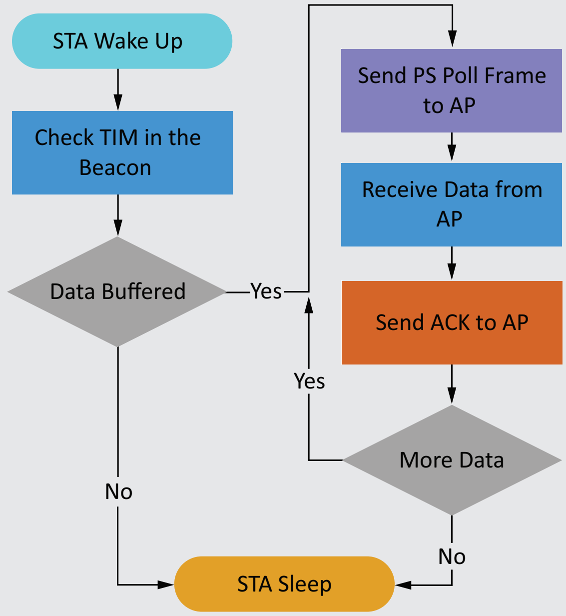
PS-Poll

PS-Poll is a legacy power save mechanism defined in the 802.11 spec. This mechanism allows the client to indicate to the AP that it is going to sleep until the next beacon. The AP buffers frames while asleep, then lets the client know that frames are buffered via an advertisement in the beacon.

The STA starts by checking the TIM (Traffic Indication Map) in the Beacon for any buffered data.

Once the STA realizes it has buffered frames at the AP, it sends PS-Poll frames to request the data. The AP replies with the buffered data and indicates the remaining buffer status with the "more data" flag. The STA can repeat requesting more data using the PS-Poll frames before dozing off.

TIM is the buffer status of unicast frames buffered at the AP and sent with every Beacon. DTIM is the status of buffered broadcast and multicast frames at the AP and sent with the Beacon at a periodic rate.



Power Management Bit
The frame control section of the Wi-Fi MAC packet header contains the Power Management Bit. Typically, the STA sends this message using a null data frame which is a data frame with the number of data bytes in the message set to zero. Setting the Power Management Bit set to "1" indicates to the receiver that the sender will sleep. The AP buffers the data until the STA is awake.

DMS (Directed Multicast Service)
The STA notifies the AP to convert the multicast and broadcast messages to unicast messages. This enables Wi-Fi transmissions at a higher PHY rate, reducing the packet size and STA awake time and improving battery life.

PSMP (Power Save Multi-Poll)
This scheme is an enhancement of U-APSD. The AP allocates a DTT (Downlink Transmission Time) and a UTT (Uplink Transmission Time) schedule for each STA, avoiding contention overhead. In this TDMA style scheme, the STA checks the program and sleeps when the AP targets the other STAs.

Wi-Fi Terminology

Station (STA): IoT Device

Access Point (AP): Wi-Fi Router or Gateway

Beacon: Frame transmitted by the AP approximately ten times a second

Service Set Identifier (SSID): Type of identifier that uniquely identifies a wireless local area network (WLAN)

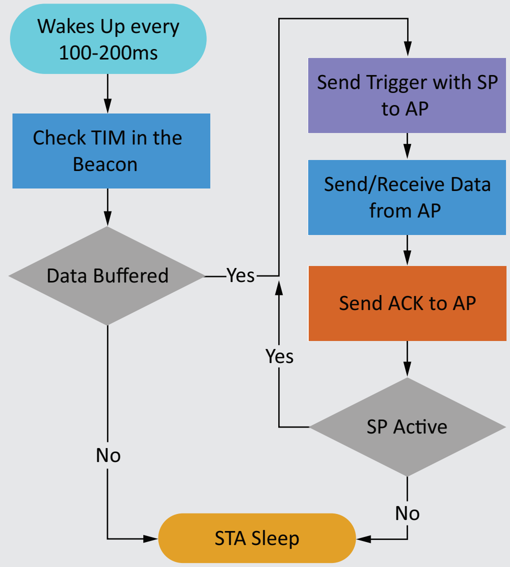
The STA uses the Beacon to find the AP with the SSID of interest

WMM-Power Save / U-APSD

Unscheduled Automatic Power Save Delivery is a WMM-Power Save feature that provides additional power-savings functionality for some types of clients/applications. U-APSD uses the triggered mode for all four AC (Access Categories) voice, data, etc. The STA wakes up every 100 to 200 ms to check the TIM in the Beacon and starts the downstream transfer for buffered data. The STA activates the AP to send data using a trigger frame with the service period (SP). The AP then starts filling the service period airtime with data for the STA.

WMM-PS offers significant power savings and airtime efficiency over the legacy PS-Poll mode due to not sending the PS-Poll for every data frame request.

The STA wakes up immediately from sleep when there is upstream traffic to be sent.



WNM-Sleep Mode

The STA tells the AP how often it will wake up to receive the Beacons. During the sleep slot, the STA will not wake up to receive the DTIM and does not perform any GTK/IGTK updates. There was a security vulnerability in this mode where the attacker used the previous GTK and made a replay attack to gain access. These vulnerabilities have since been fixed with WPA2 and WPA3 updates.

VHT TXOP PS

When a Wi-Fi 5 STA receives a VHT MU PPDU determines that it is for another STA, it dozes off for the remainder of the TXOP duration.

OPS (Opportunistic Power Save)

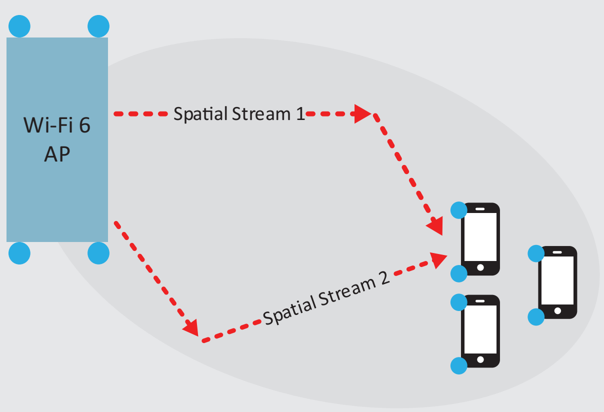
Allows the STA to sleep for a block of time, thereby saving battery life.

- ***FILS*** The typical Wi-Fi connection sequence includes SSID discovery, Probing, Authentication, and Association and takes 5 seconds. FILS helps make this initial link setup happen in around 100 ms. The Probe Request frame from the STA tells an AP which SSID it is expecting a response from, and the AP's probe responds with the neighboring report, consequently speeding up the association procedure.
- ***Aperiodic*** The AP sends an OPS/FILS Discovery frame with the schedule for all OPS STAs. Based on this information, the STAs can optimize their sleep.
- ***Periodic*** The Beacon interval is split into several periodic broadcast TWT service periods. At the beginning of each SP, an aperiodic OPS style procedure occurs, enabling the STA to sleep at a regular rate.

SMPS

MIMO introduced in Wi-Fi 4 supports multiple spatial streams by integrating multiple transmitter and receiver chains. This improves the power efficiency of the Wi-Fi subsystems. SMPS is an elegant way to turn off unnecessary hardware paths to match the transmission streams.

- ***Static SMPS*** *The STA sends action frames to the AP, telling it the number of active antennas.*
- ***Dynamic SMPS (Wi-Fi 6R2)*** *Introduced for certification in Wi-Fi 6R2, this feature enables turning on and off receive paths more rapidly to improve power savings. The data transmission sequence starts as a single spatial stream and RTS/CTS. After receiving the packet, the addressed STA goes to maximum capability. The unaddressed STA dozes off.*



ARP (Address Resolution Protocol)

The ARP discovers the MAC address of devices on a network. All devices on the network have to respond to ARP requests. Even though this is a worthy cause, it uses valuable network bandwidth. The ARP is sent as a broadcast and transmitted at the lowest mandatory PHY rate taking up valuable airtime in the BSS. IoT device developers and AP vendors are trying to increase the efficiency of these requests by offering the below features.

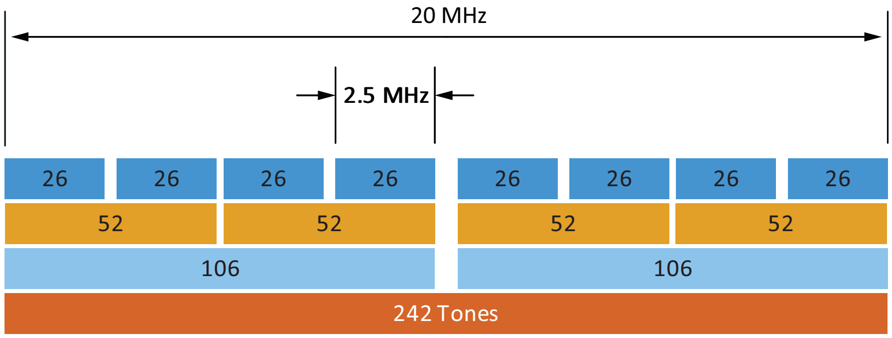
- ***Proxy ARP/Proxy ND (Neighbor Discovery)*** The AP is aware of the associated STA and intercepts the ARP request and replies on behalf of the STA. This results in fewer STA wake-ups and less broadcast traffic on the BSS, consequently improving wireless bandwidth efficiency. ARP in IPv4 changed to the ND protocol in IPv6; hence Proxy ND is used in IPv6.
- ***Hardware ARP offload*** Wi-Fi STA SoCs support hardware offloads to reduce battery usage. They do not wake up the CPU to respond to the ARP request because it is slower from the software TCP stack.

TWT (Target-Wakeup Time)

- ***Individual TWT*** An STA can choose to have its custom wake-up schedule to match its use case. Applications such as audio streaming need regular low latency data transfers. Using this scheduled scheme, the STA can achieve low latency data transfers and sleep between Wi-Fi transmissions conserving battery life.
- ***Broadcast TWT (Wi-Fi 6R2)*** The AP creates wake-up schedule groups and lets STA join them. It is helpful in broadcast traffic scenarios and helps the STA sleep between Wi-Fi transactions conserving battery life, achieving low latency, and improving air time efficiency.

20 MHz STA (Wi-Fi 6 R2)

20 MHz STA is the power-saving feature introduced in Wi-Fi 6 (802.11ax) for IoT devices. A 20MHz channel using OFDM technology has 242 tones or useful subcarriers. They are sub-divided into smaller groups called RU (Resource Units). The RU can be as small as 26 tones. The AP can now assign these smaller RU concurrently to STA, needing only a small bandwidth. Even with many IoT devices grouped into a 20 MHz band, this feature offers less contention, longer battery life, and lower latency.



Note:

- A similar capability exists in the 80 MHz Primary channel.
- SST feature enhances this capability and uses secondary channels on the Downlink and Uplink.

Intra-PPDU PS

While receiving a frame, an STA can decide to sleep if there is a BSS color mismatch or if the frame is addressed to another STA. The NAV(Network allocation vector) field indicates how long the STA can sleep to skip the entire transaction.

BSS Max Idle Period (Wi-Fi 6R2)

An STA associated with an AP must wake up to receive DTIM Beacon and group transmissions before the AP declares it a bad connection and disassociates. BSS Max Idle feature permits an STA to doze for up to 80 hours by increasing the timeout for inactive connections, improving battery life.

Conclusion

MaxLinear actively participates in many standards bodies and the Wi-Fi Alliance. While as an industry, we are working on the next technological advancements like the Wi-Fi 7 standard. Wi-Fi 6 R2 aggregates the latest features of any Wi-Fi certification and offers the best power-saving for IoT and IIoT devices. Wi-Fi 6 R2 devices have the highest throughput and lowest latency available today. Gateways designed using Maxlinear's Wi-Fi Alliance certified chipsets ensure the best possible Wi-Fi ecosystem.

About the Author

Saju Palayur is a Senior Technical Director at MaxLinear. He partners with engineering to ensure MaxLinear products meet industry standards. He has over 25 years of experience in SoC architecture, embedded software, broadband, and wireless. Saju has an MS in Software Systems from BITS Pilani, India, and CWNA and CWAP wireless certifications

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Acronyms

STA: Wi-Fi Client Device Ex: Battery-Operated IoT Edge Device

AP: Wi-Fi Access Point

TIM: Traffic Indication Map

DTIM: Delivery Traffic Indication Message

WMM-PS: Wi-Fi Multi-Media Power Save

PS-Poll: Power Save Poll

U-APSD: Unscheduled Automatic Power Save Delivery

S-APSD: Scheduled APSD

PS: Power Save

PSMP: Power Save Multi-Poll

DTT: Downlink Transmission Time

UTT: Uplink Transmission Time

SMPS: Spatial Multiplexing Power Save

TWT: Target Wake Time

ARP: Address Resolution Protocol

ND: Neighbor Discovery

NAV: Network Allocation Vector

DMS: Directed Multicast Service

OPS: Opportunistic Power Save

FILS: *Fast Initial Link Setup*

SP: *Service Period*

AC: Access Categories – Data Traffic Priority Example: Voice, video, and data

VHT: Very High Throughput

TXOP: Transmission opportunity

VHT TXOP PS: VHT TXOP Power Save

GTK/PTK: Master Session Key/ Pairwise Master Key

PPDU: Protocol Data Unit

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