AN4696
Application note

SPWF01Sx power management options

Introduction

The purpose of this application note is to describe the power management options available on the SPWF01Sx Wi-Fi module [1].

It introduces the IEEE 802.11 power management operations and details its implementation for a WLAN device. STM32 power control modes are also detailed.

The module's power states, along with the corresponding power consumption, are reported as the result of the combination of the WLAN device and the STM32 power states. Finally, some typical application use cases are presented.

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1 IEEE 802.11 power management

The power management of the Wi-Fi client is fully specified by the IEEE 802.11 protocol [2]. Briefly, the STA may be in one of two different power states:

- **Awake**: the STA is fully powered
- **Doze**: the STA is not able to transmit or receive and therefore it consumes very low power

The power consumption associated with each power state depends on the specific implementation.

The transitions between the two states are determined by the STA’s power management modes, summarized as:

- **Active mode (AM)**: the STA may receive 802.11 frames at any time and shall be in the awake state
- **Power save (PS)**: the STA shall be in the doze state and shall enter the awake state to listen to selected beacon frames and to send PS-Poll frames to the AP if the AP has buffered pending frames for that STA (indicated by the TIM element in most recent beacon frame).

An STA shall remain in its current power management mode until it informs the AP of a power management mode change via a frame exchange that includes an acknowledgment from the AP.

The AP shall buffer frames addressed to the STA operating in a PS mode. These buffered frames shall be transmitted only at designated times.

The complete handshake between the AP and the STA is described in [2].

2 WLAN power states and power management

The WLAN device implements the IEEE 802.11 power management based on the following internal power states [4]:

- **Standby**: completely powered down
- **Sleep**: largely powered down. It operates from the low power sleep clock (32 kHz)
- **Active**: partially or completely powered up depending on the following sub-states:
  - Rx Idle: the device is listening to the medium, only part of the receiver is active while the transmit circuits are disabled
  - Rx Active: the device is receiving a frame, the transmit circuits are disabled
  - Tx Active: the device is transmitting a frame

The WLAN device implements two different PS modes:

- **Legacy PS mode**: the WLAN is in PS mode as defined in [2].
- **Fast PS mode**: the device is typically in PS mode. If the host has queued a packet or the device has detected pending data from AP by listening to beacons, the device will enter the AM mode. After an idle period specified by the host, if no traffic is detected, the device will revert to the PS mode.

3 STM32 power control

The STM32 supports the following power modes:

- **Run**: normal functioning of the microcontroller with no power saving features.
- **Stop**: when operating in stop mode, SRAM and register content are preserved. All I/O pins keep the same state as in run mode. The wakeup latency when exiting stop mode is the internal 8 MHz RC oscillator wakeup time (internal clock source) plus the voltage regulator wakeup time from low power mode.
- **Standby**: this mode allows the lowest power consumption. It is based on the ARM Cortex-M3 deep-sleep mode, with the voltage regulator disabled. When operating in standby mode SRAM and register content are lost except for registers in the backup domain and standby circuitry. All I/O pins are kept in high impedance. The wakeup latency when exiting standby mode is the same as in the reset phase

Entering either stop or standby mode depends on the specific application requirements in terms of low-power consumption, startup time and available wakeup sources.

The stop mode is typically used to minimize STM32 power consumption while maintaining the WLAN device active. The STM32 can easily switch from stop mode to the run mode upon reception of an interrupt from the WLAN device indicating that data or management frames are ready to be processed.

The standby mode is the deepest power saving state. During standby the STM32 is not able to listen for the WLAN device interrupt. Once the standby state is entered, it can be awakened only via the wake-up pin or the RTC alarm.

4 Power related AT commands

The host can configure the WLAN device power strategy with the following AT commands:

```
at+s.scfg=wifi_powersave,mode
at+s.scfg=wifi_operational_mode,state
```

The wifi_powersave configuration variable allows a choice between active (0), PS (1) or Fast-PS (2) modes.

The wifi_operational_mode configuration variable allows users to select whether the WLAN device must use the doze (1) or quiescent (2) power-state when entering the sleep state during PS or Fast-PS mode.

Table 1: wifi_operational_mode configuration variable settings

Mode	State	
0	-	Active, no PS is used
1	1	Use PS mode, doze when sleeping (default)
1	2	Use PS mode, quiescent when sleeping
2	1	Use Fast-PS mode, doze when sleeping
2	2	Use Fast-PS mode, quiescent when sleeping

To define the behavior of the STA when in PS or Fast-PS mode, the following commands are used:

```
at+s.scfg=wifi_beacon_wakeup,beacon
at+s.scfg=wifi_listen_interval,interval
```

The wifi_beacon_wakeup configuration variable is used to set the wakeup interval of the WLAN device (i.e. the number of beacons after which the WLAN must wake up to receive a beacon). Note that a beacon value greater than the DTIM value dispatched by the AP would cause the loss of multicast frames from the AP. Further details about TIM and DTIM management can be found in [2].

The wifi_listen_interval variable is used to set wake-up at fixed interval (0) as specified by the beacon value, or using a proprietary adaptive algorithm (1) to extend the wake-up, depending on the traffic.

Table 2: wifi_listen_interval configuration variable settings

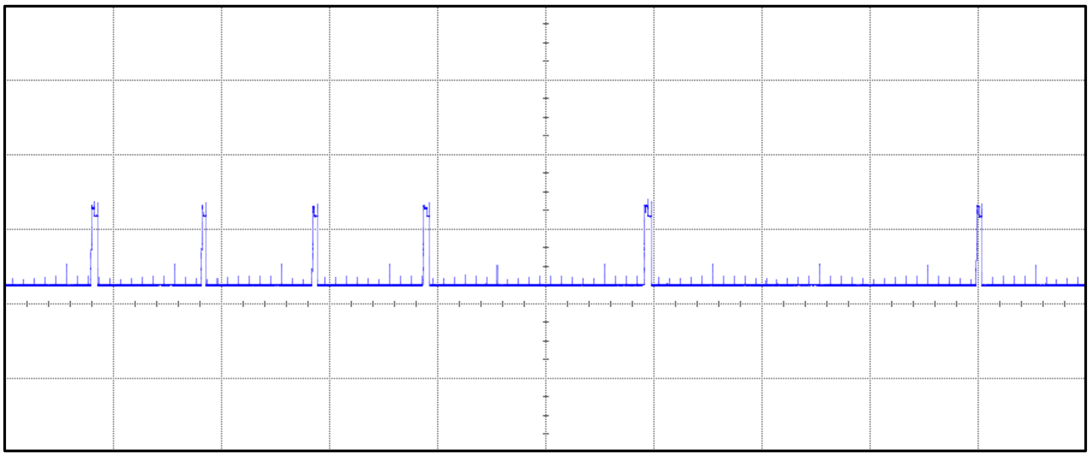
Beacon	Interval	
0	0	Device will wake-up every DTIM interval (default)
0	1	Device will wake-up depending on the traffic within a maximum of DTIM interval
X	0	Device will wake-up every X beacons
X	1	Device will wake-up depending on the traffic within a maximum of X beacons

The following figures illustrate the current consumption (x=500 ms/div, y=50 mA/div) of the WLAN module when using the proprietary adaptive algorithm to extend the wake-up period depending on the traffic (with an upper limit of 10 beacons). For the specific AP settings, DTIM occurs at every beacon, i.e. at every 100 ms.

```
at+s.scfg=wifi_powersave,1
at+s.scfg=wifi_operational_mode,1
at+s.scfg=wifi_beacon_wakeup,10
at+s.scfg=wifi_listen_interval,1
```

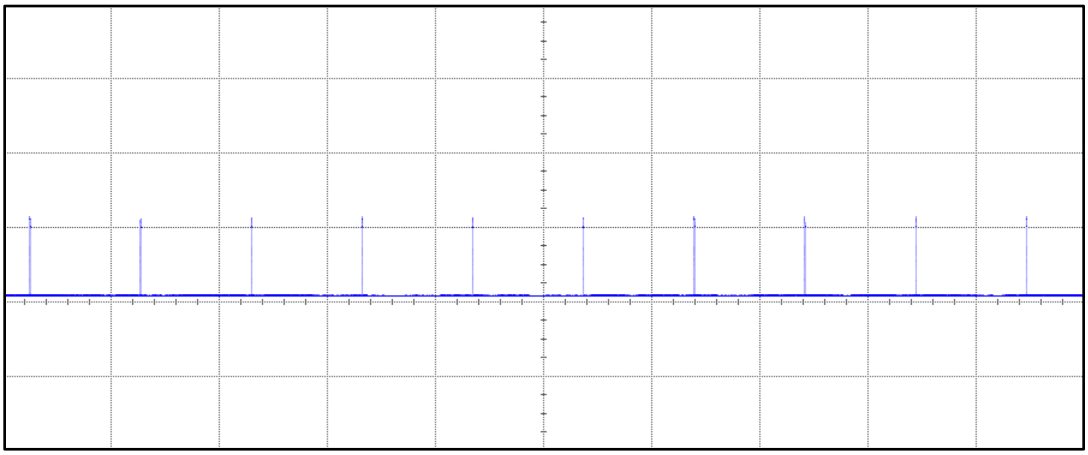
During the initial phase, the STA wakes up at every beacon (x=100 ms/div, 50 mA/div).

Figure 1: SPWF01Sx current consumption during initial phase



After the initial period, the algorithm adapts the wake-up time to match the traffic while staying within the limit of 10 beacons interval set by the command (x=1s/div, y=50mA/div).

Figure 2: SPWF01Sx current consumption using adaptive algorithm



Apart from the AT commands used to manage the power-state of the WLAN device, two additional commands are provided to manage the power-states of the STM32.

The following command can be used to allow the STM32 to enter the sleep mode (corresponding to the stop state):

```
at+s.scfg=sleep_enabled,1
```

Once the Stop state is entered, the STM32 can be awakened by an interrupt from the WLAN device or by the wake-up pin.

It must be noted that the STM32 can be switched on-the-fly from/to the Run state to/from the Stop state by remotely accessing the WLAN device from a browser:

```
CGI engine
```

To enter Stand-by mode for a pre-defined (by dedicated configuration variable) amount of time, the following command must be used:

```
at+cfun=4
```

Where time is expressed in seconds. The STM32 will then enter the stand-by mode and will be awakened by the RTC alarm after some time.

5 SPWF01Sx power states and scenarios

For module power consumption figures in the possible power states (i.e. Standby, Sleep, Power Save, Active Rx, Active Tx) refer to the module's datasheet.

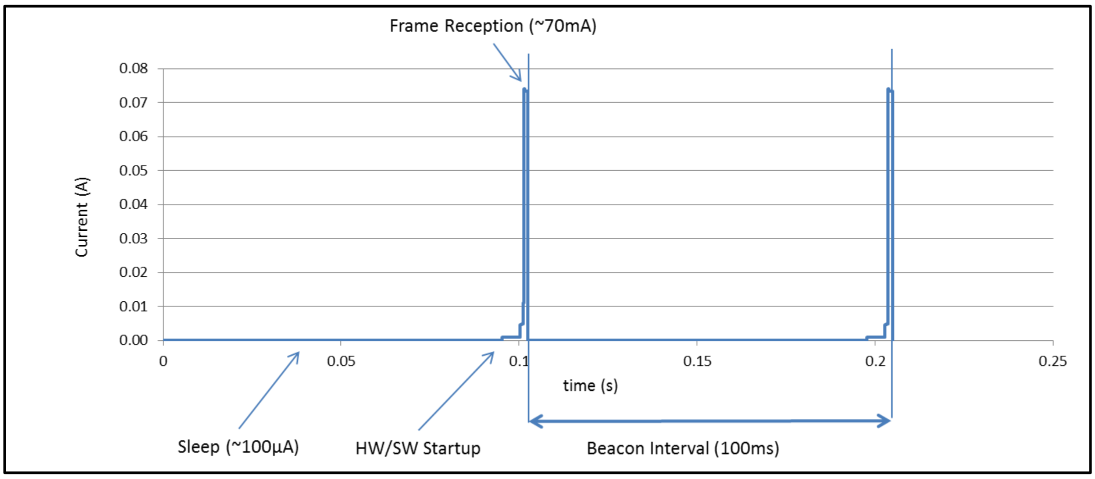
The following table summarizes the available power modes.

Table 3: SPWF01Sx power modes

Module power modes	STM32 power states	WLAN power states	AT commands
Standby	Standby	Standby	at+s.scfg=standby_time,t
Sleep	Stop	PS or Fast PS	at+s.scfg=sleep_enable,1 at+s.scfg=wifi_powersave,1|2 at+s.scfg=wifi_operational_mode,1|2 at+s.scfg=wifi_beacon_wakeup,x at+s.scfg=wifi_listen_interval,0|1
Power save	Run	PS or Fast PS	at+s.scfg=sleep_enable,0 at+s.scfg=wifi_powersave,1|2 at+s.scfg=wifi_operational_mode,1|2 at+s.scfg=wifi_beacon_wakeup,x at+s.scfg=wifi_listen_interval,0|1
Active	Run	Rx Idle Rx Active Tx Active	at+s.scfg=sleep_enable,0 at+s.scfg=wifi_powersave,0

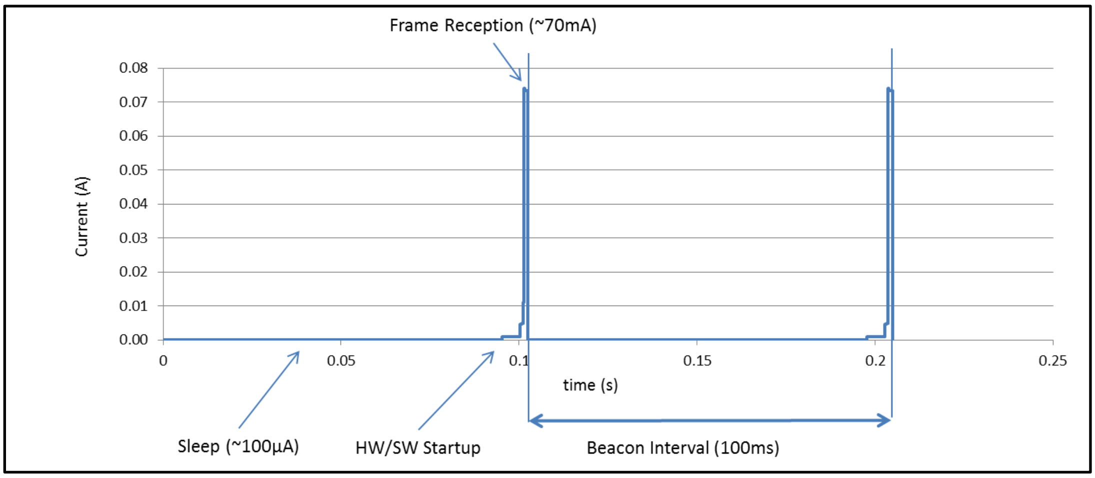
The figure below shows the current consumption of the WLAN device in PS mode during the reception of beacons.

Figure 3: SPWF01Sx current consumption in power save mode



The following figure details the startup timing when the WLAN device wakes up to receive a beacon.

Figure 4: SPWF01Sx current consumption after wake up from power save



The standby power state is suited for low duty-cycle application, where the WLAN device is required to wake up for a very short-time at specific time intervals (e.g. a few bytes transmission at every hour and then sleep).

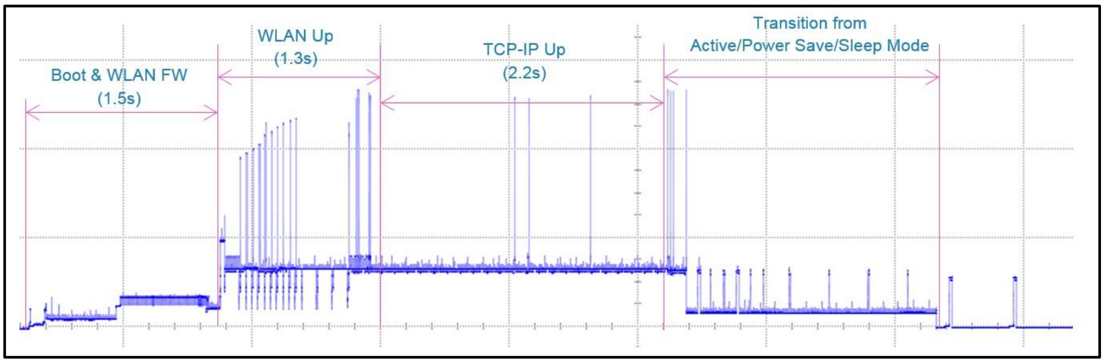
Sleep or power save states are suited for most of applications, including battery-operated devices.

The active state is suited only for high-throughput or very responsive applications.

6 SPWF01Sx power-up

The following figure (x=1 s/div, y=100 mA/div) illustrates the current consumption of the Wi-Fi module from reset until it enters a deep low-power state.

Figure 5: SPWF01Sx current consumption during access to deep low_power state



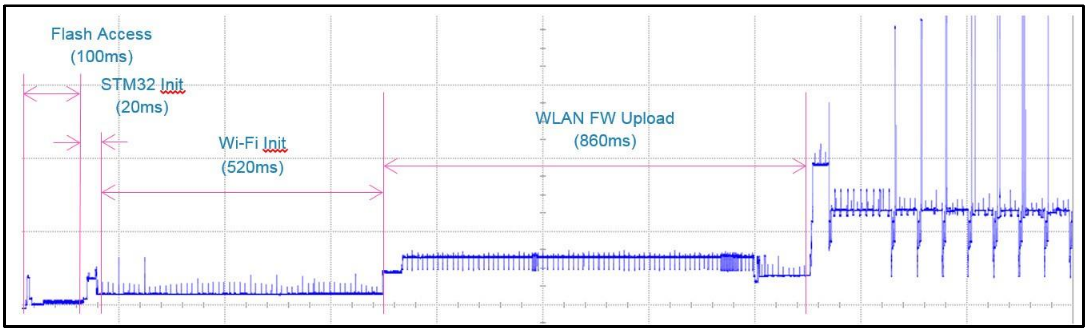
The process can be roughly divided into the following steps:

1. STM32 boot, WLAN power-up and FW upload (1.5 s)
2. WLAN initialization, scan, authentication, association (1.3 s)
3. TCP-IP power-up and DCPH IP address release (2.2 s)
4. Wi-Fi module transition from active to sleep mode (ranges from 1 s to 2 s)

The WLAN is ready to operate after about 2.8 s while the IP address is released after 5 s. The Wi-Fi module can fully operate in deep low-power mode after around 7 s from the reset.

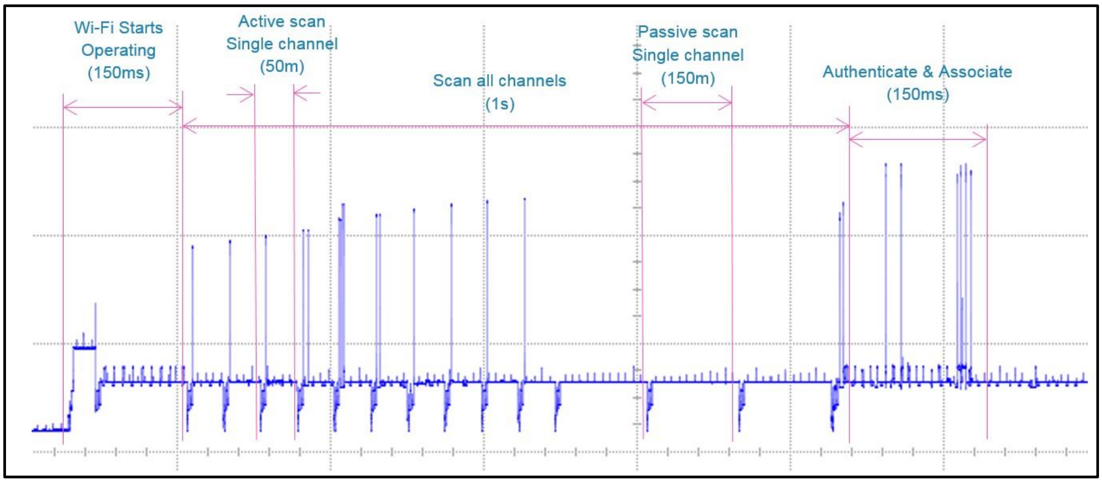
Step 1 can be further detailed as illustrated in the figure below (x=200ms/div, y=50mA/div):

Figure 6: SPWF01Sx current consumption during power-up



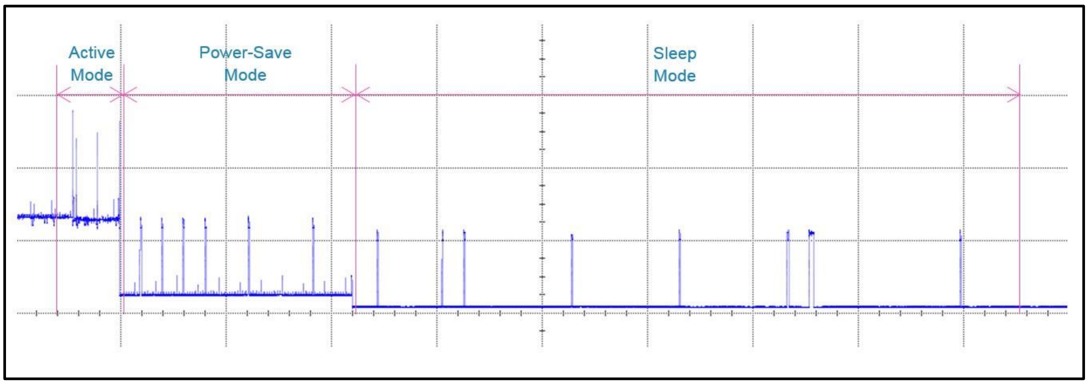
Step 2 can be further detailed as in the figure shown below (x=200ms/div, y=100mA/div):

Figure 7: SPWF01Sx current consumption during initialization, scan, authentication and association



Transition from active to sleep mode is shown in the figure below (x=500 ms/div, y=50 mA/div):

Figure 8: SPWF01Sx current consumption during switch from active to deep low-power mode



7 Glossary

Table 4: Glossary of terms

Term	Definition
AP	Access point
RTC	Real-time clock
STA	Station
U-APSD	Unscheduled automatic power save delivery
WMM-PS	Wi-Fi MultiMedia - power save

8 References

1. SPWF01Sx Wi-Fi module http://www.st.com/wifimodules
2. “IEEE Standard 802.11™-2012. Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications”
3. “Wi-Fi Multimedia™ Technical Specification 4 (with WMM-Power Save and WMM-Admission Control)”, Version 1.2.0, Wi-Fi Alliance® Technical Committee, WMM®-Admission Control Technical Task Group
4. “CW1100 802.11n WLAN System on Chip”, CW1100 Datasheet
5. “RM0008 Reference manual STM32F103xx advanced ARM-based 32-bit MCUs”
6. “UM1695 - Command set reference guide for AT full stack for SPWF01Sx series of Wi-Fi modules”, user manual of SPWF01Sx

9 Revision history

Table 5: Document revision history

Date	Revision	Changes
01-Aug-2017	1	Initial release.

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