AN1430: SiWG917 Low-Power Application Note

This document provides information about the SiWx917 SoC, referred to as SiWG917, low-power modes and current consumption in different power modes and power states. It also details the low-power reference examples in the WiSeConnect3 SDK.

Note: This content may contain offensive terminology that is now obsolete. Silicon Labs is replacing these terms with inclusive language wherever possible.

KEY POINTS

- SiWG917 system blocks
- M4 Power Modes, Wakeup Sources
- NWP Power Modes, Sleep-Wakeup illustrations
- Typical Current Consumption of SiWG917
- Energy Profiling and example use cases of SiWG917 low power modes

1. Introduction

The SiWG917 System on Chip (SoC) delivers ultra-low power consumption without compromising on performance. This application note delves into the advanced features and design strategies that enable the SiWG917 to achieve exceptional power efficiency.

The SiWG917 integrates two processors: Silicon Labs' ThreadArch® (TA) as the Network Wireless Processor and the ARM® Cortex® M4 Processor as the Microcontroller Unit (MCU). By leveraging Dynamic Voltage and Frequency Scaling, meticulous optimization, and a hierarchical design approach, the SiWG917 ensures optimal power management across all components. This dual-processor architecture allows the networking and wireless stacks to operate independently on the Wireless Processor, while the MCU is dedicated to handling peripheral and application-related tasks.

This document aims to provide a comprehensive overview of the SiWG917's low-power capabilities, offering insights into its architecture, design considerations, and practical applications. Whether you are developing battery-operated devices or seeking to enhance the energy efficiency of your existing systems, the SiWG917 offers a robust solution tailored to meet your needs.

Note: Throughout this document, the ***Network WirelessProcessor***, ***Cortex-M4***, and ***SiWG917*** shall be referred to as ***NWP***, ***M4***, and ***SoC*** respectively

2. System Overview

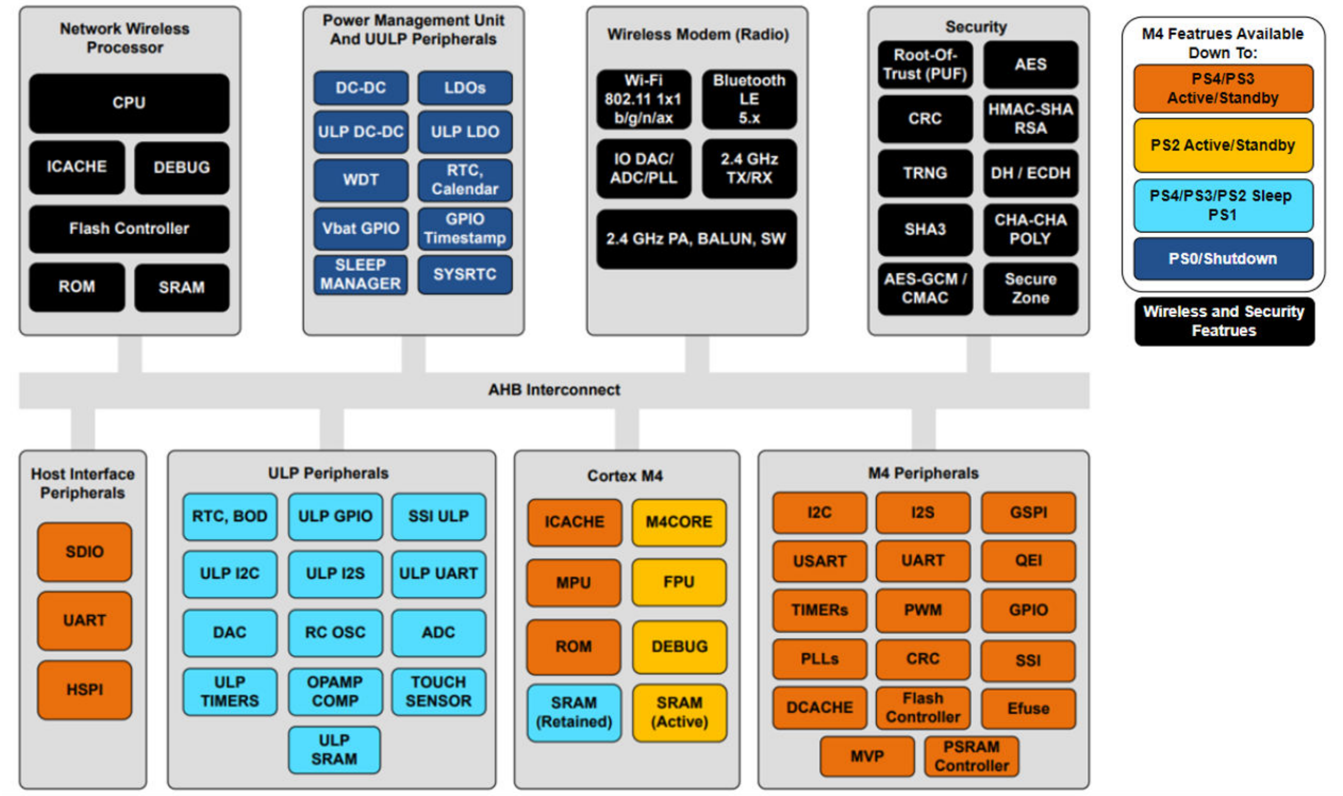


Figure 2.1. SiWG917 System Block Diagram

The basic blocks of SiWG917 can be listed as the following:

- **Network Wireless Processor**: Multi-threaded processor that runs wireless and network stacks on independent threads
- **Power Management Unit**: Responsible for supplying power required for various domains of SiWG917 chipset
- **Wireless Modem (Radio)**: Includes Wi-Fi, Bluetooth, Analog Front-End, 2.4 GHz RF transceiver, and integrated power amplifier sub-systems
- **Security**: Contains security feature blocks like PUF and Secure Zone.
- **Peripherals** such as High-speed peripherals, ULP peripherals, M4 peripherals
- **Cortex-M4**: A high-performance 32-bit processor that runs the microcontroller unit

The SoC low-power compatibility matrix can be illustrated as below:

Table 2.1. SiWG917 M4 vs NWP Power Modes Compatibility Matrix

	NWP Active	NWP Connected Sleep	NWP Unconnected Sleep with Retention	NWP Unconnected Sleep without Retention
M4 Active (PS4/PS3/PS2)	✓	✓	✓	✓
M4 PS4/PS3/PS2 Standby		✓	✓	
M4 PS4/PS3/PS2 Sleep or PS1		✓	✓	
M4 DeepSleep				✓

M4 Application/Firmware should be executed from RAM in the following scenarios:

- M4 Active and NWP Unconnected Sleep without Retention mode.
- M4 in PS2 Active and NWP in Unconnected Sleep with/without Retention.
- M4 in PS2 Active/Standby/Sleep and NWP in Active/Connected Sleep is not supported.

3. M4 Power States

The operational states of the SiWG917 M4 sub-system are called power states (PSx) and are numbered from PS4 to PS0. The PS number is directly proportional to the current consumption. The power states offer different levels of functionality and thus also varying power consumption, allowing designers to scale the resources to fit the bare minimum of what is needed in the application at any given time.

The M4 power states are segregated into power modes as listed below:

- **Active mode**: CPU is powered ON, operating at the configured frequency
- **Standby mode**: CPU is clock-gated, the remaining system operating at the configured frequency
- **Sleep mode**: CPU is power-gated, RAM can be retained
- **Deep sleep/Shutdown mode**: CPU is power-gated, RAM cannot be retained

3.1 Active Mode Power States

The SoC in Active Mode can be in any of the four power states (i.e., PS4/PS3/PS2/PS1).

After reset, the processor starts in the PS4 Active state, the highest activity state where full functionality is available. The other Active states (PS3/PS2/PS1) will have limited functionality or processing power.

PS4 Active: Highest power consumption state, having complete functionality available for M4

PS3 Active: Complete functionality is available, operating at a lower voltage thereby reducing current consumption

PS2 Active: Limited functionality is available, operating at a much lower voltage compared to PS4 and PS3

PS1: CPU is off, and limited peripherals are powered ON; these peripherals need to be configured for desired functionality before entering this state

The functional characteristics of each of the active modes can be understood using the following table:

Table 3.1. M4 Active Mode Power States

	PS4 Active	PS3 Active	PS2 Active	PS1
CPU operating frequency (max)	180 MHz	90 MHz	20 MHz or 32 MHz	OFF
SRAM operating voltage	LDO SoC 1.1 V	LDO SoC 1.0 V	LDO SoC 0.7 V or DC-DC 1.0 V	LDO SoC 0.7 V or DC-DC 1.0 V
Power domains ON	All	All	Applications ULP peripherals UULP peripherals Analog peripherals	ULP peripherals UULP peripherals Analog peripherals
GPIOs available	SoC GPIOs ULP GPIOs UULP GPIOs	SoC GPIOs ULP GPIOs UULP GPIOs	ULP GPIOs UULP GPIOs	ULP GPIOs UULP GPIOs
SRAM powered ON	320 kB LP SRAM 8 kB ULP SRAM	320 kB LP SRAM 8 kB ULP SRAM	320 kB LP SRAM 8 kB ULP SRAM	320 kB LP SRAM (can be retained but not executable) 8 kB ULP SRAM

Note: For more information on power domains, refer to the SiWG917 Hardware Reference Manual .

3.2 Standby States

The M4 in Standby Mode can be in three power states (i.e., PS4-Standby, PS3-Standby and PS2-Standby). Each power state can be entered from its respective Active state using the Wait For Interrupt (WFI) instruction.

The functional characteristics of this mode include the following:

- CPU clock-gated
- SRAM operates at the same voltage as its respective Active state
- Peripherals, GPIOs and SRAM available are same as its respective Active state

Any interrupt can be used as a wakeup source in the Standby mode to achieve the transition from Standby mode to Active mode.

3.3 Sleep States

The M4 in Sleep Mode can be in three states, i.e., PS4-Sleep, PS3-Sleep, and PS2-Sleep. Each power state can be entered from its respective Active state using software instruction.

The functional characteristics of this mode include the following:

- CPU power-gated
- UULP peripherals are functional. Peripherals need to be configured for desired functionality, before entering this state.
- UULP-VBATT GPIOs are powered ON
- 320 kB LP-SRAM can be retained

3.4 Deepsleep/Shutdown Mode

PS0, also known as deepsleep state, can be entered from any active state through software instruction.

The functional characteristics of this mode include the following:

- CPU power-gated
- UULP peripherals are functional and need to be configured before entering this state
- UULP-VBATT GPIOs are powered ON
- SRAM cannot be retained

The flowchart below gives an overview on the power state transitions, CPU, and SRAM configurations available in various power states.

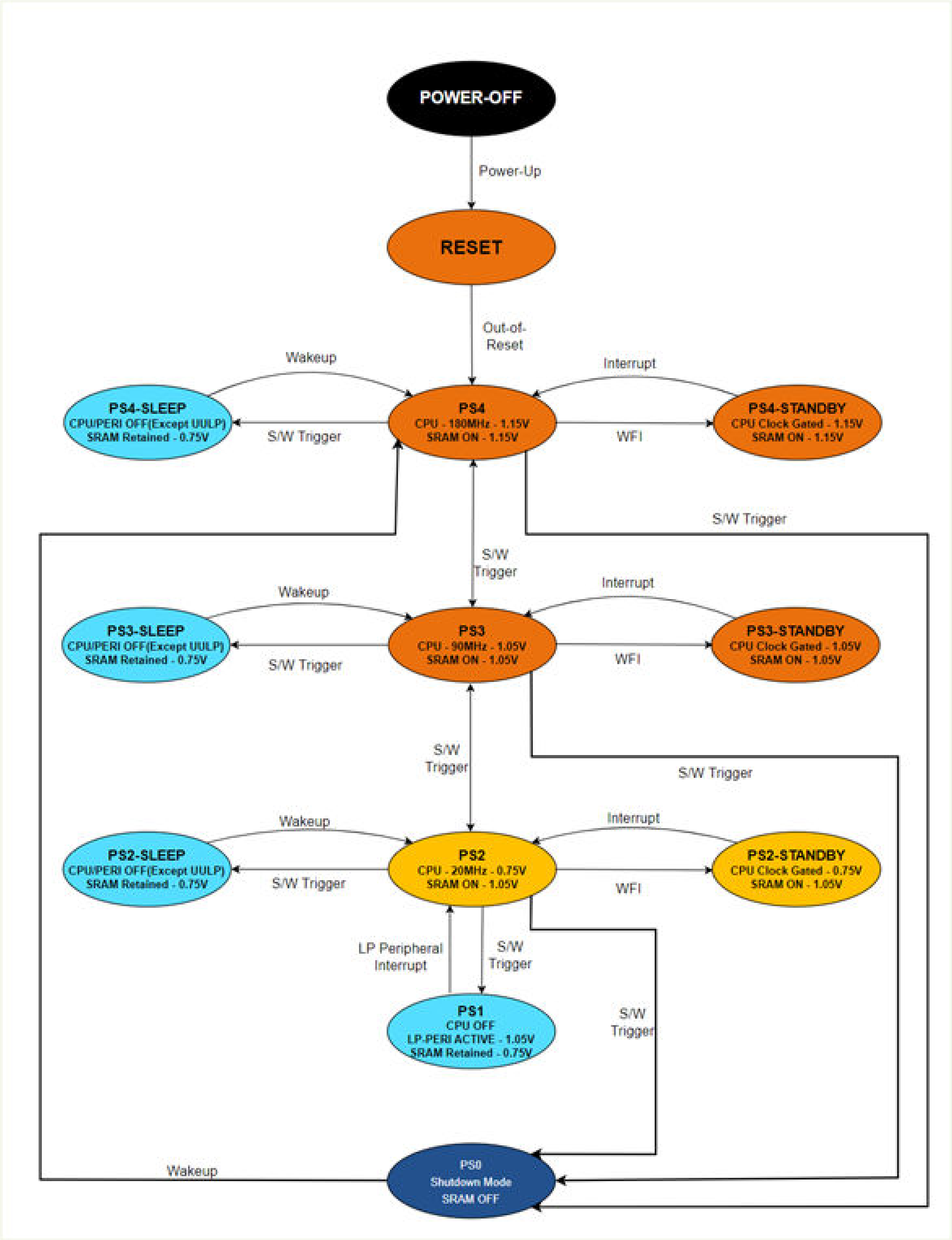


Figure 3.1. SiWG917 M4 Power State Transitions

A transition from active states to any other state can be triggered through software.

A transition from Standby/Sleep/Shutdown state can be triggered by an enabled interrupt as configured by software before entering the state.

4. M4 Power Save Wakeup Sources

The table below indicates the wakeup sources available in Standby/Sleep/Shutdown states.

Table 4.1. Standby/Sleep/Shutdown Wakeup Sources

Wakeup Source	Wakeup Source, as present in the software	PS4/3/2 Standby	PS1	PS4/3/2 Sleep	PS0 (Deep sleep)
Deep-Sleep Timer (DST) Interrupt	DST_BASED_WAKEUP	Yes	Yes	Yes	Yes
UULP VBAT GPIO	GPIO_BASED_WAKEUP	Yes	Yes	Yes	Yes
SYSRTC Interrupt	SYSRTC_BASED_WAKEUP	Yes	Yes	Yes	Yes
Alarm Interrupt	ALARM_BASED_WAKEUP	Yes	Yes	Yes	Yes
Second Interrupt	SEC_BASED_WAKEUP	Yes	Yes	Yes	Yes
Milli-Second	MSEC_BASED_WAKEUP	Yes	Yes	Yes	Yes
Watch Dog Interrupt	WDT_INTR_BASED_WAKEUP	Yes	Yes	Yes	Yes
Wireless Processor Interrupt	WIRELESS_BASED_WAKEUP	Yes (PS4/PS3 only)		Yes (PS4/PS3 only)	
ULP Peripheral SDC (Sensor Data Collector	SDCSS_BASED_WAKEUP	Yes	Yes		
ULP Peripheral ADC/DAC Interrupt	ULPSS_BASED_WAKEUP	Yes	Yes		
ULP timer interrupt	ULPSS_BASED_WAKEUP	Yes	Yes		
ULP Touch Sensor Interrupt					
ULP GPIO Pin/ Group Interrupt					
ULP Peripheral DMA Interrupt					
ULP Peripheral ADC/DAC Interrupt					
ULP Peripheral UART Interrupt					
ULP Peripheral I2C Interrupt					
ULP Peripheral I2S Interrupt					
ULP Peripheral IR Interrupt					
ULP Peripheral SPI /SSI Interrupt					

Note: For more information on M4 Wakeup Sources, refer to the SiWx917 SoC Hardware Reference Manual.

5. NWP Power States

The SiWG917 SoC NWP can be in any of the following power states:

- Active or High-Performance State: All the power domains are powered ON and are active.
- Sleep State: Based on the power save mode used, certain power domains are active, certain domains are powered OFF, and certain domains are in sleep (consume low power).

5.1 Active or High-Performance State

The NWP can be in three operational modes in Active State as described below:

5.1.1 Transmit Mode

In the transmit mode, all the power domains of the NWP are active/operational except the receiver section of the Base Band Processor (BBP), Analog Front End (AFE), and RF Front End (RFFE). This is the highest power-consuming mode of NWP.

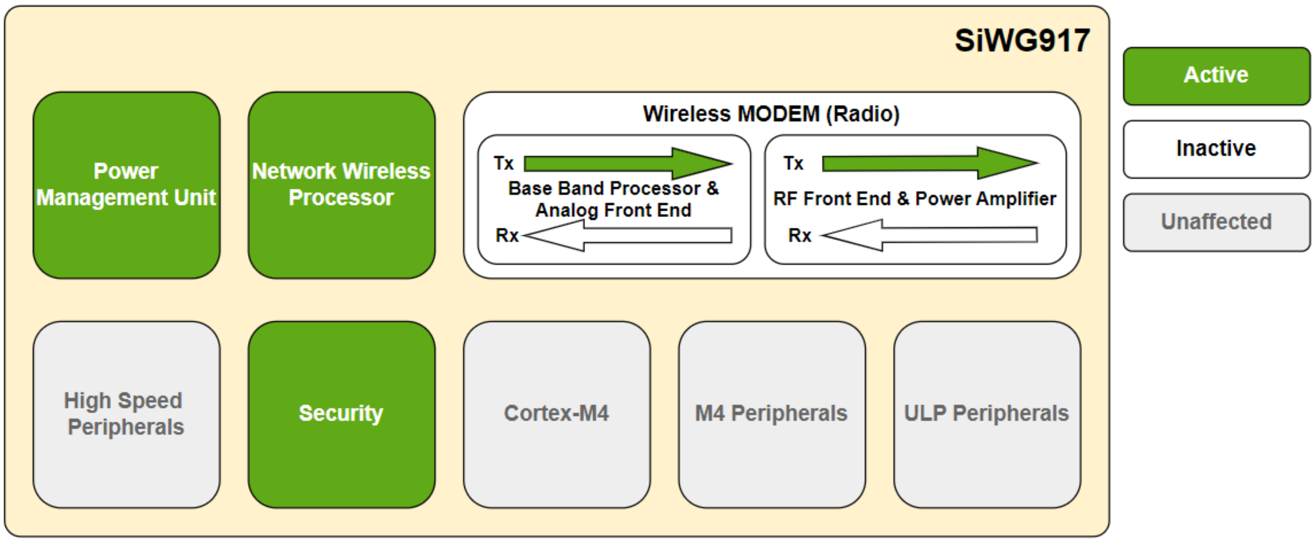


Figure 5.1. Transmit Mode

5.1.2 Receive Mode

In the receive mode, the transmit sections of the BBP, AFE, and RFFE are inactive.

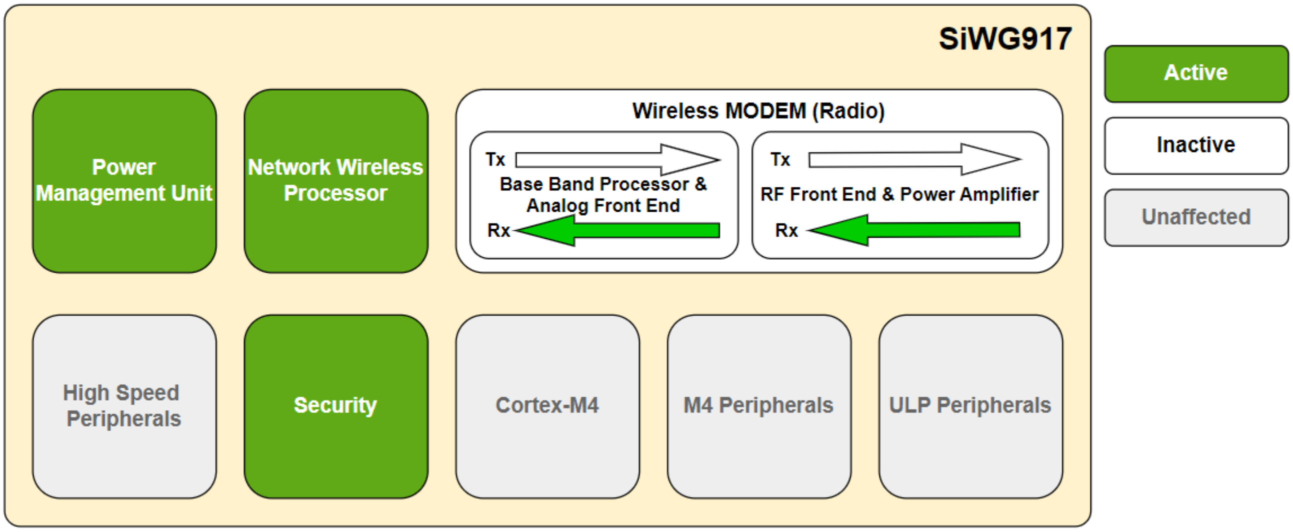


Figure 5.2. Receive Mode

5.1.3 Listen Mode

This mode is a subset of the receive mode where certain receive portions of the BBP and AFE are inactive as no packet reception is in progress.

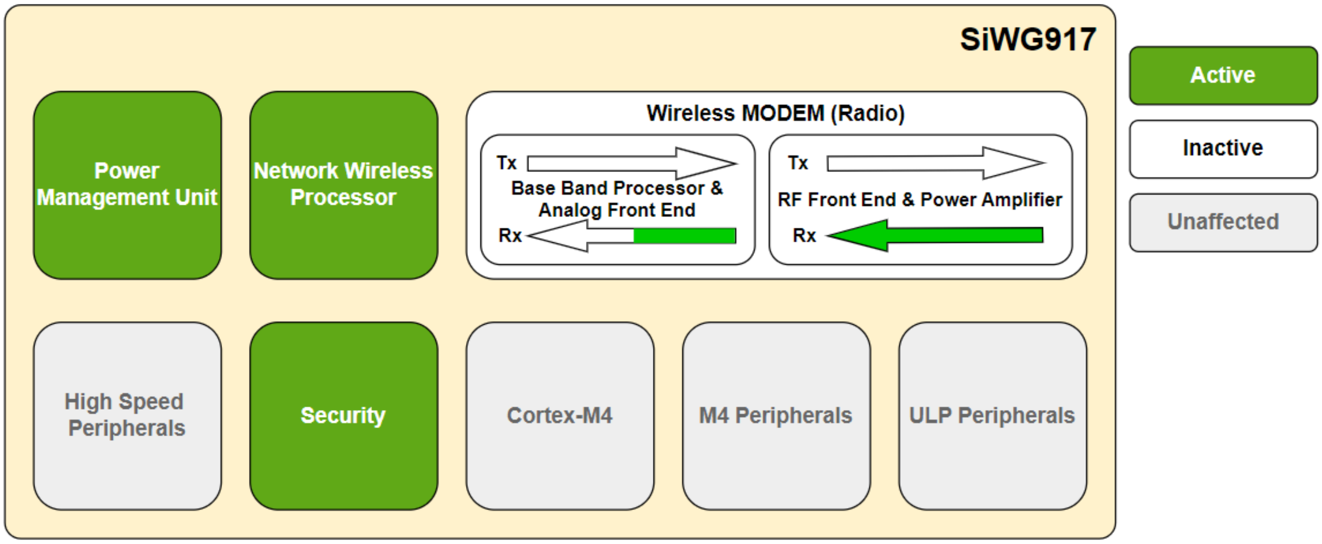


Figure 5.3. Listen Mode

5.2 Sleep State (Ultra-low-power Mode)

The Wireless Modem, NWP, and Security sections are inactive in the ultra-low-power mode. The Power Management Unit (PMU) has control over the other sections of the chip.

The ULP mode can be categorized into the following modes:

- With RAM Retention the SiWG917 NWP SRAM is retained.

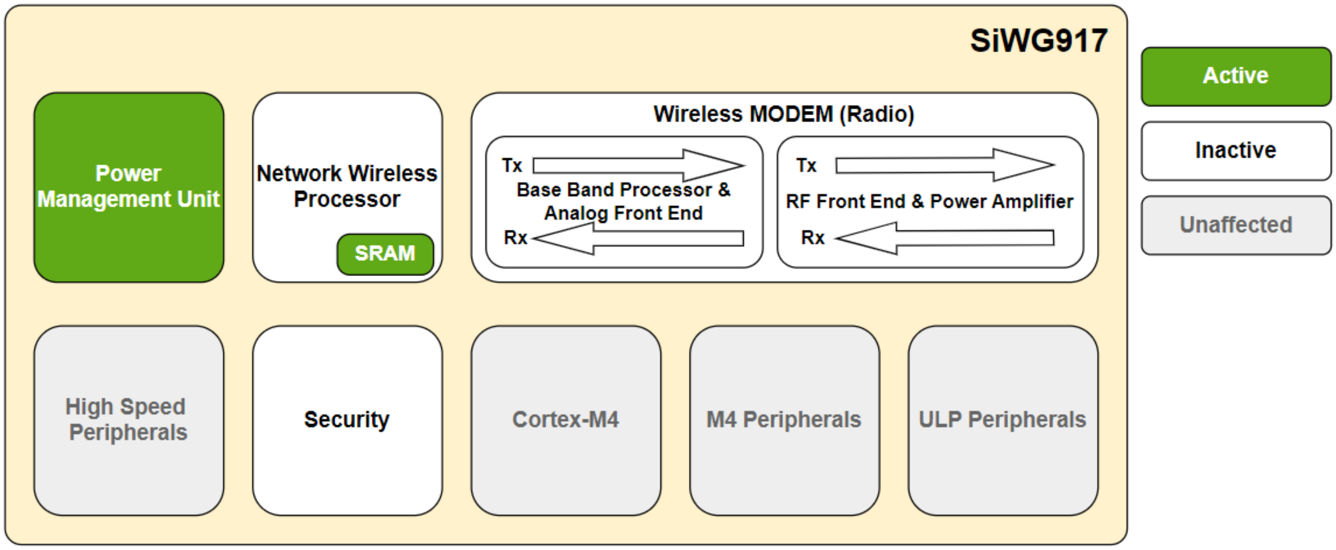


Figure 5.4. NWP Sleep With RAM Retention Mode

- Without RAM Retention the NWP SRAM is not retained.

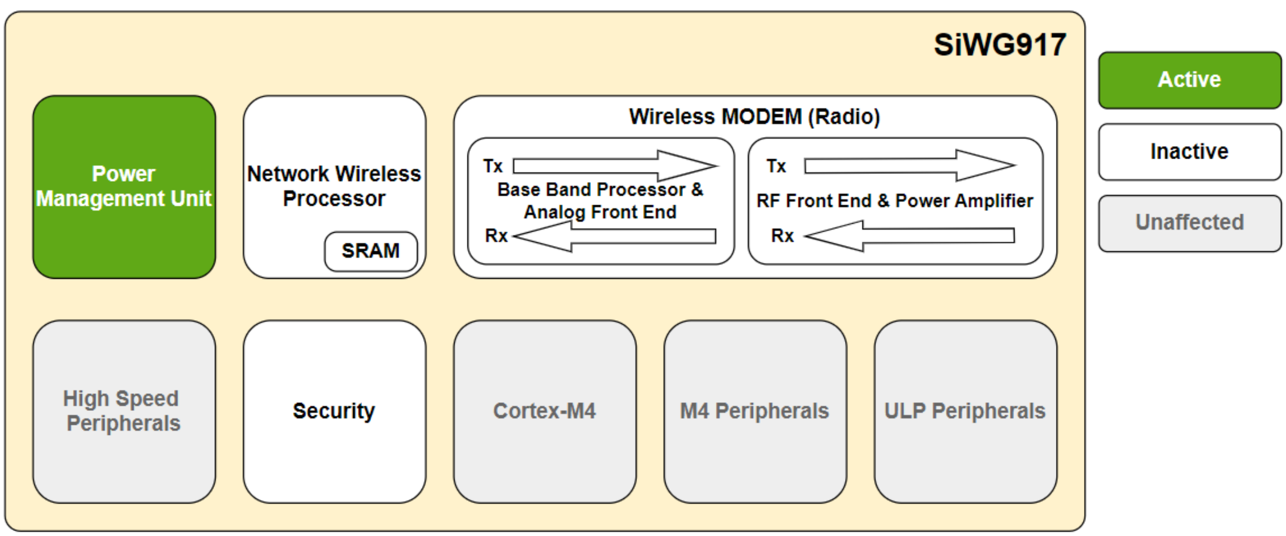


Figure 5.5. NWP Sleep Without RAM Retention Mode

6. NWP Power Save Modes

The SiWG917 NWP can be set to Power Save state via any of the Power Save Modes below based on the application use case. The NWP Power Save Modes are broadly classified into the following:

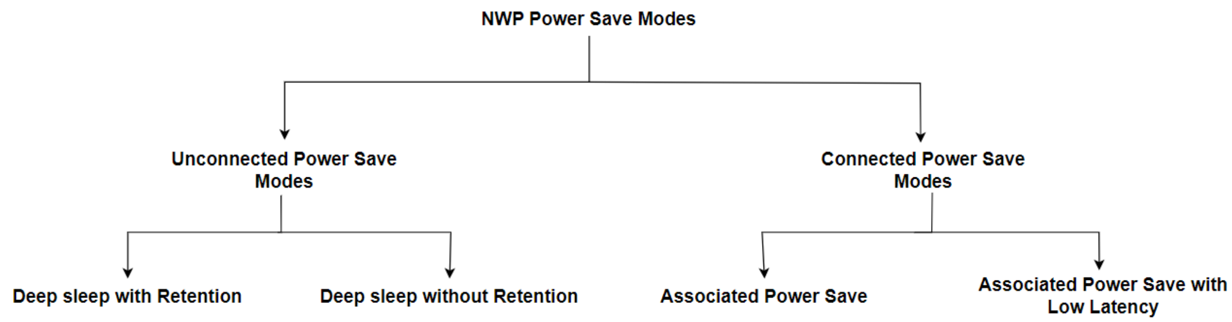


Figure 6.1. NWP Power Save Modes

Note: For Connected Power Save, the RAM Retention configuration alone is supported, while for Unconnected Power Save, with and without RAM Retention configurations are supported.

The SiWG917 uses the following four flags as a handshake mechanism between M4 and NWP over the sleep-wakeup cycles:

1. **TA_wakeup_M4**: Set when NWP needs M4 to be awake. Cleared to indicate NWP allowing M4 to sleep.
2. **TA_is_Active**: Set when NWP is in high-power mode. Cleared when NWP is going to sleep.
3. **M4_wakeup_TA**: Set when M4 needs NWP to be awake. Cleared to indicate M4 allowing NWP to sleep.
4. **M4_is_Active**: Set when M4 is in high-power mode. Cleared when M4 is going to sleep.

Note: The above flags are modified by the internal driver APIs and should not be modified in the application layer.

6.1 Unconnected Power Save Modes

The NWP can be set into Unconnected Power Save before establishing a wireless connection.

6.1.1 Deep Sleep with RAM Retention

In Deep Sleep with RAM Retention mode, the NWP SRAM contents are retained. After wake up, the NWP can continue the execution.

Configuration:

1. After wireless initialization and before establishing a wireless connection, the NWP can be set into Deep Sleep with RAM Retention.
2. To configure the NWP to Standby Powersave mode, call the sl_wifi_set_performance_profile() API with the performance profile set to **DEEP_SLEEP_WITH_RAM_RETENTION**.
3. To switch the NWP back to High Performance mode, call the sl_wifi_set_performance_profile() API with the performance profile set to **HIGH_PERFORMANCE**.
4. Once the NWP is shifted back to High Performance mode, there is no need to perform NWP initialization again, as the previous state of the device is retained.

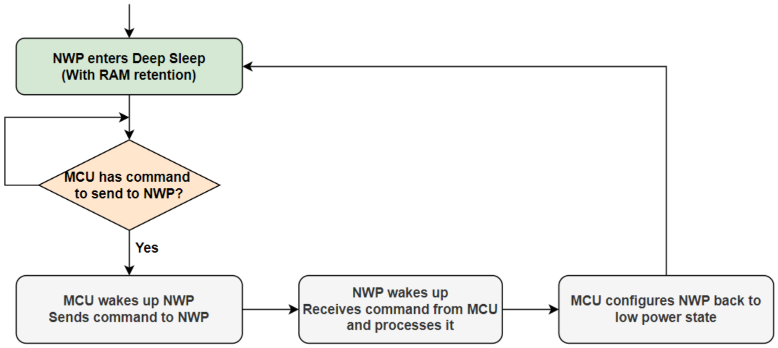


Figure 6.2. Sleep Wake-up Sequence of NWP during Standby/Unconnected Power Save with Retention

6.1.2 Deep Sleep without RAM Retention

In Deep Sleep without RAM Retention mode, the NWP SRAM content and current state are not retained. Upon wake up, the NWP needs to be re-initialized again.

Configuration:

1. After the wireless initialization and before establishing wireless connection, the NWP can be set to Standby Power Save (Without RAM Retention).
2. To configure the NWP to Standby Powersave, call the sl_wifi_set_performance_profile API with the performance profile set to **DEEP_SLEEP_WITHOUT_RAM_RETENTION**.
3. To switch the NWP back to High Performance mode, the NWP needs to be initialized again, as the previous state of the NWP is not retained. Call the sl_net_init() API to initialize the NWP and bring it back to Active mode.

6.2 Wi-Fi Associated Power Save Modes

NWPcan be set into Associated/Connected Power Save after wireless connection during the NWP idle times, which can be switched back to Active state for transmitting/receiving data to/from Access Point.

Before going through the types of Associated Power Save Modes, it is important to understand the sleep/active state switching mechanism and wake interval concepts of NWP during Associated Power Save Mode.

Sleep/Active State Switching

1. The SiWG917 NWP connects to an Access Point and goes to sleep state.
2. When the NWP is in Associated Power Save Mode, it can be configured to wake up every Delivery Traffic Indication Message (DTIM) Interval or Beacon Interval (BI) or Listen Interval (LI) or Target Wake Time (TWT) Wake Interval during its Connected Power Save Mode.

   Beacon Interval-based wakeup: Beacon Interval is the period between two subsequent beacon frames transmitted by AP. The station wakes every beacon interval.

   DTIM Interval-based wakeup: DTIM period specifies how often an AP beacon includes Buffered Traffic Indication to its connected clients via TIM element in the beacon frame. When the AP includes TIM information in a beacon frame, the beacon is called DTIM beacon. DTIM interval is the time between two subsequent DTIM beacons transmitted by AP. DTIM Interval = Beacon Interval * DTIM Period.

   Listen Interval-based wakeup: Based on the Listen Interval configured, the station wakes up at the nearest integral multiples of DTIM beacon/beacon interval broadcasted by the connected AP which is just less than or equal the Listen Interval.

   Note: In case of Listen Interval based wakeup, configuring larger listen intervals greater than 1000 milliseconds might lead to AP disconnecting the NWP. It is highly recommended to use 1000 ms as Listen Interval for low power consumption.

3. When the station wakes up to receive the beacon, it checks if there are data packets to send or receive to/from the remote peer and performs data transfer according to the Power Save Mode configuration.
4. After performing the data transfer/receive, the station goes back to sleep state.

Beacon Interval

- The SiWG917 NWP wakes every Beacon Interval configured in the AP. Longer Beacon Interval implies reduced current consumption.
- - Call sl_si91x_set_join_configuration() API with join_feature_bitmap set as **NULL**, before calling Wi-Fi connection APIs.
  - Set the DTIM alignment type in sl_wifi_set_performance_profile() API to **SL_SI91X_ALIGN_WITH_BEACON**.
- The following figure illustrates the BI-based wakeup of NWP when AP BI = 100 ms and DTIM period = 3. In this case, the SiWx917's wake interval = 100 ms.

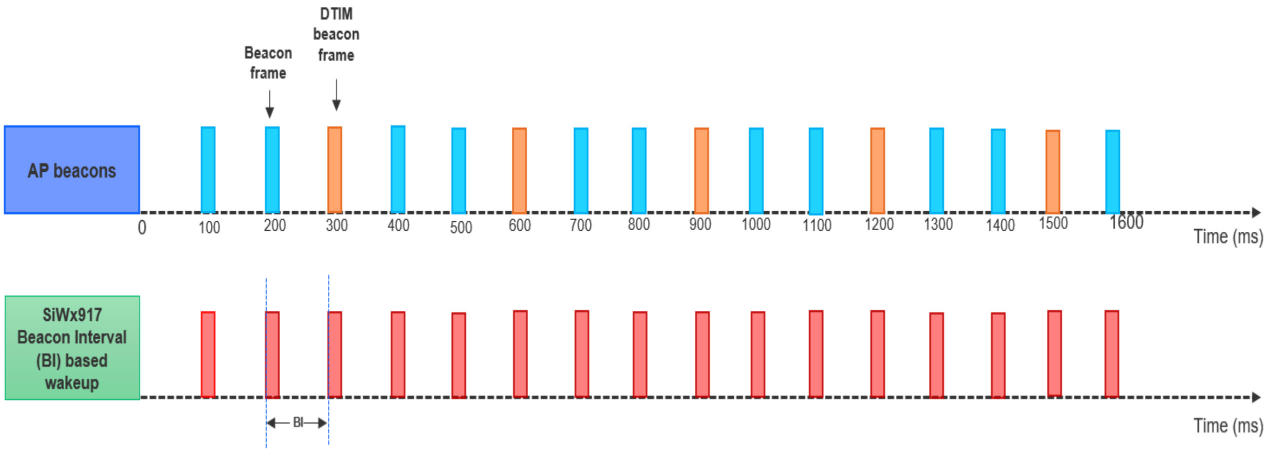


Figure 6.3. BI-based Wakeup of NWP when AP BI = 100 ms and DTIM Period = 3

DTIM Interval

- The SiWG917 NWP wakes every DTIM Interval, as per DTIM period configured in the AP. Shorter the DTIM interval, implies reduced RX latency to retrieve data from the remote peer.
- Configuration:
- Call sl_si91x_set_join_configuration() API with join_feature_bitmap set as NULL, before calling Wi-Fi connection APIs.
- Set the DTIM alignment type in sl_wifi_set_performance_profile()API to **SL_SI91X_ALIGN_WITH_DTIM_BEACON**
- The following figure illustrates the DTIM Interval-based wakeup of NWP when AP Beacon Interval = 100 ms and DTIM period =3, then the NWP wake interval would be 300 ms.

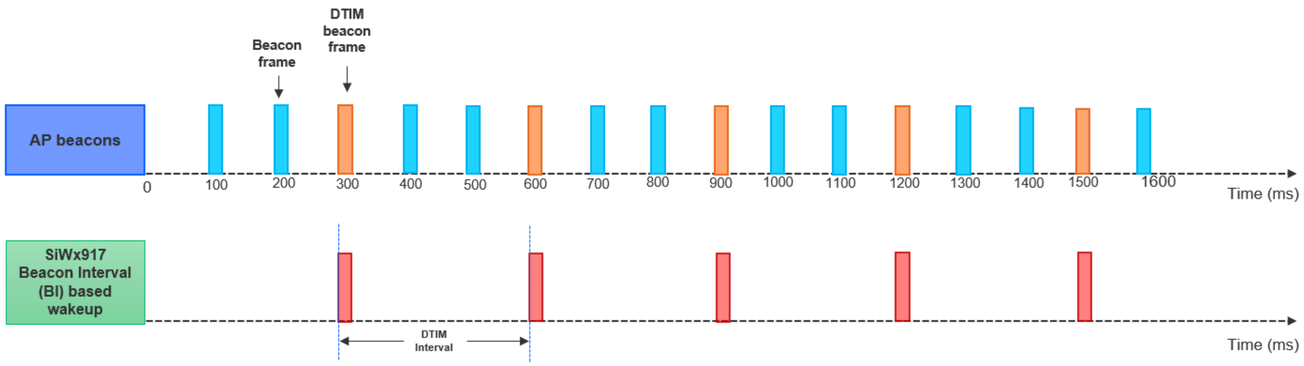


Figure 6.4. DTIM Interval-based Wakeup of NWP when AP BI = 100 ms and DTIM Period = 3

Listen Interval

- The Listen Interval indicates how often the SiWG917 NWP in Connected Power Save Mode wakes to listen to AP beacons.
- The Wake Interval of NWP can be aligned with the DTIM interval or Beacon Interval of the AP.
  - For example, If Listen Interval = 1000 ms, the DTIM period = 3 and Beacon Interval = 100 ms at AP (It means every third beacon contains DTIM information.).
  - If DTIM alignment type is **SL_SI91X_ALIGN_WITH_DTIM_BEACON**, NWP wakes every 900 ms (<= Listen Interval).
  - If DTIM alignment type is **SL_SI91X_ALIGN_WITH_BEACON**, NWP wakes every 1000 ms (<= Listen Interval). In this case, the NWP does not take DTIM period of AP into consideration.
- Configuration: The Listen Interval can be configured in two methods:
- To configure Listen Interval before association with an AP:
  1. Set SI91X_JOIN_FEAT_LISTEN_INTERVAL_VALID in join_feature_bitmap and call sl_si91x_set_join_configuration() before calling Wi-Fi connection APIs.
  2. Call sl_si91x_set_listen_interval() API to set the listen interval.
  3. Call sl_net_up() API to establish Wi-Fi connection with the AP.
- To configure Listen Interval after association with the AP (Recommended for Dynamic Listen Interval modification):
  1. Set SI91X_JOIN_FEAT_PS_CMD_LISTEN_INTERVAL_VALID in join_feature_bitmap, and call sl_si91x_set_join_configuration() before calling Wi-Fi connection APIs.
  2. Call the sl_net_up() for associating with an AP.
  3. To change the listen interval dynamically after associating with the AP, call the sl_wifi_set_performance_profile() API with the updated Listen Interval.

Note: The Listen Interval configured in the sl_wifi_set_performance_profile() API must not be greater than the Listen Interval set using sl_si91x_set_listen_interval() API. The default Listen Interval configured in the WiSeConnect SDK is 1000ms.During association with an AP.

The following figure illustrates the Listen Interval based wakeup of NWP when

- AP Beacon Interval = 100 ms
- DTIM period = 3
- Listen Interval = 800 ms
- In this case, the NWP's wake interval = 600 ms with DTIM-aligned configuration, or 800 ms with Beacon-aligned configuration.

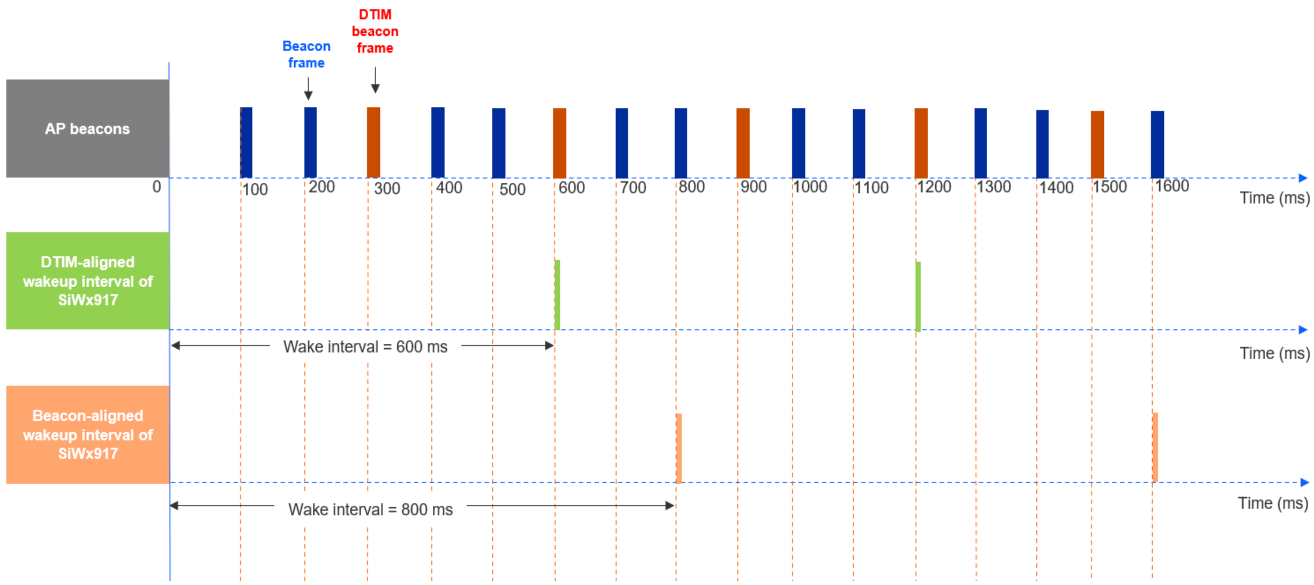


Figure 6.5. LI-based Wakeup of SiWx917 for AP's BI = 100 ms and DTIM period = 3, LI = 800 ms

Note: For Listen Interval-based wakeup, the broadcast and multicast frames transmitted by the AP when the device is asleep may be lost.

6.2.1 Associated Power Save

The Associated Power Save Mode follows Max PSP.

Communication between AP and SiWG917 NWP: When in the Associated Power Save Mode, the NWP can send data to AP at any instance. Fore retrieving unicast data buffered at the AP, the following mechanism is used:

Maximum Power Save Profile (Max PSP):

1. Whenever the AP receives packets that are destined for a station (NWP), it buffers the frames.
2. NWP wakes up for every DTIM or Listen Interval as configured in the application, reads the beacon and checks the TIM bit.
3. If the data pending (TIM) bit is set in the beacon, NWP sends a Power Save Polling (PS-Poll) frame to the AP, to retrieve the data frame.
4. The AP acknowledges the PS-Poll frame and transmits a data frame with the "More Data" field set to 1 in case there are more data frames buffered for the station.
5. NWP receives and processes the data frame.
6. NWP repeats the cycle by sending a PS-Poll frame to retrieve each data frame from the AP.
7. While sending the last data frame to the station, the AP shall set the "More Data" field to 0.
8. After receiving the last data frame, the NWP goes into sleep sate.

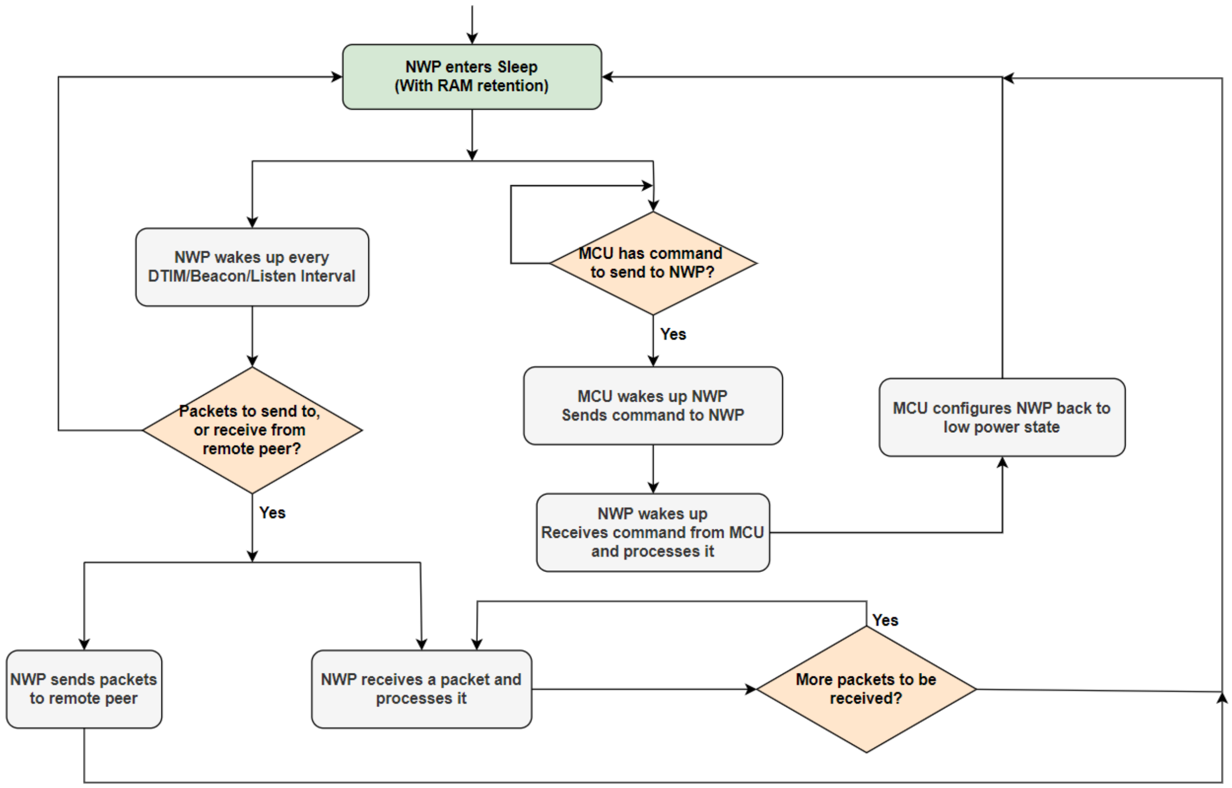


Figure 6.6. Sleep Wake-up Sequence of NWP during Associated Power Save (Max PSP)

The Max PSP saves more power but produces lower throughputs. Sending a PS-Poll frame to retrieve each packet affects the through-put as it induces a considerable amount of delay when bulk data is to be retrieved.

Configuration:

- After a wireless connection, the NWP can be set into Associated Power Save.
- To configure NWP in Max PSP mode, call sl_wifi_set_performance_profile() with power save profile set to **ASSOCIATED_POW-ER_SAVE**.
- The listen interval can be configured as described in the Sleep/Active State Switching subsection at the beginning of the Associated Power Save Modes section.

6.2.2 Associated Power Save with Low Latency

The Associated Power Save with Low Latency Mode follows Fast PSP.

Communication between AP and NWP: When in the Associated Power Save Mode, the station can send data to AP at any instance. For retrieving unicast data buffered at the AP, the following mechanism is used.

Fast Power Save Profile (Fast PSP):

1. Whenever the AP receives data frames that are destined for a Station (NWP), it buffers the packets.
2. NWP wakes up for every DTIM or Listen Interval as configured in the application, reads the beacon and checks the TIM bit.
3. If the data pending (TIM) bit is set in the beacon, NWP switches to active state, and indicates the AP using a NULL data frame with PWR MGT bit set to '0', to retrieve all the data frames.
4. The AP transmits a data frame with the "More Data" field set to '1' in case there are more data frames buffered for the station.
5. NWP receives and processes the data frame.
6. If the AP sends the next data packet within ***Monitor Interval***time, NWP receives the packet. Else, NWP goes back to Sleep state by sending a NULL data frame with the PWR MGT bit set to 1 to the AP.
7. While sending the last data frame to the station, the AP shall set the "More Data" field to 0.
8. After receiving the last data frame, the NWP goes into the sleep state.

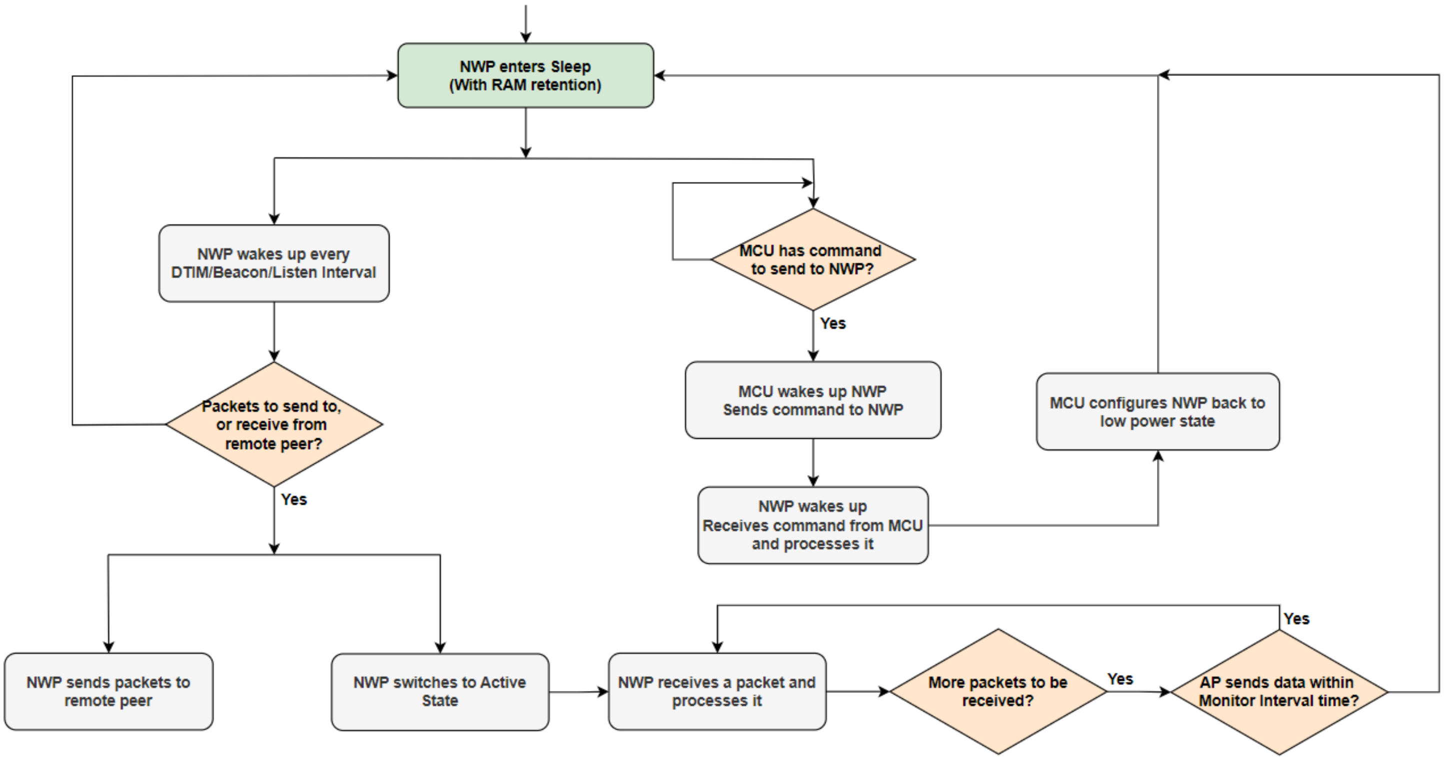


Figure 6.7. Sleep Wake-up Sequence of NWP during Associated Power Save with Low Latency (Fast PSP)

Configuration:

1. After a wireless connection, the NWP can be set into Associated Power Save with low latency.
2. To configure NWP in Fast PSP, call sl_wifi_set_performance_profile() with performance profile set to **ASSOCIATED_POW-ER_SAVE_LOW_LATENCY**
3. The Monitor Interval can be configured by defining the structure parameter's member sl_wifi_performance_profile_t.moni- tor_inter-val.
4. The listen interval can be configured as described in the Sleep/Active State Switching subsection at the beginning of the Associat-ed Power Save Modes section.

Enhanced Max PSP Feature:

In Associated Power Save Mode, during unicast data retrieval, some Access Points do not acknowledge the PS-Poll frames and do not deliver buffered data destined for the Station. This interoperability issue can be avoided with the Enhanced Max PSP feature.

Configuration:

1. Enable the **SL_SI91X_ENABLE_ENHANCED_MAX_PSP** in config_feature_bit_map of the structure sl_wifi_device_configuration_t.boot_config
2. Call sl_wifi_set_performance_profile() with performance profile set to **ASSOCIATED_POWER_SAVE_LOW_LATENCY**.

Internal Functionality:

1. Initially, the NWP Power Save Mode will be set to **ASSOCIATED_POWER_SAVE**.
2. After sending a PS-Poll frame to AP, if the AP delivers the buffered data within 20 ms, the NWP remains to be in **ASSOCIATED_POWER_SAVE**.
3. When the AP does acknowledge PS-Poll and does not deliver the buffered data within 20 ms, the Power Save Mode is switched to ASSOCIATED_POWER_SAVE_LOW_LATENCY, where the NWP switches to Active mode by sending Null data frame to AP and waits for Monitor Interval time to retrieve the buffered data from AP.

Note: To switch the NWP from connected power save to active mode, call the sl_wifi_set_performance_profile API with the profile parameter sl_wifi_performance_profile_t.sl_performance_profile_t set to **HIGH_PERFORMANCE**.

6.2.3 Target Wake Time (TWT)

In the Legacy Power Save Modes, the Wi-Fi stations go to sleep and wakeup at random times to perform data transfer independent to the wakeup timings of other stations. With TWT, the AP schedules wake timings for its connected stations, ensuring no two Wi-Fi stations wake up at the same time. This method helps avoid packet collisions, thus reducing retransmissions and in turn reducing the station's current consumption.

Along with this, TWT allows the Wi-Fi stations to be in sleep for longer durations. TWT is a beneficial Wi-Fi6 feature which allows connected stations to manage power efficiency with the reduced network contention.

The SiWG917 NWP supports two ways of configuration for Individual TWT as follows:

1. Using Manual TWT configuration: The TWT parameters such as sleep duration, wakeup duration, and the wake interval will be calculated based on the TWT specification parameters configured in the application. User needs to have knowledge of individual TWT setup negotiation.
2. Using Automatic (Auto) TWT: Auto TWT is a Silicon Labs implementation that configures TWT parameters automatically based on the user application requirements. The user can provide the application requirements in terms of average Throughput and RX latency. Based on these inputs, the SiWG917 NWP automatically configures the TWT parameters and negotiates them with the AP.

Note: It is recommended to use Auto TWT over standard TWT for better throughput and interoperability. The configuration structure parameters and example usage are explained at TWT TCP Client example documentation.

6.2.4 TWT-based Power Save Mechanism

This section explains the TWT Power Saving Mechanism of SiWG917 NWP with the following TWT parameters set:

- Individual TWT: The connected station (NWP) indicates a negotiation with the Access Point using its individual TWT Wake Interval and Wake duration.
- Broadcast TWT: The AP broadcasts predefined TWT parameters (TWT Wake Interval and Wake duration) in its beacon and schedules wake times for different connected stations (not supported by SiWG917).
- Implicit TWT: The TWT requesting station (NWP) calculates the next TWT by adding a fixed value to the current TWT value.
- Explicit TWT: The start time of the next TWT period is calculated and intimated to the station by the AP (not supported by SiWG917).
- Unannounced TWT: The TWT requesting STA does not announce its wake up to AP through PS-POLLs or UAPSD Trigger frames.
- Announced TWT: The TWT requesting station transmits a PS-POLL or a UAPSD trigger frame to the AP to indicate it’s ready to receive data.
- Non-triggered TWT: The TWT SP does not contain any triggered frames.
- Triggered TWT: AP sends a trigger frame to solicit data from the station.

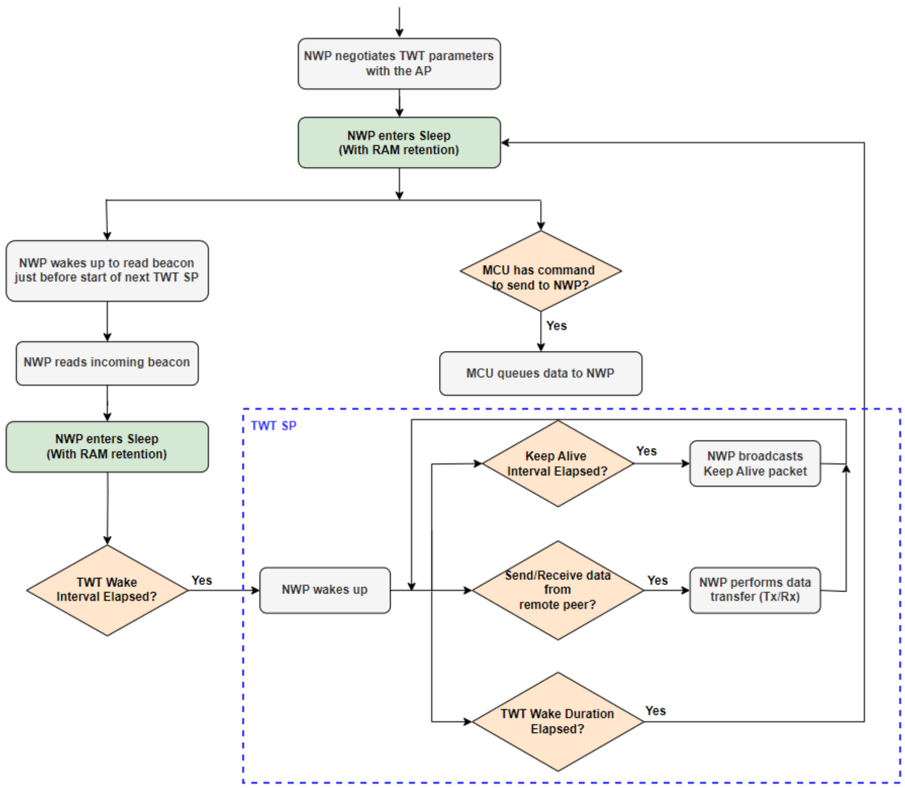


Figure 6.8. Sleep Wake-up Sequence of NWP during Associated Power Save with Legacy TWT

Communication between AP and NWP: When in the Associated Power Save Mode with TWT, the station can send or receive data to/from AP only during the twt_wake_duration.

1. The SiWG917 NWP sends an Association frame with TWT Requester Support bit set in the High Efficiency (HE) MAC capabilities field.
2. After connecting to an Access Point, the NWP transmits a TWT Setup frame with the TWT parameters depending on the request type (Request TWT/Suggest TWT/Demand TWT).
3. If the AP agrees on the TWT parameters, it transmits a TWT Accept frame.
4. The NWP sends a Null data frame and goes to sleep.
5. Whenever the AP receives destined packets for a station (NWP), it buffers them.
6. The AP sets the corresponding AID in the TIM element of the upcoming beacons to indicate that the data is available for the station. The TIM bit will remain set until the station wakes up to receive the data.
7. The NWP wakes just before its TWT SP (as per the programmed TWT wake interval) to read the incoming beacon from the AP for Time Synchronization.
8. As soon as it reads the beacon, the NWP goes back to sleep and wakes at start of TWT SP.

9. In standard TWT, irrespective of TIM element being set or not, the NWP wakes up at the scheduled TWT SP and receives the buffered data within the TWT SP if there is any.
10. The AP transmits a data frame with the "More Data" field set to 1 in case there are more data packets buffered for the Station.
11. After receiving a data packet, the NWP sends it to the host.
12. In case there are no data frames to be received, the station will be active for the rest of wake duration and goes back to Sleep state.
13. Immediately following the TWT SP, the device enters sleep mode, even if there are additional data frames pending transmission or reception. These data transfers will be conducted during the subsequent TWT SP.

TWT Mechanism can be used when your M4 application has predictable and deterministic data traffic. The M4 application should be aware of the times at which data traffic is expected.

Configuration:

- Ensure that the SLI_SI91X_ENABLE_TWT_FEATURE and SLI_SI91X_CONFIG_WIFI6_PARAMS pre-processor macros are enabled in the project settings..
- After calling sl_net_up() API, register a callback function for TWT negotiation response events using the API **sl_wifi_set_twt_config_callback ()**
- Trigger the TWT parameters negotiation by calling the API **sl_wifi_enable_target_wake_time ()** with the structure parameter sl_wifi_performance_profile_t.sl_wifi_twt_request_t set with TWT setup configuration.
- Once the AP sends a TWT response frame, the registered callback function gets triggered. The callback function gives the negotiated TWT parameters that are agreed with the AP.
- ext, set the SiWx917 into Associated Power Save by calling the **sl_wifi_set_performance_profile()** API with the performance profile set to ASSOCIATED_POWER_SAVE

Auto TWT

- TWT parameters (wake duration and wake interval) are computed based on the latency and throughput parameters as configured by the user in the application.
- The Auto TWT algorithm also checks if TWT is useful for a specific combination of the latency and throughput parameters. If found inefficient, TWT is not enabled, instead legacy listen Interval-based power save is enabled.
- It uses a combination of LP and HP chains to reduce current consumption. It also infers internally based on traffic patterns when to wake up next.
- It does not wake up unnecessarily and sleep for an extended time when there is no data. But if there is data to receive and transmit, it wakes up on TWT to meet the latency requirements and ensures timely data transfer.

Benefits of Automatic TWT over TWT

- Power optimization when compared to standard TWT
- Handles TX and RX activities based on latency that the application can withhold, which is not possible with standard TWT.

7. SiWG917 Typical Current Consumption

This section lists the typical current consumption of SiWG917 observed at room temperature, with supply voltage of 3.3V, M4 and NWP configured in 320-352 KB SRAM configurations respectively.

The table below gives an overview of possible power state combinations and their power numbers

Table 7.1. Current Consumption for Possible M4-NWP Power States

		NWP Associated Powersave (With Retention)		NWP Deep Sleep with Retention	NWP Deep Sleep without Retention
		Sleep Current	Average Current		
Active/Standby Mode	PS4	8.81 mA	8.88 mA	8.81 mA	8.803 mA
	PS3	5.91 mA	5.98 mA	5.91mA	5.903 mA
	PS2	NA		824 µA	817.5 µA
	PS1	NA		453 µA	NA
Sleep Mode	PS4/3 Sleep	21.9 µA	77.9 µA	21.9 µA	NA
	PS2 Sleep	NA		21.9 µA	NA
Deepsleep Mode	PS0	NA		NA	3.8 µA

The current consumption numbers in the above table are obtained by combining respective M4 and NWP current numbers from the datasheet. Apart from these, M4 current varies with the SRAM retained, as configured in the M4 application.

7.1 M4 Power States Active and Sleep Currents (Excluding NWP)

The following current consumption numbers are obtained by configuring NWP in shutdown mode, that consumes minimal current consumption. The NWP shutdown mode here is used only to simulate the M4 sub-system current consumption numbers. NWP shutdown mode cannot be used in real time applications.

Table 7.2. Current Consumption of M4 Power States

Power Mode	Power State	Current Consumption	Units
Active/Standby	PS4	8.8	mA
	PS3	5.9	mA
	PS2	815	µA
	PS1	444	µA
Sleep	Sleep with 320 KB RAM	12.9	µA
	Sleep with 192 KB RAM	9	µA
	Sleep with 128 KB RAM	7.2	µA
	Sleep with 64 KB RAM	4.7	µA
Deepsleep	PS0	1.3	µA

7.2 NWP Power States Current Consumption

The table below shows the difference between NWP current consumption with different SRAM configurations.

Table 7.3. NWP Current Consumption at different RAM configurations

Configuration	NWP Retention		
	352 KB	416 KB	480 KB
NWP in Associated/Standby Powersave with retention M4 in PS4 Sleep with 192 KB RAM retention	15.5 µA	16.6 µA	17.7 µA

8. SiWG917 Energy Profiling

This section lists the reference examples and the setup procedure used to measure the current consumption.

8.1 Reference Examples

The following are the reference examples in the WiSeConnect 3 SDK for configuring Power Save Modes:

- For various M4 Active state transitions, refer to the Power Manager Wireless example.
- For Tickless Idle Mode implementation usage, refer to the Power Manager Tickless example
- For M4 in PS4 sleep with retention, NWP in Associated power save mode configuration, refer to the Power Save Standby Associated example.
- For M4 sleep with retention, NWP in Connected Power Save Mode with TWT, refer to the TWT TCP Client example.
- For M4 and NWP in deepsleep without retention, refer to the Powersave Deep Sleep example.

Note:

- The current consumption details present in this section are measured using the Energy Profiler tool from Simplicity Studio IDE.
- All the current consumption values mentioned in this section are measured with 352-320 KB memory configuration for NWP and M4 respectively.
- A variation of current consumption by ±10% might be expected from board to board.
- For the latest/updated current consumption numbers, refer to the SiWG917 datasheet.

8.2 Setup Diagram

For measuring current, the following setup is used:

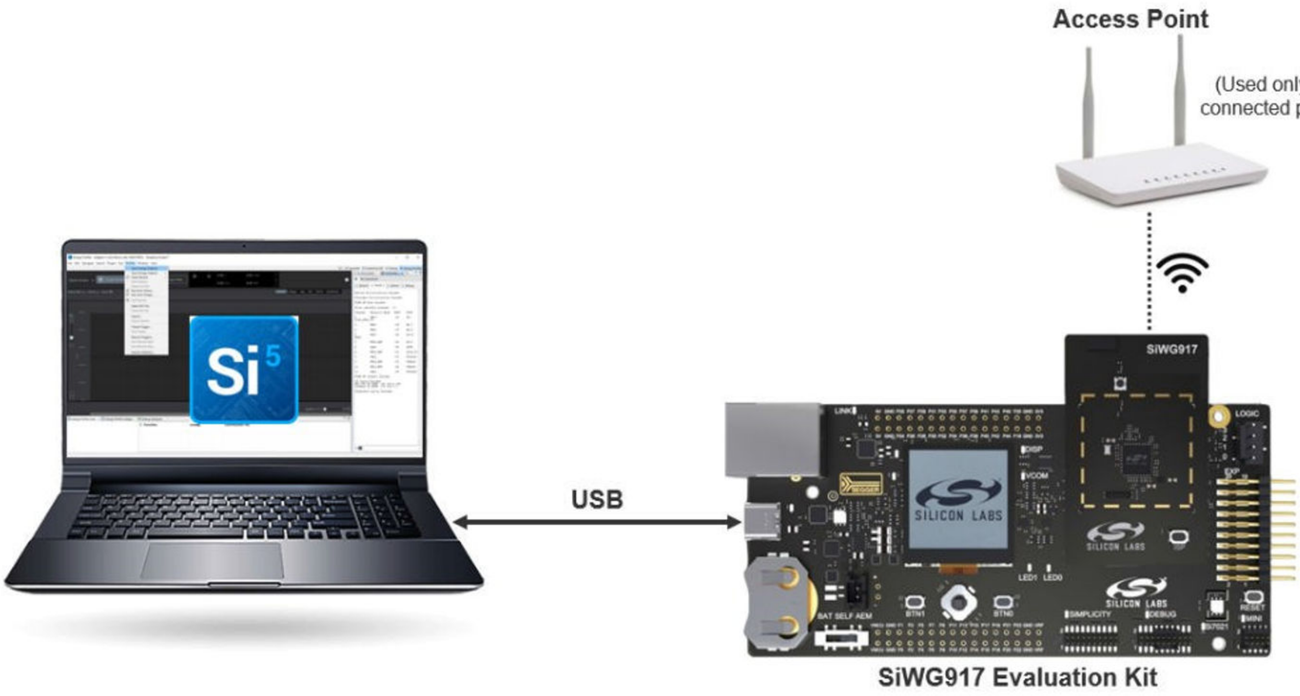


Figure 8.1. Setup Diagram for Energy Profiling

8.3 SiWG917 (M4+NWP) Power Consumption

8.3.1 Powersave Standby Associated Example

The Powersave Standby Associated example has the functionality below:

1. M4 and NWP are initialized.
2. NWP configured as WLAN station, connects to an Access Point and gets the IP address via DHCP.
   - By default, the applications are configured to scan on 2.4 GHz channels (1-11) for the specified SSID. The SoC sends a directed Probe Request specifying the SSID it is looking for on the 2.4 GHz channels.
   - By default, the SoC sends a unicast probe request, gets a probe response, and then connects to the AP.
3. SoC connects to a UDP socket and performs data transfer with configured amount of data.
4. NWP is configured to Associated Powersave (Enhanced Max PSP).
5. M4 is configured to PS4 Sleep.

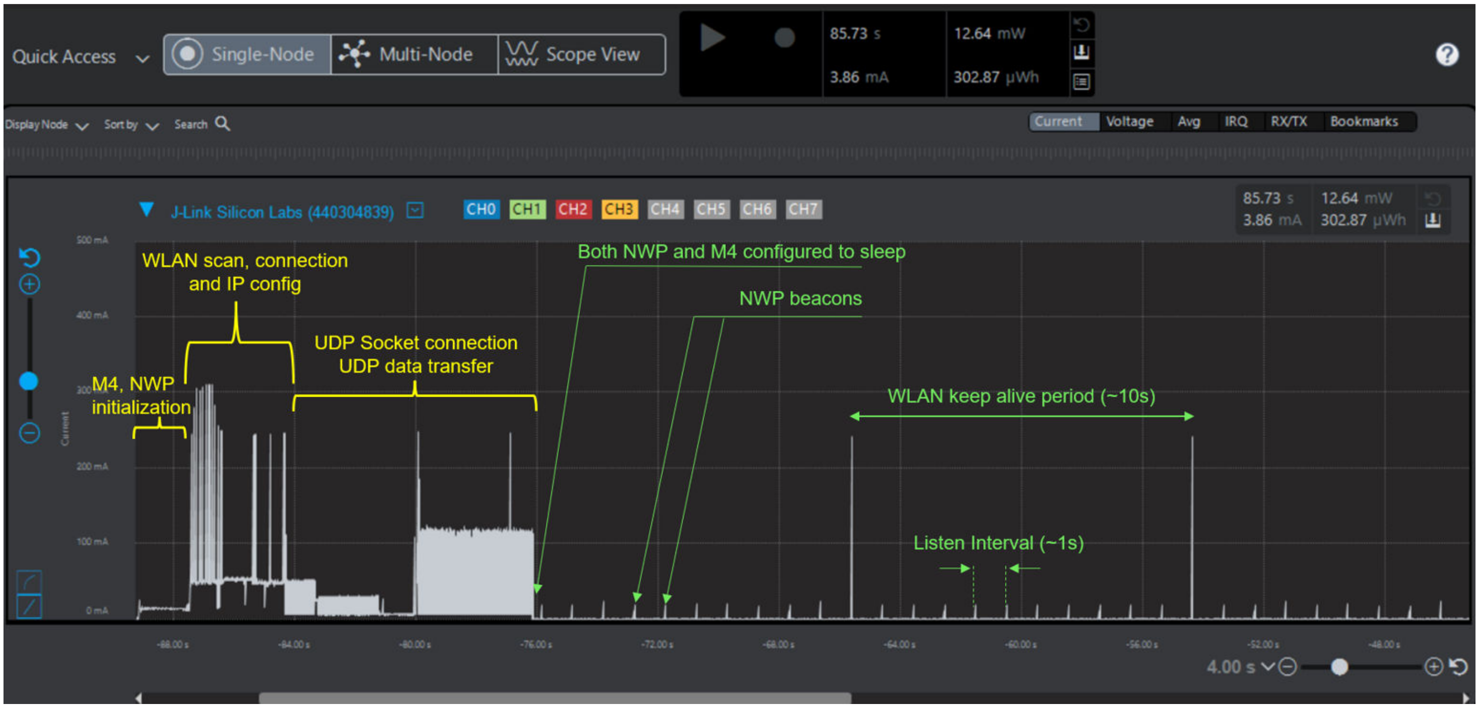


Figure 8.2. Powersave Standby Associated Example Current Consumption Graph

Table 8.1. SiWG917 Current Consumption

State	Average Current Consumption	Time Taken
SoC power-up to firmware load	15.93 mA	1.50 s
SoC power-up to radio initialization	15.94 mA	1.54 s
Radio initialization to wireless scan	61.5 mA	1.88 s
WLAN scan	56.5 mA	1.01 s
WLAN connection	59.8 mA	1.08 s
SoC power-up to IP configuration (Using DHCP)	47 mA	5.33 s

Note:

- Quick scan feature in the SoC enables the NWP to scan for a particular access point in a particular channel. This feature benefits you if your application connects to a known SSID on a specific channel number. This helps in reducing the time taken for scanning for APs as well as lowers the current consumption.
- The dwell time of the scan in each channel can be configured using sl_si91x_configure_timeout() API, as needed to reduce current consumption further.
- Quick join feature in the SoC enables the NWP to send authentication and association frames without unicast probe requests. To use the Quick Join feature, enable SI91X_JOIN_FEAT_QUICK_JOIN feature in the **join_feature_bitmap** and call the below API.

SiWG917 during WLAN Data Transfer

The NWP can be in the following atomic states:

- TX_ACTIVE: Current consumption during active transmission at a given on-air data rate such as 6 Mbps, and a given output power level.
- RX_ACTIVE: Current consumption during active reception at a given on-air data rate.
- LISTEN: Current consumption when the NWP is waiting for data reception.

The NWP current consumption values during data transfer, are mentioned in the WLAN 2 GHz section of the SiWG917 data sheet.

NWP in Associated Powersave and M4 in PS4 sleep current is mentioned in 7. SiWG917 Typical Current Consumption section.

8.3.2 TWT TCP Client Example

The TWT TCP Client example has the below functionality:

1. M4 and NWP are initialized.
2. NWP configured as WLAN station connects to the Access Point, and gets the IP address via DHCP.
3. SoC configured as TCP client, connects to a TCP server, using the credentials present in the application.
4. If the connected AP supports 11ax TWT, NWP is configured to 11ax TWT Associated Powersave.
5. If the connected AP doesn't support 11ax TWT, NWP is configured to 11n Associated Powersave.

Current numbers:

- The current numbers from initialization to IP config are same as the Powersave Standby Associated example.
- When NWP is in Associated Powersave with TWT and M4 is in PS4 sleep, the sleep current is as mentioned in WLAN 2 GHz section of the SiWG917 datasheet.

M4 in Sleep with Retention, NWP in Associated Power Save with TWT Enabled

By default, the TWT parameters configured in TWT TCP client example brings in a TWT Wake Interval of ~ 61 seconds.

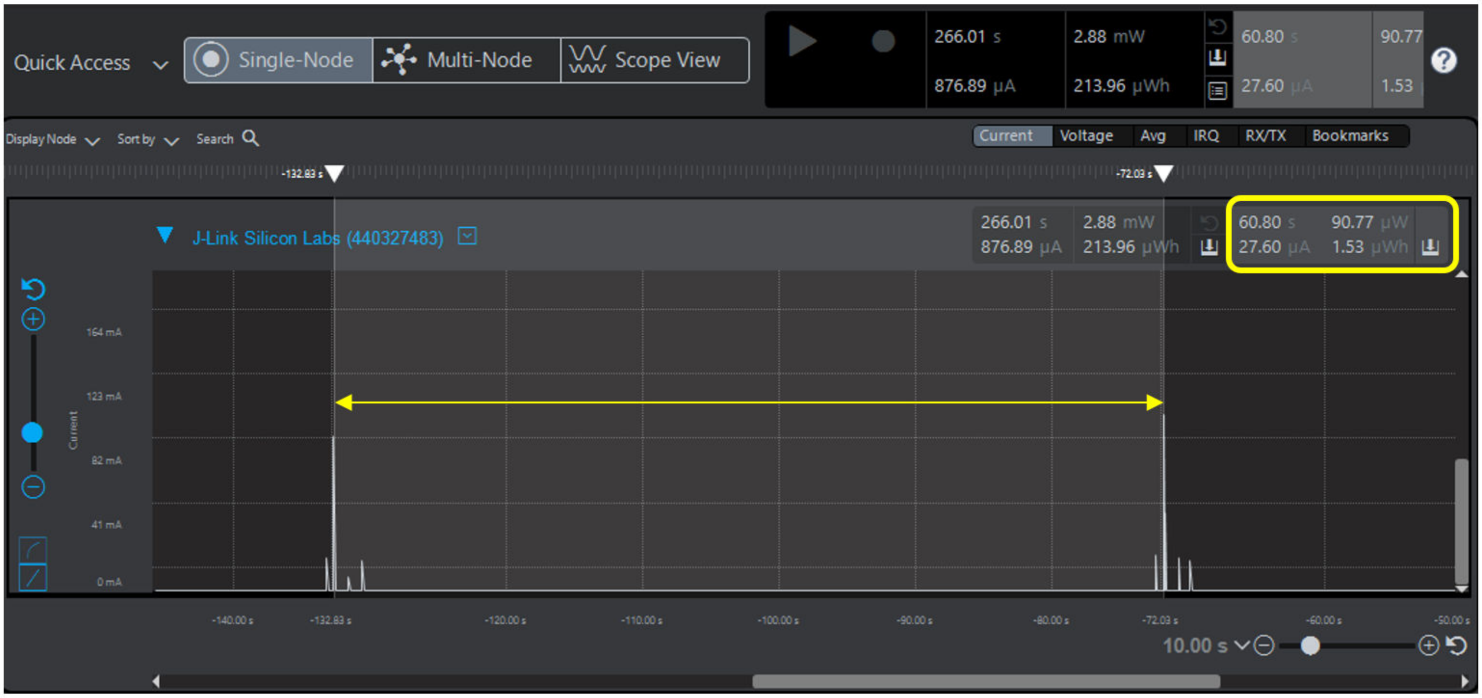


Figure 8.3. TWT TCP Client Example Current Consumption Graph

The current above consumption values are mentioned in the WLAN 2 GHz section of the SiWG917 datasheet.

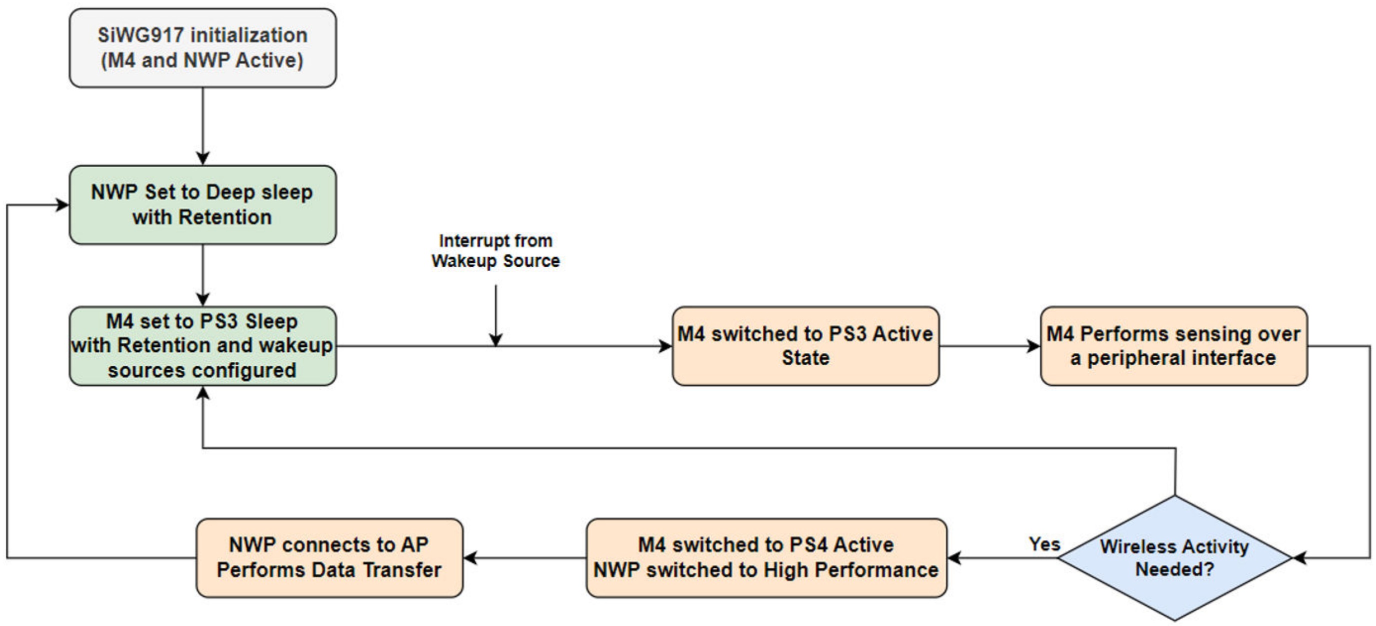
9. Example Use Cases

9.1 M4 Sensing over a ULP Peripheral with Intermittent Wi-Fi Communication

The reference application flow can be illustrated as follows:

1. SiWG917 comes out of RESET, NWP, and M4 initialization.
2. NWP set to unconnected sleep (Standby Power Save/without Retention).
3. M4 set to PS2 Sleep with retention for 200 milliseconds.
4. M4 gets back to PS2 Active upon RTC timer expiry; M4 receives data from ULP peripheral/sensor.
5. M4 processes the data received, based on data, and a decision is taken to execute either step-6 or step-8.
6. If wireless activity is needed, M4 switches back to PS4, and NWP is switched back to High Performance Mode.
7. NWP is configured as WLAN station, connects to a AP, performs data transfer over WLAN, disconnects from WLAN, and execution continues from step-2.
8. If wireless activity is not needed, execution continues from step-3.

Figure 9.1. SiWG917 Low-power Mode Use Case 1



9.2 NWP in Connected Power Save, M4 Performing Activties Based on the Wireless Message Received (Smart Lock)

The application flow can be understood as the following:

1. SiWG917 comes out of RESET, NWP, and M4 initialization.
2. NWP configured as WLAN station, connects to AP, connects to AWS Cloud over MQTT.
3. NWP set to Connected Power Save (Associated Power Save).
4. M4 set to PS4 sleep with retention having RTC timer, UULP GPIO, and Wireless message as wakeup sources.
5. Upon Wireless based wakeup, based on the wireless message received, the smart lock is either locked, unlocked, or simply the current state of lock is published to AWS Cloud.
6. Upon GPIO based wakeup, the smart lock status is toggled (if the device is in Locked state, the state is switched to Unlocked), and updated lock state is published to AWS Cloud.
7. Upon every RTC timer expiry, the device wakes up and publishes the current state of lock to AWS Cloud.
8. Once the desired functionality is complete, the M4 permits NWP to sleep and execution continues from step-4.

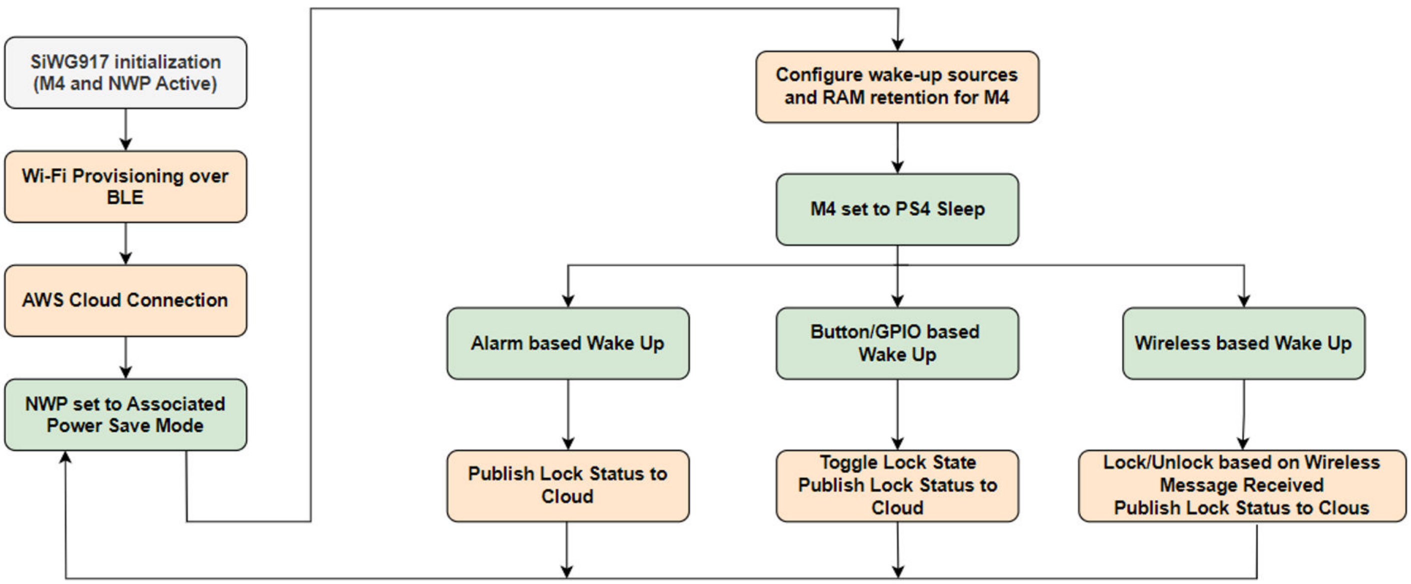


Figure 9.2. SiWG917 Low-power Mode Use Case 2

9.3 Neutral Less Switch

Neutral-less switch allows for smart switch installation without the need for a neutral wire, making it ideal for retrofitting existing homes. This design ensure seamless integration with smart lighting systems, enhancing convenience and energy efficiency. This application is designed to minimize current consumption by optimizing the NWP wireless scan and connection phases.

The application has the below functionality:

1. M4 and NWP are initialized.
2. NWP configured as WLAN station connects to the Access Point, and gets the IP address via DHCP.
    a. The scan process is as follows:
        i. Each channel is scanned for 30 milliseconds.
        ii. NWP is set to STANDBY_POWERSAVE_WITH_RETENTION for 100 milliseconds.
        iii. The above sequence is repeated for each channel.
    b. There is an intermediate phase between WLAN scan and join, during which passphrase is translated to PSK, which lasts about 1 second. NWP is set to STANDBY_POWERSAVE_WITH_RETENTION during this phase, to reduce current consumption to 19 mA from 50 mA.
    c. After establishing the WLAN connectivity, NWP is set to ASSOCITED_POWERSAVE and IP configuration via DHCP is performed.
3. By default, the WLAN disconnection scenario is handled at firmware level wherein the WLAN reconnection attempts are made with NWP being in the Active state. In this application, configuration is such that the rejoin algorithm at firmware level is bypassed and it is instead handled at the application level.
4. NWP is set to STANDBY_POWERSAVE_WITH_RETENTION and rejoin process is performed with the optimizations in place.

Table 9.1. Optimized SiWG917 Current Consumption

State	Average Current Consumption	Time Taken
WLAN scan	25.4 mA	1.31 s
WLAN scan to connection	18.5 mA	1.46 s
WLAN IP configuration (Using DHCP)	10 mA	1.04 s

10. Low Power and Interoperability Considerations

- It is recommended to set the device into Connected Power Save Mode only after IP configuration.
- If a wireless disconnection happens when the SiWG917 NWP is in Power Save Mode, disable the power save and try to reconnect to the AP.
- To avoid interoperability issues with various APs, enable the Enhanced Max PSP feature.
- For applications where throughput is not a major concern, consider disabling the higher data rates (MCS5, MCS6, and MCS7).
- To do this, make sure BIT(19) - SL_SI91X_FEAT_DISABLE_MCS_5_6_7_DATARATES in config_feature_bit_map is enabled in the boot configuration.
- Make a smart configuration of WLAN Keep-Alive, TCP Keep-Alive, and MQTT Keep-Alive parameters as per your application to reduce the current consumption.
- In power save modes, if the DNS requests fail with a few APs, the SL_SI91X_FEAT_AGGREGATION in feature_bit_map is to be enabled in boot configuration. If this does not help, it is recommended to disable the power save and then make a DNS request API call and configure the device back into power save mode.
- If broadcast/multicast data is not important for your application, further power consumption can be reduced using the broadcast filter() API.

11. Revision History

Revision 1.1

October, 2024

- Major rewrite.

Revision 1.0

January, 2024

- Initial Revision.

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Silicon Laboratories Inc.
400 West Cesar Chavez
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USA

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