Application Report
SWRA502–February 2017

SimpleLink™ CC3120, CC3220 Wi-Fi® Internet-on-a chip™ Networking Subsystem Power Management

ABSTRACT

The CC3120 and CC3220 devices are part of the SimpleLink™ microcontroller (MCU) platform, which consists of Wi-Fi®, *Bluetooth*® low energy, Sub-1 GHz and host MCUs, which all share a common, easy-to-use development environment with a single core software development kit (SDK) and rich tool set. A one-time integration of the SimpleLink platform enables you to add any combination of the portfolio's devices into your design, allowing 100 percent code reuse when your design requirements change. For more information, visit www.ti.com/simplelink.

This application report describes the best practices for power management and extended battery life for embedded low-power Wi-Fi devices such as the SimpleLink Wi-Fi Internet-on-a chip™ solution from Texas Instruments™.

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1 Introduction

Power management and extended battery life are primary focus areas for embedded low-power Wi-Fi devices such as the SimpleLink™ Wi-Fi Internet-on-a chip™ solution. Handling power regimes effectively is fundamental for any battery-operated device. This problem is especially challenging for standards-based wireless devices that need to comply with certain requirements for Transmit power, Beacon interval, and data rates, as is the case with embedded Wi-Fi devices. This application note covers the CC3120 and CC3220 Wi-Fi Internet-on-a chip Networking subsystem power management (PM) capabilities, describes the basics of system behavior, and provides the basic toolbox for developers to design an optimal system.

The CC3120 device contains the Networking subsystem only and is driven by an external MCU host. The CC3220 contains the same Networking subsystem along with an internal MCU application processor. This document describes the Wi-Fi subsystem power management aspects, making it applicable for both devices.

1.1 Terminology

This document refers to several power related measurement units:

- Current [ampere] – Refers to average current at 3.3 V, unless otherwise specified.
- Charge [coulomb] – [1C = 1 ampere × 1 second], refers to 3.3 V unless otherwise specified. Charge is used when discussing finite processes (such as connection). Battery capacity is referred as mA × hour.
- Energy [joule] – [1 joule = 1 coulomb × 1 volt]

2 Low Power Internet Systems Considerations

When designing a low power networking system specifically based on 802.11 protocols, a designer should consider several key aspects.

2.1 Power Supply

Lined-power or battery-powered device: line-powered systems are typically less sensitive to power consumption than battery-operated systems. Battery-operated systems must consider the battery capacity, along with the average usage profile against the lifetime target. However, there are cases where power considerations apply to line-powered systems, such as when an energy budget is associated with each endpoint. This is more common in managed deployment scenarios, such as enterprise environments.

2.2 Traffic Properties

- Traffic Model – The payload to be transmitted or received and the frequency of this activity. For example, a sensor may typically deliver 100B every few minutes; alternatively, a video camera may stream a throughput of 4 Mbps on average, delivering 1500B every ≈ 3 ms.
- Protocol Properties – This includes the transport protocol (UDP/TCP), the application protocol running on top, and associated overheads.
- Type of Connection – The security protocols at the link layer and the transport layer, if any.
- System Latency – The expected latency time responding to incoming traffic. This parameter is dominant in determining the sleep policy of the networking device.

2.3 Network Topology

The following questions should be answered when approaching a low power networking system design. These considerations apply to the specific problem the system will solve, before any specific considerations of the networking device.

- Is the system expected to work as a server or a client?

  As a server, it might be expected to be always responsive, while as a client it may initiate the communication events on its own timing, and may be off for a defined period of time.
- Does the system always need to be connected to the Access Point?

  Maintaining the connection with the AP enables the system to receive messages with low latency. However, maintaining the connection usually consumes a significant amount of energy.

- Does the system always need to be connected to the server?

  Maintaining a TCP or SSL connection with periodic keep alive messages consumes significant amounts of energy. The alternative of initiating a TCP/SSL connection every time implies overhead energy for the connection setup.
- Does the system communicate with a remote server or with a local one?

  In case of a local system (client or server), consider all related background processes. For instance, service discovery protocols such as mDNS tend to create excessive current draw owing to their defined nature.
- Is the IP acquisition method static IP or DHCP?

  DHCP processes may consume a significant amount of energy.
- Is the IP addressing method IPv6 or IPv4?

  The IPv6 method may consume more energy; for applications that are sensitive to power consumption and where IPv6 is not mandatory, TI recommends disabling the IPv6 interface.
- Is a provisioning process required?

  AP provisioning is the method used to obtain initial connection between the device and the AP. One popular method is using the device as an AP, accessing from a mobile device, or using a PC to the device as an AP for its configuration. Although provisioning is an infrequent event, the power consumed during the process may be much higher than the power in regular device operation.
- What is the Round Trip Time (RTT), the typical delay between the end device and its peer?

  This delay affects the maximum throughput of the system and the power consumption required per KB.

For example, consider a sensor system that both communicates with a server for a remote on line capabilities (configuration, observation and alert indications), and provides the option for local access directly from smartphone or PC while at home. The first requirement can be supported by a system that is off for long period of times (minutes), checks the server periodically, or accesses the server whenever it detects an environmental change. The second requirement of local accessibility is more challenging from a power perspective. The system must always be responsive, thus it must be connected to the AP at all times.

2.4 Solution-Specific Parameters

This section describes some of the critical factors and parameters of the networking system that become the building blocks of a use case, and defines the total power consumption.

- Maximum throughput – This factor corresponds to the time it takes the system to receive or transmit a fixed amount of data, and thus the power consumption required per KB. This number should reflect the lowest common denominator in the system. For example, assume that the host interface can deliver 12 Mbps and a Wi-Fi connection can deliver 60 Mbps. For UDP TX, expect to get closer to 12 Mbps. For a TCP connection with very long RTT, the maximum TP may be lowered to 2 Mbps or lower.
- Initialization time and energy – For periodic use cases that involve frequent short activity cycles with a long off-time in between, energy consumed during initialization may become a major contributor.
- Static current consumption – Any system use case is constructed from several building blocks, such as RX current, TX current, sleep current, and so forth.
- Dynamic energy consumption – System optimization for low power, and the system's efficiency with respect to power consumption while performing a specific activity. For example, connecting to an AP, initiating TCP connection, maintaining a connection with AP, and sending or receiving a fixed amount of data.

3 Networking Subsystem Quick Overview

The CC3120 and CC3220 devices belong to a family of wireless networking devices for the deeply-embedded market. Devices that belong to this product line consist of a full network stack over 802.11b/g/n. These devices are highly-integrated solutions both from the hardware and software standpoint, including internal PA and DC-DC circuit hardware accelerators for software offloading. The device supports industry-standard BSD socket API, internal SSL/TLS security protocols, very low footprint driver requirements, and advanced low power modes.

The two main variants for Simplelink Internet-on-a chip device are:

- CC3120 – Full networking device controlled by an external host MCU.
- CC3220 – Full system containing a networking subsystem, along with ARM® Cortex®-M4 MCU (CM4) and peripherals.

In the CC3220 device, the user programming the CM4 controls the power mode of the CM4 sub system, however in the networking subsystem, the power management cannot be directly controlled by the user. Once enabled, it always seeks to consume as little power as possible. The focus in this document is on the networking subsystem to better equip the programmer of CM4 in the CC3220 device or external host MCU in the CC3120 device with the required knowledge to build an optimal power efficient system.

3.1 CC3120, CC3220 Main Blocks

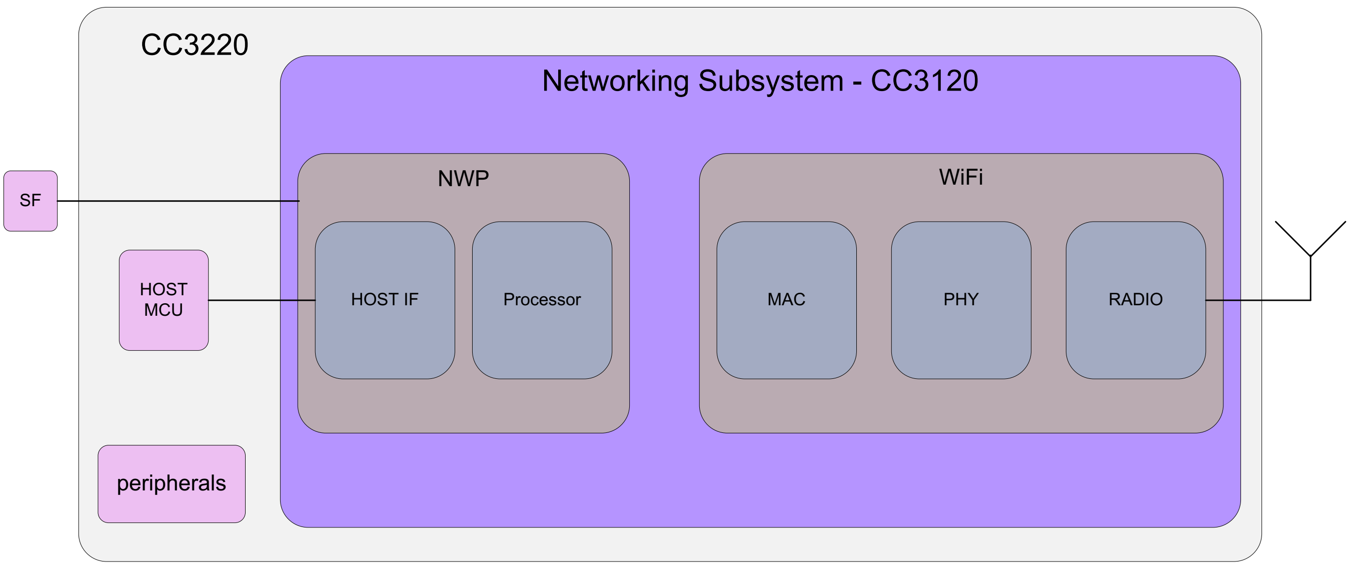

Figure 1. CC3120, CC3220 Block Diagram

The Networking subsystem contains two main blocks:

- Wi-Fi block
- NWP (network processor) block

4 CC3120 Power Modes

The CC3120 device contains only the Networking subsystem and is self-contained in terms of power optimization. The CC3120 has four power modes:

- **Shutdown** – Lowest power mode. Memories are not retained. RTC is not running. Requires cold boot initialization, including slow clock stabilization. Device is powered off.
- **Hibernate** – Lowest power mode which keeps the RTC clock and RTC counter running. Requires cold boot initialization. Device is powered off except for the hibernate logic.
- **Low Power Deep Sleep (LPDS)** – Voltage levels are lowered, fast clocks (40-MHz XTAL and internal PLL) are off. Memories are in retention mode. Device stays in low power deep sleep mode if the Wi-Fi and NWP blocks have no immediate activity. Each of them manages its own sleep and wakeup events, and when both are in their low power mode, the entire Networking subsystem is in LPDS mode.
- **Active** – Device is fully active, voltage levels are at their operational value, and all clocks are ticking. At least one block (NWP or Wi-Fi) is running. This mode may represent a wide variety of intermediate power states which are of transient nature and not explicitly controlled by the system.

Table 1 lists the CC3120 power modes and the block states.

Table 1. CC3120 Power Modes

Networking Subsystem Power Mode	CC3120 Device Power Mode	CC3120 Block State	
		NWP	Wi-Fi
Shutdown	Shutdown	Off	Off
Disabled (OFF)	Hibernate	Off	Off
LPDS	LPDS	Retention	Retention
Active[(1)]	Active	Active	Retention
		Retention	Active
		Active	Active

(1) In Active mode, NWP and Wi-Fi can be in active or retention mode separately. If both are in retention, then the system is in LPDS mode.

5 CC3220 Power Modes

For complete understanding of the CC3220 power modes, consider these three aspects:

- MCU subsystem power mode – Controlled by the MCU application.
- Networking subsystem power mode – Maintains power modes automatically when enabled.
- Device level (chip) power mode – Derived from a combination of MCU subsystem and Networking subsystem power modes.

5.1 Device Power Modes

The device can be in one of four modes:

- **Shutdown** – Lowest power mode. Memories are not retained. RTC is not running. Requires cold boot initialization, including slow clock stabilization. Device is powered off.
- **Hibernate** – Lowest power mode which keeps the RTC clock and RTC counter running. Requires cold boot initialization. Device is powered off except for the hibernate logic.
- **Low Power Deep Sleep (LPDS)** – Voltage levels are lowered, fast clocks (40-MHz XTAL and internal PLL) are off. Memories are in retention mode. Most of device logic is power-gated except for hibernate logic and top level logic.On wake-up, the MCU starts from the reset vector.
- **Active** – Device is fully active, voltage levels are at their operational value and all clocks are ticking.

5.2 Networking Subsystem Power Modes

Networking subsystem may be in one of three modes:

- **Disabled** – NWP is off and requires a cold or warm boot when enabled, depending on the power mode state (hibernate or shutdown).
- **Low Power Deep Sleep (LPDS)** – Networking subsystem is in LPDS mode if the Wi-Fi and NWP blocks have no immediate activity. Each of them manages its own sleep and wakeup events, and when both are in their low power mode, the entire networking subsystem is in LPDS mode.
- **Active** – At least one block (NWP or Wi-Fi) is running. This mode may represent a wide variety of intermediate power states which are of transient nature and not explicitly controlled by the system.

5.3 MCU Power Modes

MCU can be in one of five power modes, as dictated by the MCU programmer:

- **Shutdown** – Lowest power mode. Memories are not retained. RTC is not running. Requires cold boot initialization, including slow clock stabilization. Device is powered off.
- **Hibernate mode** – Lowest power mode that still keeps the RTC running to enable faster wakeup.
- **Low Power Deep Sleep mode (LPDS)** – While the MCU in this mode, two scenarios may occur:
  – The networking subsystem is disabled and the device mode is LPDS.
  – The networking subsystem is enabled and the device mode is LPDS (if networking subsystem is in LPDS mode) or active (if networking subsystem is active).

- **Sleep mode** – The MCU clocks are gated off in sleep mode and the entire state is retained. Device mode is active. The MCU application exercises this mode using CM4 instructions, such as WFI or WFE.
- **Active mode** – MCU is running and the device mode is active.

6 Networking Subsystem Mode Switching

There are three modes that the networking subsystem may be in during normal operation: Active, LPDS, and disabled (OFF).

- Transitioning from OFF to active mode and from active mode to OFF mode is controlled by a host application using SimpleLink APIs.
  - **sl_Start** API takes the networking subsystem immediately to active mode.
  - **sl_Stop** API puts the networking subsystem in disable mode no later than the timeout parameter specified by the API.

  In the CC3120, **sl_Start** asserts the nHIB pin of the device, and **sl_Stop** de-asserts this pin after sending a stop command to device. In the CC3220, **sl_Start** configures the internal register that enables the NWP. **sl_Start** initiates the cold boot initialization process of the networking subsystem. Initialization is finished when the networking subsystem asserts the IRQ line and the SL driver reads the **sl_Start** API status.
- Transitioning between LPDS and Active modes: in the context of the networking subsystem, entry and exit of LPDS mode is dictated by activity. There is no direct intervention of the host application. Both Wi-Fi IP and NWP IP manage their activity according to their state (such as connected to AP, connected to server, and so forth). When one of the IPs has no immediate activity (within a near specific threshold) it may go to lower power mode. When both IPs are in their lower power mode, the entire networking subsystem is in the LPDS mode. Neither the host application nor the SL driver know whether the networking subsystem is in active mode or LPDS mode. When the host application wants to communicate with the NWP (assuming it is not disabled) it simply sends a command. If it is in LPDS mode when the command is sent, then NWP wakes up and handles the command thereafter. Note that the networking subsystem does not enter LPDS mode while the IRQ line signaling an event to the host is active. The IRQ line is cleared once the host driver reads the event status back from the NWP. Therefore it is advised that power consumption-sensitive systems respond to NWP IRQ interrupts as quickly as possible.

Figure 2 presents the possible transitions between states, and the trigger for the transition.

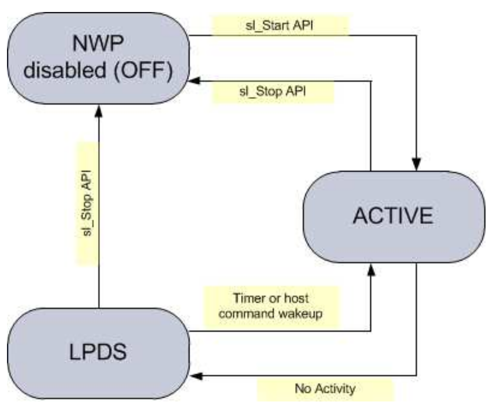

Figure 2. Transitions Between States

7 Power Policies

From the host application perspective, there are only two modes of operation explicitly selected by the host: NWP disabled (OFF) or NWP enabled (ON). Selection between Active or LPDS states is managed internally by the NWP, using power management algorithms.

The networking subsystem is equipped with a policy management entity which allows a developer (host application programmer) to guide the behavior of the power management algorithm through pre-defined power policies. The **sl_PolicySet** API configures the device power management policy. The available policies are:

- **Normal (Default)** – Best tradeoff between traffic delivery time and power performance. When connected to an AP, the Wi-Fi module wakes up for every beacon reception. Wi-Fi and NWP modules enter their low power mode after considering current activities and predict future activities.
- **Low power** – The NWP power management algorithm is more opportunistic, exploiting opportunities to lower the power mode. Tradeoff tends toward power conservation performance (for example, tag application). The networking subsystem enters LPDS immediately once the activity is over, without predicting future activities. Almost every communication between the host and NWP takes the overhead of waking up the subsystem, without any time in idle mode predicting future events. Low Power policy is suitable primarily for unconnected applications (such as applications that use transceiver mode, and not connecting to AP). When used in a connected scenario, behavior and service is not guaranteed.
- **Long Sleep Interval (LSI)** – When an 802.11 station is connected to the access point, it must receive the beacons transmitted by the AP. APs generally transmit a beacon every 102.4 ms. 802.11 standards define the DTIM (Delivery Traffic Indication Map) as a specific beacon that contains information regarding incoming packets for the STA. The AP may choose its DTIM interval (such as 1-every beacon, 2-every other beacon, and so forth). This special low-power policy instructs the networking subsystem to skip beacons and DTIM packets, and comes with a desired max sleep time parameter. The parameter reflects the desired sleep interval between two consecutive wakeups for beacon reception. The Wi-Fi module computes the desired time and wakes up to the next DTIM that does not exceed the specified time (see Table 2 for examples). The maximum-allowed desired maximum sleep time parameter is 2 seconds. TI strongly recommends setting the LSI parameter to less than half a second to ensure reliable service while lowering current consumption.

NOTE: This policy only works in client mode and external connection (internet connection via gateway). It automatically terminates mDNS and internal HTTP server running on the device. TCP/UDP servers initiated by the user application lead to unpredictable system behavior and performance.

Table 2. Power Policies

AP Beacon Interval [T.U][1]	AP DTIM Configuration	Desired Max Sleep Time [mSec]	Actual Wi-Fi Sleep Time [mSec]
100	DTIM=1	200	204.8
100	DTIM=2	500	409.6
100	DTIM=1	500	512
100	DTIM=3	1400	1228.8
100	DTIM=1	2000	2048
100	DTIM=4	800	819.2

(1) T.U = Time Unit = 1.024 mSec

Idle connected current consumption is specified in Section 8.9.

- **Always On** – Both Wi-Fi and NWP modules remain active and do not enter their low power modes. Wi-Fi does not enter 802.11 power save mode.

8 Low Power Design with CC3120, CC3220

This section merges the low power considerations from the first chapter with the detailed characteristics of the CC3120 and CC3220 products. The section introduces key features in the networking subsystem targeted to save power and explains the key tradeoffs that a designer should consider and resolve while working with this product.

8.1 Connection Policies

The networking subsystem is equipped with an advanced connection policy manager. The user may define up to seven connection profiles stored in the device NVMEM.

A profile (set using **sl_WlanProfileAdd**) is a structure of SSID, password, and a priority for the profile. Whenever the networking subsystem is enabled and not connected to an AP, it strives to connect to the AP with the higher priority profile. This behavior is enabled when the automatic connection policy is set (using **sl_WlanPolicySet**). While connected to an AP, the networking subsystem does not switch to another AP with higher priority.

A key feature of the connection manager is the fast connect feature (also set using **sl_WlanPolicySet**). Fast connect policy dictates that upon initialization (transition from NWP disabled to NWP enabled modes) or in the event of a disconnect, the networking subsystem immediately tries to connect to the last AP that it was connected to. It remembers the SSID, security credentials, and the channel of the last AP and automatically tries to connect to that network. The main advantage of fast connect over auto connection is that the system skips the scan. When both auto connection and fast connection are configured, the system first tries to connect to last AP according to fast connect policy; if it fails, it runs the scan process and looks for the highest priority profile, then connects to it.

By skipping the scan process, a significant amount of energy is preserved. The scan process may be long (few hundreds of milliseconds), during which the modem is active, switching between channels, sending probe request packets, and listening for responses. Therefore, for every system use case that contains multiple connections, using the fast and auto connect features is recommended.

8.2 Service Discovery

Upon connection to an AP, NWP automatically starts advertising itself by sending mDNS packets. Stop the mDNS feature when it is not required by the system application. Stopping the mDNS feature is done using the **sl_NetAppStop** API, and can be done once as an indication is stored in NVMEM.

8.3 Host Interrupt (IRQ) Handling

The networking subsystem handles its own power states, seeking to move to the lower power state (LPDS) whenever possible. However, the NWP does not move to LPDS mode while the host IRQ line is high (only applicable for CC3220). NWP asserts the IRQ toward the host to indicate on a command response or asynchronous event. The host is then expected to read the event from the NWP, and the NWP clears the IRQ line. Because the NWP does not enter LPDS with the IRQ line asserted (only applicable for CC3220) and does not clear it until the host reads the status, ensure that the host handles the IRQ line as soon as possible.

8.4 Reducing Host Wakeups using Device Built-in System Filters

The device is equipped with an advanced and configurable filtering mechanism in different layers. Smart usage of the filters can reduce the amount of unwanted packets transferred to the host, and cause host unwanted wakeup. By default, the device filters MAC layer broadcast and multicast and IP layer multicast (that are not for the mDNS application).

8.5 Serial Flash Handling

The CC3120 and CC3220 devices use the serial flash (SF) for nonvolatile storage. With respect to power management, verify that the SF does not become a system bottleneck. SF may be in one of three modes:

- **Active** – When the device reads from the SF or writes to the SF. NWP uses the SF to store internal data and may write to SF asynchronously or to any other event.
- **Standby** – When the device does not use the SF, the CS (chip select) line is held high. This is also the SF status during LPDS mode.
- **Power Down** – Before the CC3120 device or the CC3220 device enters hibernate, it sends the power down command to the SF. This command is handled by the NWP in the CC3120, and by the hibernate driver in the CC3220. For the CC3120, use the timeout parameter along with the **sl_Stop** command to allow the NWP to send the power down command.

8.6 TX Output Power

The networking subsystem transmits with its maximum output power by default. The programmer may reduce this parameter by setting a back off parameter using the **sl_WlanSet** API. This parameter defines the additional back off (in dB) that the radio takes. If the user sets the value to four or above, the networking subsystem radio switches to use a low power PA, and TX current is reduced significantly.

NOTE: The output power is reduced by the same factor to all rates. For example, a maximum output power for 1 Mbps is 18 dBm, and 14.5 dBm for 54 Mbps. If the value is set to 4, the output power of 1 Mbps is reduced to 14 dBm and the 54 Mbps to 10.5 dBm. Therefore, if the user decides to reduce the maximum output power to reduce overall power consumption, the transmission rate drops, the transmission length is higher, and overall power consumption may increase.

8.7 CC3120 (Networking Subsystem) Current Consumption

The *CC3100 SimpleLink™ Wi-Fi® Network Processor, Internet-of-Things Solution for MCU Applications Data Sheet* should be used as the main source of current consumption numbers.

8.8 CC3220 Current Consumption

The *CC3200 SimpleLink™ Wi-Fi® and Internet-of-Things Solution, a Single-Chip Wireless MCU Data Sheet* should be used as the main source of current consumption numbers.

8.9 Always-Connected Current

Idle connected current is an important parameter, especially for always-connected systems. This is the average current that the entire system consumes while connected to the access point without any traffic exchange. The Wi-Fi uses the 802.11 power save to reduce its power and only receive beacons. While in this mode, the networking subsystem is in LPDS mode most of the time. The Wi-Fi block wakes up to receive a beacon, and goes back to sleep. If the beacon carries an indication that the AP holds a packet for the device or an indication for a broadcast packet that follows the beacon, the system fully wakes up to handle the traffic. By default, the Wi-Fi IP wakes up for every beacon according to the AP TBTT parameter, and transmits a keep alive packet to the access point every 55 seconds while in this mode.

As mentioned in Section 7, the networking subsystem introduces an advanced feature of (LSI) Long Sleep Interval. In this mode the programmer sets the desired sleep time between beacons, understanding that beacons are missed in between. Table 3 presents the expected average current consumption per sleep interval.

Table 3. Expected Average Current Consumption Per Sleep Interval

PM Mode	Wakeup Interval Time [mSec]	Average Current [mA]
Default	102	0.690
LSI	204	0.419
LSI	510	0.284
LSI	1020	0.233
LSI	1530	0.208
LSI	2000	0.2

Notes:

- Serial flash current in standby mode is not included.
- 2 seconds is the maximum allowed LSI, while the maximum recommended value is 500 ms.
- Tested in a clean environment
- Tested with Cisco 1250
- Measured at 3.3-V VBAT
- Measurements are based on an R2 CC3220 device.

Referring to the default TBTT (102.4 ms), the CC3120 average current during idle connected period is 0.69 mA. This performance is a result of over of ten years of Wi-Fi experience.

NOTE: This parameter may vary between different access points. Some access points and networks send many broadcast packets that force the networking subsystem to stay active longer. Some access points do not send their beacons with exact timing, missing beacons and other phenomena. Networking subsystem algorithms try to overcome many of the above phenomena, but the average current consumption may still vary.

8.10 NWP Initialization Time

This parameter is critical for several use cases that frequently enable and disable the networking subsystem. For example, a system that spends most of the time in hibernate mode and every T minute initiates a connection to the cloud. Initialization time is measured from the point the NWP was enabled, using the **sl_Start** command to the time the NWP asserts the IRQ line. This time may vary based on the following:

- Size of the service pack loaded from serial flash.
- Number of configurations stored in the serial flash. For example, connection profiles, static IP, MAC address, and so forth.
- Calibration (if running and not using a one time calibration option) adds around 200 ms to the NWP initialization time.

The typical initialization time for the NWP is 60 ms, with a charge of approximately 1000 µC @ 3.3 V (measured on CC3120 SPxxx).

8.11 Wi-Fi Connection Charge

When using the fast connect feature (skipping the scan process), the networking subsystem automatically connects to the access point. The charge that connection process consumes is an important parameter for systems that are not in always-connected use case. Connection time and charge may vary significantly from one access point to another, and can also vary within the same access point from one connection attempt to another based on the access point load and activity.

The typical charge for WPA2 connection is 1000 µC to 2000 µC @3.3 V, and is highly depending on the AP used. The measurements listed in Table 4 were done on the CC3120 device R1 SP1 and MSP430™ host using fast connect feature.

Table 4. Wi-Fi Connection Charge

AP	WPA2 Connection Charge [µC]
Cisco 1250	1000
Netgear 3500	1400
TP-Link WR2041	1300

8.12 TCP and SSL/TLS Connection Charge

This parameter varies significantly from one server to another and according to the selected cypher suite. The typical connection time and charge to a server that responds quickly are presented in Table 5.

Table 5. TCP and SSL/TLS Connection Charge

Cipher Suite	Connection Charge [µC]
Open (non secure TCP)	3500
SSL/TLS (RSA RC4-128 MD5)	4500
SSL/TLS (RSA RC4-128 SHA)	4200
SSL/TLS (RSA AES-256 CBC SHA)	4000
SSL/TLS (DHE RSA AES-256 CBC SHA)	9700

Table 5. TCP and SSL/TLS Connection Charge (continued)

Cipher Suite	Connection Charge [µC]
TLS (ECDHE RSA RC4/AES SHA)	44500

Notes:

- A PC server was used for the measurement.
- Zero round trip delay time assumed. Larger round trip delay time increases the connection time significantly. However, the charge per connection may remain closer to the specified result here because most of the time increase is spent in power save mode.
- Measurements are taken on a R1 SP1 device.

8.13 Traffic Exchange Charge and Considerations

Application traffic patterns vary from one use case to another. From a power consumption perspective, the characteristics of the traffic make a great difference.

While there is no traffic, the system is in idle connected mode. The system inspires to stay in low power mode as long as possible, and every traffic event initiated by the host (TX) or by the AP (RX) takes the system out of idle connected mode.

The overhead when waking the system for traffic and exiting 802.11 power save mode is not negligible. Therefore, the amount of times the system wakes up for traffic should be minimized. Minimize the amount of wakeups over the duration of each wakeup. For example, sending 10 packets as fast as possible is much better than sending same packets with 30 ms delay between them.

The following guidelines improve overall power consumption:

- Use large packets.
- Concentrating traffic in bursts is better than uniform distribution of the traffic.
- If a system includes the server, than the server should also concentrate the traffic in bursts.

UDP TX is an exception to the above guidelines. If the use case requires transmission of a small amount of packets at each time (up to 5), better results are achieved when delay between packets is greater than 50 ms.

Table 6 presents the average current consumption of TX/RX in UDP/TCP use cases when traffic is transmitted and received as burst. The specified payload is transmitted or received as a burst, then the device is in idle for the remaining time of the second. The process repeats every second.

Table 6. Average Current for TX/RX in Burst

TP [Mbps]	UDP		TCP	
	TX [mA]	RX [mA]	TX [mA]	RX [mA]
0.1	5.8	5.6	6.5	6
0.5	9.1	8.05	9.5	10
1	13.5	11.5	14	15.5
2	22	18	22	26
3	30	24	31	36
5	46.5	36.5	47.5	57
12	105	80	107	94

Note:

- 1460B packet length
- Excellent link quality assumed
- Cisco 1250 AP
- Clean environment

9 Battery Powered System Considerations

For battery-operated systems, some considerations should be understood.

9.1 Minimum Operating Voltage

The CC3120 or CC3220 device specifies that the minimum operating voltage is 2.1 V. To ensure proper operation, the battery voltage should always be above this threshold. Battery voltage tends to drop while the battery discharges, according to battery specification and chemistry. The battery voltage also drops when a high current is drawn from it, according to its internal resistance. Typical internal resistance for an AA battery is 1 Ω. Considering the TX current and the calibration peak current, the voltage drop can reach 400 mV on alkaline batteries. Based on this system characteristic, the minimum operational for an AA battery is 2.5 V for 2AA on alkaline batteries.

9.2 Usable Battery Capacity

The usable battery capacity is the battery capacity that the battery supplies before the voltage drops below 2.5 V. It depends on the battery discharge characteristics. For Alkaline batteries (analysis is done using Duracell MN1500 AA) the capacity increases as the average current drops. The battery data sheet indicates the capacity listed in Table 7 while the voltage remains above 2.5 V.

Table 7. Battery Capacity

Average Current	Capacity Above 2.5 V
50 mA	1550 mAh
25 mA	1850 mAh
10 mA	1990 mAh
5 mA	2090 mAh

The trend is expected to continue down to an average current of 1 mA and below. The usable capacity for an average current of less than 1 mA reaches 2200 mAh for this specific battery.

Lithium batteries have better internal resistance (analysis based on the Energizer® L91) and their voltage and service hours curve is more flat. This gives an advantage to lithium batteries, as almost the entire capacity can be used. With the analyzed battery, more than 3000 mAh can be used.

10 Example Test Cases

10.1 Intermittently Connected Test Case

A CC3120-based system must transmit 100B and check messages on the server every few minutes. In this test case, the system initiates the communication and is not responsive at all times. Therefore, the system can initiate a new connection on every cycle and does not have to keep connection. If the cycle time is long enough, the system conserves more power if it switches to hibernate mode between transactions, and reconnects to the AP and server every time rather than maintain the connection.

In this test case, the total energy per activity cycle is a summation of the following activities:

- E1 is energy spent during system initialization.
- E2 is energy spent during reconnecting to the AP (802.11 association and authentication).
- E3 is energy spent while reconnecting to the server (IP layer and transport layer protocols per application requirements).
- E4 is energy spent during application traffic.
- E5 is energy spent by the CC3120 device between cycles while in hibernate mode.

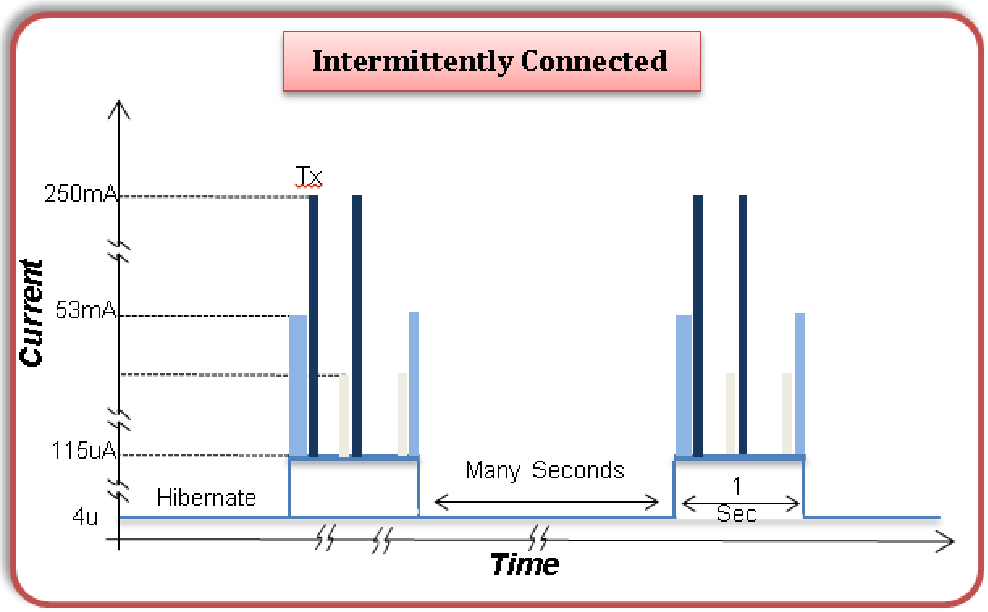

Figure 3. Test Case

In this test case, the application enables the CC3120 device, the device automatically reconnects to the AP, the application opens and binds a socket, initiates traffic and disables the device. While the CC3120 device is enabled, it manages its power state according to a defined policy. For example, it may be in LPDS state while waiting for a server response, or if the host delays between commands.

The total energy spent and system life span are given by Equation 1.

$E = £^{5}_{n=1} E_n$

$T = V \times B / E \times C \times 1 / 400$

where

- E is Total energy per cycle [joule]
- B is Battery capacity [mAh]
- C is Cycle time [min]
- V is Voltage [volts]
- T is Device life span [days] (1)

10.1.1 Example

Energy

- C – (Activity period) = 2 min
- Typical average current draw over a single activity period:
  - E1 = 1700 µC @ 3.3 V = 5.6 mJ
  - E2 = 2000 µC @ 3.3 V = 6.6 mJ
  - E3 = 4000 µC @ 3.3 V = 13.2 mJ
  - E4 = 5000 µC @ 3.3 V = 16.5 mJ
  - E5 = 600 µC @ 3.3 V = 2 mJ
  - E_{Total} = 44 mJ
  - Average Current = 111 µA

Battery: 2AA alkaline batteries rated at 1.5 V, each connected in series with a capacity of 2000 mAh:

- B = 2000 mAh
- V = 3.0 V

T (device life span) = 3 × 2000 × 2 / 0.044 / 400 = 681 days

10.2 Always-Connected Test Case

In this test case, the application requires that the system maintain its connection (see Figure 4). The system must stay online and respond to notifications within certain latency (a few seconds). The traffic is scarce and most of the time the system is idle. For example, a server waiting for clients to connect or a client constantly connected to a cloud server. In this case, the host enables the NWP once and initiates a connection to the AP. As long as there is no activity in the system, the system is in the lowest possible mode (using the 802.11 power save protocol to handle low power at the link layer). The system manages the following activities:

- Wakeup for beacons to check if an incoming traffic exists at AP buffers
- Upon indication of incoming traffic, the system exits low power mode, receives the traffic and transfers to the host if necessary, according to configured filters.
- Manages keep alive handshake with the AP to maintain a connection.

The average energy consumed by the system is a summation of the following activities:

- E1 is energy spent for connection maintenance
- E2 is energy spent during application traffic

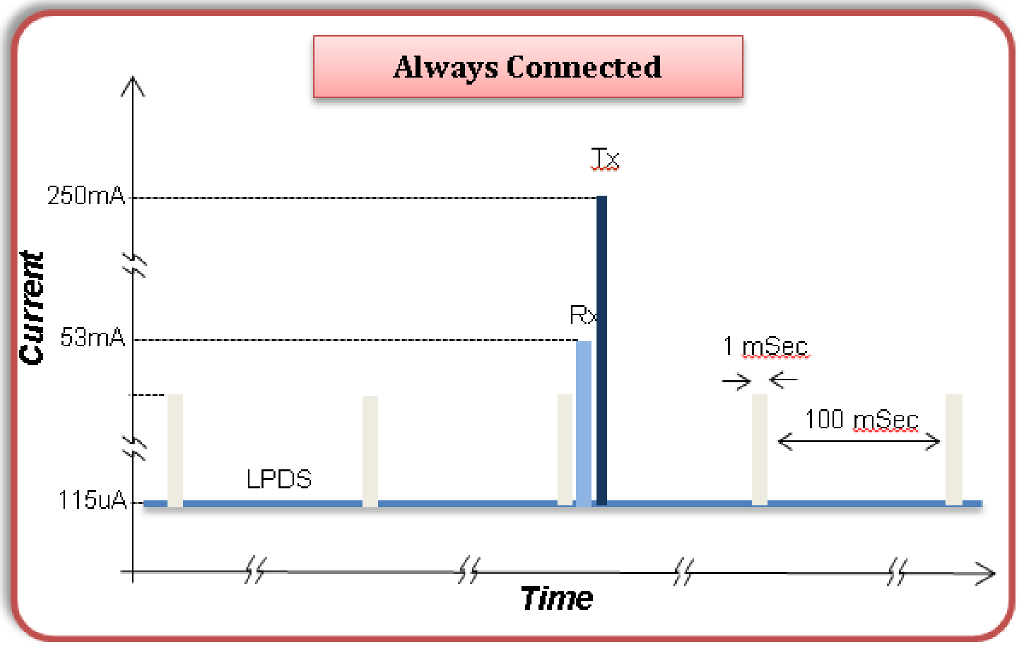

Figure 4. Test Case

The total energy spent and the system life span is given by Equation 2.

$$T = B \times V / W_1 + E_2 / P_2 \ (1 / 1000 \times 24) \text{ days}$$

where

- B is Battery capacity [mAh]
- V is Voltage [volts]
- P_2 is Period cycle for application traffic activity [Sec]
- W_1 is Power consumed during idle connection time [Watt].
- E2 is Energy spent during application traffic [Joule] (2)

Energy spent during the initial phase of device initialization and connection establishment can be neglected, because this is a one-time event.

10.2.1 Example

Energy

- P_2 = 60 Sec
- W_1 = 233 µA × 3.0 V = 0.0007 W (assuming a long sleep interval of 1 Sec)
- E_2 = 25 mA × 200 mSec × 3.0 V = 15 mJ (assuming part of the 200 ms is at RX current, very short time at TX current, and part in LPDS current resulting in 25 mA average over the 200 mSec)

Battery: 2AA alkaline batteries rated at 1.5 V, each connected in series with a capacity of 2000 mAh:

- B = 2000 mAh
- V = 3.0 V

T (device lifespan) = 2000 × 3.0 / (0.0007 + 0.015 / 60) / (1000 × 24) = approximately 263 days

Revision History

Date	Revision	Notes
February 2017	SWRA502*	Initial release