NOVUS LABS

RS9116W – AWS IOT WIRELESS INTEROPERABILITY AND POWER CONSUMPTION UNDER CONGESTION ACROSS 100 ROUTERS REPORT

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Date: 01/07/2022

Rev 1.1

I. SUMMARY

Widespread adoption of Smart IoT devices such as smart locks, video doorbells, and smart watches rely on device vendors meeting two key challenges unique to these devices: 1. Staying connected securely to their Wi-Fi Access Point (routers), and cloud while, 2. Adhering to ultra-low power budgets that are much more stringent than a Smartphone. Connectivity and power consumption of an always-ON connection measured under ideal conditions with only a few wireless routers doesn't show the complete picture. Wireless channel congestion, router make and model, can affect interoperability and power consumption. Given the importance of the interoperability and "connected power" metric for IoT devices – Silicon Labs commissioned Novus Labs to evaluate interoperability and power consumption of their silicon by connecting securely across 100 popular wireless routers. For each router, a 25-minute test was conducted to check robustness and measure the power consumption under varying levels of network congestion. The end-results have been tabulated by Novus Labs and can be used by device vendors, looking at using Silicon Labs Wireless chips, as a measure of robustness, to compute battery life under various real-life conditions and predict variations across routers in their user base. Also, Silicon Labs commissioned Novus Labs to test and evaluate interoperability and power consumption of their silicon by connecting securely with 100 wireless routers using MQTT IoT traffic between the tested devices and an internet-located AWS server.

KEY HIGHLIGHTS

Below are the key highlights from the testing conducted on RS9116W -WiseConnect AWS IoT Wireless SoC:

1. Robust secure connectivity and interoperability observed during the whole test for all 100 routers with:
    a. Zero Wi-Fi disconnects
    b. Zero AWS disconnects
    c. 100% reception of application messages sent once every 55 seconds during the test.

2. Ultra-Low power consumption
    a. With clean channel, average of only 116 uA across all 100 routers
    b. With 'close to saturation' channel utilization of 90% the average power consumption increases to only 364 uA averaged across all 100 routers

3. Significant battery life Achievable:
    a. Based on above measurements the typical battery life for an "Always Connected" Smart-lock application is 3.03 years for a low congestion environment (e.g., single-family home) and about 2.08 years for a dense and congested wireless environment (e.g., some apartments, offices, and hotels) (see Appendix B: IoT Battery Life Computation under Congestion)

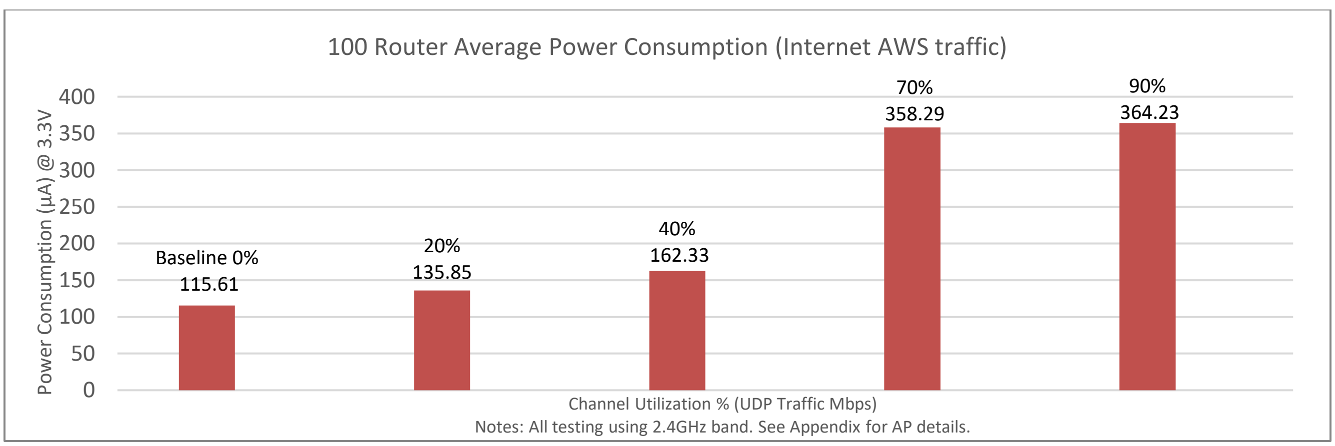

Figure 1: 100 Router Average Power Consumption (AWS Traffic)

II. TEST SETUP DESCRIPTION

RS9116W - WiseConnect:

Silicon Labs’s newest generation 40nm wireless chips RS9116W include optimized network processor and radio functions to enable ultra-low-power secure connection to the internet. The RS9116W (DUT) is an IoT wireless connectivity SoC that provides Wi-Fi, BT, BLE, embedded protocol stacks and network stacks and is used in conjunction with user application residing on external microcontroller SoC. The RS9116W EVK connects to a host MCU using UART or SPI interfaces. The RS9116W EVK is connected to an EFR32 embedded host MCU using the WiseConnect Simple Application Programming interface (SAPI). Since the test includes application-level packets exchanges every 55 seconds, the RS9116W EVK is used for all the tests to better represent the end-system power consumption. The testing was conducted on the RS9116W EVK + EFR32 MCU board provided by Silicon Labs.

Wireless Routers:

Different wireless routers have different protocol implementations in hardware and firmware that affect how long a sleeping 802.11n device must stay awake to receive beacons and buffered frames at the router. It is important to select a large number of routers covering various brands, chipsets and popularity to weed out all issues that device makers may face in the field. 100 retail wireless routers were selected using above criteria - see appendix A for a full list of wireless routers used for the tests. All testing was done using Out-of-box configuration of the routers.

Test Setup

1. Place the power analyzer, RS9116W EVK, and WiFi sniffer inside the isolated RF chamber.
2. Factory reset AP and configure: SSID, Ch. 6, and WPA2 key. Leave all other settings default.
3. Start Wi-Fi sniffer.
4. Start serial log.
5. Power on RS9116W EVK.
6. DUT connects to AWS server and connection is verified using MQTT.
7. Wait 1 minute and verify Association to AP and steady state.
8. Start KickStart software and 5-minute timer.
9. Once the 5-minute timer is up, stop Kickstart, save the file, and record average power consumption for 5 minutes.
10. Start interference and repeat step 7-8 for the following:
    a. 0% channel saturation (0Mbps) for 5 minutes.
    b. 20% channel saturation (15Mbps) for 5 minutes.
    c. 40% channel saturation (30Mbps) for 5 minutes.
    d. 70% channel saturation (70Mbps) for 5 minutes.
    e. 90% channel saturation (90Mbps) for 5 minutes.
11. Stop Wi-Fi sniffer and serial logs.Upload full Wi-Fi sniffer, serial logs, and all 5 Kickstart files to SharePoint.

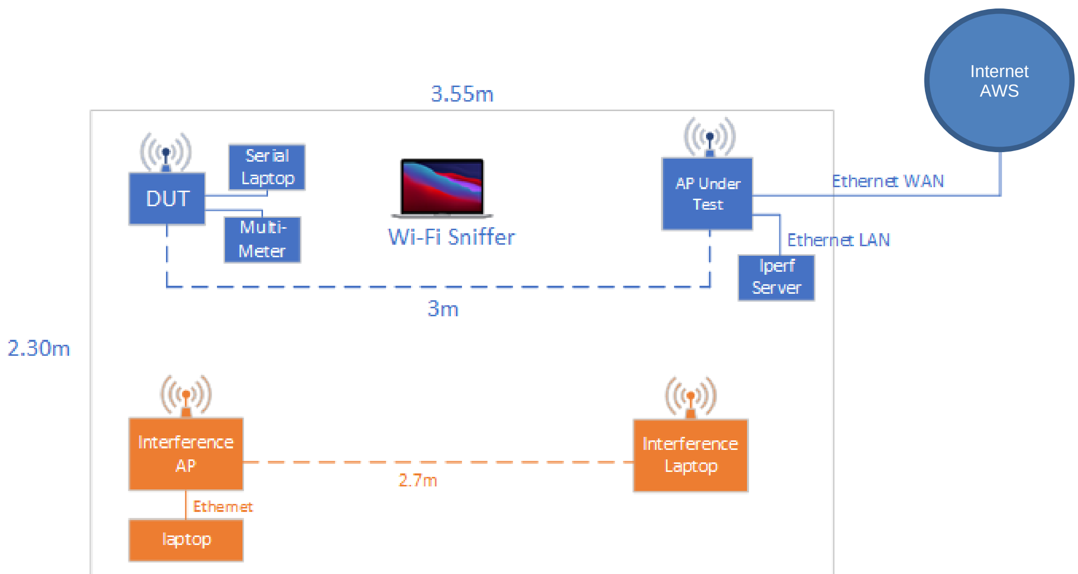

Figure 2: Test Setup Picture and Block Diagram

III. TEST PROCEDURE DESCRIPTION

The DUT EVK was configured to establish a WPA2 secure connection with the AP and the DUT then connects wirelessly via the AP to an AWS server located on the internet. Once securely associated with the AP and having established the connection to the internet located AWS server, the application on the Wireless MCU would periodically send keep alive packets every 55 seconds to the server. The DUT EVK is connected to AWS server, and MQTT is used to send packets every 55 seconds to the server. Power consumption was measured for 5 minutes for each of the 5 channel congestion scenarios, while the EVK sent application messages to the AWS server once every 55 seconds to the server. The EVK would go into power save and would wake up with a listen interval of 1 sec to check for any messages back from the server. The 5 interference scenarios included, baseline (no congestion), 20%, 40%, 70% and 90% channel congestion. The average power consumption was recorded for each RF congestion level. Sniffer traces were captured for all the tests. The goal of this test, in addition to test connectivity robustness, was to also measure the effect on current consumption that different traffic levels had on the system to thus mimic real world environments.

Tools used:

- Iperf (traffic generator): This tool was used for generating throughput congestion during the test. Commands used during the test are shown below:
    - Ethernet Laptop: iperf -c <IP> -u -b <amount of UDP traffic> -P1 -fm -i1 -t 300
    - Wi-Fi Station: iperf –s -u
- Tera Term extracting serial logs and updating the firmware of the EVK.
- MacBook Pro to capture sniffers for 0% channel congestion for Wireshark traces for each AP.
- Keithley DMM6500 7 1/2 Digit Multimeter: A multimeter with a 1A DC range used to measure power consumption of the EVK

Test Results

The RS9116W EVK is optimized for ultra-low power operation during an active connection to the internet. Detailed testing done over multiple weeks by Novus labs has shown that this ultra-low power operation is sustained with multiple routers under multiple channel congestion scenarios. The Summary plot of the results is presented in Figure 1, which shows the current consumption for each channel congestion % averaged over all 100 routers used in the test. It was seen during the tests that the average power consumption increased by only 248uA for a close to saturation traffic channel. In addition – all routers passed the test with zero disconnects at wireless, AWS and application levels. Battery life computations for IoT device like a smart-lock device under two extreme real-world traffic profiles is presented in Appendix B.

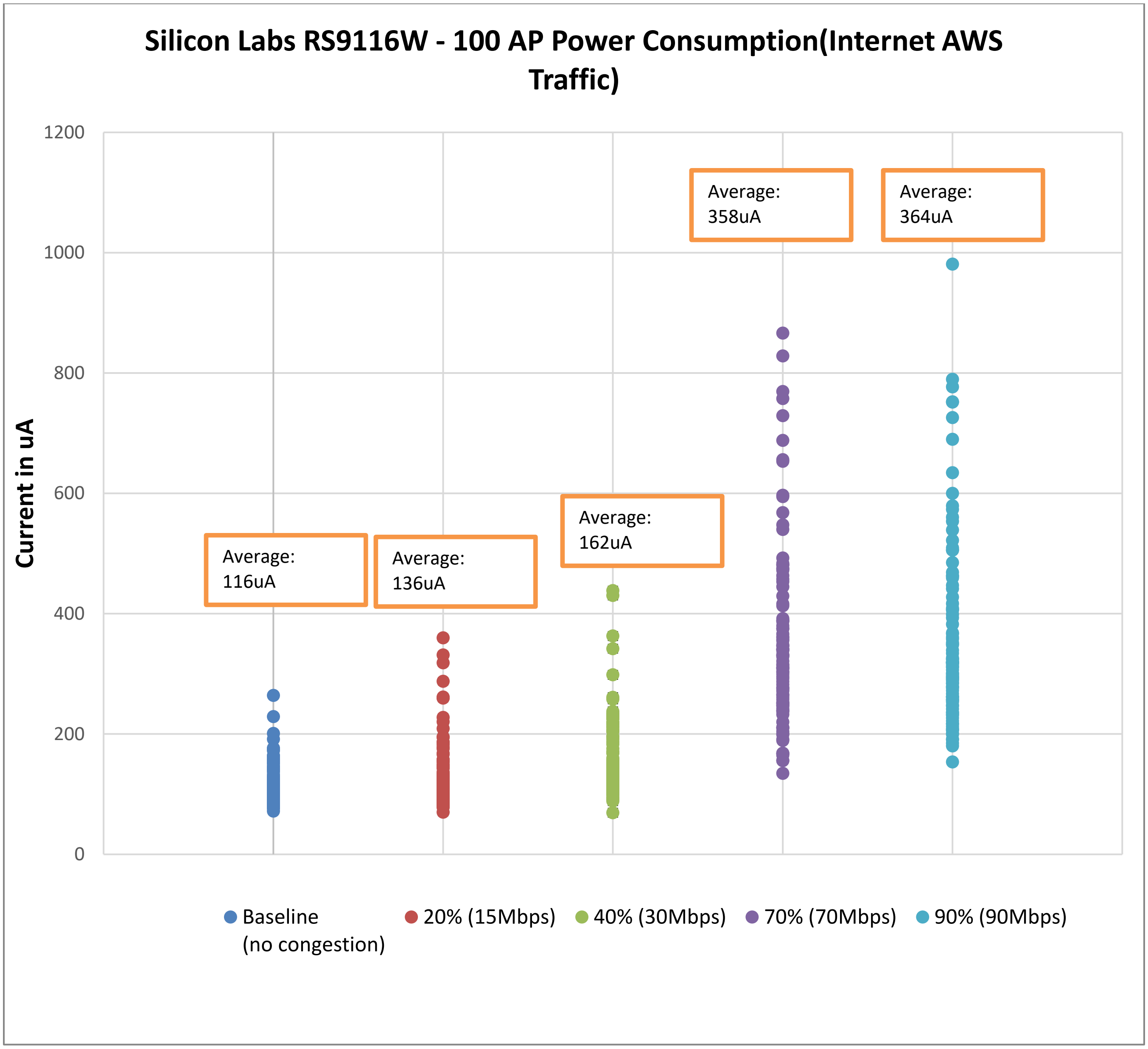

Figure 3: Silicon Labs RS9116W – 100 AP Power Consumption (AWS)

IV. APPENDIX A: 100 ROUTERS LIST

Device: Silicon Labs RS9116W EVK running Firmware RS9116W.2.4.0.36 , Board rev: RS9116W EVK 1.4
All tests were run with same RS9116W application code with all 100 routers. These routers were configured to their default setting out of the box. The firmware version of RS9116W.2.4.0.36 was used during the full 100 AP test.

AP Make	AP Model	AP Firmware
Actiontec	GT784WN v5A	NCS01-1.0.14
Actiontec	C1000A	CAC002-31.30L.76
Actiontec	MI424WR Rev. I	40.20.4.2
ActionTec	C2300A	CAS001-31.165L.11
Amplifi	Afi-R	3.6.1
Apple	AirPort Extreme Base Station A1354	7.8.1
Apple	AirPort Extreme Base Station 5th Gen A1408	7.8.1
Apple	AirPort Express A1392	7.8.1
Apple	Time Capsule A1409 (MD032LL/A)	7.6.9
Arris	BGW210	1.5.12
Arris	NVG599	9.1.6h1d25
Arris	SBG6950AC2	9.1.103AA72
Arris	SURFBoard mAX Model W31	AXR.0207.190926.61
ARRIS	SBG6900-AC	D30GW-OSPREY-1.5.4.0-GA-10-NOSH
ARRIS	SVG2482AC	12
Arris/Motorola	TG1682G	10.1.27B.SIP.PC20.CT
Asus	RT-AC86U	3.0.0.4.386_44470
Asus	Blue Cave AC2600	3.0.0.4.384_46630
Asus	DSL-AC88U	v1.10.06 build591
Asus	RT-AC1900P	3.0.0.4.386_43129
ASUS	RT-AX56U	3.0.0.4.386_44266
ASUS	Lyra Voice	3.0.0.4.384_46770
ASUS	Lyra Trio (ASUS MAP-AC1750)	3.0.0.4.384_46630
Asus	RT-AC66U B1	3.0.0.4.386_43129
Belkin	F9K1105 v2	2.10.07
Binatone	WR3000N	WR3000N v1 00000000
BT	Home Hub 6A (Smart Hub)	SG4B100021EC
BT	Smart Hub Type A	SG4B10002244
AP Make	AP Model	AP Firmware
TP-LINK	Archer AX11000	1.2.3 Build 20210719 rel.14861(5553)
Cisco	WAP300N	1.0.03, build 1, Dec 22, 2014
D-Link	DIR-636L revA1	1.04

D-Link	DIR-860L (CA)	1.08
D-Link	DIR-850L vB1	2.01
D-Link	DWR-118 A2	V01.01.3.032
EERO	Home Wifi System (B010001)	v6.4.0-2092
FAST	FWR310	1.0.41 Build 150519 Rel.42557n
FRITZ BOX	WLAN 7490	FRITZ!OS 06.05
Google	WIFI (NLS-1304-25)	13729.57.27
Google	Nest Wifi (H2D)	13729.57.19
H3C	WAP722S	1.06
Huawei	A1 WS852	2.1.17
Linksys	EA8300	1.1.5.201210
Linksys	E8400	1.0.03.01
Linksys	MX5300	1.1.9.200251
Linksys	Velop (WHW03)	1.1.18.206964
Luma	WRTQ-329ACN	0.9.14
Mercury	MAC1200R v2.0	3.14.8 Build 150228 Rel.49905n
Meshforce	M3/M3 Dot	V1.0.0.36(233)
Motorola	MG7550	7550-5.7.1.43
NEC	Aterm WG1200HP3	1.4.2
NetComm	NF18ACV	NF18ACV.NC.AU-R6B016.EN
Netgear	C6300	V3.01.14
Netgear	R7800	V1.0.2.84
Netgear	R9000 (Nighthawk X10 - AD7200)	V1.0.5.28
Netgear	ORBI UNITS RBR50 AND RBS50	V2.7.3.22
Netgear	R7000	V1.0.11.126_10.2.112
Netgear	WNR2020	V1.1.0.44_1.0.1
Netgear	CG4500BD	2.05A2
Netgear	Nighthawk AX8 (RAX80)	V1.0.5.126_1.0.65
Netgear	C6220-100NAS	V1.02.11
Netgear	R6230	V1.1.0.110_1.0.1
AP Make	**AP Model**	**AP Firmware**
Netgear	R6250	V1.0.4.38_10.1.30
Netgear	R6800	V1.2.0.76_1.0.1
Netgear	Nighthawk R7000P	V1.3.1.64_10.1.36
Netgear	Nighthawk RAX120	V1.2.2.24
Netgear	Nighthawk RAX40	V1.0.3.94_1.0.1
Netgear	R6700 v3	V1.0.4.118_10.0.90
Netgear	RAX15	V1.0.3.96_2.0.59
Netgear	XR700-100NAS	V1.0.1.36
NETGEAR	Nighthawk C7800	V3.01.43

NETGEAR	R6260	V1.1.0.78_1.0.1
Netgear	Nighthawk EAX80	V1.0.1.64_1.0.1
Netgear (Orbi)	RBR850 (Base Station) RBS850 (Sattelite)	V3.2.18.1_1.4.14
Plume	SuperPod (B1A)	1.0.1-59.gcd42768-prod
Roqos	Core RC10	2.1.79
Sagemcom	F@ST1704N	7.247_F1704N_WS
Sagemcom	RAC2V1S	SGAC11003K
Samsung	Smart Things WiFi (ET-WV525)	1.3.02.1011
Securifi	Almond 2015	AL2-R109
SMC	SMCD3GNV	3.1.5.8_IMS
Spectrum	RAC2V1A	1.0.11
Spectrum	RAC2V1K	1.1.16
Technicolor	CGM4140COM (XB6-T)	2.2
Technicolor	C2000T	CTH005-4.12.1.44
Tenda	FH1202	V1.2.0.14 (408)
Tenda	AC6	V15.03.05.16_multi
Tenda	AC18	V15.03.05.06(10082)
TP-LINK	Archer C9 v3	1.0.0 Build 20160330 rel.52750
TP-LINK	TL-WR902AC	0.9.1 0.1 v0089.0 Build 170828 Rel.57433n(4555)
TP-LINK	TL-WR841N	0.9.1 4.16 v009e.0 Build 180516 Rel.81030n
Linksys	EA9500	1.1.8.204089
TP-LINK	Archer AX50	1.0.9
TP-LINK	Archer AX6000	1.2.4
TP-LINK	Archer AX11000	1.2.3 Build 20210719 rel.14861(5553)
Ubee	EVW3210	9.12.6002
AP Make	**AP Model**	**AP Firmware**
VANIN	Juplink RX4-1500	V1.0.5
Verizon	Fios-G1100	02.01.00.05
Verizon	Fios Home Router G3100	1.3.6.4
Wise Tiger	K2 (WT-RT8501)	1.27.6
Xiaomi	MiWiFi 3(MIR3)	2.26.39
Xiaomi	Mi WIFI Router Pro	2.16.6

V. APPENDIX B: IOT BATTERY LIFE COMPUTATION UNDER CONGESTION

Based on a study done by Silicon Labs, lower power consumption with an Always-ON AWS connection under congestion translates to longer battery life in the real-world. To quantify the impact on battery life we consider two scenarios. The first one is a Low-Congestion case of a single-family home with wireless traffic limited to single television and a few smartphones and laptops. The second one is a High-congestion case typical to multi-user dwellings like Apartments or Hotels – or enterprise environments like Office, retail space, etc.

Table of % Time in a typical Day seeing Channel Occupancy in the specified ranges:

Channel congestion	**<10%**	**10-30%**	**30-55%**	**55-80%**	**80-100%**
Low-Congestion (Single Family Home) %	85	10	2	2	1
High-Congestion (Apartments, Hotels and Offices) %	15	25	30	20	10

Below table summarizes the measured average power consumption of RS9116W (uA @ 3.3V) with a secure and robust always ON 1-second latency wireless AWS connection and 55 second application keep-alive handshake:

Channel Congestion	**0%**	**20%**	**40%**	**70%**	**90%**
Measured Power Consumption (uA @ 3.3V) vs Channel congestion %	116	136	162	358	364

The average uA @ 3.3V for **Low-Congestion** traffic profile is computed from above two tables as:
116 * 0.85 + 136 * 0.10 + 162 * 0.02 + 358 * 0.02 + 364 * 0.01 = **126uA**

The average uA @ 3.3V for **High-Congestion** traffic profile is computed from above two tables as:
116 * 0.15 + 136 * 0.25 + 162 * 0.30 + 358 * 0.20 + 364 * 0.10 = **208uA**

Consider a Smart Lock with 4x Energizer Lithium AA cells providing 3000mAh @ 6V. The battery life of the Smart lock without Wi-Fi connectivity is 10 years => average power consumption of rest of the Smart lock electronics is 3000mAh/ (10*365*24h) = 34.2uA @ 6V.

With addition of RS9116W for secure, robust, always-ON AWS connectivity (1 second latency, 55 second application handshake) the above Smart Lock would have battery life computed as follows:

Low Congestion Environment:
RS9116W consumes 126uA @ 3.3V => 77uA @ 6V (assuming 90% efficiency step down regulator from 6V down to 3.3V) => total current of Lock = 77uA + 34.2uA = 111.2uA. Battery life of Lock = 3000mAh /111.2uA = 26978 hours = **3.08 years**

High Congestion Environment:
RS9116W consumes 208uA @ 3.3V => 127.1uA @ 6V (assuming 90% efficiency step down regulator from 6V down to 3.3V) => total current of Lock = 127.1uA + 34.2uA = 161.3uA. Battery life of Lock = 3000mAh /161.3uA = 18599 hours = **2.12 years**

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