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REDPINE SIGNALS WIRELESS INTEROPERABILITY AND POWER CONSUMPTION UNDER CONGESTION ACROSS 100 ROUTERS

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Summary

Widespread adoption of Smart IoT devices such as smart locks, video door bells, and smart watches rely on device vendors meeting two key challenges unique to these devices – staying connected securely to their Wi-Fi Access Point (routers) and cloud while 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 – Redpine Signals 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 and 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 Redpine 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.

KEY HIGHLIGHTS

Below are key highlights from the testing conducted on Redpine Signals Wireless MCU SoC:

1. Robust secure connectivity and interoperability observed during the whole test for all 100 routers with:
   a. Zero Wi-Fi disconnects
   b. Zero TCP 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 113uA across all 100 routers
   b. With 'close to saturation' channel utilization of 90% the average power consumption increases to only 293uA averaged across all 100 routers
   c. 98% of the routers were within 2x of the 100-router average power consumption

3. Significant battery life Achievable:
   a. Based on above measurements the typical battery life for an "Always Connected" Smart-lock application is 3 years for a low congestion environment (e.g., single-family home) and 2 years for a dense and congested wireless environment (e.g., some apartments, offices and hotels) (see Appendix B)

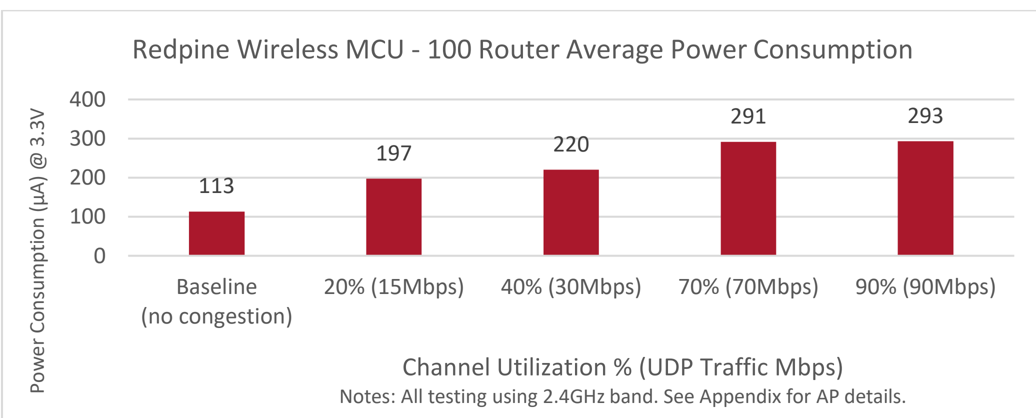

Figure 1 100 Router Average Power Consumption

Test Setup Description

Redpine SoC and platform:

Redpine's newest generation 40nm wireless chips RS9116 and RS14100 include optimized network processor and radio functions to enable ultra-low-power secure connection to the internet. The RS9116 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 RS14100 IoT Wireless MCU is a superset and integrates an ARM Cortex M4F microcontroller-based application processing subsystem along with the networking and wireless processing subsystem from RS9116. Since the test includes application level packets exchanges every 55 seconds, the RS14100 Wireless MCU is used for all the tests to better represent the end-system power consumption. The testing was conducted on the RS14100-SB-EVK1 provided by Redpine Signals.

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

All testing was performed inside a 12'x8' RF shield room. The wireless router under test was placed 11 feet away from the RS14100 (EVK), and the interference setup was placed on the opposite side of the room. Below pictures show the room used for the testing and the setup diagram.

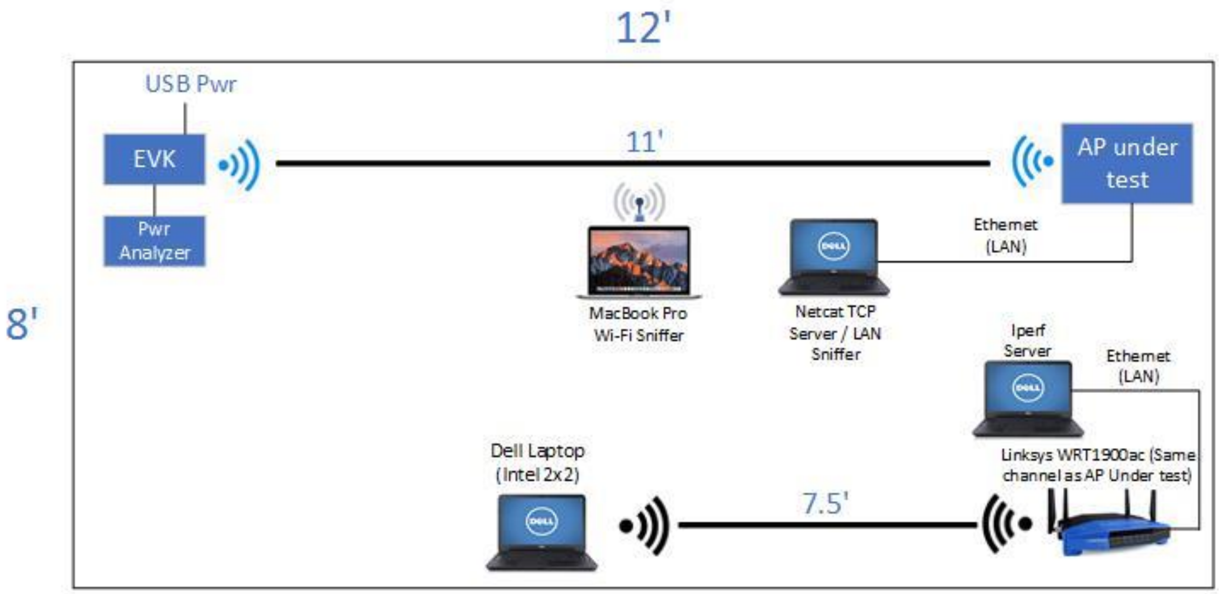

Figure 2 – Test Setup Picture and Block Diagram

Test Procedure Description

The DUT EVK was configured to establish a WPA2 secure connection with the AP and the TCP server connected over LAN to the router. Once securely associated with the AP the application on the Wireless MCU would periodically send keep alive packets every 55 seconds to the server and upon response timeout it terminates the connection (test failure).
Power consumption was measured for 5 minutes for each of the 5 channel congestion scenarios, while the EVK sent application message 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 robust connectivity was to also measure the effect on current consumption with different traffic levels to 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
- Netcat TCP Server: An open source TCP server used for receiving TCP requests from the EVK
- Keithley DMM7510 7 1/2 Digit Multimeter: A multimeter with a 1A DC range used to measure power consumption of the EVK

Test Results

The Redpine RS14100 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. Summary plot of the results are presented. Figure 1 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 180uA for a close to saturation channel traffic. In addition – all routers passed the test with zero disconnects at wireless, TCP and application level. Battery life computations for IoT device like a smart-lock device under two extreme real-world traffic profiles is presented in the Appendix B.

Appendix A 100 Routers List

Device: Redpine RS14100 EVK running Firmware 1.0.6x.
Board rev: RS14100 EVK 1.3
All tests were run with same RS14100 application code with all 100 routers. These routers were configured to their default setting out of the box. Minor revisions of firmware versions of 1.0.6 were used during the full 100 AP test. All the changes were rolled into a final version of the firmware and spot checks were done to ensure there are no failures.

AP Make	AP Model	AP Firmware
2 Wire	3800HGV	6.3.7.50
2 Wire	3800HGV-B	6.11.1.29
Actiontec	C2000A	CAH006-31.30L.95
Actiontec	PK5000	QAP002.3.60.3.0.9.9.PK5000
Actiontec	Mi424-WR Rev. F	20.12.2.4
Actiontec	C1000	CAC002-31.30L.76
Actiontec	Q1000	QAQ004-31.20L.7
Actiontec	GT784WN	NSC01-1.0.14
Amped	R1000G	v2.5.2.09
Apple	Airport Extreme A1143	7.6.9
Apple	Time Capsule A1254	7.6.9
Apple	Airport Extreme A1521	7.7.9
Apple	Time Capsule A1470	7.7.9
Apple	Airport Express A1392	7.8
Apple	Airport Express A1264	7.6.9
Arris	TG862G	9.1.10M2AM.SIP.PC20.CT
Arris	TG1682G (XB3) X	10.1.27B.SIP.PC20.CT
Asus	RT-AC88U	3.0.0.4.348_45149
Asus	RT-N56U	3.0.0.4.374_979
Asus	Asus RT-AC68U	3.0.0.4.384_92799
Asus	RT AC3200	3.0.0.4.382.50010
Asus	GT-AC5400	3.0.0.4
Belkin	F9K1118 v1 X	1.03.04
Belkin	F9K1112	1.00.26
Belkin	F9K1001	1.00.13
Belkin	F9K1102v1	10.00.19

AP Make	AP Model	AP Firmware
Belkin	F9K1102v1	10.00.19
Belkin	F9K1113v1	1.03.04
Belkin	F7D8302	1.00.28
Buffalo	WZR-1750DHP	Version 2.29
Buffalo	WZR-D1800H	1.99
Buffalo	WZR-600DHP	DD-WRT v24sp2-Multi
Buffalo	WCR-GN	1.08(R4.25/B1.13)
Cisco	WRT54G v.6	8.00.0
Cisco	E2500	2.0.00
Cisco	EA4500	2.1.42.183584
Cisco	WRT160NL	1.0.04
Cisco	DPC3941T (XB3)	2.3.10.13_5.5.0.5
Cisco	E2000	1.0.06
Cisco	WRT320N	1.0.05
Cisco	EA2700	1.1.40.189581
Cisco	E1000 v2.1	2.1.03
D-Link	DIR-868L	1.12
D-Link	DIR-655	2.11NA
D-Link	DIR-655	2.11NA
D-Link	DIR-815 Rev. A1	1.04
D-Link	DIR-860L	1.08
Edimax	BR-647AC	2.2
Edimax	RG21S	0.0.13
Eero	A010001 (3 Part Mesh)	v3.10.1-1
Google	NLS-1304-25	11021.84.4
Linksys	WRT1900AC	1.1.10.187766

AP Make	AP Model	AP Firmware
Linksys	Velop WHW03 (3 Part Mesh)	1.1.7.191689
Linksys	EA9500v1.1	1.1.7 180968
Linksys	EA6300	1.1.40.184085
Linksys	EA6900	1.00.28
Linksys	EA6500 v2	1.1.41.183873
Medialink	MWN-WAPR300N	V5.07.50
Medialink	MWN-WAPR150N	11.83.3.0
Motorola	NVG510	9.0.6h0d48
Motorola	SBG6580	8.9.0.1
Netgear	R6300v2	V1.0.4.28_10.0.89
Netgear	R6700v3	v1.0.22.60_10.0.44
Netgear	R7000	V1.0.9.42_10.22.44
Netgear	WNR2000v4	v1.0.0.70
Netgear	R8000	1.0.4.28_10.1.54
Netgear	7550	2.6.20.19
Netgear	WN2000RPT-100 v3	1.0.0.24
Netgear	ORBI UNITS RBR50	2.2.1.210
Netgear	XR500	v2.3.2.32
Netgear	WNDR3800	V1.0.0.52
Netgear	WNDR4500	V1.0.1.46_1.0.76
Netgear	WNDR3400v3	V1.0.1.18_1.0.63
Netgear	WNDR3700v4	v3.0
Netgear	WNR1000v3	V1.0.2.72_60.0.96NA
Netgear	WNDR4300	V1.0.2.104
Netgear	R6200	V1.0.1.58_1.0.44
Securifi	Almond (2012)	AL1-R201-L302-W34
SMC	SMCD3GNV	3.1.5.6_IMS
TP-LINK	RE200 Range Extender	1.0.0
TP-LINK	RE540 Range Extender	1.0.0
TP-Link	DECO M5 (3 Part Mesh)	1.2.5

AP Make	AP Model	AP Firmware
TP-Link	Archer C3200	0.9.1.0.1
TP-Link	Archer C1900	3.17.0
TP-Link	Archer C3150	0.9.1.0.0
TP-Link	TL-WR940N V6	3.18.1
TP-Link	TL-WR841N v9.2	3.16.9
TP-Link	TL-WDR4300	3.14.3
TP-Link	TL-WR841N v7.2	3.13.9
TP-Link	Archer C7 AC1750 v2	3.15.3
TRENDnet	TEW-812DRU	2.1.2.0
TRENDnet	TEW-639GR v3	1.0.2.0
TRENDnet	TEW-602GR	1.0.2.0
TRENDnet	TEW-818DRU	1.0.14.6
Ubiquiti	AMPLIFI Mesh Router	2.9.3
Ubiquiti	Air Router	XM v6.1.2
Westell	7500	5.01.01.04
Westell	A90-9100EM15-10	1.03.00.08
Western Digital	AC1300-J2F	1.03.09
Western Digital	My Net N900-F2F	1.07.16
Zyxel	PK5001Z	CZP003-4.3.009.35

Appendix B IoT Battery Life Computation under Congestion

Based on a study done by Redpine Signals, lower power consumption with an Always-ON TCP 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 benign 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 RS14100 (uA @ 3.3V) with a secure and robust always ON 1-second latency wireless TCP connection and 55 second application keep-alive handshake:

Channel Congestion	**0%**	**20%**	**40%**	**70%**	**90%**
Measured Power Consumption (uA @ 3.3V) vs Channel congestion %	113	197	220	291	293

The average uA @ 3.3V for **Low-Congestion** traffic profile is computed from above two tables as:
113 * 0.85 + 197 * 0.10 + 220 * 0.02 + 291 * 0.02 + 293 * 0.01 = **129uA**

The average uA @ 3.3V for **High-Congestion** traffic profile is computed from above two tables as:
113 * 0.15 + 197 * 0.25 + 220 * 0.30 + 291 * 0.20 + 293 * 0.10 = **220uA**

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 RS14100 for secure, robust, always-ON TCP connectivity (1 second latency, 55 second application handshake) the above Smart Lock would have battery life computed as follows:

Low Congestion Environment:
RS14100 consumes 129uA @ 3.3V => 78.8uA @ 6V (assuming 90% efficiency step down regulator from 6V down to 3.3V) => total current of Lock = 78.8uA + 34.2uA = 113uA. Battery life of Lock = 3000mAh /113uA = 26544 hours = **3.03 years**

High Congestion Environment:
RS14100 consumes 220uA @ 3.3V => 134.3uA @ 6V (assuming 90% efficiency step down regulator from 6V down to 3.3V) => total current of Lock = 134.3uA + 34.2uA = 168.5uA. Battery life of Lock = 3000mAh /168.5uA = 17803 hours = **2.03 years**

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