AN1425: Large Network Performance with Dynamic Multiprotocol Bluetooth LE and Zigbee System-on-Chips

This application note summarizes the results of Zigbee/BLE dynamic multiprotocol (DMP) large network performance tests using Zigbee unicast and broadcast packets to measure the reliability, latency, and loss of a variety of scenarios. The system-on-chip test nodes are running dynamic multiprotocol software combining Zigbee with Bluetooth LE (BLE) advertising.

KEY POINTS

- Test approach
- Zigbee/BLE DMP large network test results
- Zigbee/BLE DMP large network with high stress BLE data traffic test results

1 Introduction

The tests and results provided are used as quality benchmarks for large network testing with DMP BLE and Zigbee. Two different scenarios were tested.

Zigbee/BLE DMP Large Network Broadcast

The Central Node is a Zigbee coordinator (high RAM concentrator) that forms a centralized security network. The Zigbee coordinator sends out a many-to-one route request (MTORR) at a default randomized period of 60 second minimum to 300 seconds maximum. All other nodes are Zigbee router device types. All devices use a DMP stack and send out a connectable BLE advertisement with max payload once every 152.5 ms when advertising is enabled.

The purpose of this scenario is to compare Zigbee broadcast performance for when all devices are sending BLE advertisements and when they are not.

Zigbee/BLE DMP Large Network with High Stress BLE Data Traffic

This is a multifaceted scenario that combines the test above with unicast traffic and BLE connections and high-stress BLE data traffic for 3 pairs of devices.

The purpose of this scenario is to simulate real-life usage scenarios of DMP nodes and ensure that the network remained stable.

2 Test Setup

The sections below describe the test setup used in two different scenarios. All nodes are in the same physical location and with transmission (TX) power adjusted to achieve the stated number of hops were used to allow for best comparability of the results. The nodes were located throughout an active office environment with typical Wi-Fi and other interference. No efforts were undertaken to shield the test network from that environment.

2.1 Test Parameters

The applications used for this test effort generally have the following configurations.

Note that most of these settings are default settings for the base sample application used.

Configuration Item	Value	Default
Zigbee Table Sizes		
Neighbor table size	26	16
Routing table size	200	16
Source route table size	200	7
Discovery table size	8	8
Broadcast transaction table	128	15
Zigbee Stack Profile Parameters		
Max hops	30	Default
MAC indirect Tx timeout	7680 ms	Default
nwkMaxBroadcastRetries	2	Default
Passive Ack threshold	6	Default
Retry queue size	29	Default
Radio Scheduler (Zigbee)		
ZB background RX	255	Default
ZB active RX	255	Default
ZB TX	100	Default
Radio Scheduler (BLE)		
scan (min,max)	191, 143	Default
adv (min,max)	175, 127	Default
conn (min,max)	135.0	Default
init (min,max)	55.15	Default
threshold_coex	175	Default
rail_mapping_offset	16	Default
rail_mapping_range	16	Default
threshold_coex_req	255	Default
coex_pwm_period	0	Default
coex_pwm_dutycycle	0	Default
afh_scan_interval	0	Default
adv_step	4	Default
scan_step	4	Default

2.2 General Test Methodology

This testing used a custom command line interface (CLI) to transmit a broadcast that has a unique signature in packet. Upon receipt of this special broadcast packet, emDebugBinaryPrint() is used to create the timestamp receipt of this packet to the packet trace interface (PTI) stream to ensuring that there is a timestamp on the transmitting device, and a timestamp on each receiving device.

Silabs-pti.jar was used to collect the PTI streams of all devices under test. This is a publicly available Silabs tool that essentially runs Network Analyzer in a headless manner.

To keep time synchronization between all devices, Silicon Labs used the wireless starter kit (WSTK) adapter's time sync functions by setting up the transmit device as the time server and configuring all receiving devices as clients to that server.

2.3 General Test Topology

Tests were performed on the Silicon Labs Boston office open wireless test network using a mixed collection of EFR32MG boards. For all testing conducted, a dozen EFR32MG21 boards and a dozen EFR32MG24 boards were used, and all other devices were EFR32MG12 boards.

Five network topology sizes are normally under test for large scale performance testing: 24, 48, 96, 144, and 192 devices. Each of these topologies uses the previous smaller topology set of devices plus the additional devices. For this test effort, Silicon Labs used 48, 96, and 192 device network sizes.

The same physical device is used as the Zigbee coordinator for every network topology, and this is the device that originates any broadcasts sent for the test scenarios. For example, below is a basic office floorplan layout showing the physical location of test devices, where the concentric circles approximate the devices used in each topology. The smallest circle shows the 24-node topology while the next larger circles illustrate the idea of including extra nodes farther away to create larger network topologies. The white devices just mean they are reserved and not important to this illustration.

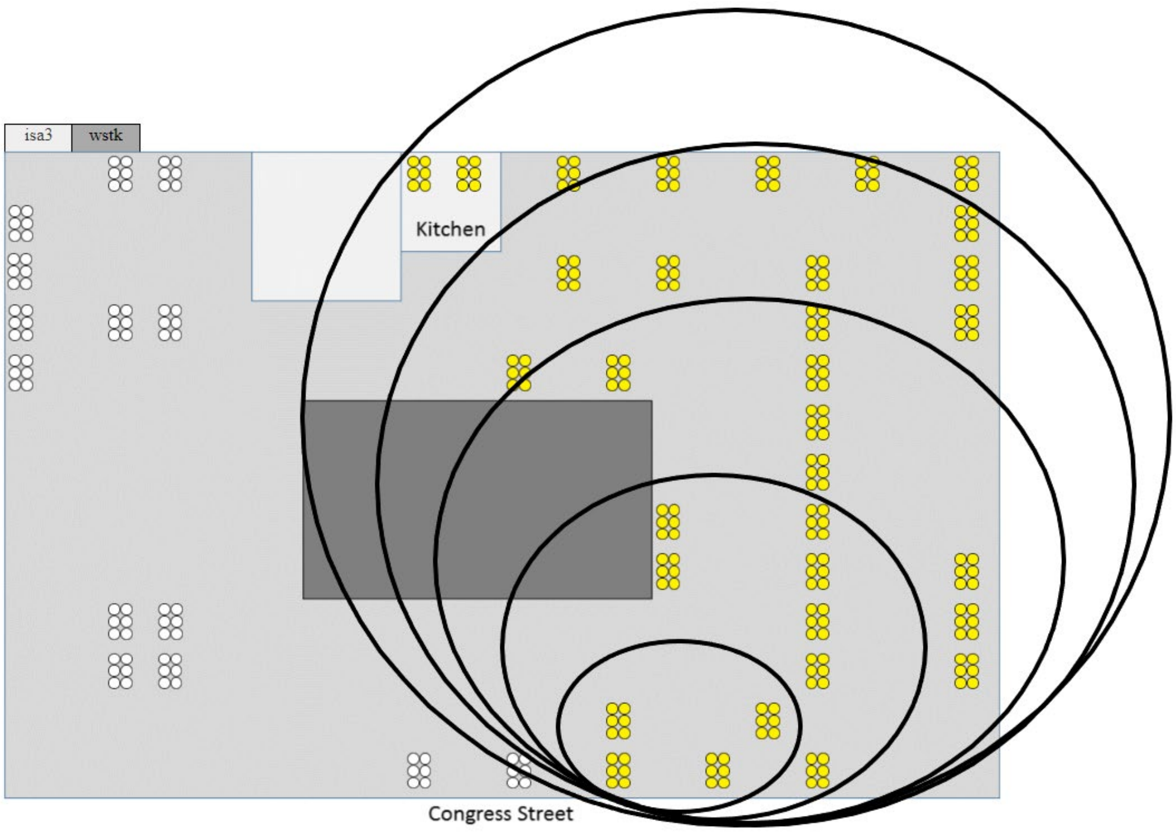


Figure 2.1. Boston Office Open Network

3 Test Results

3.1 Zigbee/BLE DMP Large Network Test Results (Broadcast)

3.1.1 Test Setup Details

This test scenario is similar to the basic testing Silicon Labs does for Zigbee-only large network testing using broadcast packets to measure the reliability and latency of each discrete broadcast (AN1138: Zigbee Mesh Network Performance) but adds a BLE advertising vector.

Two network size topologies were used for this testing: 96 and 192 devices.

A customized sample application, Zigbee - SoC DynamicMultiprotocolLight, was used for all testing. This app was configured the same for all devices, with the exception that the ZC (Zigbee Coordinator) was configured as a High RAM concentrator.

One set of tests were conducted with BLE advertisements disabled for all nodes, and another set of tests with all connectable BLE advertisement with max payload once every 152.5 ms enabled. All devices were configured with a passive ACK threshold of 6. The ZC was the broadcast originator for all testing.

Broadcast packets are not actively acknowledged. However, the Zigbee stack uses the notion of neighboring nodes rebroadcasting the same packet as "passive ack". So, setting the passive ACK threshold to 6 means that a node will wait for at least 6 rebroadcasts from neighboring nodes before deeming the broadcast transmission complete.

3.1.2 Test Results

The following images show the time in milliseconds after transmission of the original broadcasts on the x-axis versus the percentage of nodes in the network to receive the broadcast in that given time. One specialty is the entry for -10ms, which includes broadcasts not received by all nodes in the network.

There are separate images for network sizes of 96 and 192 devices both with and without BLE advertisement. Additionally, the test was run with 5 broadcasts per second as well as 1 broadcast every two seconds. Each of the images includes results for broadcast payload sizes of 8, 16, 32, and 64 bytes represented by different shades of blue as explained in the legend.

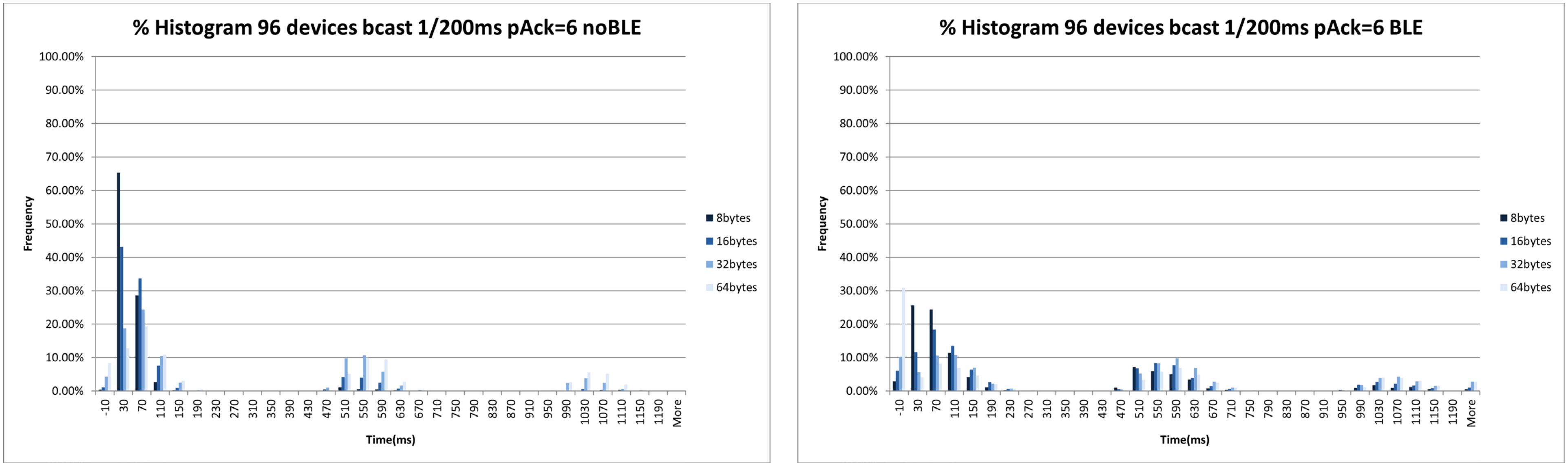


Figure 3.1. 96 devices, 200 ms

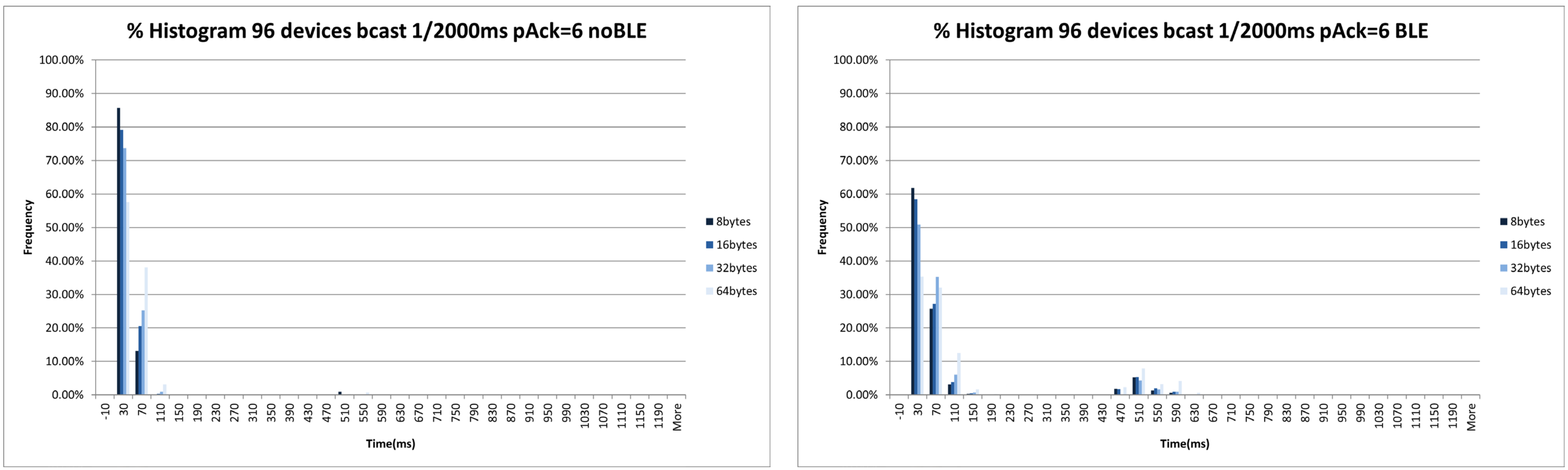


Figure 3.2. 96 devices, 2000 ms

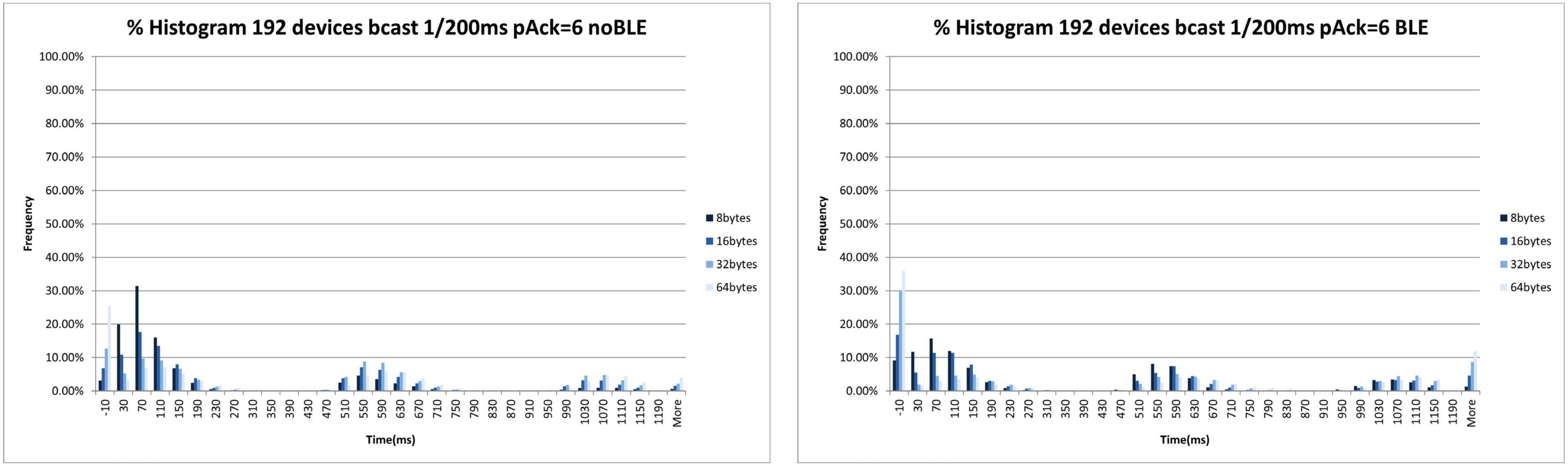


Figure 3.3. 192 devices, 200 ms

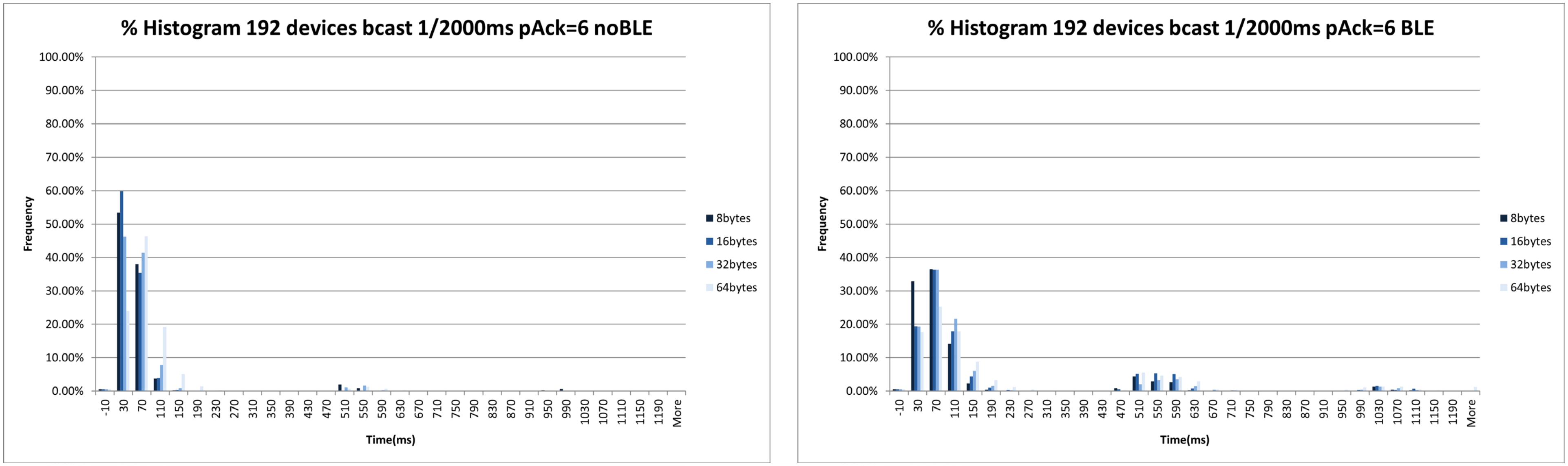
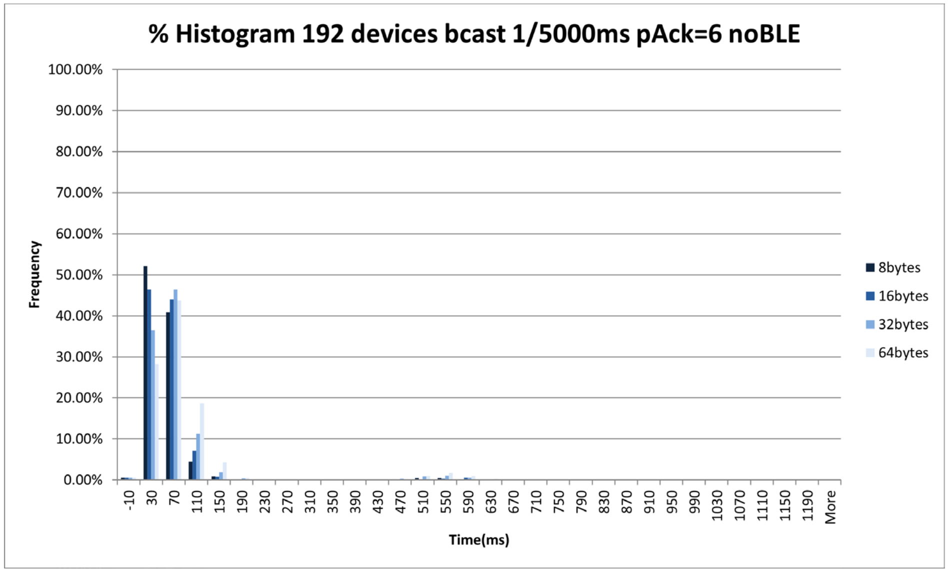


Figure 3.4. 192 devices, 2000 ms



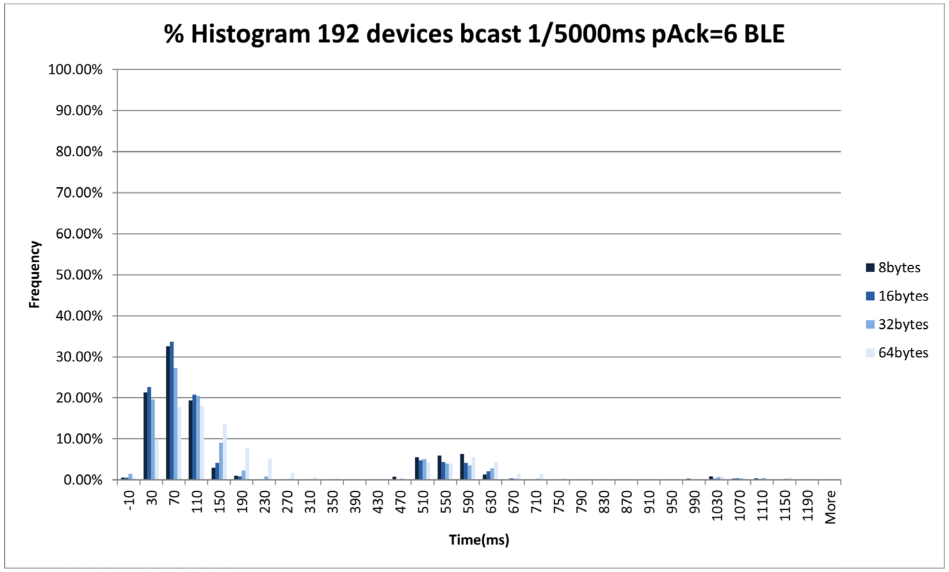


Figure 3.5. 192 devices, 5000 ms

3.1.3 Test Conclusion

The test results were within expectations.

With greater traffic rates we observe more latency and loss. We also observe greater latency and loss when all devices are sending BLE advertisements versus when they are not.

3.2 Zigbee/BLE DMP Large Network with High Stress BLE Data Traffic Test Results

3.2.1 Test Setup Details

For these test scenarios, several different functions were performed at the same time. To accomplish this, multiple Java threads were used that interact with the CLI of these devices.

Each of these Java threads collected different sets of metrics and combined them into a generated report, along with individual result sets for the Zigbee broadcast, Zigbee unicast, and BLE testing.

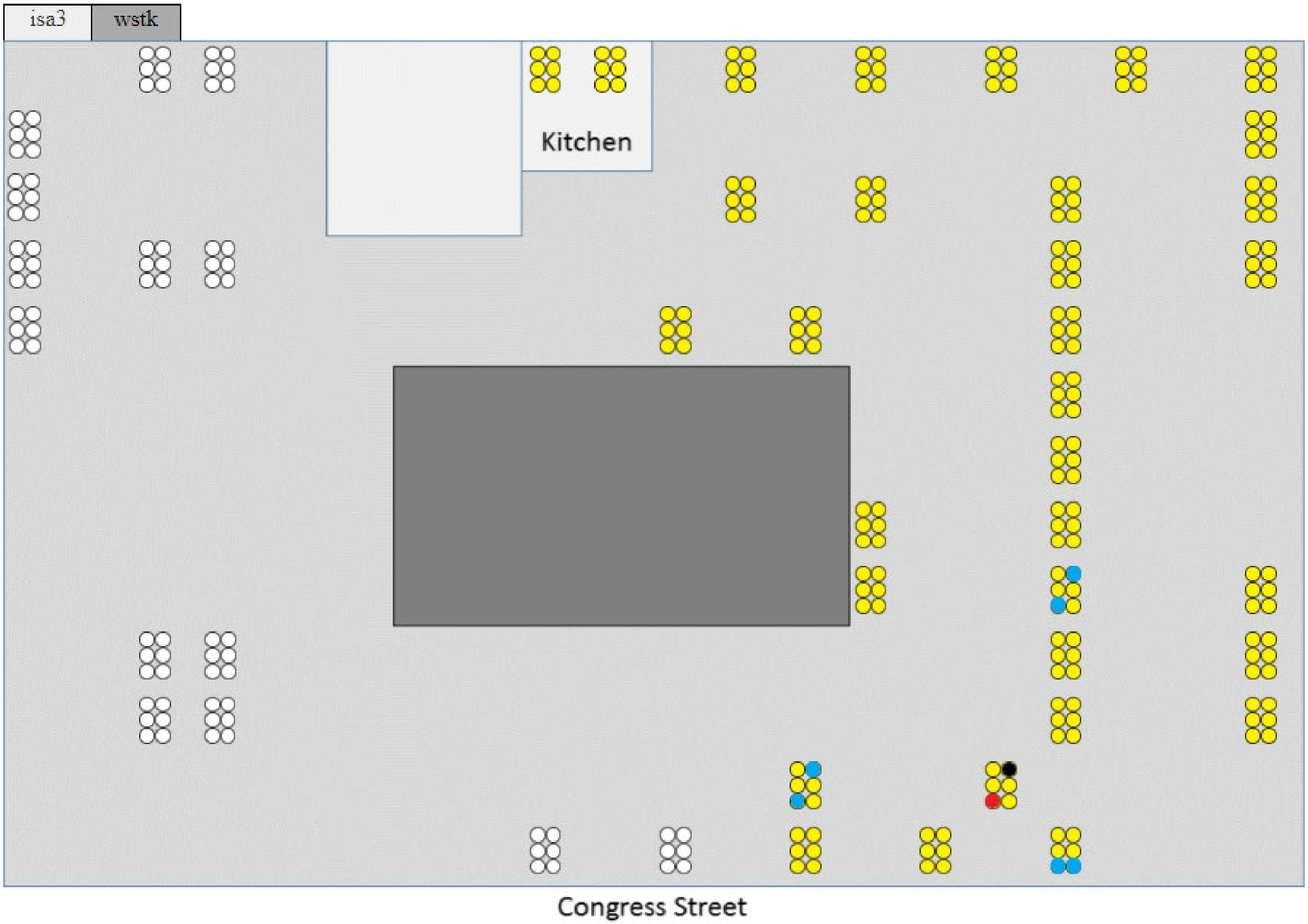
For Zigbee broadcast testing, as previously, the Zigbee coordinator always originated the broadcast. If a receiver did not receive a packet, a value of -10 was used, or the value was the time delta between transmit and receipt.

For Zigbee unicast testing, one device (not the Zigbee coordinator) was selected to transmit to all other devices in the network. A custom application CLI was used where, on receipt of this special unicast 50-byte packet, the receiving device transmitted a 50-byte packet back to the sender. A loss occurred if the sender did not receive this packet back within 500-1000 ms.

For Bluetooth testing, three pairs of other devices were selected to be the BLE devices under test. These devices opened a BLE connection for each pair and transmitted BLE data for a period of time, then close BLE connection and repeat. The devices that open BLE connections also send periodic Zigbee broadcasts where the broadcast interval is 60-300 seconds randomized.

3.2.2 Test Topology Details

For these tests, four device types were part of the whole network under test. The meaning of device type was the function that each device was serving under the duration of the test. The map below of the Silicon Labs Boston office illustrates those roles.



The yellow circles are the 192 nodes joined in a Zigbee network. Only 96 of these nodes were used for the 96-node scenarios.

The black circle indicates the ZC that forms the network and is also responsible for transmitting the broadcast packets under test.

The red circle indicates the ZR that is transmitting unicast in a round-robin fashion to the other nodes.

The blue circles indicate the devices that are doing BLE connection pairings. One device in each pair of blue nodes are configured to send Zigbee broadcasts as needed to introduce extra network traffic, as described in each test scenario later.

3.2.3 Test Results

Most of the data described in this section are variable, such as which devices do what, rate, size, and duration.

Given that these testing scenarios have multiple network actions occurring at the same time, some timing measurements were added to the results to record when those actions started in the test and the duration of those actions.

The broadcast results are further displayed as a histogram representing both the loss and the latency of the broadcast test portion. As previously, a value of -10 indicates that a receiver missed a broadcast that was transmitted.

The broadcast time series illustrates the chronology of the test execution by displaying all receiver timings for each broadcast sequence transmitted. The ~500 milliseconds bumps are a symptom of Broadcasts being initiated in “waves” consisting of the initial broadcast and two re-transmissions with about 500ms in-between them. This was included in the results because the test was measuring the time from when the transmitter internally queued up the broadcast and before the packet was actually transmitted over the air by the radio.

3.2.4 48 Node EFR32MG12 Network

For this topology, only EFR32MG12 boards were used.

Also, for this test, the ZC was set to be a high RAM concentrator, and three other devices (one in each pair of the blue nodes) were configured to send periodic Zigbee broadcasts.

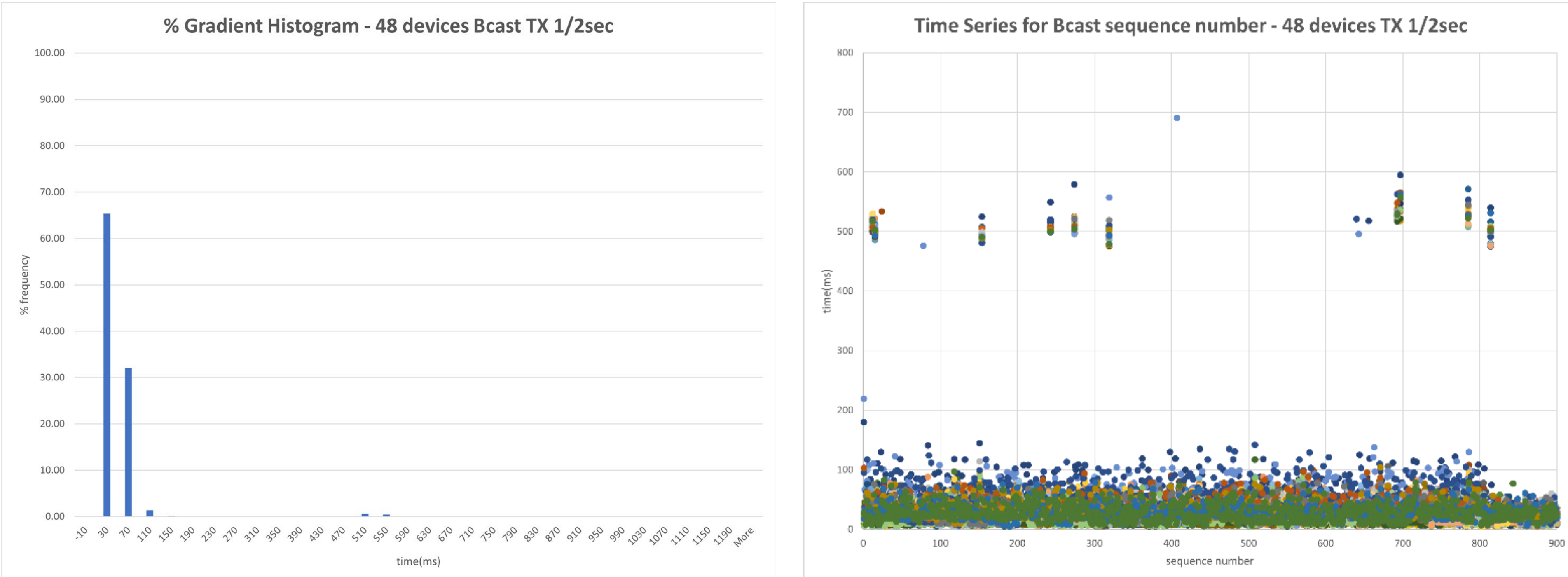
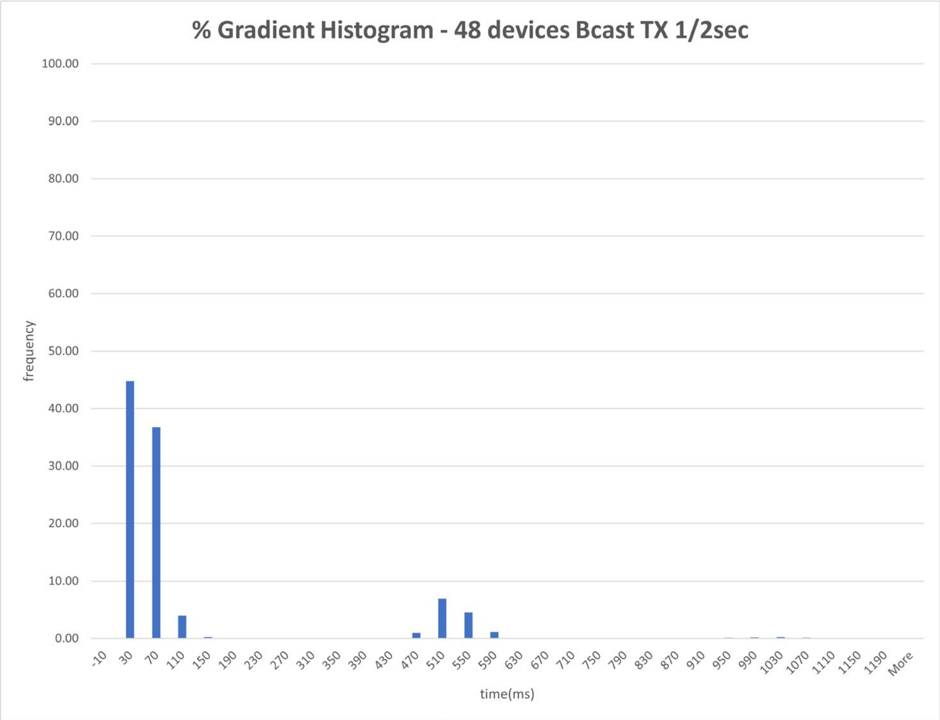


Figure 3.6. 48 devices, Zigbee Broadcasts every 2000 ms, no BLE



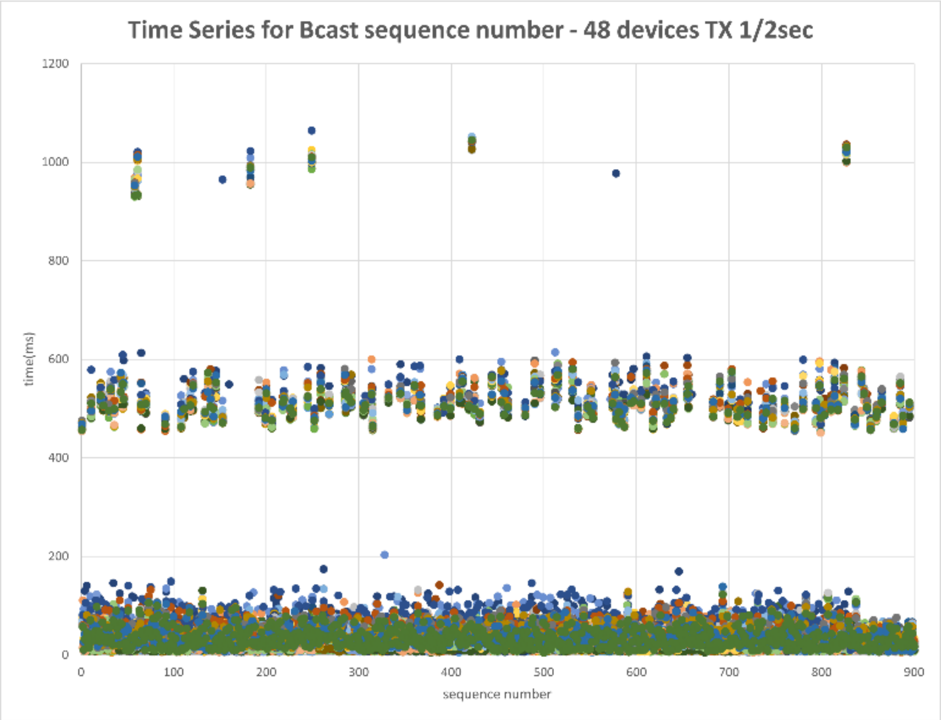


Figure 3.7. 48 devices, Zigbee Broadcasts every 2000 ms, BLE

Summary Data

Below is the summary data of two additional tests where the ZC was a high RAM concentrator with a 60-300 randomized MTORR period. Devices that initiate BLE connections (in the BLE Data table) also each send periodic Zigbee broadcasts.

The BLE connection remained open for time approximately equal to the Duration divided by the ConnPass value, which was approximately 170 seconds in the below runs. The duration field is cumulative value of how long BLE connections were open for the entire test.

Zigbee Broadcast:

TX Node	BLE Adv Enabled	Broadcast Rate (ms)	Size	# RXs	Broadcasts Sent	Unique Receives	Duration (sec)	Start Time (sec)	% Pass Rate
10.4.186.6	False	2000	25	47	900	43200	1919	1675458287	100.00
10.4.186.6	True	2000	25	47	900	43200	1918	1675460344	100.00

Zigbee Unicast:

TX Node	BLE Adv Enabled	Broadcast Rate (ms)	Size	RRLoop	# RXs	Unicast Sent	Responses Received	Duration (sec)	Start Time (sec)	% Pass Rate
10.4.186.9	False	200	50	120	47	5640	5610	1782	1675458287	99.47
10.4.186.9	True	200	50	120	47	5640	5624	1868	1675460344	99.72

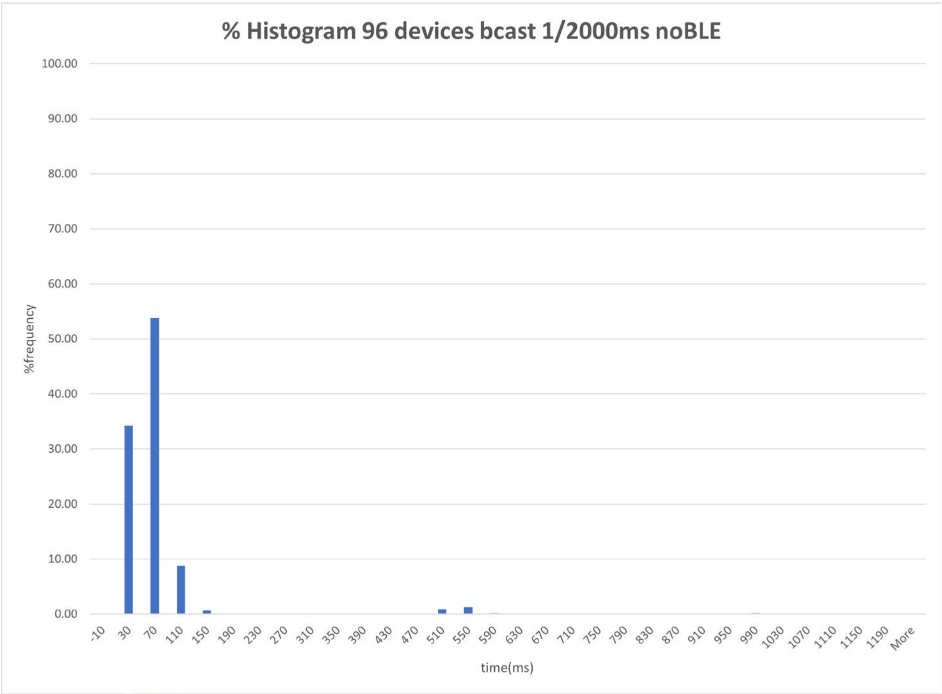
BLE Data:

TX Node	RX Node	BLE Adv Enabled	Rate (ms)	Size	ConnAtt	ConnPass	Unicasts Sent	Responses Received	Duration (sec)	Start Time (sec)	% Pass Rate
10.4.186.12	10.4.186.13	False	100	185	10	10	7000	6999	1742	1675458287	99.99
10.4.186.18	10.4.186.19	False	100	185	10	10	7000	7000	1720	1675458287	100.00
10.4.186.96	10.4.186.97	False	100	185	10	10	7000	7000	1711	1675458287	100.00
10.4.186.12	10.4.186.13	True	100	185	10	10	7000	6299	1771	1675460344	89.99
10.4.186.18	10.4.186.19	True	100	185	10	10	7000	6300	1742	1675460344	90.00
10.4.186.96	10.4.186.97	True	100	185	10	10	7000	6999	1711	1675460344	89.99

3.2.5 96-Node Mixed Network

For this topology, a mixed network comprised of x72 EFR32MG12, x12 EFR32MG21, and x12 EFR32MG24 was used.

Also, for this test, the ZC was set to be a high RAM concentrator, and three other devices (one in each pair of the blue nodes) were configured to send periodic Zigbee broadcasts.



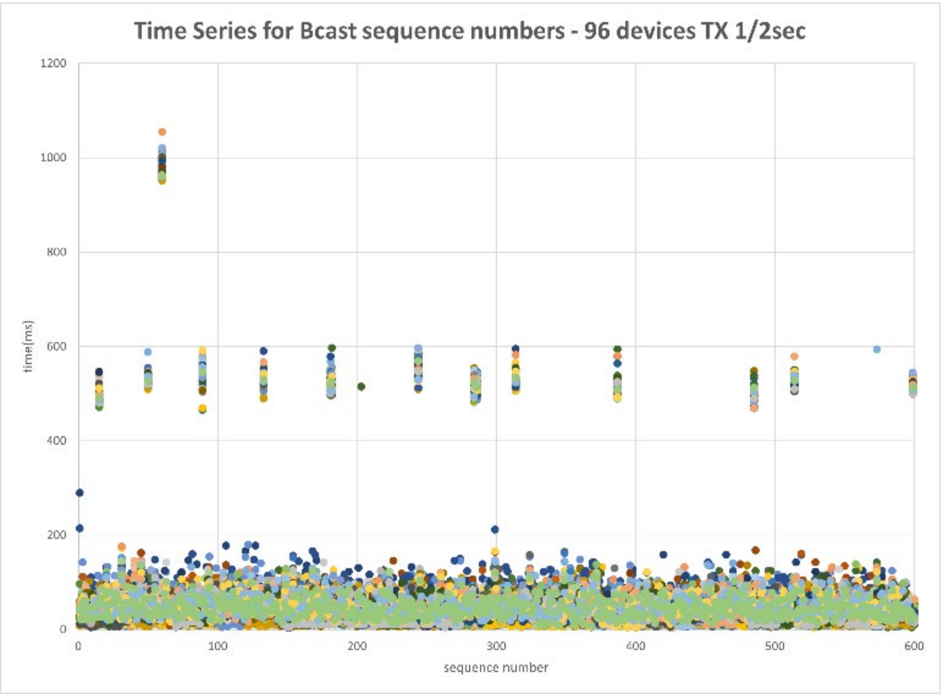
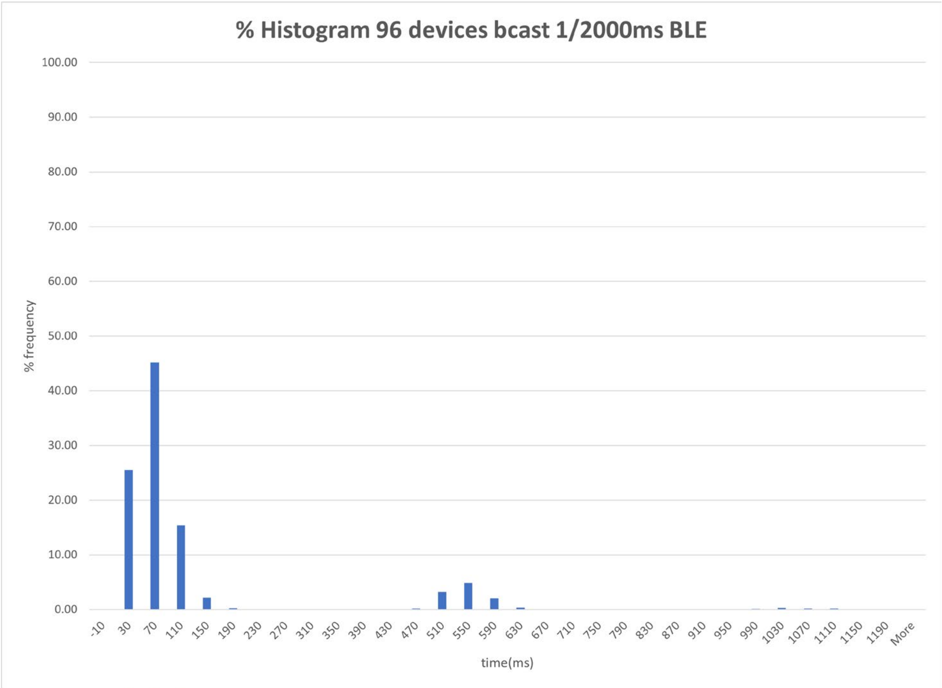


Figure 3.8. 96 devices, Zigbee Broadcasts every 2000 ms, no BLE



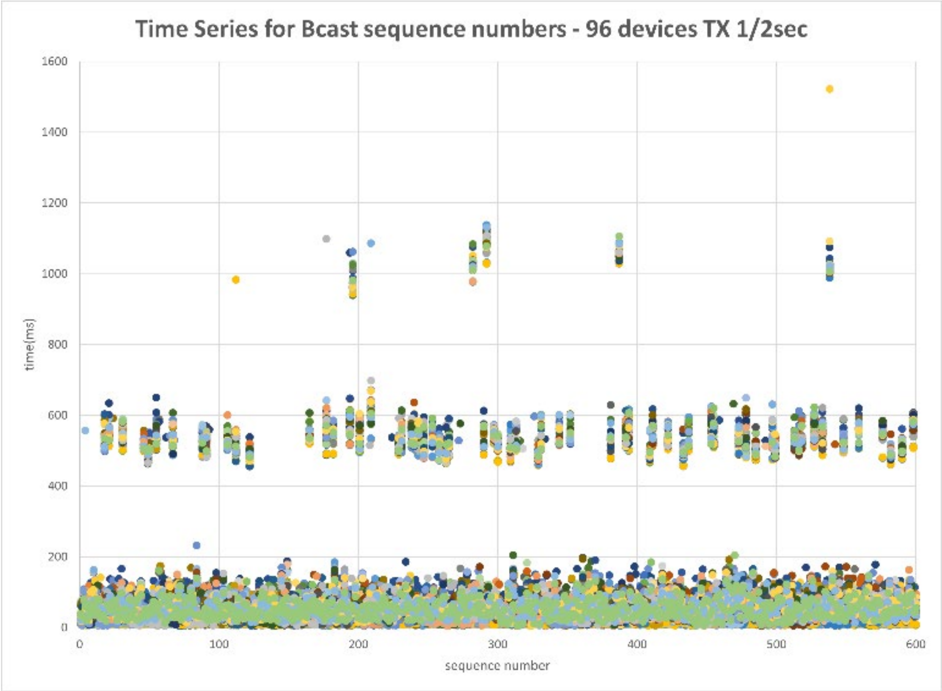


Figure 3.9. 96 devices, Zigbee Broadcasts every 2000 ms, BLE

Summary Data

Zigbee Broadcast:

TX Node	BLE Adv Enabled	Broadcast Rate (ms)	Size	# RXs	Broadcasts Sent	Unique Receives	Duration (sec)	Start Time (sec)	% Pass Rate
10.4.186.6	False	2000	25	95	600	57599	1227	1673119598	99.99
10.4.186.6	True	2000	25	95	600	57600	1227	1673130775	100.00

Zigbee Unicast:

TX Node	BLE Adv Enabled	Broadcast Rate (ms)	Size	RRLoop	# RXs	Unicasts Sent	Responses Received	Duration (sec)	Start Time (sec)	% Pass Rate
10.4.186.9	False	200	50	40	95	3800	3793	1254	1673119598	99.82
10.4.186.9	True	200	50	40	95	3800	3780	1348	1673130775	99.47

BLE Data:

TX Node	RX Node	BLE Adv Enabled	Broadcast Rate (ms)	Size	ConnAtt	ConnPass	Unicasts Sent	Responses Received	Duration (sec)	Start Time (sec)	% Pass Rate
10.4.186.12	10.4.186.13	False	100	185	8	8	4800	4800	1182	1673119598	100.00
10.4.186.18	10.4.186.19	False	100	185	8	8	4800	4800	1203	1673119598	100.00
10.4.186.96	10.4.186.97	False	100	185	8	8	4800	4799	1215	1673119598	99.98
10.4.186.12	10.4.186.13	True	100	185	8	8	4800	4800	1223	1673130775	100.00
10.4.186.18	10.4.186.19	True	100	185	8	8	4800	4800	1168	1673130775	100.00
10.4.186.96	10.4.186.97	True	100	185	8	8	4800	4799	1166	1673130775	99.98

CPU Profiling

CPU profiling is a little more complex as it requires manual use and observance on one device.

With BLE advertisements disabled:

- Given that Zigbee unicast was the most constrained in this test, monitoring of that device over most of the test found that the CPU was idle ~90% of the time with Zigbee using 6-7%.
- Another short run with similar results showed that the ZC showed similar results.
- The devices using the most CPU were the BLE devices that were doing the connection/data payloads. These showed about 60-65% idle: ~10% to Zigbee, 4% to BLE event, 2% to BLE link layer, and <1% BLE stack.

With BLE advertisements enabled:

- The CPU generally used another 10% for CPU, with Zigbee hovering at 10-15%.

3.2.6 192-Node Mixed Network

For this topology, a mixed network comprised of x168 EFR32MG12, x12 EFR32MG21, and x12 EFR32MG24 was used.

At the time of publication, large networks under stress were outside the scope of the tool used to collect timing deltas so charts are not available but summarized reports are below.

Also, for this test, the ZC was set to be a high RAM concentrator, and three other devices (one in each pair of the blue nodes) were configured to send periodic Zigbee broadcasts.

Zigbee Broadcast:

TX Node	BLE Adv Enabled	Broadcast Rate (ms)	Size	# RXs	Broadcasts Sent	Unique Receives	Duration (sec)	Start Time (sec)	% Pass Rate
10.4.186.6	False	2000	25	191	900	167773	1845	1673280624	97.09
10.4.186.6	True	2000	25	191	900	166463	1846	1673456545	96.33

Zigbee Unicast:

TX Node	BLE Adv Enabled	Broadcast Rate (ms)	Size	RRLoop	# RXs	Unicasts Sent	Responses Received	Duration (sec)	Start Time (sec)	% Pass Rate
10.4.186.9	False	200	50	22	191	4202	3781	1829	1673280624	89.98
10.4.186.9	True	200	50	22	191	4202	2997	2365	1673456545	71.32

BLE Data:

TX Node	RX Node	BLE Adv Enabled	Broadcast Rate (ms)	Size	ConnAtt	ConnPass	Unicasts Sent	Responses Received	Duration (sec)	Start Time (sec)	% Pass Rate
10.4.186.12	10.4.186.13	False	100	185	10	10	7000	6286	1771	1673280624	89.80
10.4.186.18	10.4.186.19	False	100	185	10	10	7000	6983	1734	1673280624	99.76
10.4.186.96	10.4.186.97	False	100	185	10	10	7000	6982	1684	1673280624	99.74
10.4.186.12	10.4.186.13	True	100	185	10	10	7000	6980	1659	1673456545	99.71
10.4.186.18	10.4.186.19	True	100	185	10	10	7000	6284	1778	1673456545	89.77
10.4.186.96	10.4.186.97	True	100	185	10	10	7000	6289	1730	1673456545	89.84

3.2.7 Test Conclusion

The test results were within expectations.

As expected, we observe more loss when all devices are advertising BLE versus when they are not and also when multiple devices are configured to send periodic broadcasts versus when they are not.

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