AN1031: Thread Large Network Scalability

This application note details methods and results for Thread large network scalability and performance testing. This testing focuses on the scalability of these networks while carrying out unicast and multicast traffic typical of a large commercial installation. The methodology for performing the benchmarking tests is defined to allow others to run the same tests. These results are intended to provide guidance on design practices and principles as well as expected field performance results.

SUMMARY

- Wireless test network in Silicon Labs Boston office is described.
- Wireless conditions and environment are evaluated.
- Thread large network scalability as measured by multicast reliability and latency is presented.

1 Introduction

Silicon Labs has provided performance testing results from embedded mesh networks as part of developer conferences and industry white papers. The basic performance data of throughput, latency, and impact of security can be used by system designers to define expected behavior. Evaluation of Thread networks also must consider the scalability of the network as the basic network design and routing is different than previous 802.15.4 mesh networking technologies.

One of the key design aspects of Thread is its scalability to large networks. This has previously been seen as a limitation for embedded 802.15.4 networks because the network flooding in the presence of a large number of routers limited the frequency and reliability of multicast traffic. This paper specifically evaluates the scalability and reliability of large networks operating with a standard Thread networking stack. While this paper is based on standard Thread networking software, the results and methods are suitable for other mesh networking software.

Note This performance data is for the Silicon Labs implementation of the Thread stack. As is shown in the test network and infrastructure provided for this testing, no tests were performed with other Thread stacks or systems.

2 Goals and Methods

This paper defines a set of tests performed to evaluate large network scalability and reliability of the Thread network. The test conditions and infrastructure are described, in addition to the message latency and reliability.

Thread is evaluating requirements for larger networks and commercial buildings. Because of the limited data available publically on Thread network performance in large networks today, it is difficult to have industry discussions on possible improvements or changes. For example, in commercial buildings there is concern over:

- Other 802.15.4 traffic, since there may be many subnets
- Wi-Fi interference from the normal building Wi-Fi infrastructure
- Large network multicast latency and reliability, since multicasts are commonly used for lighting controls in dense office environments

Note: The test results here are limited to comparison of system performance under normal operating conditions, or under stress as noted in particular tests. This paper does not specifically address system interference or other such effects that have been addressed in other published results.

Review of other Benchmarks

There are no specific defined methods for evaluating and reporting large network reliability, scalability or latency. Silicon Labs has published such papers in the past to compare network performance. This testing focused on device behavior and impact on battery life, and network throughput and latency. Large scale multicast testing was not previously performed because it is difficult to capture accurate timing from large distributed networks, and existing 802.15.4 mesh networks were limited in their multicast traffic. For Thread, it is important to evaluate the large scale multicast testing since it is a key improvement to the scalability based on the Thread network design.

3 Test Network and Conditions

To minimize the variability of device testing, it is often done in fixed topologies where we wire the RF paths together through splitters and attenuators to ensure the topology does not change over time and testing.

A typical wired test configuration is shown below:

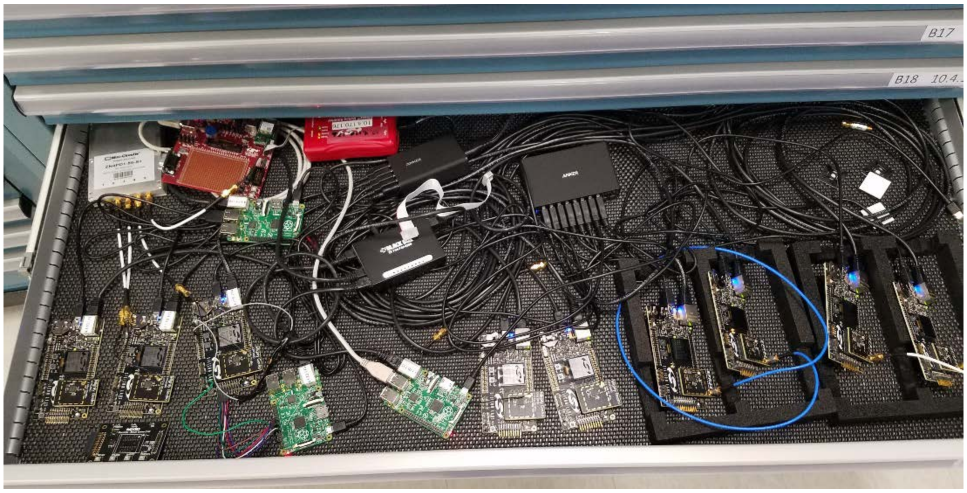


Figure 1. Wired RF Devices in Drawer with Splitter and Coax Cable Connectivity

However, large network testing is best conducted in an open air environment where device behavior is based on the existing and varying RF conditions. The Silicon Labs office in Boston is used for this open air testing.

3.1 Office and Test Network Conditions

The existing office consists of a central core with elevator shaft and other services with open floor plan on the West end of the building and offices and conference rooms on the East end. The overall office measures approximately 120 feet by 200 feet. The image below shows the office layout. The darker lines represent hard walls and everything else is split up with cube partitions.

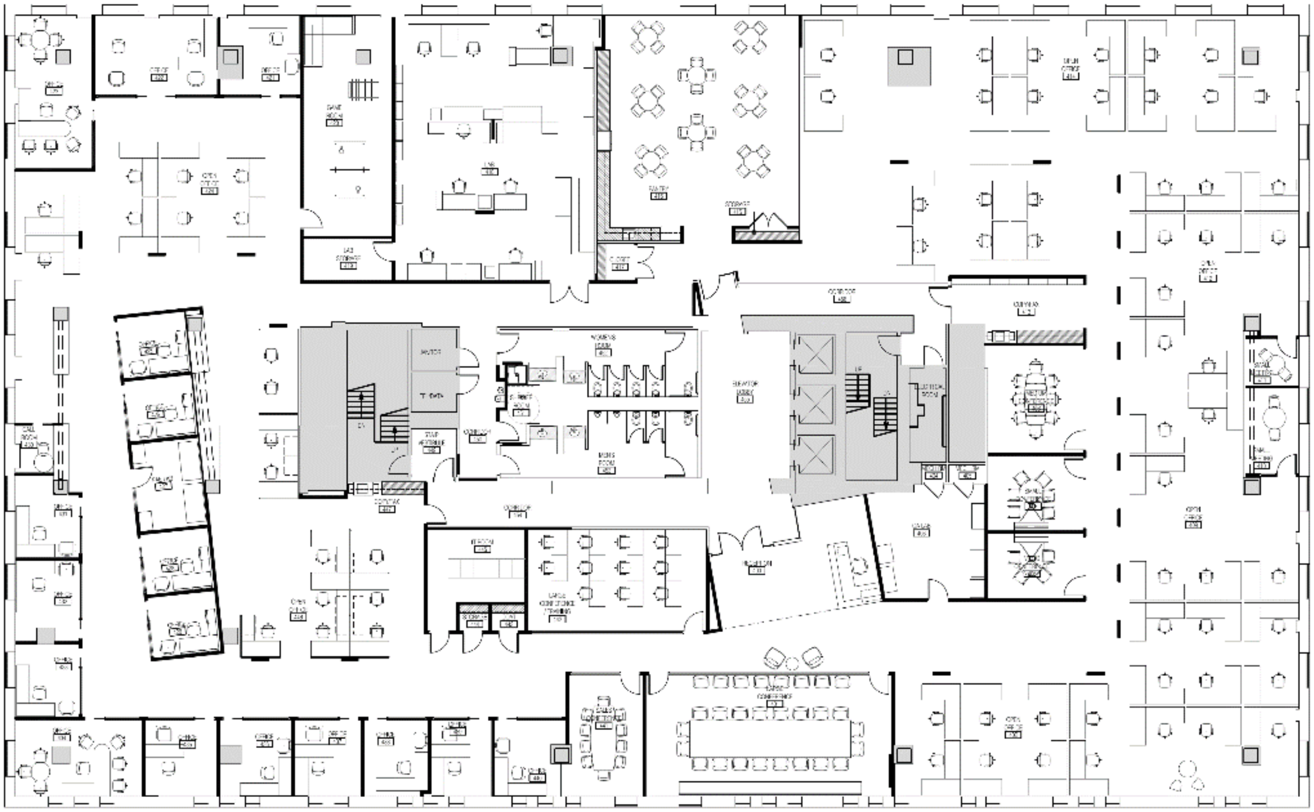
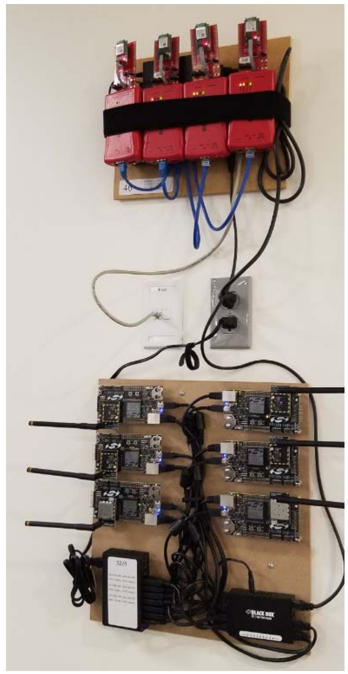


Figure 2. Boston Office Layout used for Wireless Testing

At various locations around the office the testing devices are installed. These devices all have Ethernet backchannel connectivity to allow:

- Firmware updates
- Command line interface
- Scripting
- Timing analysis
- Packet capture
- Energy measurements



Four EM35x Devices using PoE

Six EFR32MG (Mighty Gecko) devices

Multi-band support to allow testing both 2.4 GHz (PCB antenna) and proprietary sub-GHz protocols (external antenna)

USB power and Ethernet connectivity

Figure 3. Typical Testing Cluster

The testing clusters are spread throughout the office both high and low, in open areas and in enclosed meeting rooms and offices.

Figure 4. Testing Clusters in the Boston Office

This test network has devices added or removed from it on a regular basis but at the time of this testing it consisted of the following devices:

- 112 EM357 devices
- 168 EM358x devices

- 76 EZR32 devices
- 152 EFR32MG devices

This represented 508 devices that were used for open air testing by the networking and software quality assurance teams. All devices are controlled from a central test server and infrastructure, which allows scripted regression testing or manual testing by engineers.

3.2 Wireless Conditions in the Office

The Boston office has a full ZigBee lighting control system including motion and lighting sensors and switches. This is not part of the test network and is used as a normal building control system independent of any testing being run.

The Boston office is also downtown and, in addition to our existing Wi-Fi infrastructure, there are over 100 Wi-Fi access points within RF distance of the office. The following charts were taken as a snapshot of a snapshot of a normal work day Wi-Fi scan. This is considered the normal Wi-Fi background traffic.

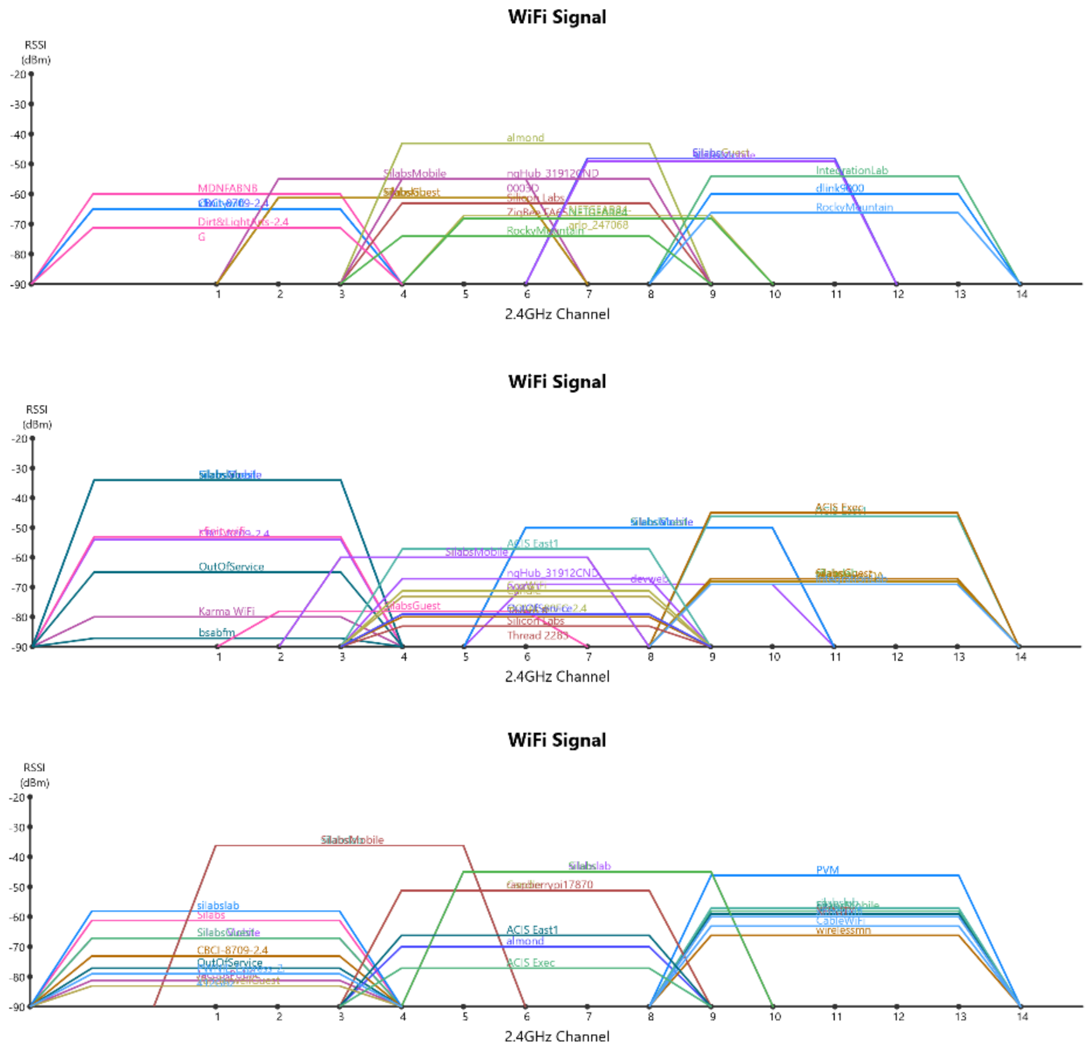


Figure 5. Wi-Fi Scans on a Normal Day

These Wi-Fi scans were taken at the South East corner office, the West side, and the North side in the main conference room, respectively. These locations showed 41, 92 and 111 Wi-Fi access points within RF range.

3.3 Typical Test Network

Within the test network, a given test can select and use a given set of devices for a test. The network is established and devices joined using the Ethernet backchannel to send commands to devices. A typical network during testing is shown below. The blue devices are Thread Routers and the green devices are Thread Router-eligible End Devices (REEDs). The black and grey lines show the router connectivity and strength.

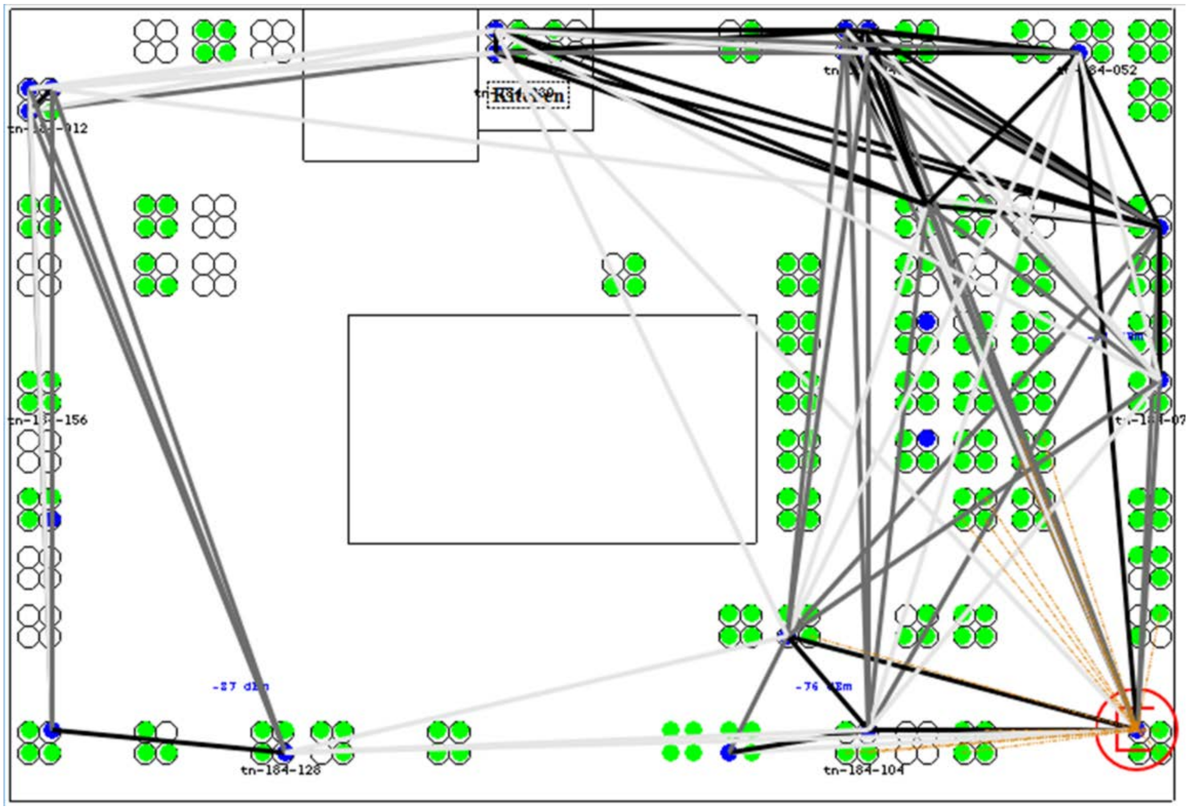


Figure 6. A Typical Network During Testing

4 Testing and Results

4.1 Initial Tests versus Network Size

In initial testing, the network size was varied to evaluate the distribution of multicast latency and reliability. The network was tested using 47, 101, and 137 devices using a single multicast source sending a multicast every 4 seconds. Note the timing in the graph is based on the Ethernet network reported timing and this is estimated to be within approximately 10 milliseconds across the network.

To understand the graph requires understanding the Thread network multicast behavior. The initial device sends the multicast. It can be expected to be heard by all routers within RF range as well as any REED devices having that initial device as a parent from which they can hear messages. REED's are required by the Thread specification to synchronize with a single primary parent but also to synchronize with at least three additional parents to improve multicast reliability.

Thread devices use a multicast backoff of 32-64 milliseconds before a device relays the multicast. As such, the initial multicast can be seen in the 40-millisecond timeframe, and the second relay is spaced out in time as devices perform the backoff and relaying.

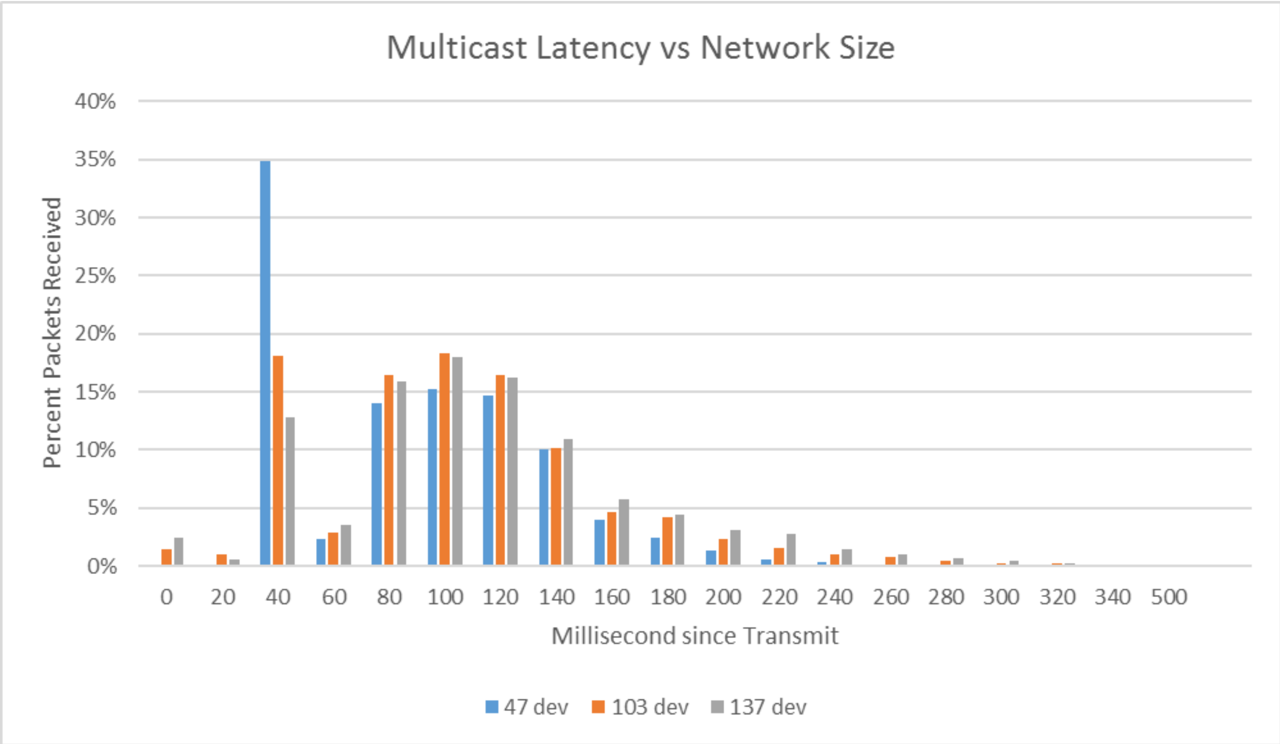


Figure 7. Multicast Latency vs. Network Size

4.2 Multicast Testing with Unicast Traffic

Testing was also done to evaluate unicast behavior in the presence of the multicast traffic. The 139-device network was used with a single device multicasting every 4 seconds. Three devices were then selected to randomly send an ICMP (Internet Control Messaging

Protocol) unicast message every 1 second to a random device on the network. The multicast latency was not impacted by this unicast traffic and the reliability of these unicast messages was 99.56%.

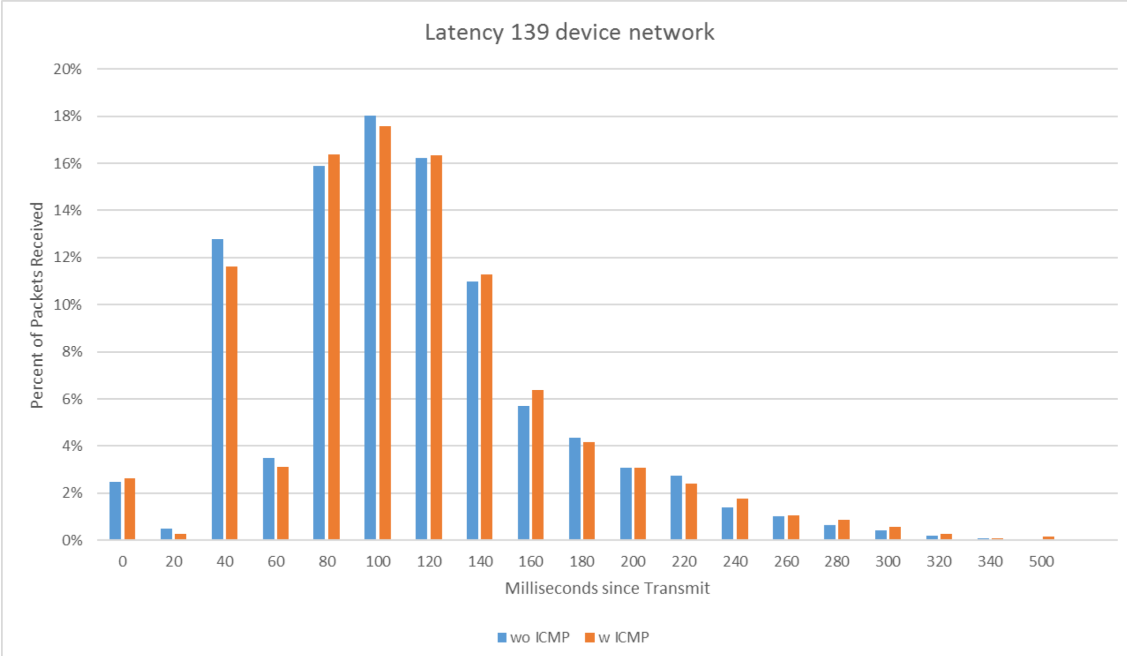


Figure 8. Multicast Latency with and without ICMP

4.3 Large Network Scaling

The system was then extended to a 217-device network. This network used a slightly different test scripting mechanism to allow increasing the multicast traffic on the Thread network without overloading the Ethernet backchannel network reporting data. These scripts reported the latency for each multicast received, but also the time the last node received the multicast.

The multicast source has 8 devices being used in a round-robin manner. Once the last device reported a multicast received, the test initiated the next multicast message. In this manner the multicasts are overlapping in the network, as one multicast dampens out but another is then initiated. This test was run for 1000 multicasts with zero multicast failures.

In these tests the average device received the multicast in 33.5 milliseconds from the initiation of the test and the distribution is shown in the Average Latency graph below. The worst latency averaged 55 milliseconds, with 191 milliseconds as the last received over the 1000 tests, as shown in the Worst Latency graph below.

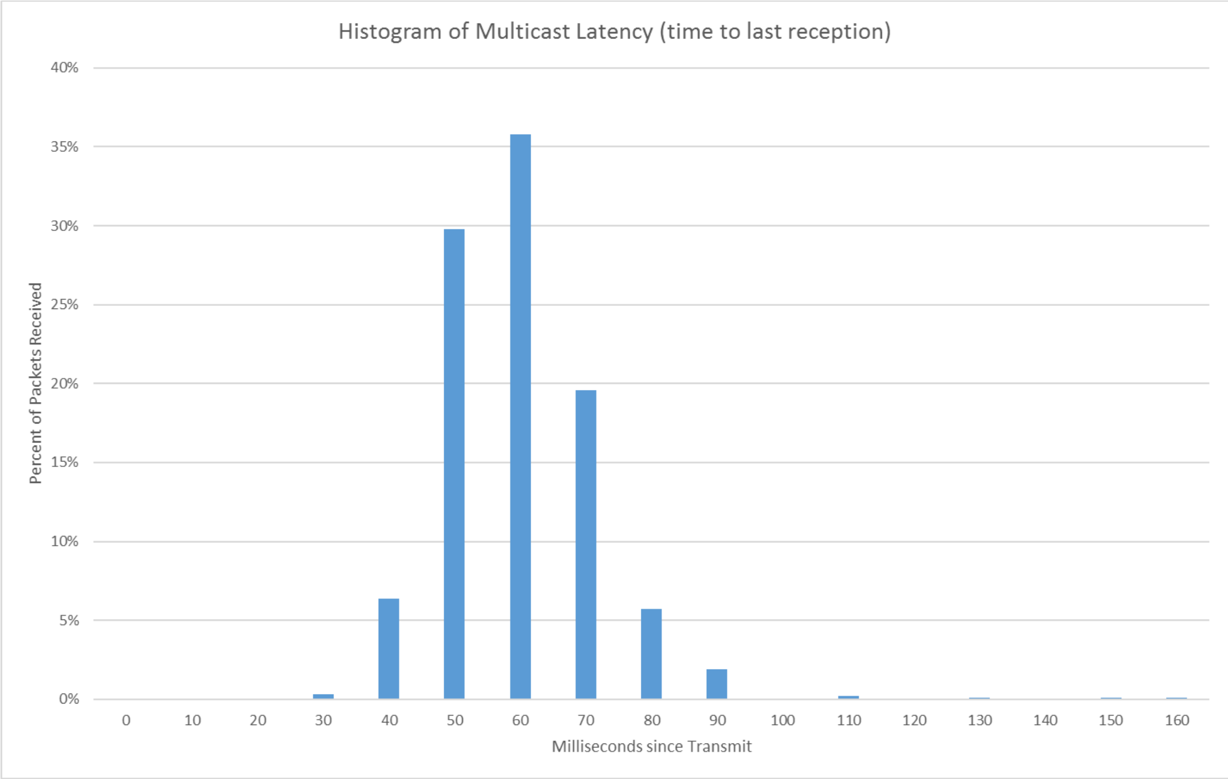


Figure 9. Worst Latency

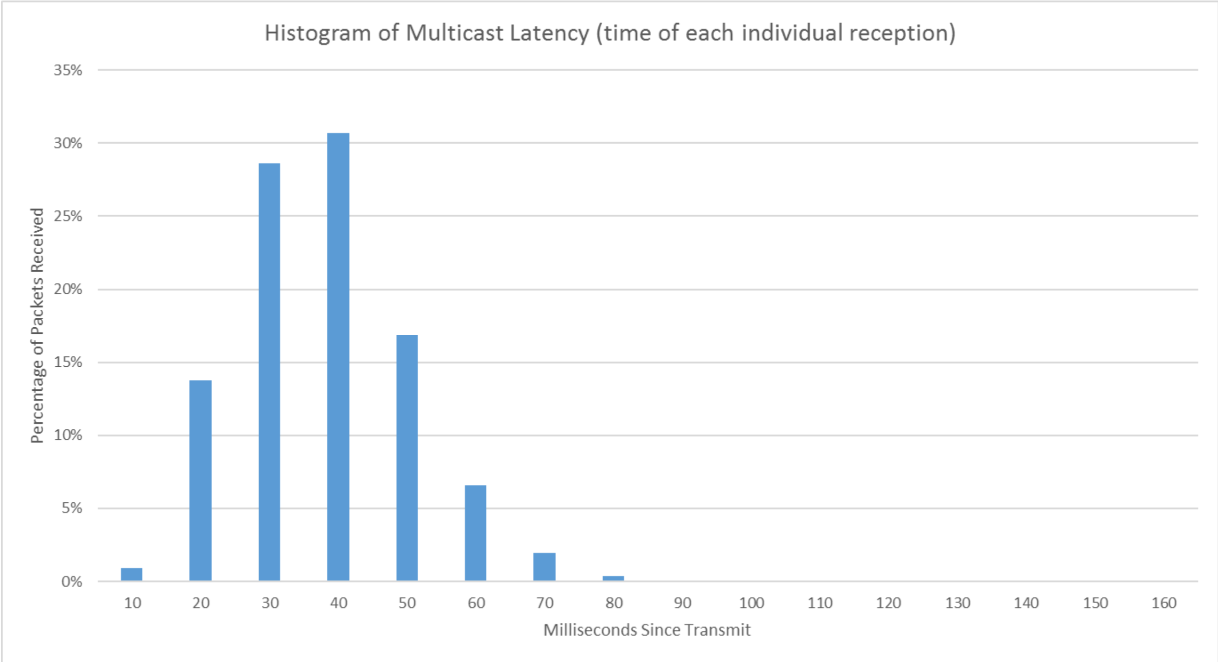


Figure 10. Average Latency

4.4 Large Network Extended Testing

The testing with the 217-node network was extended to run over 10000 multicasts to evaluate performance over a longer time period. The test conditions were the same as above, where 8 devices are sending the multicast in round-robin fashion once the last device has received the previous multicast. In this testing there were 3 lost multicast messages from the 2.17 million messages for a reliability of 99.9998%.

These multicasts are being sent on an average of every 70 milliseconds into the Thread network.

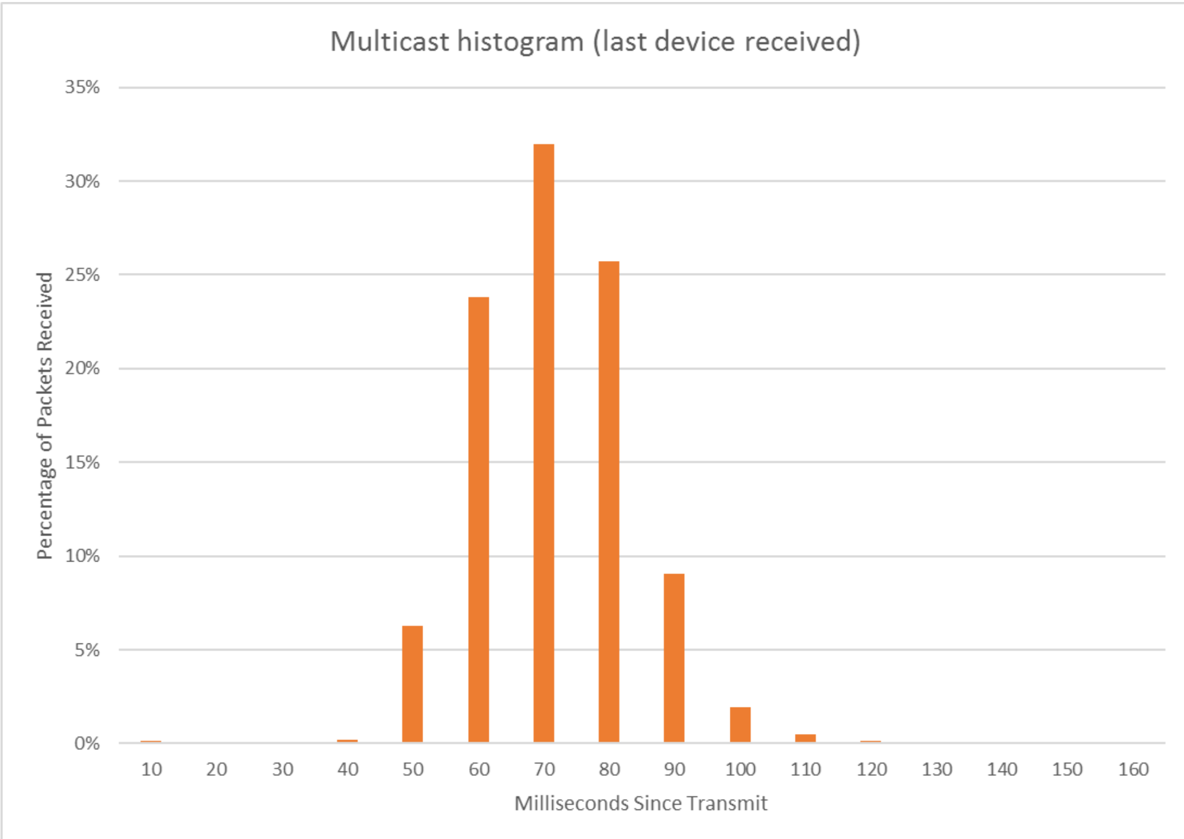


Figure 11. Last Device Received

5 Summary

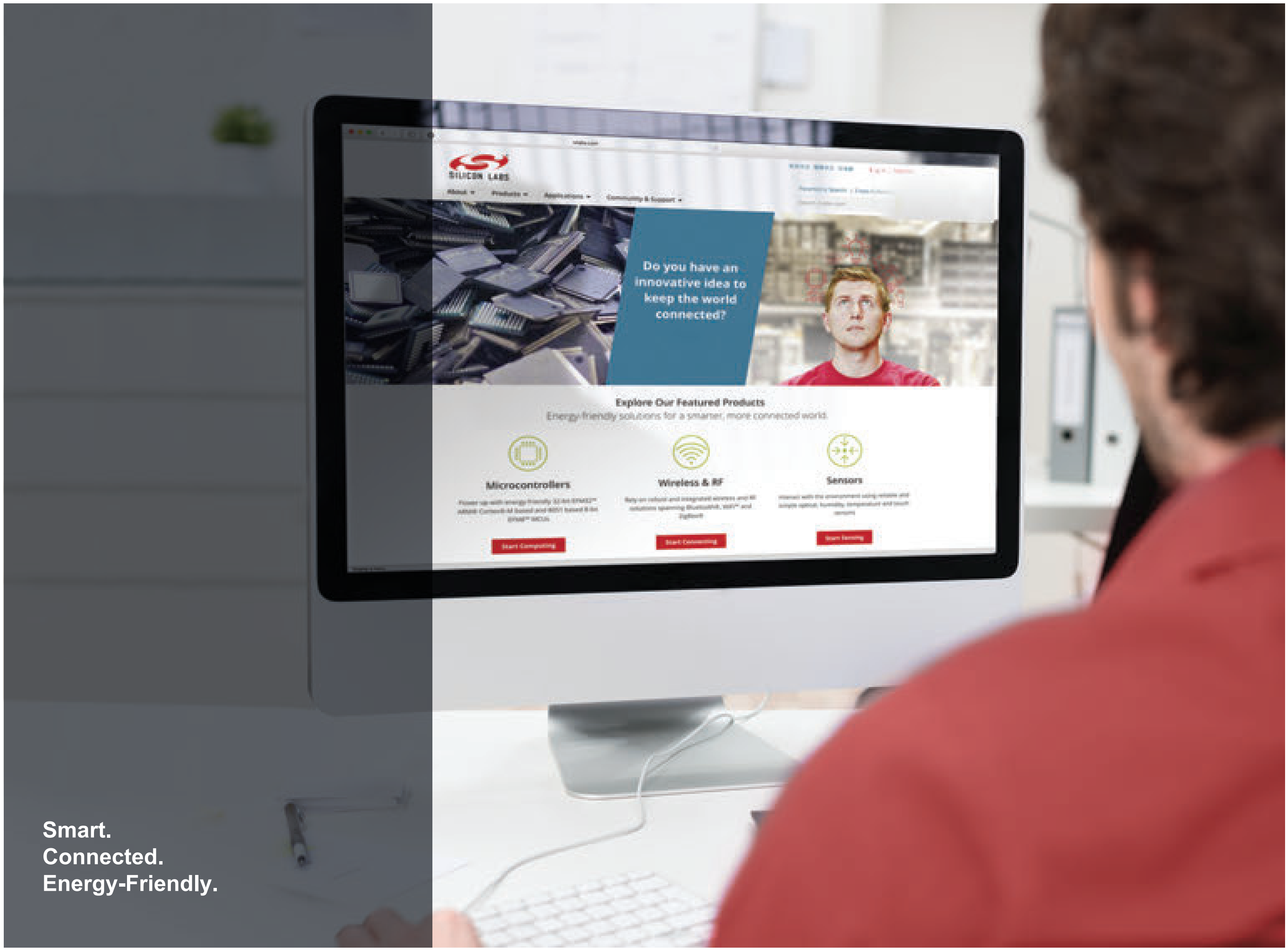
This initial testing is sufficient to allow analysis of some of the basic Thread network scalability expectations for large networks.

It is clear Thread networks provide a level of multicast performance that has not previously been possible for networks of this scale. The reliability is excellent and the latency meets the normal requirements for human interaction of less than 200 milliseconds, even in the worst case testing.

5.1 Follow On Testing Considerations

Testing such as this results in follow-on tests to further define the device behavior and network operations. The following specific items are noted for follow up testing:

1. Additional tests with crossing unicast and multicast packets should be run. These tests also need to be modified to use a confirmable CoAP (Constrained Application Protocol) message instead of an ICMP to better evaluate the reliability.
2. Larger networks up to 300 devices should be run to evaluate if any further changes are noted. It is not currently intended to scale Thread beyond 300 devices, so this is a good upper limit for the testing.
3. Failure testing can also be added by dropping routers out of this network during these tests to evaluate recovery time and impact on reliability.
4. Testing should be performed with different device types running in System-on-Chip and Network Co-Processor (NCP) modes. Previous testing has revealed some differences between these modes of operation, so this should be further characterized.



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