



AN1142: Mesh Network Performance Comparison

It is important for designers to understand the capabilities and performance characteristics of mesh networking technologies to determine the appropriate one for a given application or product. Networking performance characteristics such as throughput, latency, and the impact of network size on scalability and reliability should be considered. Additional factors such as technologies used in different ecosystems, gateway interfaces, and cloud connectivity should also be factored in when [making a determination](#).

This application note reviews the Zigbee, Thread, and Bluetooth mesh networks to evaluate their differences in performance and behavior. Tests were conducted using Silicon Labs' Wireless Gecko SoC platform capable of running Bluetooth Mesh, Thread, Zigbee, and Proprietary protocols. Silicon Labs Bluetooth Mesh, Thread, and Zigbee software stacks were utilized. The test environment was a commercial office building with active Wi-Fi and Zigbee networks in range. Wireless test clusters were deployed in hallways, meeting rooms, offices, and open areas. These results are intended to provide guidance on design practices and principles as well as expected field performance results.

Additional performance benchmarking information for other technologies is available at <http://www.silabs.com/mesh-performance>.

SUMMARY

- Mesh network performance including throughput, latency, and large network scalability is presented.
- Benchmarks performed with Silicon Labs SDKs and Stacks for Bluetooth Mesh, Thread, and Zigbee.

1. Introduction and Background

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. This testing has been previously presented for Zigbee and Thread networks as basic 15.4 mesh networking technologies. These were presented because performance varies even though both systems use the same underlying physical layer defined by IEEE 802.15.4. More recently, we have also published data on Bluetooth Mesh performance using the same test network in our Silicon Labs Research and Development (R&D) facility. The underlying performance details for each of these three mesh technologies are covered in the following individual application notes covering the testing conditions and results:

- [AN1137: Bluetooth Network Performance](#)
- [AN1138: Zigbee Mesh Network Performance](#)
- [AN1141: Thread Mesh Network Performance](#)

This paper is intended to present results from the three technologies so they can be evaluated against each other. No single technology is expected to be used for connecting all devices, therefore, this paper provides performance comparisons so networks are used in situations best suited for the technology. Companies developing products can test the network's performance for the expected use case, and then use this data to assist in selecting the appropriate technology.

This paper does not cover testing conditions and topology as this is covered in each of the individual performance papers. Each mesh network was tested under the same conditions and using the same wireless devices in our Silicon Labs R&D facility.

2. Comparison of Results

2.1 Throughput and Latency

Throughput and latency is tested in a controlled network (wired configuration) to test each hop against different packet payloads.

The normal configuration is to test to 6 hops. Testing is done with 1 source node and a series of routing nodes to allow the number of hops to be varied.

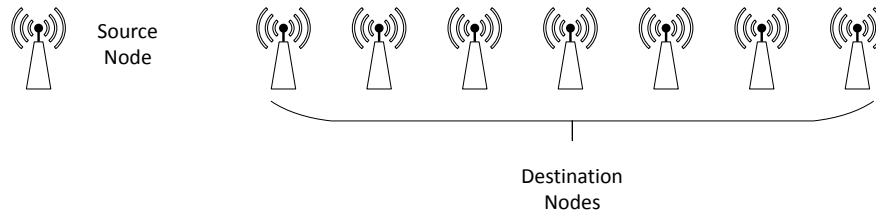


Figure 2.1. Throughput and Latency Test Configuration

2.1.1 Mesh Multi-Hop Throughput

Throughput testing uses the same single setup to evaluate the expected application level throughput of different payload sizes across a different number of hops.

For smaller payload sizes, the throughput is lower as the network spends more time sending packet overhead versus application data.

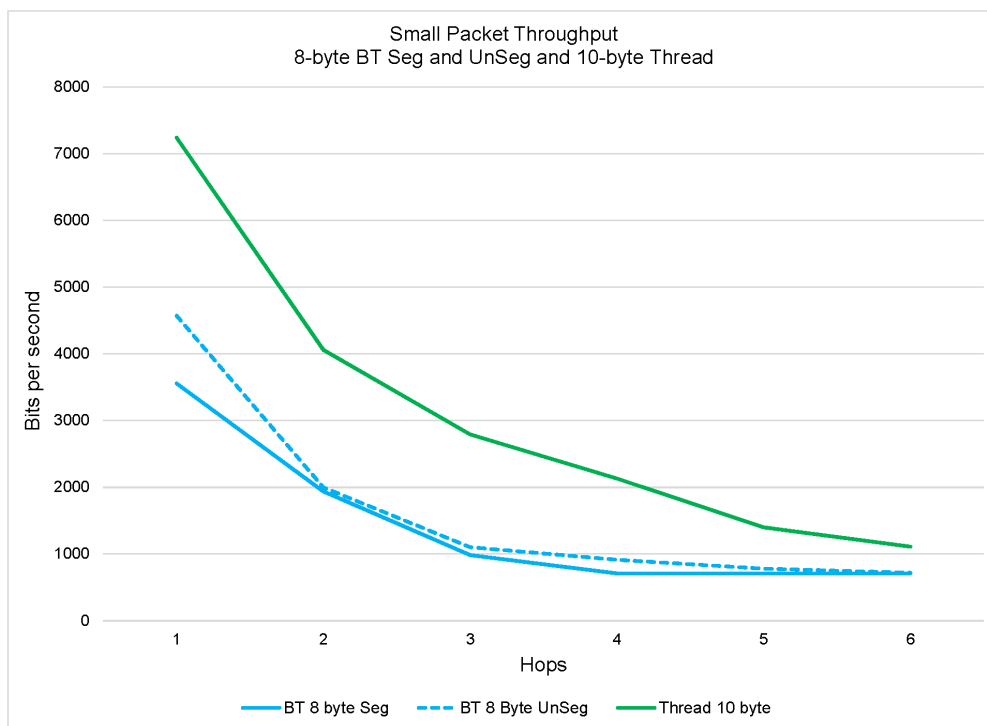


Figure 2.2. Small Packet Throughput 8-byte BT Seg and UnSeg and 10-byte Thread

For larger payload sizes, the throughput is increased overall for Zigbee and Thread; however, the smaller payload size of Bluetooth Mesh does not result in the same increase in throughput. Note that all three technologies are fragmenting packets at this size.

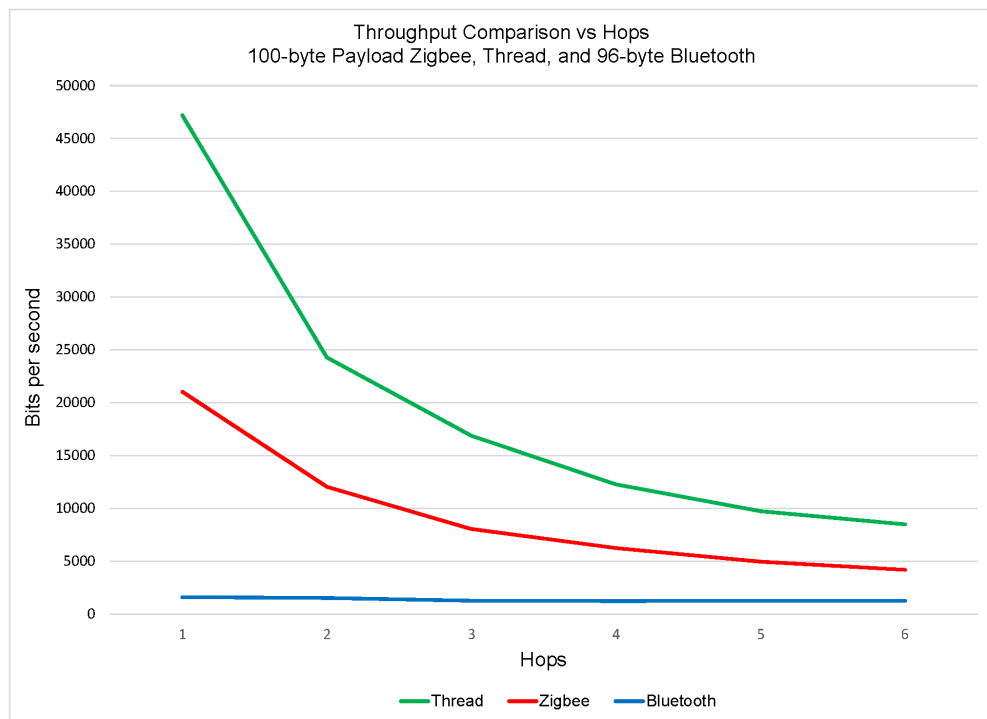


Figure 2.3. Throughput Comparison vs Hops 100-byte Payload Zigbee, Thread, and 96-byte Bluetooth

If we measure latency instead of throughput, we look at the small payloads first and see similar latency numbers between the different technologies. Adding segmentation to Bluetooth increases the latency but everything stays below 200 milliseconds in round trip time.

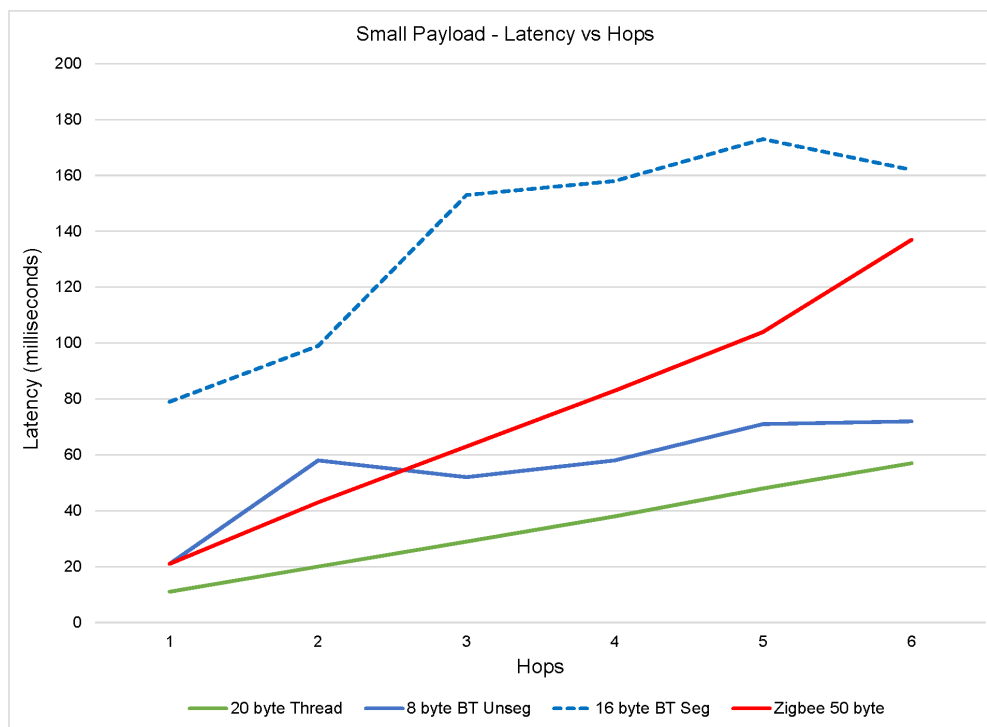


Figure 2.4. Small Payload - Latency vs Hops

If we look at a 4-hop chart versus a different payload size, we can see the increase in latency versus payload for the different technologies. All different mesh networks increase latency as the application payload increases. How well the network does under these conditions is related to the underlying fragmentation method as well as the congestion in the network when sending the data. Bluetooth must send many more packets as the payload size increases, so this segmentation adds more latency.

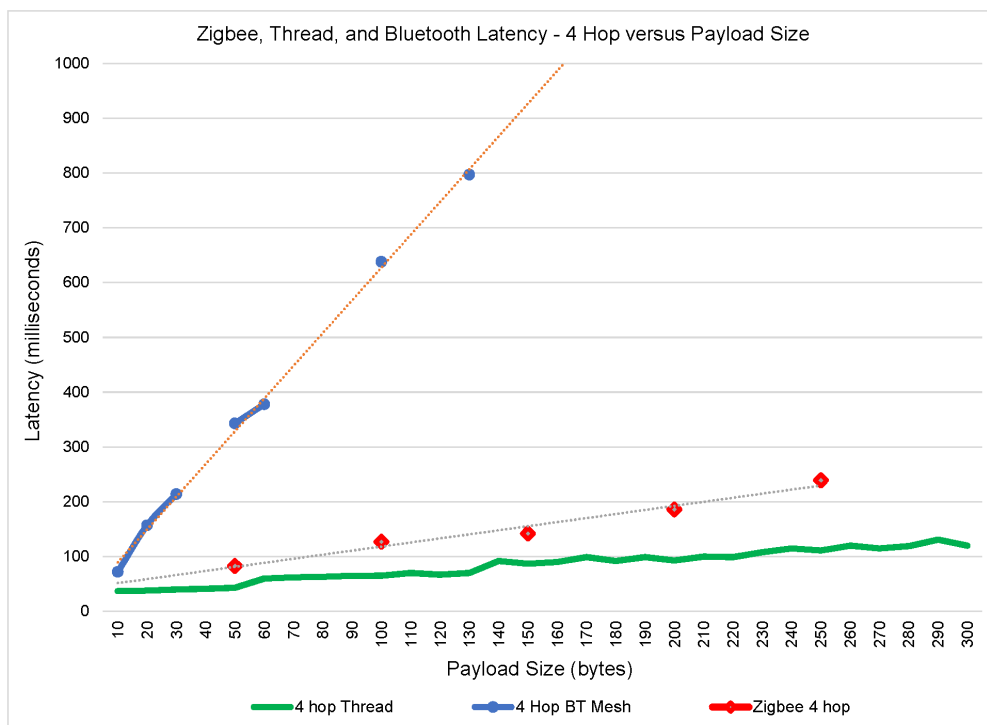


Figure 2.5. Zigbee, Thread, and Bluetooth Latency - 4-hop versus Payload Size

2.2 Multicast Network Tests versus Network Size

The throughput and latency results shown in [Mesh Multi-Hop Throughput](#) are somewhat constrained by the nature of the testing since it is a single string of devices. Open-air testing is required to validate stack performance under less controlled conditions. These networks are configured within Silicon Labs office space with normal Wi-Fi interference, other network operations, and building control systems. No attempt is made to isolate this network's RF conditions.

Because this testing is all multicast delivery, the Bluetooth flooding mesh is behaving the same as Zigbee and Thread because all-device multicasts generally flood the network with three re-broadcasts from each router. These tests are all for relatively lightly loaded networks where the multicast is sent every 3 seconds. In our individual testing, we noted that some network performances deteriorate further as this multicast load is increased.

The networks to be tested for each stack include:

- Small network: 24 devices
- Medium network: 1 – 48 devices
- Medium network: 2 – 96 devices
- Large network: 1 – 144 devices
- Large network: 2 – 192 devices

For any of these tests, any number of devices within +/- 10% of these network targets is acceptable. These networks are all configured as powered devices. For each of these networks, the testing will validate reliability and latency for a set of traffic conditions. Testing is intended for over 100 packets.

2.2.1 Small Networks and Different Packet Sizes

For each of these networks, we want to start testing with a small network and small payload sizes as the simplest comparison point. As shown below, all three mesh networks provide very good performance with latency well under 200 milliseconds.

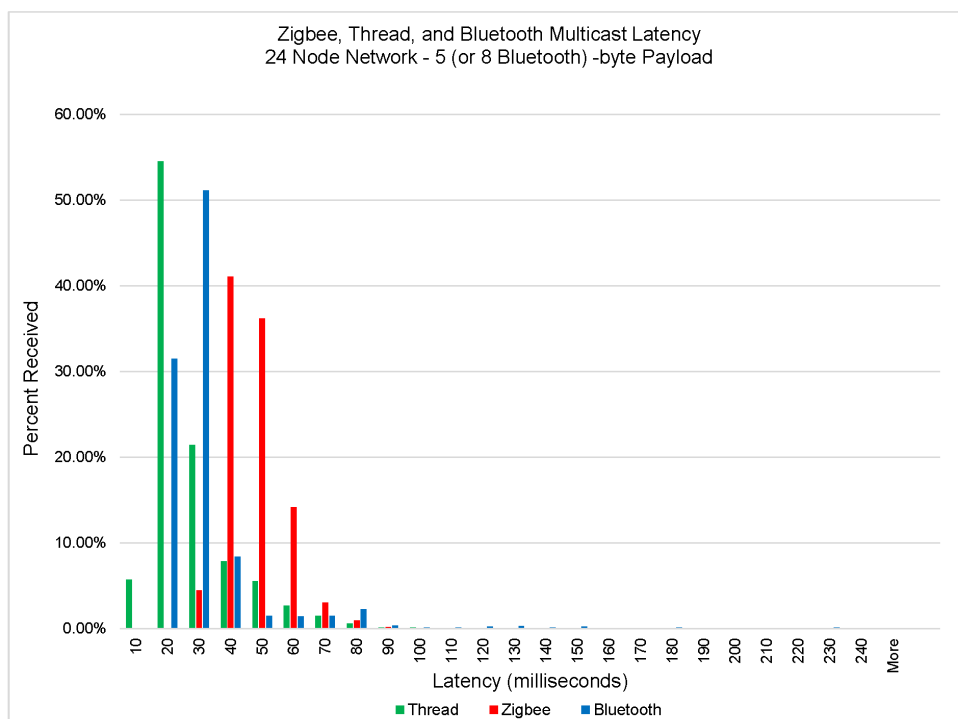


Figure 2.6. Zigbee, Thread, and Bluetooth Multicast Latency 24 Node Network - 5 (or 8 Bluetooth) -byte Payload

As the packet size increases, we start to see some differences in the multicast latency where it increases and spreads out. Thread latency increases slightly, Zigbee increases and spreads out, and Bluetooth Mesh becomes very distributed in latencies from 20 milliseconds up to 220 milliseconds.

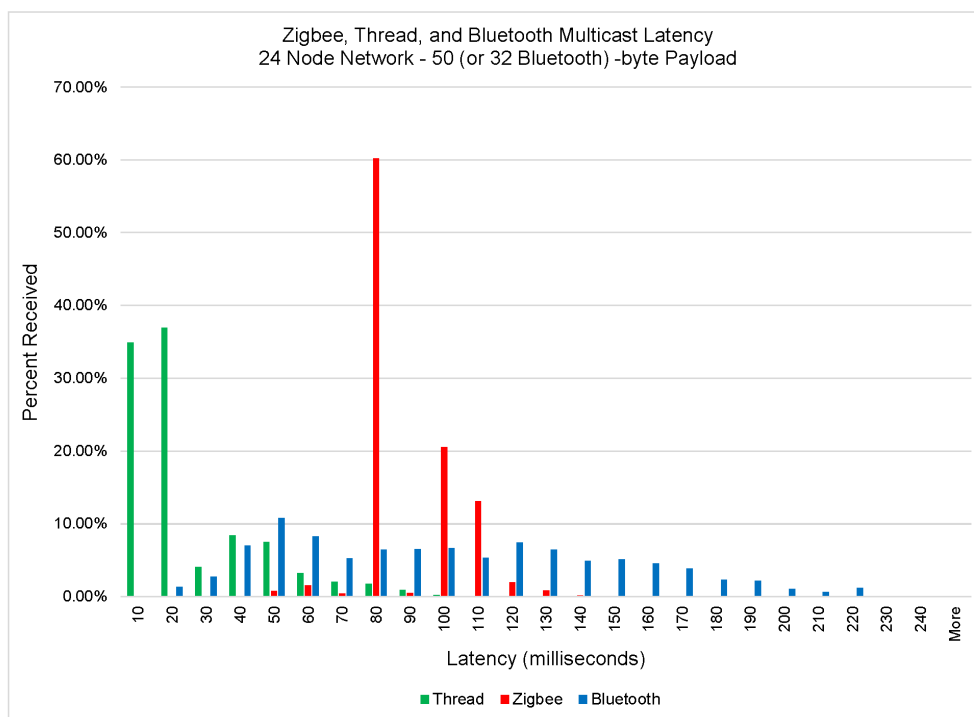


Figure 2.7. Zigbee, Thread, and Bluetooth Multicast Latency 24 Node Network - 50 (or 32 Bluetooth) -byte Payload

2.2.2 Large Networks and Different Packet Sizes

As the network scales up, we expect an increase in latency due to added congestion and increased number of hops in the network. Since this is an open-air network, we do not control the number of hops a particular message takes, we only record the actual results. The chart below shows that for small packet sizes, all three networks behave reasonably with an increase and spreading of the latency to slightly longer latencies. The only point of note is the ~3% of Bluetooth packets that end up with latency larger than 250 milliseconds.

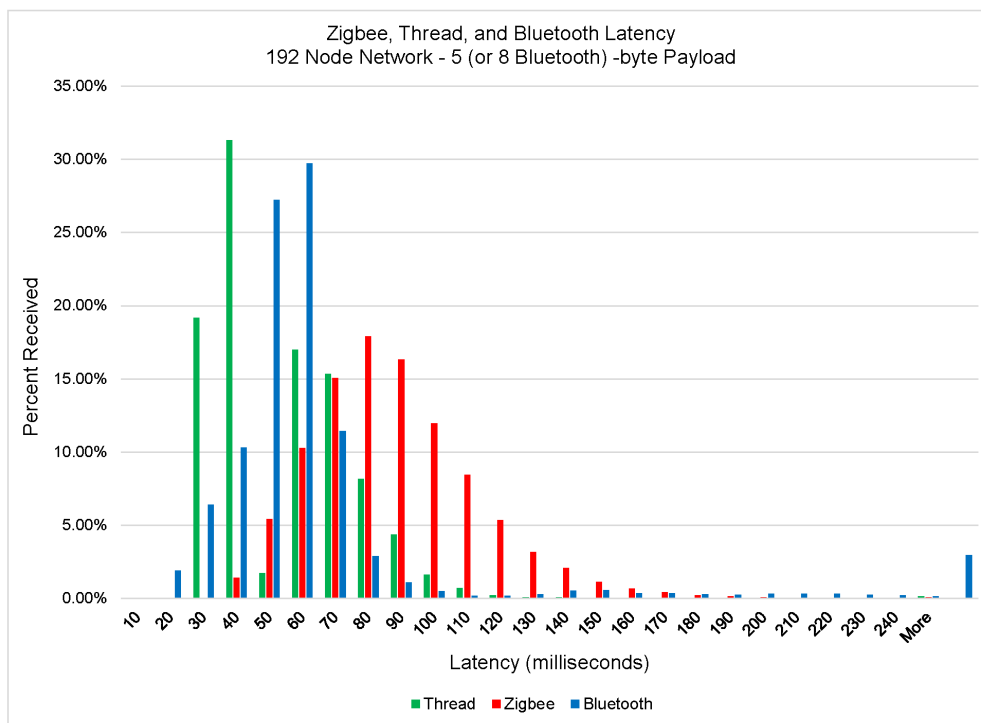


Figure 2.8. Zigbee, Thread, and Bluetooth Multicast Latency 192 Node Network - 5 (or 8 Bluetooth) -byte Payload

As the packet payload increases, we expect to see further increases in latencies across each of the mesh networks, particularly in the larger networks where fragmentation of packets will result in even more congestion due to the multicast flooding. We increase the payload only slightly and see the latencies spread substantially. In the graph below, we have increased the X axis to better show the latency spreading in this larger network. All the networks spread out, but the Bluetooth network spreads well past 500 milliseconds. Further increases in packet size only make this spreading worse.

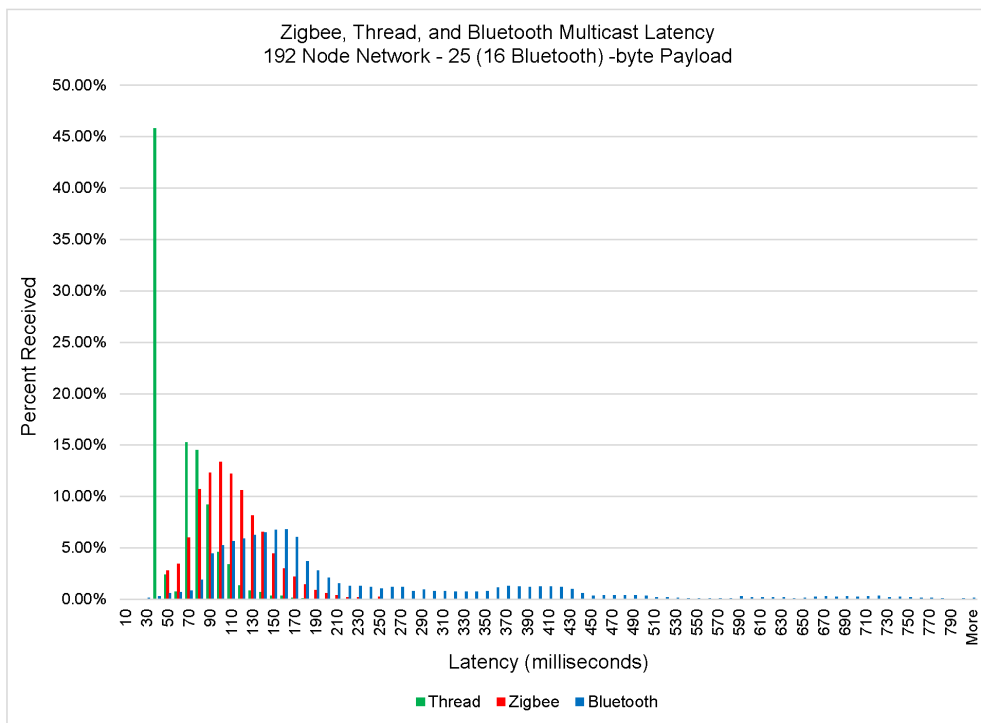


Figure 2.9. Zigbee, Thread, and Bluetooth Multicast Latency 192 Node Network - 25 (or 16 Bluetooth) -byte Payload

3. Summary

Comparing different mesh technologies allows designers to review expected performance under different conditions. To allow as fair a comparison as possible, we ran these tests using the same wireless devices under generally the same open office conditions. We also attempted to minimize other factors impacting the testing such as the backchannel timing from the development kits, latency within the testing infrastructure, and differences in radio architecture or MCU speeds, which can all impact results. Even when controlling these factors, we must caution that these results are our first attempt and further optimizations and improvements are likely possible within the standard or within our implementation. We have been running tests like these with our Zigbee stack since 2006, with Thread since 2015, and on Bluetooth only within the past year.

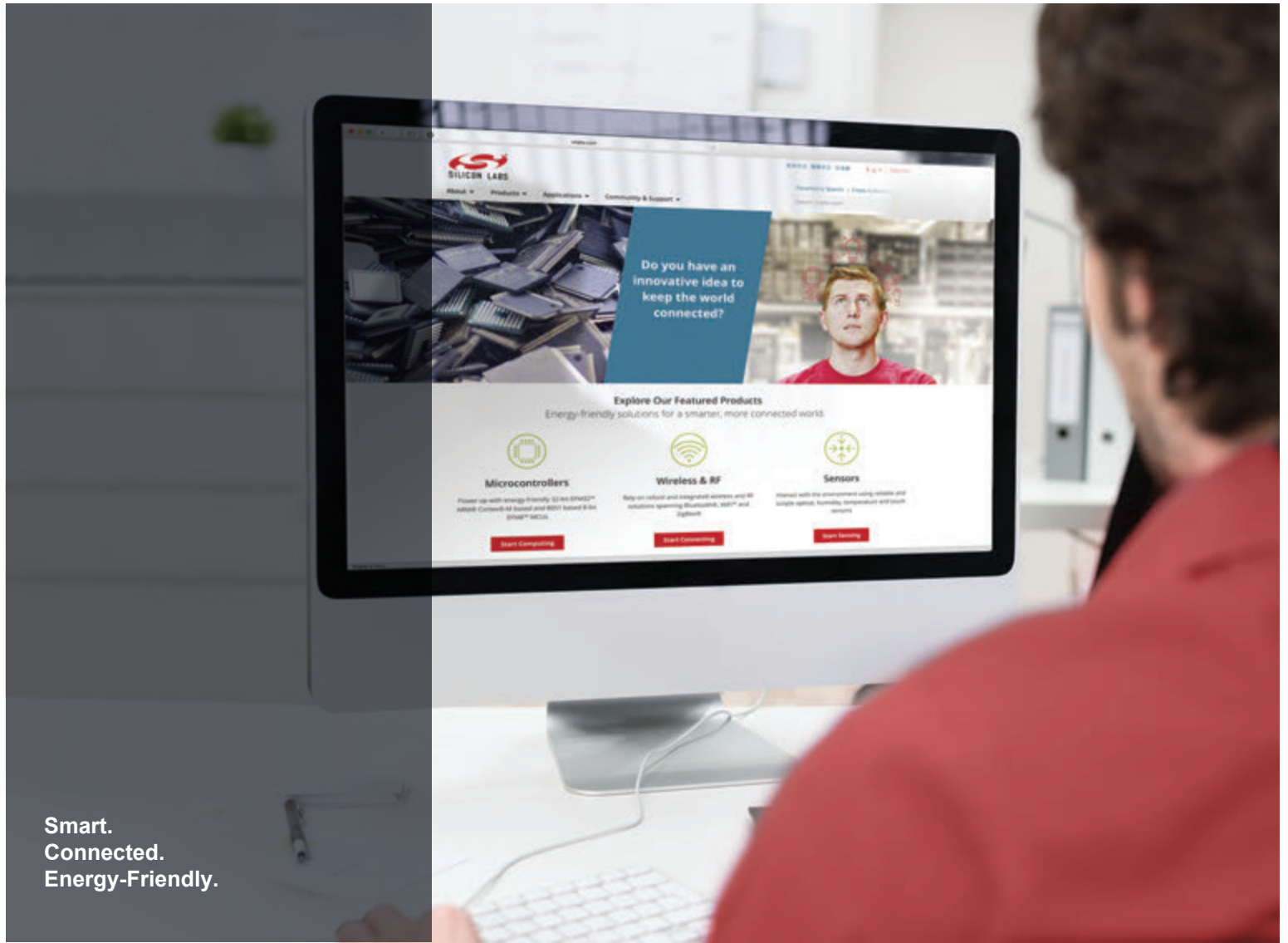
Each mesh network is designed differently and behaves differently. One network is not expected to be perfect for all conditions, so the selection of a particular technology involves criteria such as battery life, expected ecosystem and preferred connectivity, and the performance requirements of the device and network. This application note only compares the performance of these networks and not some of these other critical parameters.

From a performance standpoint, we see that all relatively small networks with small payload sizes perform similarly. As payload sizes and throughput needs increase, both Thread and Zigbee are better able to carry the load and maintain lower latencies. Latencies increase for all large networks, but Bluetooth experiences the largest increase. If we increase the payload in these larger networks, we see even more substantial increases in latency. This increase is expected; therefore, larger networks should be moved to a routing solution to minimize this latency. In all our multicast testing, however, we should note that our reliability is generally 99.9% or better as the multicast does a good job of ensuring delivery of the messages.

3.1 Related Literature

This application note has provided a comparison of the three mesh network technologies, Bluetooth, Zigbee, and Thread. For specific information on each of these technologies, refer to the following application notes:

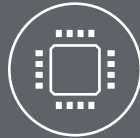
- [AN1137: Bluetooth Network Performance](#)
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- [AN1141: Thread Mesh Network Performance](#)



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