The challenges and importance of testing mesh networks prior to deployment

Despite the rapid growth of wireless mesh networking technology as the primary infrastructure for several broadband services, including wide-area voice and data transmission, the industry lacks an established process for testing wireless mesh networks. And, without thorough testing, mesh networks cannot be deployed on a large scale. Consequently, pre-deployment testing that automates the performance testing of wireless mesh networks in a controlled laboratory environment is required to establish its credibility for mission-critical metro-area network applications.

By Fanny Mlinarsky

Performance, simplicity and the powerful economics of Wi-Fi mesh networking make this technology a serious contender in the 3G/4G infrastructure market. Fixed mobile convergence (FMC), enabling handsets to roam between Wi-Fi and cellular networks, is opening the door for Wi-Fi mesh to become an extension of cellular infrastructure. According to a recent *Wall Street Journal* article[1], more than 50 municipalities around the country have installed Wi-Fi metropolitan networks and many more are in the deployment process, including Philadelphia, Chicago, San Francisco and Houston. Until recently, Wi-Fi technology has been confined to the SOHO environment, where performance and network robustness take second place to cost. With the emergence of citywide Wi-Fi infrastructure this is about to change. Carriers and service providers deploying Wi-Fi mesh networks are demanding professional testing to ensure success of this emerging technology and to establish its credibility for mission-critical metro-area network (MAN) applications. Metro Ethernet Forum (MEF) is working to incorporate Wi-Fi mesh infrastructure into its extensive certification programs for municipality and carrier access infrastructure, as a part of the MEF access strategy and certification, according to Nan Chen, president of MEF.

The time has come for Wi-Fi to compete with 3G/4G technologies such as CDMA-2000 EV-DO, W-CDMA and UMTS. The transition from low-cost consumer technology to carrier-grade networking infrastructure calls for improved performance and robustness. Carriers and service providers are acutely aware of how costly it can be to deploy early-stage technologies. If the new network does not work reliably, customers will desert the fledgling service. If unstable components are deployed, carriers and service providers carry the cost of customer support and troubleshooting in the field.

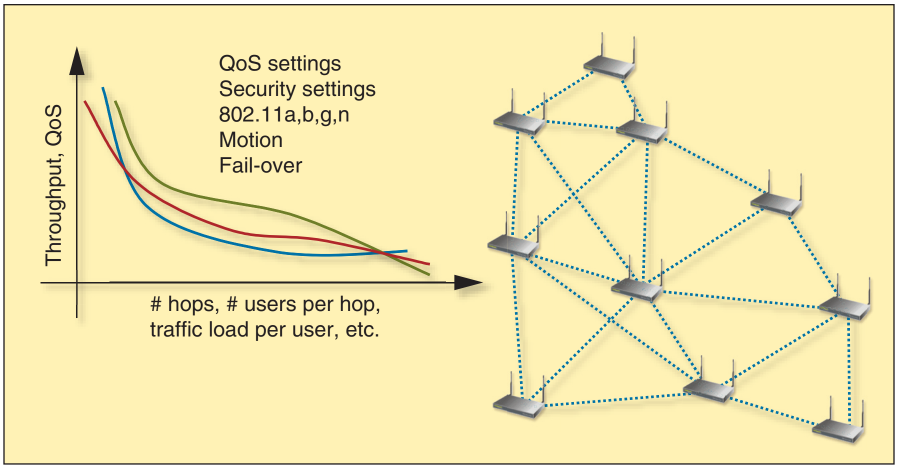

Figure 1. Throughput and QoS performance of a mesh network degrades with increased number of hops. Network and device configuration settings, as shown in (Table 1, also impact mesh performance).

Optimal performance and robustness of networks is achieved through thorough testing, which shines the light on technological flaws and weaknesses, helping vendors fix problems before products are shipped into the field, where finding problems is logistically challenging and costly. The most cost-effective way of introducing new and complicated networking technology is through step-by-step testing in a controlled laboratory environment before deployment. In the absence of automated methods, testing lacks the scalability to test all possible load, motion, background interference and device configuration scenarios—leaving some bugs and network vulnerabilities unchecked.

Testing of wide-area infrastructure technology such as Wi-Fi mesh presents unique testing challenges, as this type of network supports mobile users using high throughput data, voice and video applications. Rather than connecting through traditional cabled backhaul, Wi-Fi mesh nodes automatically create wireless infrastructure and use sophisticated routing algorithms to direct traffic to its destination. Therefore, it is not enough to test mesh nodes as single access points. They need to be tested together as a self-configuring self-healing system.

Fortunately, emerging specifications from the IEEE 802.11 committee define thorough and repeatable testing of complex devices and systems. This article outlines the challenges of mesh testing and ways of addressing them.

Performance requirements

Key performance requirements for communications networks are throughput and quality of service (QoS). In a Wi-Fi mesh system, throughput degrades with increased number

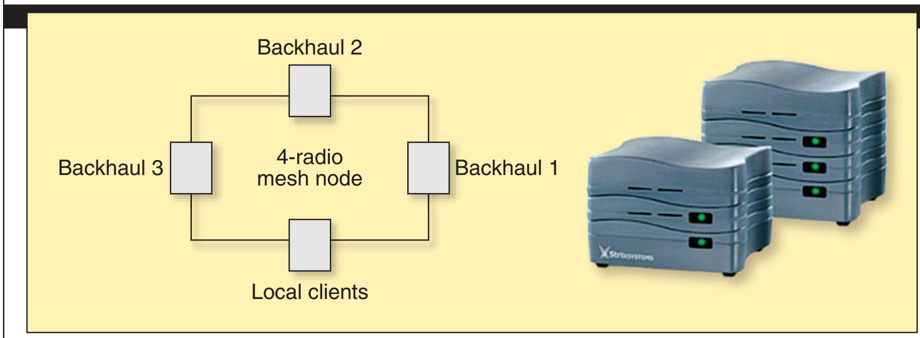

Figure 2. Mesh nodes can have one or more radios and in some products the number of radios is configurable. One of the radios is typically configured to communicate with local clients and the other radios are dedicated to routing traffic on the wireless backhaul. For example, the stackable Strix mesh node can be flexibly configured with one or more radios by snapping radio modules together.

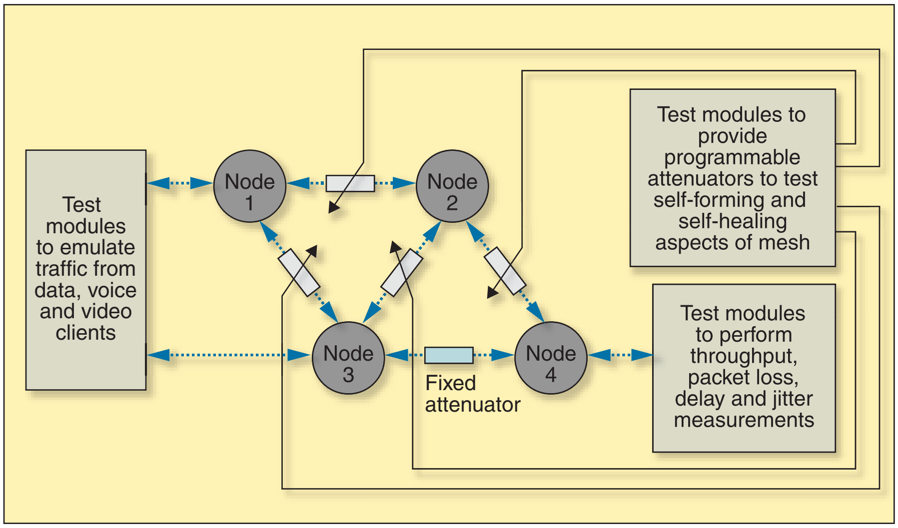

Figure 3. Mesh test configuration using 802.11T conducted environment. Mesh nodes are interconnected using programmable or fixed attenuators to emulate a variety of path losses causing the mesh to self-configure and select backhaul and client channels. Client traffic can be emulated using specialized test equipment. Throughput and QoS measurements can be performed at different points in the mesh and cover multiple hops.

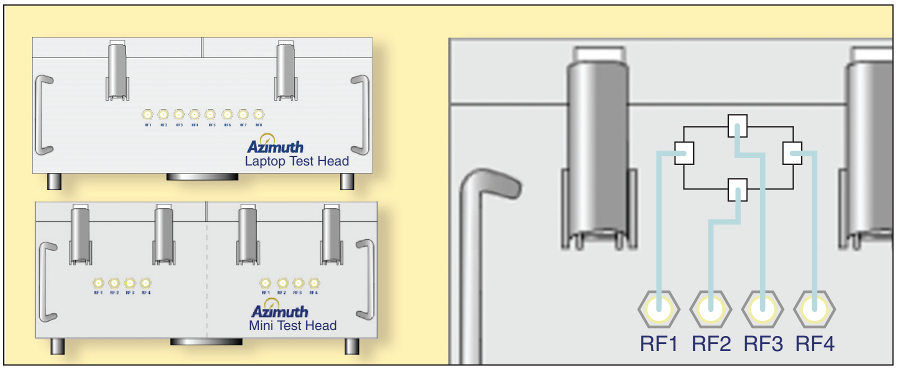

Figure 4. Each mesh node in the test setup must be placed into a shielded isolation chamber with all the radio antenna ports cabled to the outside world for interconnection in a test network. This ensures that each mesh node communicates with clients or with neighboring nodes through conducted paths rather than through uncontrolled coupling. Isolation chambers also protect against external interference making the testing robust and repeatable.

of hops (Figure 1). In a recent test of Wi-Fi mesh networks, NASA observed throughput degrade by a factor of two through each successive hop[2].

QoS for services such as voice and video is highly dependent on throughput, packet loss, delay and jitter, all of which degrade per hop. Therefore, the fist new metric introduced by Wi-Fi mesh networks is the measurement of throughput, packet loss, delay and jitter vs. hops in a test network of N hops.

Throughput tends to be better for mesh networks employing multiradio nodes that use different channels to communicate with neighboring nodes and with local clients. Early single-radio implementations had to share one channel for client and backhaul traffic. Multiple radios enable the mesh to segregate local client traffic and backhaul traffic to multiple simultaneous channels (Figure 2).

Mesh networks are self-configuring and self-healing. Mesh nodes discover each other and determine the optimum frequency scheme for communicating with the neighboring nodes and with local clients. Mesh nodes must be constantly aware of the network conditions and promptly respond to any changes in the environment and to fault conditions by rerouting traffic or by reconfiguring the frequency channel scheme.

These self-configuring and self-healing capabilities are key to network robustness and must be tested in a variety of topologies and physical layer conditions. This is a complicated and time-consuming test. What's the best test setup for such a test?

Wi-Fi mesh test methodology

It's important to verify the intrinsic performance of mesh devices and systems under controlled conditions. In the field, too many uncontrolled variables impact performance, which makes it difficult to isolate the causes of poor performance. For proper test methodology we turn to the emerging IEEE 802.11 test specification being developed by the 802.11T committee.

Multiradio mesh test setups can be configured for controlled laboratory testing by interconnecting various mesh topologies using conducted test setup as described in the 802.11T draft document, "Recommended Practice for the Evaluation of 802.11 Wireless Performance." An example of how a simple mesh topology can be configured is shown in Figure 3.

For conducted test setups, 802.11T requires that each mesh node be isolated from neighboring nodes using shielded enclosures (Figure 4). These enclosures ensure that signal flows through the intended conducted paths instead of coupling over the air.

Throughput and QoS parameters such as packet loss, delay and jitter can be measured in a controlled laboratory environment by interconnecting a variety of network topologies in a conducted test setup recommended by the IEEE 802.11T specification (Figures 3 and 4). Programmable attenuators can be used to vary path losses among mesh nodes and thereby test self-configuration and self-healing abilities of mesh networks. Fail-over conditions can be created by programming high attenuation on active backhaul interconnections thereby forcing the traffic flow to be redirected by the mesh. Throughput and QoS performance should be measured under such failover conditions as well as under normal conditions.

Table 1. Settings for mesh tests that impact mesh performance.

Number of hops	Throughput and QoS are directly impacted by the number of hops through the mesh network. Measurements should be performed over different hop counts and plotted vs. hops.
Number of users per hop	Emulate traffic load from groups of clients using data, voice and video services. Emulate 802.11e prioritization for voice data and video per group.
Traffic load per hop	Emulate a variety of traffic loads and packet sizes at each mesh hop.
Backhaul traffic load	Each mesh node routs local traffic and forwards traffic from other nodes via its backhaul links. Depending on the efficiency of the routing algorithms congestions can occur on backhaul links impacting performance of the entire mesh. Configure traffic source and destination addresses in such as way as to exercise routing logic.
Direction of traffic flow	Throughput and QoS must be measured in upstream and downstream directions. The test application should allow controlled upstream, downstream and bi-directional measurements.
Number of radios in mesh nodes	Number of radios in mesh nodes significantly impacts performance. Perform measurements with different number of radios activated and compare the results.
Security settings	Throughput and routing efficiency may be impacted by security settings. Test with a variety of standard IEEE 802.11i security settings for groups of emulated clients.
QoS settings	Emulate a mix of data, voice and video clients while measuring throughput and QoS to test ability of mesh infrastructure to prioritize voice and video over data. Plot voice and video quality metrics vs. hops, vs. load and other settings.
Range and multipath conditions	Emulate path loss and multipath conditions between clients and mesh nodes. Measure and plot throughput and QoS (packet loss, delay and jitter) vs. path los and multipath models.
	Emulate path loss and multipath conditions between backhaul radios. Measure and plot throughput and QoS vs. multipath models and path loss.
Fail-over conditions	Emulate failure conditions by setting programmable attenuators to cause traffic flow reconfiguration.
Interference including adjacent-channel interference (ACI) and co-channel interference	Throughput and QoS performance is affected by interference. Co-channel and ACI are normal in mesh networks since neighboring radios can communicate on the same or adjacent channels and interfere with the channel under test. Perform throughput and QoS measurement in the presence of co-channel interference and ACI.
Mobility conditions	Emulate motion of clients with respect to mesh nodes.
	Emulate motion of mesh nodes with respect to other mesh nodes (e.g. a bus with a mesh node moving through the city mesh.)
	Emulate multiple clients moving at the same time.
	Emulate different velocities of motion, for example, people walking, mesh nodes on busses and trains, etc.
	Emulate different cell overlap conditions.

A variety of device and network settings impact mesh performance and these should be varied in a controlled laboratory environment as the measurements are performed.

Mobility

The most challenging and the most important test parameter to control is mobility. Movement of clients through the mesh and movement of mesh nodes within a mesh network impacts performance in a dramatic way. Mobility forces clients to roam from one mesh node to another and it also causes meshes to reconfigure themselves at high vehicular velocities. An example of a mobile mesh node is a mesh node in a bus or a train moving through a fixed municipal mesh. As roaming occurs, the clients or mesh nodes must disassociate from one node and associate with another causing an interruption of service. Such interruptions impact voice services dramatically and can also cause a loss of data connections. The roaming process must be fast to minimize interruptions in traffic. Roaming times must be measured under different conditions including velocity, traffic load, traffic type and amount of cell overlap.

To address fast roaming requirements for voice, the IEEE 802.11 committee is in the process of finalizing a new roaming specification, 802.11r. The IEEE 802.11T test document includes test methodology to measure the performance of fast roaming using real clients. Roaming time is related to speed of the motion and to the amount of cell overlap. Therefore, the test setup must be able to control these settings.

In addition to fast roaming, mobile voice and video services call for QoS requirements such as low delay, jitter and packet loss. The ITU-T document G.107 defines a voice quality metric, the R-factor, which is a function of packet loss, delay and jitter. The IEEE 802.11T document includes test methodology for measuring packet loss, delay and jitter. Measurements of these parameters must be performed as a function of test conditions outlined in Table 1. While measuring QoS, a mixture of different priority traffic helps test the ability of the mesh infrastructure to prioritize voice over video and video over data. Most QoS issues are caused by network congestion. Traffic prioritization is key to getting acceptable QoS on real-time services.

Range and multipath performance

It is critical to measure range and multipath performance of the mesh node radios that serve local clients and backhaul interconnections. Range and multipath conditions are fundamental factors in throughput and QoS performance. Range is emulated by varying attenuation between two devices. Multipath is emulated by using a channel emulator. Recently, the IEEE 802.11n group has standardized six multipath channel models (models A-F) corresponding to different environments ranging from small indoor spaces to metropolitan block. The range and multipath performance must be verified between clients and mesh nodes and between mesh nodes on backhaul links.

The ability of a mesh node to function in the presence of interference is another important test. Mesh networks automatically select their channel frequency scheme and nearby radios can end up on the same or adjacent channels. Therefore, interference and especially co-channel and adjacent-channel interference (ACI) should be included in the test. The 802.11T document specifies ACI measurement test methodology.

Interoperability

As the new IEEE 802.11s mesh standard matures it will become important to test interoperability of 802.11s compliant mesh nodes. Today, most mesh implementations are proprietary requiring the use of mesh nodes from the same vendor throughout the network.

Wired backhaul connections add cost to mesh installations by requiring cable runs. Therefore, mesh architects strive to maximize the number of mesh nodes per wired backhaul connection. A measurement of throughput and QoS as a function of wired backhaul connection density reveals much about the ability of a mesh to rout efficiently and to optimize throughput performance.

Conclusion

Despite the rapid growth of wireless mesh networking technology as the primary infrastructure for several broadband services, including wide area voice and data transmission, the industry lacks an established process for testing wireless mesh networks. A significant new market for the Wi-Fi industry, Wi-Fi mesh presents a set of unique testing challenges. Pre-deployment testing that automates performance testing of wireless mesh networks in a controlled laboratory environment is required to establish its credibility for mission-critical metro-area network applications. In the absence of automated methods, testing lacks the scalability to test all possible load, motion, background interference and device configuration scenarios—leaving some bugs and network vulnerabilities unchecked. Thorough and methodical lab testing catches problems with early implementations prior to being introduced into the field, where finding problems is logistically challenging and costly. Without thorough testing, mesh networks cannot be deployed on a large scale.

References

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