Mesh networking

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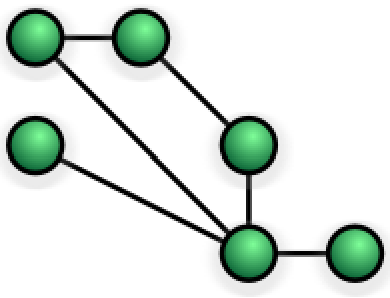

Illustration of a **partial mesh** network. A fully mesh network is where each node is connected to every other node in the network.

A **mesh network** is a network topology in which each node relays data for the network. All mesh nodes cooperate in the distribution of data in the network. It can be applied to both wired and wireless networks.

Wireless mesh networks can be considered a type of *Wireless ad hoc network*. Thus, wireless mesh networks are closely related to mobile ad hoc networks (MANETs). Although MANETs are not restricted to a specific mesh network topology, Wireless ad hoc networks or MANETs can take any form of network topology.

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Basic principles[edit]

Mesh networks can relay messages using either a *flooding* technique or a *routing* technique. With routing, the message is propagated along a path by *hopping* from node to node until it reaches its destination. To ensure that all its paths are available, the network must allow for continuous connections and must reconfigure itself around broken paths, using *self-healing* algorithms such as Shortest Path Bridging. Self-healing allows a routing-based network to operate when a node breaks down or when a connection becomes unreliable. As a result, the network is typically quite reliable, as there is often more than one path between a source and a destination in the network. Although mostly used in wireless situations, this concept can also apply to wired networks and to software interaction.

A mesh network whose nodes are all connected to each other is a fully connected network. Fully connected wired networks have the advantages of security and reliability: problems in a cable affect only the two nodes attached to it. However, in such networks, the number of cables, and therefore the cost, goes up rapidly as the number of nodes increases.

Wired Mesh[edit]

Shortest path bridging allows ethernet switches to be connected in a mesh topology, and it allows for all paths to be active.[1][2][3][4][5]

Wireless Mesh[edit]

Wireless mesh radios are different from **Wi-Fi ad hoc**, which are commonly found in **smart phone ad hoc networks**, **laptop computers**, and wireless LANs. Wireless mesh radios primarily support voice rather than desktop or software computing. A radio device is different from a computer or smart phone, since the latter is programmable and has multi-function compute capability.

Wireless mesh radio networks were originally developed for military applications. Over the past decade,[*when?*] the size, cost, and power requirements of radios have declined, enabling multiple radios to be contained within a single mesh node, thus allowing for greater modularity; each can handle multiple frequency bands and support a variety of functions as needed—such as client access, backhaul service, and scanning (required for high-speed handoff in mobile applications)—or even customized sets of them.[*clarification needed*] Work in this field has been aided by the use of game theory methods to analyze strategies for the allocation of resources and routing of packets.[6][7][8]

Early wireless mesh networks all use nodes that have a single half-duplex radio that, at any one instant, can either transmit or receive, but not both at the same time. This requires a shared mesh configuration. Some later wireless mesh networks use nodes with more complex radio hardware that can receive packets from an upstream node and transmit packets to a downstream node simultaneously (on a different frequency or a different CDMA channel), which is a prerequisite for a switched mesh configuration.

Examples[edit]

- Packet radio networks or ALOHA networks was first used in Hawaii to connect the islands. Given the bulk radios, and low data rate, the network is less useful than it was envisioned to be.
- In 1998-1999, a field implementation of a campus wide wireless ad hoc network using 802.11 WaveLAN 2.4 GHz wireless interface on several laptops was successfully completed.[9] Several real applications, mobility and data transmissions were made.[10]
- Mesh network was useful for the military market because of its radio capability and not all military missions have frequently moving nodes. The DoD JTRS radio program, which was started in 1997, for example, are wireless mesh networks (SRW). The Pentagon launched the JTRS program in 1997, with an ambitious to use software to control radio functions - such as frequency, bandwidth, modulation and security - previously baked into the hardware. This approach, in theory, would allow the DoD to build a family of radios with a common software core, capable of handling functions that were previously split among separate hardware-based radios—VHF voice radios for infantry units; UHF voice radios for air-to-air and ground-to-air communications; long-range HF radios for ships and ground troops; and a wideband radio capable of transmitting data at megabit speeds across a battlefield. However, JTRS program was shut down[11] in 2012 by US Army because the radios done by Boeing has a 75% failure rate.
- Google Home, Google Wi-Fi, and Google OnHub all support Wi-Fi mesh (i.e., Wi-Fi ad hoc) networking.[12]

Other makers such as Harris ANW2 (2007), running on AN/PRC-117, AN/PRC-152A are also a type of mesh network.

- In rural Catalonia, Guifi.net was developed in 2004 as a response to the lack of broadband Internet, where commercial Internet providers weren't providing a connection or a very poor one. Nowadays with more than 30,000 nodes it is only halfway a fully connected network, but following a peer to peer agreement it remained an open, free and neutral network with extensive redundancy.
- In 2004, TRW Inc. engineers from Carson, California, successfully tested a multi-node mesh ad hoc wireless network using 802.11a/b/g radios on several high speed laptops running Linux, with new features such as route precedence and preemption capability, adding different priorities to traffic service class during packet scheduling and routing, and quality of service.[13] Their work concluded that data rate can be greatly enhanced using MIMO technology at the radio front end to provide multiple spatial paths.
- ZigBee digital radios are incorporated into some consumer appliances, including battery-powered appliances. ZigBee radios spontaneously organize a mesh network, using specific routing algorithms; transmission and reception are synchronized. This means the radios can be off much of the time, and thus conserve power. ZigBee is for low power low bandwidth application scenarios.
- Thread is a consumer wireless networking protocol built on open standards and IPv6/6LoWPAN protocols. Thread's features include a secure and reliable mesh network with no single point of failure, simple connectivity and low power. Thread networks are easy to set up and secure to use with banking-class encryption to close security holes that exist in other wireless protocols. In 2014 Google Inc's Nest Labs announced a working

group with the companies Samsung, ARM Holdings, Freescale, Silicon Labs, Big Ass Fans and the lock company Yale to promote Thread.

Building a Rural Wireless Mesh Network: A DIY Guide (PDF)

- In early 2007, the US-based firm Meraki launched a mini wireless mesh router.[14] This is an example of a wireless ad hoc network (on a claimed speed of up to 50 megabits per second). The 802.11 radio within the Meraki Mini has been optimized for long-distance communication, providing coverage over 250 metres.

  This is an example of a single-radio ad hoc network being used within a community as opposed to multi-radio long range mesh networks like BelAir[15] or MeshDynamics that provide multifunctional infrastructure, typically using tree based topologies and their advantages in O(n) routing.

- The Naval Postgraduate School, Monterey CA, demonstrated such wireless mesh networks for border security.[16] In a pilot system, aerial cameras kept aloft by balloons relayed real time high resolution video to ground personnel via a mesh network.
- SPAWAR, a division of the US Navy, is prototyping and testing a scalable, secure Disruption Tolerant Mesh Network [17] to protect strategic military assets, both stationary and mobile. Machine control applications, running on the mesh nodes, "take over", when Internet connectivity is lost. Use cases include Internet of Things e.g. smart drone swarms.
- An MIT Media Lab project has developed the XO-1 laptop or "OLPC" (One Laptop per Child) which is intended for disadvantaged schools in developing nations and uses mesh networking (based on the IEEE 802.11s standard) to create a robust and inexpensive infrastructure.[18] The instantaneous connections made by the laptops are claimed by the project to reduce the need for an external infrastructure such as the Internet to reach all areas, because a connected node could share the connection with nodes nearby. A similar

concept has also been implemented by Greenpacket with its application called SONbuddy.[19]

- In Cambridge, UK, on 3 June 2006, mesh networking was used at the "Strawberry Fair" to run mobile live television, radio and Internet services to an estimated 80,000 people.[20]
- Broadband-Hamnet, a mesh networking project used in amateur radio, is "a high-speed, self-discovering, self-configuring, fault-tolerant, wireless computer network" with very low power consumption and a focus on emergency communication.[21]
- The Champaign-Urbana Community Wireless Network (CUWiN) project is developing mesh networking software based on open source implementations of the Hazy-Sighted Link State Routing Protocol and Expected Transmission Count metric. Additionally, the Wireless Networking Group[22] in the University of Illinois at Urbana-Champaign are developing a multichannel, multi-radio wireless mesh testbed, called Net-X as a proof of concept implementation of some of the multichannel protocols being developed in that group. The implementations are based on an architecture that allows some of the radios to switch channels to maintain network connectivity, and includes protocols for channel allocation and routing.[23]
- FabFi is an open-source, city-scale, wireless mesh networking system originally developed in 2009 in Jalalabad, Afghanistan to provide high-speed Internet to parts of the city and designed for high performance across multiple hops. It is an inexpensive framework for sharing wireless Internet from a central provider across a town or city. A second larger implementation followed a year later near Nairobi, Kenya with a freemium pay model to support network growth. Both projects were undertaken by the Fablab users of the respective cities.
- SMesh is an 802.11 multi-hop wireless mesh network developed by the Distributed System and Networks Lab at Johns Hopkins University.[24] A fast handoff scheme allows mobile clients to roam in the network without interruption in connectivity, a feature suitable for real-time applications, such as VoIP.
- Many mesh networks operate across multiple radio bands. For example, Firetide and Wave Relay mesh networks have the option to communicate node to node on 5.2 GHz or 5.8 GHz, but communicate node to client on 2.4 GHz (802.11). This is accomplished using software-defined radio (SDR).
- The SolarMESH project examined the potential of powering 802.11-based mesh networks using solar power and rechargeable batteries.[25] Legacy 802.11 access points were found to be inadequate due to the requirement that they be continuously powered.[26] The IEEE 802.11s standardization efforts are considering power save options, but solar-powered applications might involve single radio nodes where relay-link power saving will be inapplicable.
- The WING project[27] (sponsored by the Italian Ministry of University and Research and led by CREATE-NET and Technion) developed a set of novel algorithms and protocols for enabling wireless mesh networks as the standard access architecture for next generation Internet. Particular focus has been given to interference and traffic aware channel assignment, multi-radio/multi-interface support, and opportunistic scheduling and traffic aggregation in highly volatile environments.
- WiBACK Wireless Backhaul Technology has been developed by the Fraunhofer Institute for Open Communication Systems (FOKUS) in Berlin. Powered by solar cells and

designed to support all existing wireless technologies, networks are due to be rolled out to several countries in sub-Saharan Africa in summer 2012.[28]

- Recent standards for wired communications have also incorporated concepts from Mesh Networking. An example is ITU-T G.hn, a standard that specifies a high-speed (up to 1 Gbit/s) local area network using existing home wiring (power lines, phone lines and coaxial cables). In noisy environments such as power lines (where signals can be heavily attenuated and corrupted by noise) it's common that mutual visibility between devices in a network is not complete. In those situations, one of the nodes has to act as a relay and forward messages between those nodes that cannot communicate directly, effectively creating a "relaying" network. In G.hn, relaying is performed at the Data Link Layer.

Wireless Mesh vs. ZigBee vs. Ad Hoc[edit]

ZigBee is an example of a low power, low bandwidth wireless ad hoc network, among others. *Wi-Fi ad hoc* refers to the fact that wireless ad hoc networks can support higher data rates and higher mobility rates of nodes. They are suitable for mobile computing and for device-to-device communications. *Smart phone ad hoc* refers to the use of Wi-Fi ad hoc to enable chat messaging among smart phone users without relying on 4G cellular communications. Finally, very high mobility and very high data rates represent the top end of wireless ad hoc networks, and they are often found in military *tactical ad hoc radios* used in the battlefield.

AREDN Advantage

The AREDN Advantage brochures can be found here for download in English, Spanish and French.

AREDN™

AMATEUR RADIO EMERGENCY DATA NETWORK

AE6XE and KE6BXT Pleasants Peak nodes

Delivering quality, high-speed, data communications for Emcomm via Amateur Radio

Project Objectives

The AREDN™ Project's focus is Emergency Communications (EmComm). It seeks to provide hams a means to implement this technology in practical ways to support local and regional emergency communications needs. To that end, the project's objectives are to enable hams to:

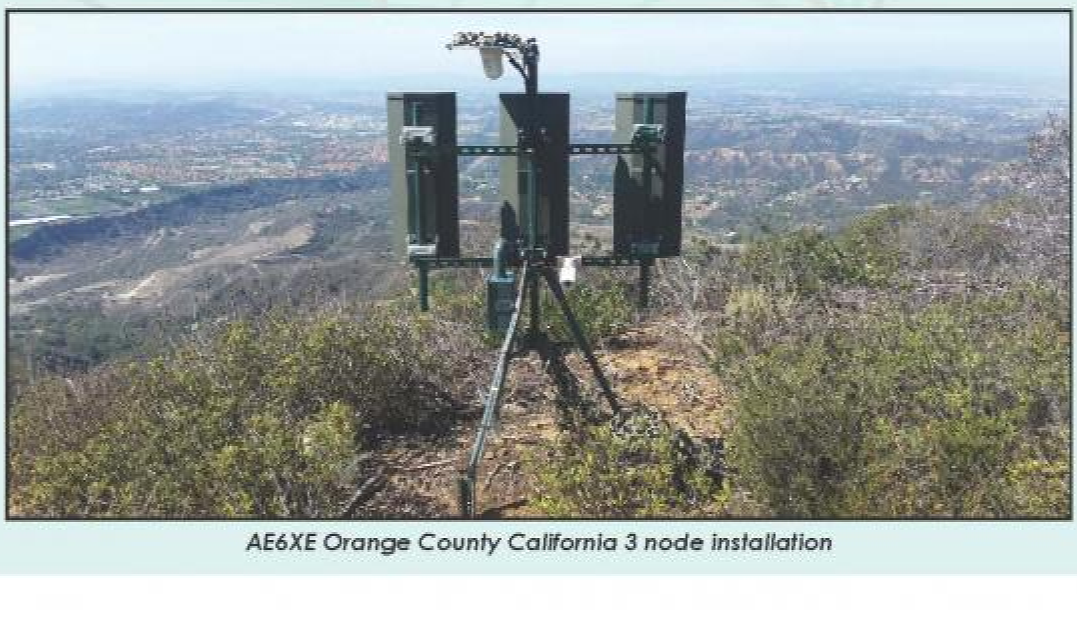
- Stand up a working mesh node with minimal expertise and effort
- Configure the mesh network automatically so that advanced network knowledge is not needed
- Use low-cost, reliable commercial equipment
- Define standards for inter-network integration
- Support those in the process of designing and implementing EmComm networks
- Refine the software to make implementation easier, more reliable, and more manageable

K6AH mobile nodes with dish and sector antennas

Features and Benefits

Getting out of the WIFI band and onto ham-only channels on 2.4 and 3.4 GHz SIGNIFICANTLY improved the performance of our local network, and the tools and metrics in the latest release give us a much better understanding of our link performance.

Exclusive Part 97 Channels	AREDN™ offers two channels on 2.4 GHZ, 24 channels on 3.4 GHz and 7 non-shared channels on 5.8 GHz that are not shared with Part 15 users.
Over-the-Air firmware upgrades	Changes to firmware can be done over an RF link without physical access to the node.
Maximum data rate of 130 Mbps	802.11n has been added to the RF protocol. This improves the maximum data rate capability from 54 Mbps to 130 Mbps and allows AREDN™ nodes to take advantage of the Ubiquiti MIMO (concurrent data channels in both the vertical and horizontal polarization domains), although proportional data rate increases can also be achieved on non-MIMO devices.
Low investment entry	Portable nodes with cable and network switch can be established inexpensively; backbone nodes with multiple transceivers and cable are affordable.
Rapid deployment and implementation	Portable nodes can be setup in a few minutes.
Multiple antenna choices	There are many choices for sector (60-, 90- and 120-degree) antennas and highly directional (Yagi and dish) antennas.
Interfaces easily with other Internet capable devices	An AREDN™ network enables emergency responders to use familiar devices such as smart phones, tablets and laptop computers.



AE6XE Orange County California 3 node installation

AREDN™ In Use

The Swallows Day Parade in San Juan Capistrano, California is, according to its organizers, the largest non-motorized parade in the United States. Hundreds of volunteers worked with local officials to maintain public safety among the estimated 35,000 people who attended the 57th annual event. A small team of FCC-licensed amateur radio operators who belong to the Radio Amateur Civil Emergency Service (RACES) provided specialized communication services.

The RACES team developed a plan to provide real-time video camera coverage of the parade route to support the Sheriff's department and emergency response agencies. Orange County Sheriff's Administrative Sgt. Joseph Cope noted that "This mesh camera system provided by RACES members was a very valuable tool for our command staff. As we were taking the calls, we could see the activity taking place in real time." In a meeting with city staff, he also stated, "The parade was the safest in years. Incredibly, there was only one arrest for fighting, which just happened to take place in the cameras view."

The parade cameras sent images across the radio network to the Orange County Sheriff's Department state-of-the-art Mobile Command Center (MCC). This MCC is a semi-tractor trailer with generated power and patch panels for video, data, and radio needs, including more than a dozen high-definition monitors positioned both internally and externally.

Orange County Mobile Command Center

Practical EmComm Uses

Many applications are available to support the critical communications requirements of CERT, law enforcement assistance, ARES, RACES and events such as fire and hurricane watches.

Telephones

- Voice over IP telephone systems
- SIP-based direct-dial calling to similarly configured smartphones within the network
- Gateway to PSTN when Internet is available to a node
- Asterisk and FreePBX

Cameras

- Streaming video with IP webcams
- Skype-like video conferencing
- VideoChat

Keyboard to Keyboard

- Email
- Chat applications – MeshChat

Mapping

- Open Street Map
- HTML mapping with Google APIs

Database and File Sharing

- CERT data gathering
- Cloud-based (OwnCloud) file sharing
- Google Person Finder

Network Monitoring

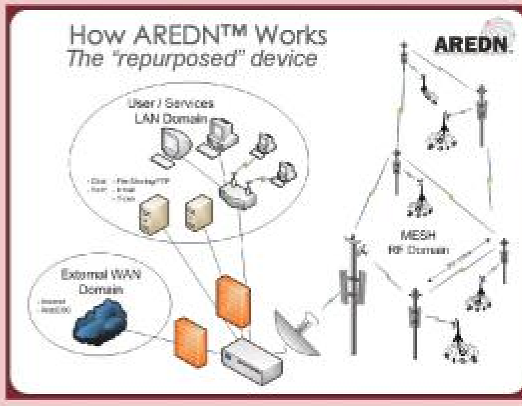
- Nagios
- Zabbix
- Iperf
- SNMP

Need Help?
Contact AREDN™
www.aredn.org

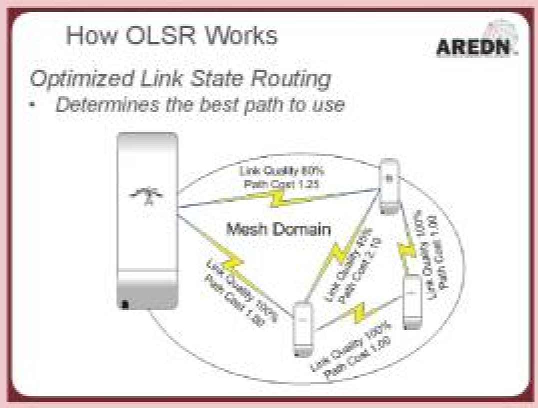
How It Works

In the AREDN™ schematic model illustrated below we see the familiar external and user domains... although the user domain now contains computers which deliver services such as email, FTP, VoIP, chat, etc.

The new domain here is an RF mesh network which forms the business end of the AREDN™ technology.



The four devices, all Ubiquiti NanoStations, illustrated below have formed a "mesh."



The route data will take through this network is dependent on the reliability of the links between them.