[Andre Hansen, K6AH, photo]

AREDN — A High-Speed Data Network

A thorough discussion of a high-speed multimedia network for public service applications.

Andre Hansen, K6AH

Traditional manual means of message passing are being quickly replaced by digital transmissions. The paper-based general message form ICS-213 has given way to the Winlink electronic ICS-213 form. In current "best practice," the form is conveyed through digital techniques, such as AX.25 packet, HF PACTOR, WINMOR, and, when available, the Internet, rather than verbally over VHF/UHF radio. These digital technologies are generally sufficient for text-based messages, but because of their limited transmission speeds, become overwhelmed with increasing traffic and message size. These services are the compelling case for the *Amateur Radio Emergency Data Network* (*AREDN*).[1]

AREDN

Implementing a high-speed network infrastructure can eliminate congestion. The network also provides the opportunity for additional digital services, such as Voice over Internet Protocol (VoIP) telephony, chat rooms, and image/video-based damage assessments and reports.

AREDN is a software development project that repurposes commercially available wireless internet service provider (WISP) radio routers to operate under the grant of our Amateur Radio licenses in the amateur microwave bands. The *AREDN* development team publishes its work under the Free Software Foundation's General Public License (GPLv3 license).

Multiple devices, called nodes, separated by as much as 50 miles, work together to form a high-speed mesh network with data rates up to144 Mbps. They provide a transmission control protocol/internet protocol (TCP/IP) medium for applications that one would typically use on an intranet or the Internet. *AREDN* is not intended to be a general internet access alternative.

The primary objective of the *AREDN* project is to empower the typical ham to deploy as part of the network by acquiring a relatively inexpensive commercial router device, installing the *AREDN* firmware, entering the station call sign and an administrative password, and then pointing the node's antenna towards an existing network node in the infrastructure. The *AREDN* firmware senses the existing network and automatically configures the node. Within a few seconds, the node is operating as part of the mesh and is ready to deliver pre-established data services. The deployed ham can then decide to attach the node to a standard Wi-Fi access point for users to access those services. This technology is described in a paper published in the *ARRL and TAPR 34th Digital Communications Conference* in 2015.[2]

There are several approaches to constructing a network based on *AREDN*. The term "mesh" is generally associated with this technology. It implies many nodes scattered about with multiple data paths between nodes. While this would result in a highly reliable network, it would also be expensive to deploy, and leave you dependent on nodes and operators outside of your direct control. A more structured approach that defines a preferred data path is most often recommended. Over time, as more and more hams become involved, the network evolves into the structure of a mesh.

Because these systems operate in the microwave spectrum, they generally require a line-of-sight path between nodes for a link to be established. This is accomplished by elevating nodes on hills, towers, buildings, water tanks, and so on. Let us take a mountainous terrain as an example, and look at how to design an *AREDN* network.

Deploying an *AREDN* Network in Mountainous Terrain

Hills and mountains present an obstacle for the longer-distance links. One obvious solution is to utilize the vertical dimension for the longer links. Think of them as repeater sites. These high-ground locations are also well suited for propagating network coverage to lower-lying users. Remaining are just those users who do not have a direct line of sight to the high-ground sites. They will require a relay. We have just defined three node types (see Figure 1): High-ground or "backbone" nodes or sites, "relay" nodes, and user or "deployed" nodes.

They all use the same technology and *AREDN* software, but clearly serve different roles in the network. Let's look in detail.

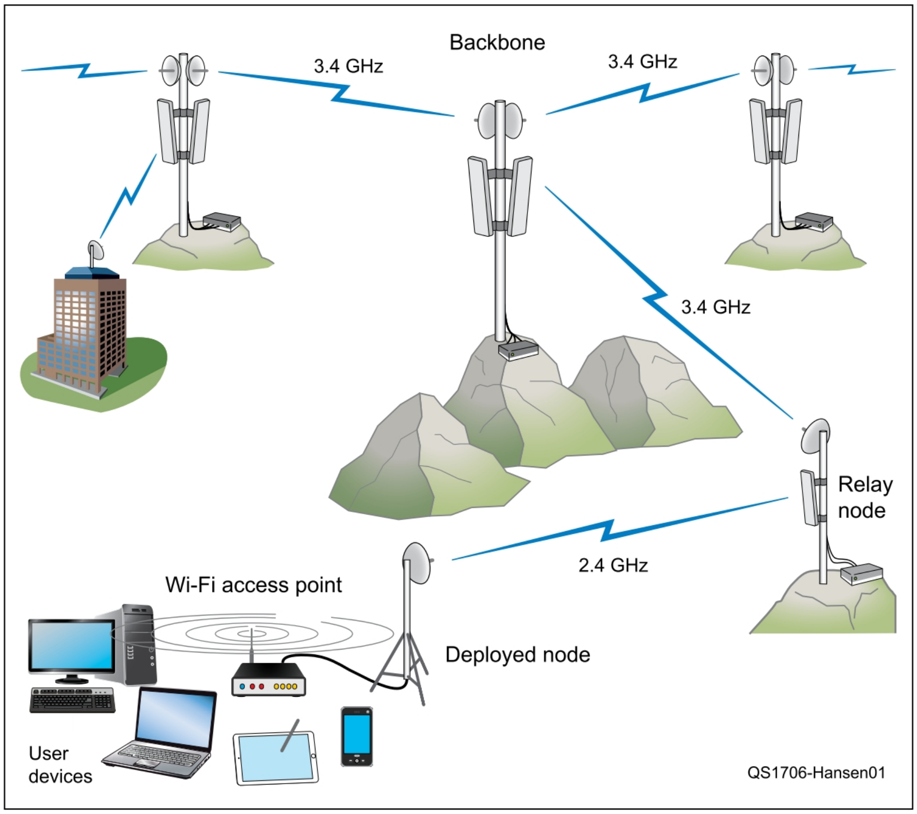

Figure 1 — A network comprises backbone nodes, relay nodes, and deployed nodes. Deployed nodes communicate with relay nodes, as shown, or directly with backbone nodes.

Fixed Backbone Node

Backbone nodes are permanent installations that extend the mesh to the extreme ends of the planned coverage area. For reliability, I prefer to build them on the least congested band — 3.4 GHz — and optimize them for data throughput with high-gain dish antennas spanning distances of 50 miles or more. Additional collocated nodes (see Figure 2) employ sector antennas designed specifically to distribute the mesh downward across 120° horizontal by 9° vertical coverage patterns and a built-in 4° down tilt, maximizing the downstream accessibility to lower nodes.

Participating disaster agencies access the backbone via fixed nodes with high-gain antennas. These agencies make routine use of the network during simulated emergency drills.

Backbone nodes are often collocated with ham repeater sites. These typically call for robust installations, requiring a fair bit of planning and frequency coordination with other ham interests and commercial tenants. RF shielding can be required to mitigate interference from other nearby transmitters. Weather will often dictate the use of radomes — weatherproof structures that protect microwave/radar antennas. If you are lucky, you will find a ham with a mountain cabin and a clear view of the planned coverage area, and a willingness to host your site. Commercial towers will likely require professional climbers and installers, and must conform to commercial installation standards.

Antenna alignment is critical, and higher antenna gains translate to a need for more precise alignment. Just two or three degrees can make the difference between good and marginal links. This needs careful planning, installation, and testing. Sector antennas are more forgiving, but you will want spotter nodes already set up at the coverage extremes to align in both azimuth and elevation.

Figure 2 — A 3.4 GHz downlink from a backbone node uses a 120° sector antenna. [Andre Hansen, K6AH, photo]

Figure 3 — This relay node shows a gain antenna pointed to a backbone node and another pointed to a deployed node at a shelter site. [Andre Hansen, K6AH, photo]

Relay Node

Relay nodes (see Figure 3) are either pre-constructed in anticipation of where deployed nodes will be required in a disaster, or installed as necessary to support ham-deployed nodes. In either case, they form reachable collection points for surrounding deployed nodes and have the required line of sight and higher-gain antenna to reach a backbone node. Sector antennas again can ascertain broad downstream accessibility.

Ham-Deployed Node

Ham-deployed nodes are carried by deployed radio amateurs to served-agency disaster sites — such as shelters, trauma centers, and transportation centers — that require the pre-established data services. The "go-kit" generally comprises a 2.4 GHz node with a high-gain antenna pointed up to a backbone node or a relay node. The kit also contains a Wi-Fi router to provide network access for the local on-site devices, such as laptops and cell phones. At a 200 – 300 mA draw per device, a 12 V dc deep-cycle RV or marine battery will power these nodes for several days.

Implementation Tips

I advise using propagation prediction software, such as *Radio Mobile*, in planning the deployment of the core nodes to avoid the hassle and expense of experimentation.[3] The tool is explained in more detail in the *ARRL and TAPR 34th Digital Communications Conference* paper. Sufficient proficiency with this tool will enable you to explore the variables of band, node-model receiver sensitivity, node-model power output, and antenna gain options.

A few basic principles to keep in mind when laying out an *AREDN* network are collocation of nodes, coordination with other users, microwave link principles, and environmental conditions.

Collocation of Nodes

Collocated nodes can interfere with each other. You can mitigate against this by choosing different bands for inbound and outbound data. You can also connect all collocated nodes together via ethernet device-to-device (DtD) linking to ensure inter-node data does not use the RF path between nodes. If you must use the same band, then select frequencies that don't overlap. For example, if you are using 10 MHz bandwidth channels, select adjacent frequencies at least 10 MHz apart. Use shielding such as RF Armor.[4] Place the nodes as far apart as physically possible.

Coordination with Other Users

Coordinate with other ham users as well as collocated commercial interests. Commercial interests are heavy users of the 5 GHz band. However, in the US and many other countries, hams have a segment of the band all to themselves. Explore the use of that segment with other hams.

There are no commercial users of the 3.4 GHz band in the US. You do need to be concerned about military radar in rare cases. Remember that coordination doesn't always mean finding another frequency. In at least one instance, *AREDN* interference with a ham moonbounce (EME) contest was mitigated by a commitment to shut down interfering nodes of the *AREDN* network during the hours of the annual contest.

While full coordination with ham spectrum committees may not be necessary, making node frequency and location information available is probably wise. Thus, in case of interference, others can research the possibility that it is one of your nodes.

Microwave Link Principles

Microwaves travel by line-of-sight communications, so they need to see the other end of the link. The path must be clear in an ellipse between the transmitter and receiver, called the Fresnel zone. The size of that ellipse is determined by the frequency and link distance. Any obstruction in the Fresnel zone tends to cause the multipath interference.

The 900 MHz band is somewhat more tolerant of propagation through light vegetation than the higher frequency bands. If you use 900 MHz channels, consider also using a narrower bandwidth, such as 5 MHz, because the entire band is just 25 MHz wide in the US band plan.

Environmental Conditions

You might need radomes to protect antennas from snow and ice. You might also need static surge suppressors to protect the node and other collocated equipment. Wiring should use ruggedized CAT5/6 ethernet cable. Finally, rely on a professional/certified tower climber.

Node Setup and Configuration

Downloading and installing *AREDN* software is documented on the *AREDN* web pages.[5, 6] Once the software is installed, use the node Help page at **localnode.local.mesh:8080/help.html** to complete the configuration.

Aligning, Testing, and Managing Links

The higher the antenna gain, the more critical is its alignment with the far end of the link. *AREDN* software includes tools to maximize the link performance. The "Realtime Signal to Noise" chart computes and displays the signal and noise in dBm each second. The spread between the curves is the signal-to-noise ratio (SNR). Moving the antenna back and forth followed by up and down will quickly identify the maximum SNR alignment.

An SNR of 15 dB or greater is generally good enough to pass data rates of 10 – 20 Mbps. The *AREDN* node will attempt using one of the IEEE 802.11 protocols to maximize the data throughput. The resulting link rate throughput is calculated and displayed on the "Mesh Status" page in the "TxMbps" column, as shown in Figure 4. Another page displays a 48-hour SNR archive, which is useful in understanding transient interference issues.

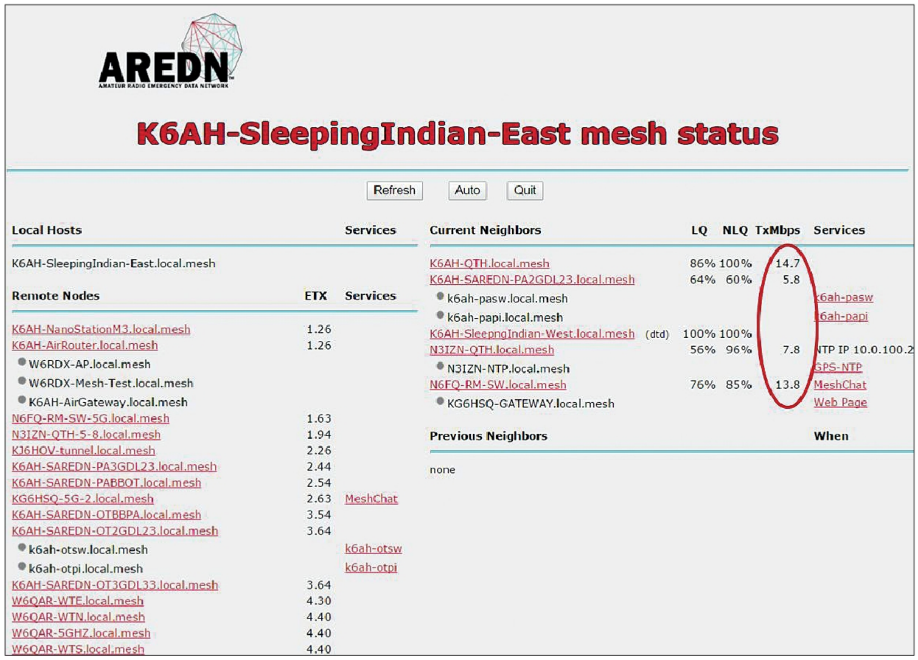

Figure 4 — The Mesh Status screen lists immediately adjacent neighbor nodes (right column) and their respective link-rate data throughputs. It also illustrates nodes beyond the neighbors (left column).

General Comments

MIMO (multiple-input, multiple-output) is a form of spatial multiplexing that transmits the node data across two independent signals from different antennas on the same channel by exploiting multipath propagation and polarization diversity. When MIMO is employed on both ends of a link, either the link rate or the SNR can increase — whichever results in the highest overall data rate. *AREDN*-supported devices are a mix of both MIMO and non-MIMO types.

The *AREDN* devices require from 10.8 to 24 V dc (measured at the device), supplied by an ethernet cable utilizing power over ethernet (PoE) technology.

Several nodes may be connected back-to-back using DtD linking. The routing protocol uses the ethernet interfaces to move data between these collocated DtD nodes.

Desktop Nodes

Desktop nodes, such as airRouter and airRouter-HP from Ubiquiti Networks, are very handy. They are the equivalent of a Ubiquiti Networks Bullet and an ethernet switch, combined.

General Purpose Nodes

These are a mix of MIMO devices, such as the Ubiquiti NanoStation and NanoStation Loco, and non-MIMO devices, such as the Ubiquiti airGrid, Bullet, and PicoStation. Hams seem to like the airGrid, which matches impressions of what a microwave dish should look like, and the Bullet, which can be attached to your antenna via an N-type connector. However, the NanoStation, which routinely makes 15-mile spans, may be a better choice. There is much to gain from MIMO technology, which non-MIMO devices cannot match.

Broader Distribution Nodes

The Ubiquiti Rocket is a general purpose MIMO radio that can be mated with a variety of antenna choices, including sector antennas with 90° and 120° wide patterns.

Long-Haul Nodes

Longer-haul devices require the extra gain achieved with dish reflectors.

Deployment Challenges

One of the most challenging aspects of a mesh implementation is inter-connecting mesh islands that have formed in the more easily meshed areas. Without a complete mesh network, it is difficult to justify the expense and effort of building out network services, such as e-mail, VoIP telephony, and web-based utilities, which are needed to demonstrate the network to prospective emergency communications clients. It may also be difficult to justify the expense of acquiring strategic high-ground locations necessary to connect the mesh islands.

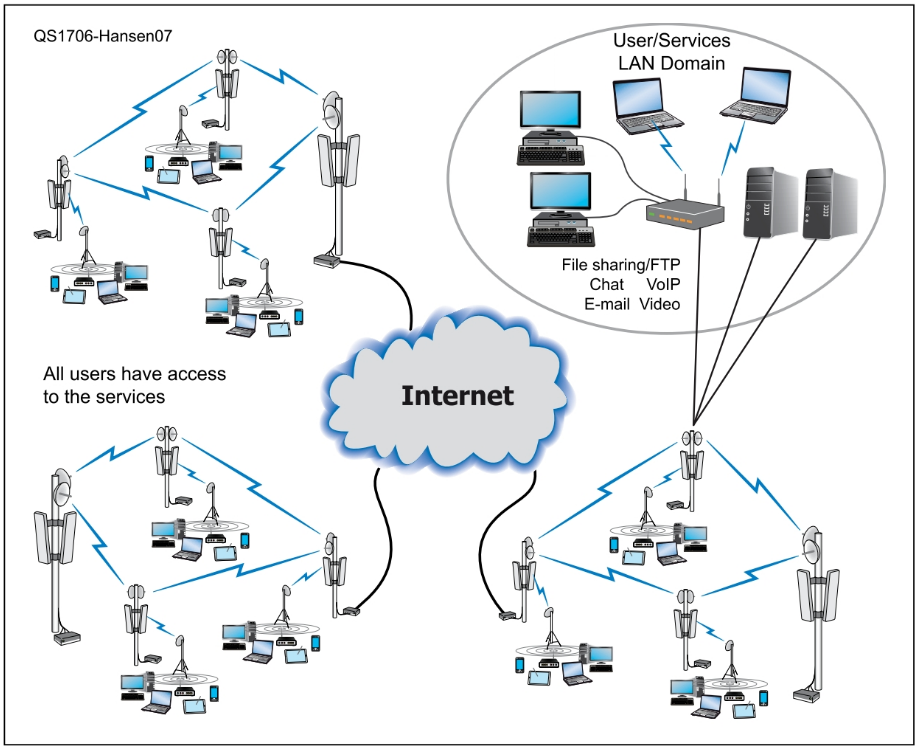

Figure 5 — The three mesh islands can be bridged by internet tunnels. Although useful for demonstrating a "complete" mesh, it is poor strategy for an emergency deployment because the Internet is not likely to be available during a disaster.

AREDN provides an interim solution based on internet tunneling (see Figure 5). This involves setting up an encrypted tunnel between one tunnel server-node and one tunnel client-node in each of the other mesh islands. This connects all participating mesh islands together in the same network. You can gain the benefits of having completed the network and, at the same time, justify the build-out of computerized services for the users and demonstrate the utility to prospective customers and agencies.

While tunneling is an effective way to gain that critical mass, it is a poor strategy for emergency and auxiliary communications (AUXCOM) deployment, and should be used on an interim basis for demonstrations. Tunnels will likely not be functional during a real disaster.

Conclusion

There are a variety of mesh network systems today. *AREDN* is unique in that it operates under Part 97 under the authorizations inherent in our Amateur Radio license grant. It is easy to configure and is deployable by typical hams without any knowledge of data networking or the design of the mesh to which a node is being connected. It can be used to support a variety of internet-based services or to restore failed intranet-based agency services.

The *AREDN* project team provides support via its web page to emergency communications and AUXCOM groups. Since this article was submitted, hams using techniques like those described in this article have deployed the final high-speed data communications links between southern California counties in support of inter-county Incident Command Systems' Memorandums of Understanding (ICS MoUs). The federated *AREDN* implementations in San Diego, Riverside, San Bernardino, Orange County, and Los Angeles counties now cover more than 16,000 square miles and have the potential to serve over 18 million people. Plans are being formulated to link Ventura and Santa Barbara counties in 2017 and San Luis Obispo, Monterey, San Benito, and Santa Clara counties in 2018.

Acknowledgments

The software development team members are Conrad Lara, KG6JEI; Joe Ayers, AE6XE; Darryl Quinn, K5DLQ; Randy Smith, WU2S; Trevor Paskett, K7FPV, and Andre Hansen, K6AH. The team was honored with the ARRL Microwave Development Award in 2014. You can meet them and discuss your *AREDN* implementation project on the *AREDN* Forums web page, at **www.aredn.org/forum**.

Notes

[1]**aredn.org**
[2]**www.tapr.org/pdf/DCC2015-AREDN-Project-K6AH.pdf**
[3]The *Radio Mobile* English language portal, **www.cplus.org/rmw/english1.html**.
[4]**www.rfarmor.com**
[5]Download from **www.aredn.org/content/software**.
[6]Install according to **www.aredn.org/content/uploading-firmware-ubiquiti**.

Andre Hansen, K6AH, has been a ham for 46 years and holds an Amateur Extra class license. He is a member of ARRL, and a frequent speaker at regional, national, and international conferences. Andre works as an IT Regulatory Compliance Consultant for Abbott Laboratories. He is also the project manager for the *AREDN* project. He finds the *AREDN* project a nice blend of his professional experience and Amateur Radio hobby. Andre spends much of his spare time working on *AREDN*, but also enjoys VHF and HF mobile operation, and contesting. In 2013, Andre won first place in the Rover category of the ARRL June VHF Contest. You can learn more about Andre at **www.aredn.org/bio/K6AH**, and can reach him at **k6ah@aredn.org**.

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