CHAPTER 1

Introduction to Radio Data Networks

Hidden in the fine print at the bottom of the ARRL Band Chart for the U.S. Amateur Radio Bands (see **Figure 1-1**), you can see that hams have frequency allocations in the 900 MHz (33 cm), 1.2 GHz (23 cm), 2.4 GHz (13 cm), 3.4 GHz (9 cm) (See the sidebar on the status of the 3 GHz band), 5 GHz (5 cm), and 10 GHz (3 cm) bands, among others. Coincidentally, some of these bands overlap with the standard Wi-Fi frequencies used in wireless routers and access points found in many home computer networks, Wi-Fi Hotspots, and the like. Using commercial off-the-shelf wireless devices, hams have adapted these devices for amateur radio use and are creating their own wireless networks. Under Part 97 of the FCC rules for the Amateur Radio Service, hams can operate these devices with higher power levels and higher-gain antennas, allowing their networks to cover a much larger area than a standard Wi-Fi access point. All you need to do is install a simple firmware upgrade to certain standard Wi-Fi devices, and in the case of HamWAN technology, you don't need to do any firmware changes at all. Using this technology, hams have developed and deployed complete high-speed data networks. And as long as the network usage remains FCC Part 97 compliant, these networks can also be linked to the internet, allowing hams to have the best of both worlds. We'll go into more detail shortly about how Part 97 applies to amateur radio data networks. In short, as long as you're not using the network for commercial purposes and you don't encrypt your data (we'll cover that later, too), you're generally in compliance.

What is Radio Data Networking?

So, what exactly is radio data networking? Radio data networking usually occurs on the microwave frequencies, which are commonly defined as occupying the frequency range between 300 MHz and 300 GHz. I've found that it's easier to think of microwave frequencies as everything above the 70 cm band and below infrared light. Within that frequency range, there are several

Status of the 3GHz Band

In search of quieter and less crowded bands, some amateur radio networks are using the 3 GHz band, primarily as links between backbone sites. Up until 2022, hams could use the 3.3 to 3.5 GHz 9 cm band on a secondary basis, meaning they couldn't cause interference to the primary users, typically military radar systems, and they would have to accept any interference from those primary users.

In 2018, The National Telecommunications and Information Administration (NTIA) identified the 3.45 to 3.55 GHz band for potential wireless broadband use. In December of 2019, the FCC formally adopted a Notice of Proposed Rulemaking to remove all amateur allocations in the 3.3 to 3.5 GHz band. Hams were required to immediately cease operation in the 3.45 to 3.5 GHz portions of the band.

As of September 2025, hams are still permitted to operate as secondary users in the 3.3 to 3.45 GHz bands, pending further FCC proceedings.

frequency bands allocated for amateur radio use. Within those bands, hams have created radio data networks that link wide areas together in a manner similar to the internet. Radio data networking makes it possible to run internet-style multimedia applications over a wireless network, while also providing the option to connect to the actual internet.

What is Multimedia?

When you watch a video or listen to music over the internet, that's multimedia. When you read your email and there's an image or video attached to it, that's also multimedia. When you browse a website that has text, images, and audio, that's multimedia. When you play computer games online, that too is multimedia. At the very basic level, multimedia is exactly what it sounds like, multiple forms of media (data) such as voice, video, data, and text that computers can extract from a data stream and present in a variety of ways. With your home computer or smartphone, you can access a wide variety of multimedia content with a simple app or web browser. For this data to be used in real time, it must be received at a speed fast enough for your computer or smartphone to reassemble the data stream into smooth, continuous video or audio, or both, without stuttering, interruptions, or dropouts.

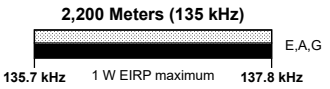
Speed Limits

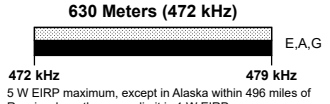
Prior to the advent of amateur radio data networks, hams were severely limited in the speeds that they could use to send and receive digital data over the air. Packet Radio at 1200 or 9600 baud was about as good as you could hope for. Sending a large, high-resolution image or file took

US Amateur Bands

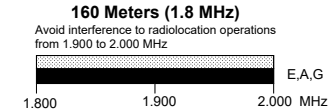
US AMATEUR POWER LIMITS — FCC 97.313 An amateur station must use the minimum transmitter power necessary to carry out the desired communications. (b) No station may transmit with a transmitter power exceeding 1.5 kW PEP.

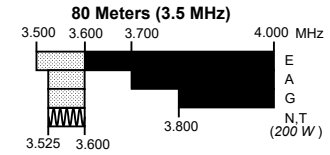
Amateurs wishing to operate on either 2,200 or 630 meters must first register with the Utilities Technology Council online at **https://utc.org/plc-database-amateur-notification-process/** You need only register once for each band.

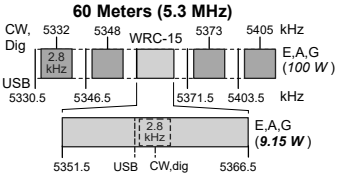




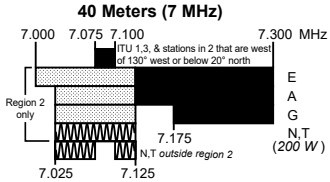
5 W EIRP maximum, except in Alaska within 496 miles of Russia where the power limit is 1 W EIRP.



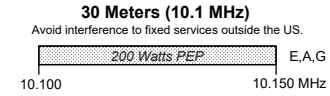


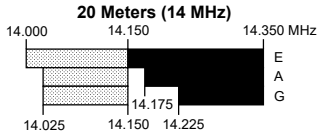


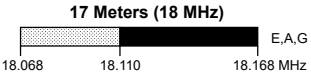
General, Advanced, and Extra licensees may operate on a *secondary* basis with an operating bandwith of 2.8 kHz, maximum ERP of 100 W (relative to a half-wave dipole antenna) on individual channels. As February 13, 2026 the WRC-15 band 5351.5 to 5366.5 kHz is available with a max. ERP of ***9.15 W***.

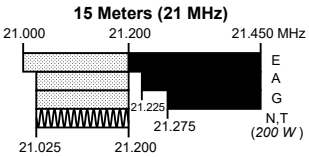


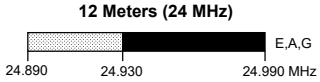
See Sections 97.305(c), 97.307(f)(11) and 97.301(e). These exemptions do not apply to stations in the continental US.

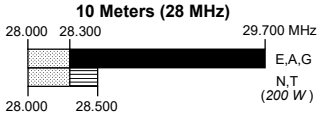


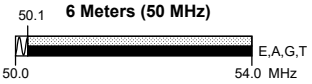


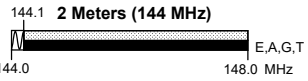


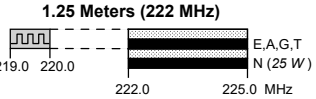


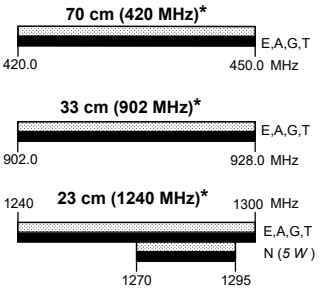












*Geographical and power restrictions may apply to all bands above 420 MHz.See FCC 97.303 Frequency sharing requirements, for information about your area.

All licensees except Novices are authorized all modes on the following frequencies:

2300-2310 MHz	47.0-47.2 GHz
2390-2450 MHz	76.0-81.0 GHz
3300-3450 MHz	122.25-123.0 GHz
5650-5925 MHz	134-141 GHz
10.0-10.5 GHz ‡	241-250 GHz
24.0-24.25 GHz	All above 275 GHz

‡ No pulse emissions

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KEY

Note:
CW operation is permitted throughout all amateur bands.

MCW is authorized above 50.1 MHz, except for 144.0-144.1 and 219-220 MHz.

Test transmissions are authorized above 51 MHz, except for 219-220 MHz

= RTTY and data
= phone and image
= CW *only*
= SSB phone
= USB phone, CW, RTTY, and data.
= Fixed digital message forwarding systems *only*

E = Amateur Extra
A = Advanced
G = General
T = Technician
N = Novice

See *www.arrl.org/band-plan* for detailed band plans.

Figure 1-1 — ARRL Band Chart

forever, and you could forget about trying to watch any sort of video. Even at 128 kilobits per second (kb/s), the Digital Data mode (DD) on D-Star, and similar digital modes, aren't robust enough to handle any serious multimedia data. The physical and regulatory data rate restrictions for the other bands and modes just don't allow for today's modern multimedia data. Current amateur radio microwave networks can transfer data at much higher speeds, up to 100 Mbps and higher, and there is no regulatory data speed limit at frequencies above 902 MHz. As technology advances, we can expect to see even higher data rates available with microwave data networks.

All of this can be done using inexpensive, off-the-shelf wireless equipment such as Ubiquiti, TP-Link, and MikroTik routers, among others. Converting these devices for use in an amateur radio network involves a simple change of the device firmware, no soldering needed. In the case of the MikroTik wireless routers used in HamWAN networks, you don't even need to change the firmware. Many of the compatible microwave routers are available for very reasonable prices, used or new. Microwave networking firmware is constantly being developed, and by the time you read this, even more off-the-shelf devices may have been adapted for use in amateur radio data networks.

Part 15 Versus Part 97: Equipment and Operation

Most of the devices currently used in amateur radio data networks, as they come from the manufacturer, are governed by the FCC under Part 15 rules regarding unlicensed radio frequency devices. Typically, this means they are intended for very short ranges and are limited to 1 watt of output power. In 2004, the FCC modified its rules to allow unlicensed commercial Wi-Fi devices to use higher-gain antennas under specific guidelines and reduced power output. This change allowed higher *equivalent isotropic radiated power* (EIRP) levels, though in most cases the EIRP of these devices is limited to 4 watts. Reduced transmitter power does allow for higher levels of EIRP achieved by using a higher-gain antenna, but the manufacturer must certify their devices with these antennas.

It's Good to Be a Ham

Here's the advantage of being a ham when it comes to Wi-Fi frequencies and devices: under FCC Part 97 rules, hams are granted band allocations in portions of the Wi-Fi bands with fewer restrictions and much higher power levels. Hams can repurpose standard Part 15 commercial Wi-Fi devices and operate under Part 97. To operate a Part 15 device under Part 97, all you have to do is connect everything and operate under the standard Radio Amateur Part 97 rules: identify every 10 minutes, avoid pecuniary interest, don't use encryption, and steer clear of any obscenity or pornography. It's as simple as that.

On certain portions of the Wi-Fi bands, you can even run up to 1.5 kilowatts (PEP) of power. Before you run out and get that amplifier (assuming you can find and afford one), remember that the Wi-Fi bands are at microwave frequencies. Your average home microwave oven puts out about 1,000 watts or more—and look at what it can do to food. Now imagine putting that kind of

power on a high-gain directional antenna on your roof. You quickly realize you could fry things outdoors, including yourself.

In all seriousness, high-powered microwave amplifiers can get expensive quickly. Since Wi-Fi frequency radio transmissions are mainly line-of-sight, using additional power to that extreme really won't buy you a whole lot. And don't forget the rule that says hams should always use the minimum power necessary to establish communication.

Fortunately, to build out a usable radio data network, you won't need much power. Most deployments are done with standard Wi-Fi devices and high-gain directional antennas. Communication distances of 10 to 15 miles are easily achievable, and based on terrain, even longer distances are possible. In 2007, a Wi-Fi link of 237 miles was achieved between two mountains in Venezuela using just 100 mW of power and standard equipment, but your mileage will almost certainly vary. Success depends on terrain, obstacles in the path, and station configuration.

Typically, you'll only need to change the device's operating system, also known as firmware, to run one of the standard amateur radio microwave networking packages. You don't even have to do that; you could just run standard Wi-Fi 802.11™. However, because encryption isn't allowed under the rules, unlicensed users could potentially access your amateur radio network, so it's best to stick with the network firmware packages. Since the HamWAN network does not use modified firmware, other methods have been devised to ensure that only licensed hams can access the network.

Microwave Networking Technologies Explained

As of fall 2025, Amateur Radio Emergency Data Network (AREDN™), HamWAN, and Meshtastic® are the primary technologies being used in amateur radio networks. Since it is a relatively new area of development, there are many other technologies being researched and deployed, but those listed above are current popular choices. You may have noticed that the European HAMNET is not listed as a technology, this is because it is more of a confederation of various technologies, both wireless and internet based. Predominantly used in German-speaking countries, HAMNET relies on various microwave technologies and the exclusive ham radio AMPRnet™ internet address range (more on AMPRnet™ later), as well as the public internet, to link sites and countries together. Each area or country can choose their own microwave technology, routing protocol, and other configurations that best suit their needs, with IP addressing resources allocated on a per-area basis.

A Constantly Moving Technology Landscape

With the amateur radio data networking landscape in a near-constant state of flux, this book will focus more on the technology, fundamentals, and applications for microwave networking. By understanding how it all works, you'll have a much better idea of how to deploy and use an amateur radio data network regardless of which technologies end up widely deployed.

Topologies

There are several basic forms of microwave network topology currently used in amateur radio data networks. A *point-to-point* topology (see **Figure 1-2**) is just that, one node communicates directly with another node, that node can then relay the data on to the next node, etc. This method is primarily used to traverse different types of terrain or to overcome obstacles in the network path.

A more common architecture is the *hub-and-spoke* topology, also known as the *star* topology (see **Figure 1-3**). This topology is now the recommended topology for AREDN. Each endpoint communicates with a central device to access the network. That central device then relays the data to other central devices, either directly, through intermediary nodes, or to a connected endpoint, depending on the destination of the data.

The data, also known as *packets*, is automatically routed to where it needs to go. As more devices are added to the network, the network automatically discovers the new nodes and modifies the data path for the packets. Similarly, if a node goes offline, that path is dropped and the packets

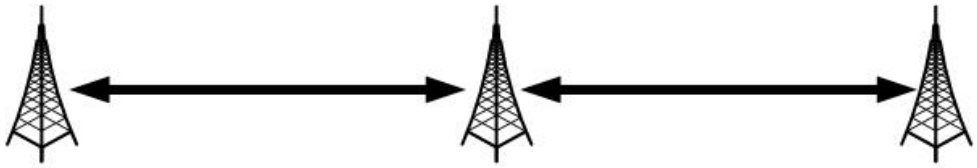

Figure 1-2 — A point-to-point network topology.

are automatically rerouted. This is one of the advantages of the routing protocols used in amateur radio data networks. Most of the networks have some form of redundancy, automatically or otherwise, built in, or they are self-discovering, self-advertising, and self-healing. As long as there's a path between the source and destination nodes, the data will get there. The downside is that your data is at the mercy of the time it takes to get from Point A to Point B, and there is a greater chance for packet loss (and the retransmission time for the lost packets). The higher the user density, the lower the individual throughput. Since devices often operate on the same channel, if two nodes that can't hear each other are sending to a third node that can hear both, the data collides and must be retransmitted. This is known as the *hidden node* issue, and it can have an impact on overall data throughput.

One major advantage of the network topologies discussed is the dynamic nature of the network structure. As new nodes come online or drop offline, the network automatically reroutes the data. This is ideally suited for portable or emergency scenarios where a data network that can rapidly adapt to changing conditions in the field needs to be set up quickly. Because the

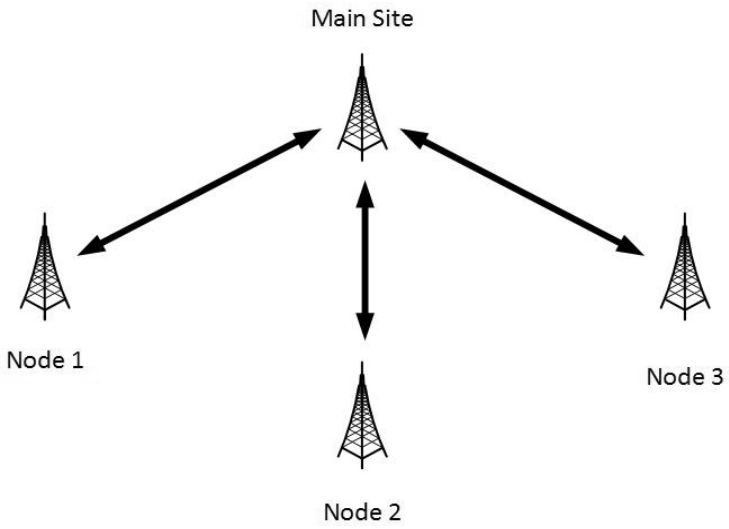

Figure 1-3 — A hub-and-spoke network topology.

equipment requires little power, microwave networks can be deployed using batteries, solar, or other alternative power sources, making them ideal for portable operations, public service events, or disaster response.

The HamWAN network also uses *a hub-and-spoke* topology. As discussed previously, all nodes in this topology communicate directly with a central site, known as a "cell site" in HamWAN terminology. The individual nodes cannot communicate directly with each other, nor can they act as relay points for nodes that can't reach a cell site. This means that every user node must be able to communicate with a cell site. The cell sites communicate between themselves to relay the traffic between the various nodes.

A typical HamWAN cell site has three antennas, each with a 120-degree arc of coverage that allows for a higher simultaneous user density by dividing the load into three zones of coverage. The big advantage of this is a much higher overall data throughput with less chance of data collisions. Because the nodes communicate directly with the cell site, there's less chance of data loss, as you're only dealing with a single 'hop' to the cell site rather than having your data relayed through multiple nodes as in other technologies. The downside of this network topology is that it creates a "single point of failure." If the cell site goes down for any reason, all users of that site are offline until it comes back online. And if the cell site that goes down is a relay point between others, it could also impact data travelling between other sites.

Meshtastic utilizes a *mesh* topology. In this topology, also known as *a peer-to-peer* network (see

Figure 1-4), all of the nodes in the network can communicate with each other, either directly or by relaying the data through intermediary nodes. A mesh topology is very resilient to network changes, as the multiple data paths provide enhanced reliability and fault tolerance by minimizing single points of failure.

None of these topologies is necessarily better than any other. Each has both advantages and disadvantages, and your choice of technology and network design will depend largely on how you plan to deploy and use your amateur radio data network.

Amateur Radio Network Frequencies

Currently, the majority of amateur networking activity occurs in the 2.4 and 5 GHz bands (see **Figure 1-5**). This is due to the adaptation of commercial off-the-shelf Wi-Fi devices for amateur radio purposes. Several of the amateur radio networking technologies are also branching out into the 900 MHz (33 cm) band. Research for microwave networking on the 10 GHz (3 cm) is also underway, particularly considering the probability of losing access to the 3 GHz band.

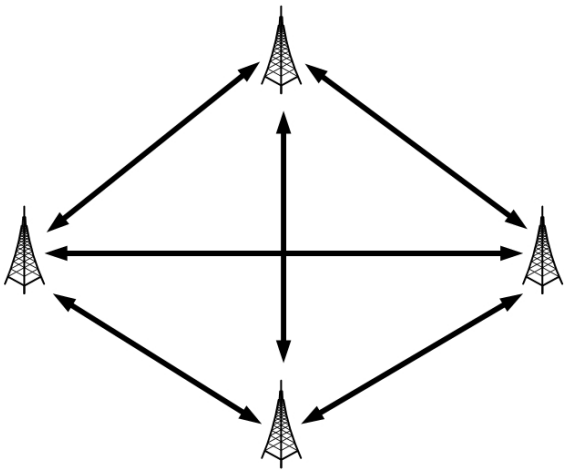

Figure 1-4 — A peer-to-peer or mesh topology.

In the 2.4 GHz band, you'll notice that, in addition to standard Wi-Fi channels 1 through 6 available for Part 97 Amateur Radio use, there are three additional channels, 0, –1, and –2, reserved as well. However, these frequencies are also used for weak-signal work and satellite links, so they must be used with care.

Since the 2.4 GHz spectrum is shared with the standard FCC Part 15 devices, amateurs can experience significant unwanted signals from these users. This interference is known as the "noise floor." Several microwave networking implementations are moving up to the quieter, less crowded 5 GHz spectrum, where standard dedicated Part 97-only channels are available for amateur use, eliminating the interference from Part 15 devices.

Typically, Ubiquiti, TP-Link, and MikroTik devices can run the AREDN™ firmware, while the MikroTik routers can also be used in a HamWAN network without requiring a firmware change. As the chart in **Figure 1-6** shows, standard Wi-Fi channels 132-140 and 169-180 do not allow Part 15 devices, so amateurs operating under Part 97 rules have a much quieter portion of the band

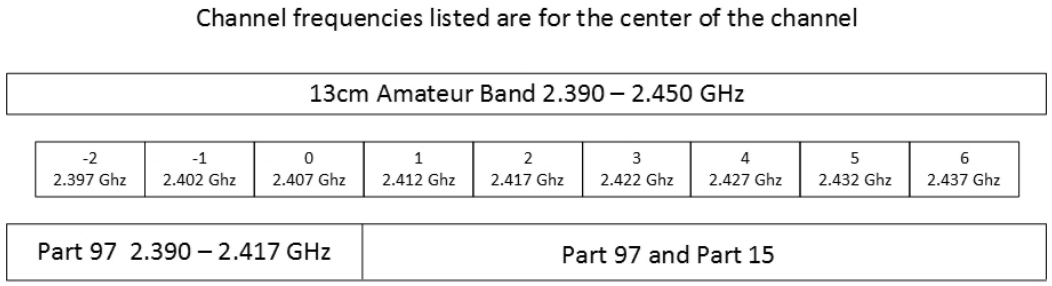

Figure 1-5 — 13 cm (2.4 GHz) band allocations.

to deploy their networks without interference worries.

The band allocations shown are for the United States. Some additional frequencies in the 2.4 and 5 GHz bands are permitted internationally. Please consult the allowed bands and frequencies for your specific country if you plan to deploy a radio data network using Wi-Fi channels other than those recommended.

Microwave Networking and TCP/IP

The main purpose of this book is to be an introduction to the world of amateur radio data networking and its use. As such, we will focus on understanding and deploying a microwave network, and how to implement the various applications and services you may want on your network. For a much more in-depth technical look at microwave networking in general, I recommend reading the free online book *Wireless Networking in the Developing World,* available at **wndw.net**. While it does not contain ham-specific information, and may be outdated, it does provide a general

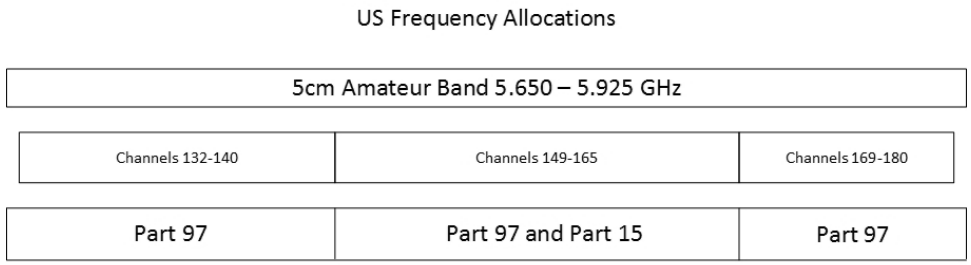

Figure 1-6 — 5 cm (5 GHz) band allocations.

discussion of the technologies used in microwave networks.

Since a microwave network is often built using repurposed commercial equipment, the networking technology used in an amateur radio data network is based on the Transmission Control Protocol/Internet Protocol (TCP/IP), or IP for short. IP is one of the most common networking protocols used today. IP is how your home computers move data to and from the internet. Computers, routers, and other network devices all "speak" TCP/IP, and use the information contained in an IP data packet to route the data to its intended destination automatically. Imagine if, instead of just dropping a letter at the post office, you had to put it in a dozen or more envelopes, each representing a separate 'hop', and at every stop someone had to open the outer envelope just to figure out where to send it next. Fortunately, you don't have to do that. Your local post office handles all the steps to get your letter across the country without you knowing how or what they use to get it there. It's the same with IP. You simply give the data packet the "destination address" and off it goes into the internet, where it eventually gets delivered without you needing to know any of the intermediate routing step to get it there. Since an amateur radio data network is independent from the internet, it's up to you to put all the infrastructure in place to handle the routing of this data. Fortunately, a lot of this is handled automatically within the network, and all you need is a basic understanding of how TCP/IP works to properly set up your amateur radio data network.

The Amateur Packet Radio Network (AMPRnet™)

In the late 1970's, long before the creation of the public internet as we know it today, Dr. Hank Magnuski, KA6M, had the incredible foresight to register an entire Class A IP address range (16.7 million IP addresses) for amateur radio use. An IP address range in the 44.0.0.0/8 internet addressing block was allocated for ham use. Don't worry about deciphering that strange bunch of numbers, it will be explained in the TCP/IP chapter.

With the internet now out of IPv4 address allocations, the AMPRnet™ block of addresses is very valuable real estate. In 2019, due to the low utilization of the overall AMPRnet™ address space and the increasing value of large internet address blocks, the 44.192.0.0/10 range, about 4 million addresses, was sold to Amazon Web Services. This sale raised over $50 million, which was used to fund the non-profit Amateur Radio Digital Communications (ARDC) organization. ARDC then established a program of grants and scholarships in support of communications and networking research.

The current address range available now is 44.0.0.0/9 and 44.128.0.0/10, with no plans to sell any additional address space. Any licensed ham can request a sub-block of this address range for free through AMPRnet™. This block of public IP addresses allows hams to access and link their networks directly with the public internet and to other amateur radio networks. For more information on how to apply for a grant or request a block of public IP addresses for your network, please visit the ARDC website at **ardc.org**.

Final Thoughts

One final thing to remember: amateur radio data networking is not an application, it's a technology. When you build a network, all you are doing is building an infrastructure for data to travel over; think of it like a road or highway. This is why the internet is often referred to as "The Information Superhighway." To travel anywhere efficiently, you need roads. Think of vehicles on the road as your applications. It doesn't really matter if it's a bicycle, car, motorcycle, or bus, getting around would be difficult at best without roads. Without the vehicles, a road just sits there and doesn't do a whole lot. You need both.

It's the same with networking. You need the infrastructure to help you move your data between places, but it is what you do with your network that turns it into a very powerful tool. The most asked question regarding microwave data networking is, "What do I do with all this once I have it running?" This is where the applications come in. Applications are the vehicles that use the roads you build. Because your network uses the TCP/IP protocol, pretty much anything you can do with the internet you can also do with your amateur radio data network. You can set up web servers, voice-over-IP systems (IP telephones), transfer files, chat, and just about anything else that you would do with your home computer attached to the internet. The main difference between your radio data network and the internet is that it is up to you to deploy the various applications you want to use on it.

About the Author

Glen Popiel, KW5GP, is a retired Network Engineer and Technology Consultant, living in Conway Arkansas. He has written numerous articles on computers and amateur radio and is the author of ARRL's *Arduino for Ham Radio* book series. In his 50+ year career, Glen has worked with TCP/IP and networking since the mid-1990's, and holds multiple industry certifications in computers and networking technologies. He has also led numerous corporate seminars on TCP/IP, Routing and Routing Protocols, Voice-over-IP (VoIP), Network Security, Firewalls, and Internet Content Filtering. Glen is also a former cat show judge and has exhibited purebred Maine Coon cats all over the country, with the highlight of winning Best in Show at the Madison Square Garden show in 1989. He continues to create fun and exciting new Arduino projects for amateur radio with his Maine Coon editors and paper shufflers, Shadow, Angel, and Odysseus.