

High-Speed Wireless Networking in the UHF and Microwave Bands

Hams are building a nationwide Amateur Radio wireless network, and you are invited to participate.

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and Keith Elkin, KB3TCB**

In the January 2012 video of the ARRL Atlantic Division training webinar, *Amateur Radio in the Next 25 Years*, Ed Hare, W1RFI, of the ARRL Laboratory, predicted that a nationwide Amateur Radio digital backbone network will emerge within the next 25 years.¹ This motivated me to think about and plan to build with fellow radio amateurs, a national Amateur Radio high-speed wireless network. About the same time, I learned about the availability of the Doodle Labs 420 MHz high-speed miniPCI data radios for Amateur Radio.² I purchased several of these data radios for members of my local club, the Montgomery Amateur Radio Club

(www.marclub.org), to experiment with.

In addition, we experimented with wireless mesh networking on 2.4 GHz, using Linksys WRT54GL Wi-Fi routers (www.linksys.com) that we reprogrammed with Broadband-Hamnet™ firmware (www.broadband-hamnet.org). At the 2012 Digital Communications Conference (DCC), I presented results of our experimentation with the Doodle Labs data radios.³ Keith Elkin, KB3TCB, contacted me after watching the HamRadioNow video of the 2012 DCC presentation.⁴ In early 2014, we decided to collaborate on establishing a high-speed network link between locations in Frederick and Montgomery counties in Maryland. Bill Kisse, W3MSH, also contacted me after

watching that HamRadioNow video. We looked at the ARRL band plan (www.arrl.org/band-plan) and discovered that the 3.3 GHz to 3.5 GHz Amateur Radio frequency allocation is not shared with unlicensed users, unlike the 2.4 GHz and 5 GHz bands.

Wireless Networking Hardware

The question arose — was there any commercial off the shelf wireless networking equipment that we can use? We discovered that Ubiquiti Networks, Inc (www.ubnt.com/airmax) manufactures and sells the airMAX® family of wireless communications products for use at 900 MHz, 2.4 GHz, 3.4 GHz, 3.65 GHz, and 5 GHz. We also learned that airMAX equipment on different frequencies running the

Figure 1 — This data radio station consists of a GXP1105 IP phone connected to a NanoStation M3 station by an Ethernet cable.



Figure 2 — A remotely controlled IP video camera can be connected to a network relay station using an Ethernet cable.



airOS® router software can interoperate over an Ethernet connection.⁵ I wanted to purchase airMAX NanoStation M3, NanoBridge M3, and Rocket M3 equipment in the 3.4 GHz to 3.5 GHz Amateur Radio band.⁶ The challenge was finding one or more Ubiquiti dealers willing to sell to US radio amateurs, since the M3 products are for foreign export. I was able to purchase M3 equipment from Streakwave Wireless Inc (www.streakwave.com/product-ubiquiti.asp) after proving that I am a licensed US radio amateur and that US radio amateurs do indeed have a frequency allocation at 3.4 GHz.

We then realized the possibility of buying and using commercial wireless networking equipment for use on Amateur Radio frequencies. More importantly, we realized just about everything that we learned about consumer IEEE 802.11™ wireless networking has now become a part of Amateur Radio. This is a big idea.

The free book *Wireless Networking in the Developing World* (www.wndw.net) was another source of inspiration. We discovered that there are many volunteers, not necessarily radio amateurs, all over the world who are actively installing high-speed wireless networks using inexpensive equipment. The book begins with the basics of radio science and then introduces basic networking. It then serves as a practical guide on installation and deployment of wireless networking equipment, with useful appendices and references. Much of this book applies directly to what radio amateurs are trying to accomplish.

A Demonstration 3.4 GHz Wireless Network

We set up a demonstration network at the 2014 ARRL National Centennial Convention with two wireless links using four Ubiquiti NanoStation M3 data radios, two Grandstream GXP1105 IP phones (see Figure 1), one Foscam FI8910W IP camera (see Figure 2), and two laptop computers. The GXP1105 IP phone is connected directly to the secondary Ethernet port of the NanoStation M3 with an Ethernet cable. A 24 V power over Ethernet (POE) device powers the NanoStation M3 over another Ethernet cable. A laptop computer connects to the NanoStation M3 through the POE device with an Ethernet cable. The GXP1105 is powered by a 5 V, 0.5 A power supply. Both GXP1105 IP phones

are configured with a unique IP address. One IP phone can call the other IP phone by dialing its IP address if they are both on the same network.

Figure 3 shows NanoStation M3 device configured as a bridge at the network layer by setting Network Mode to *Bridge*. This sets both Ethernet ports and the wireless interface to the same MAC address and the same IP address. A packet that appears on an interface will appear nearly simultaneously on the other two interfaces. This is necessary for establishing a wireless data link between two NanoStation M3 devices. A NanoStation M3 is configured as a “station” (Wireless Mode set to STATION) so it can connect to another NanoStation M3 configured as an access point (Wireless Mode set to ACCESS POINT). Ubiquiti uses the term “station” to indicate a

wireless client that connects to a wireless access point. A point-to-point wireless link can be established using a *Station* and *Access Point* NanoStation M3 data radio pair. The wireless link acts as a wireless Ethernet cable — any data that enters an Ethernet port on one NanoStation M3 device will appear on an Ethernet port of the other device. Also, a NanoStation M3 provides an LED that turns red when a link is established and three multicolored LEDs that indicate signal strength.

The demonstration wireless network in Figure 4 shows two wireless data links. Each NanoStation M3 in the network is assigned its own static IP address. The first link communicates at 3400 MHz and the second link is configured to communicate at 3450 MHz. The secondary Ethernet port of the second NanoStation M3 is con-

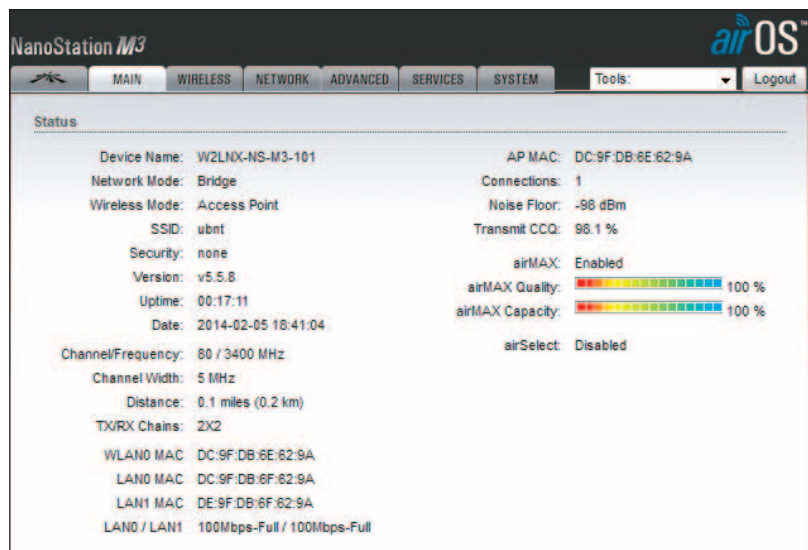


Figure 3 — The main airOS web page of this NanoStation M3 station shows it configured as a wireless bridge.

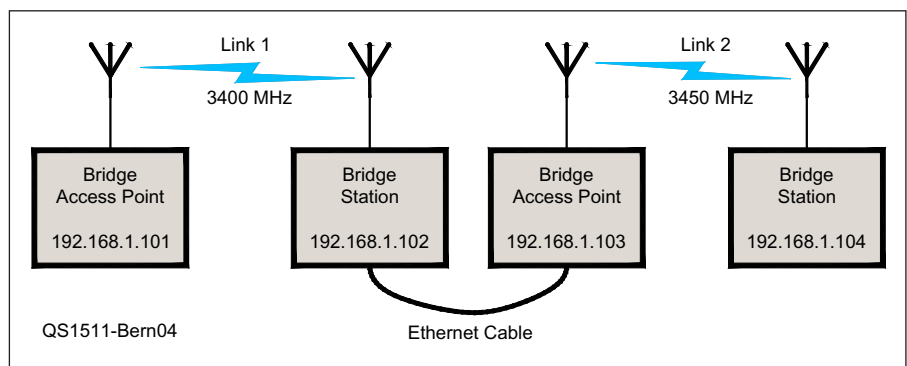


Figure 4 — A demonstration network consisting of two 3.4 GHz wireless links.

MAC Address	Device Name	Mode	SSID	Product	Firmware	IP Address
DC:9F:DB:6E:62:9A	W2LNX-NS-M3-101	AP	ubnt	NanoStation M3	v5.5.8	192.168.1.101
DC:9F:DB:6E:62:7F	W2LNX-NS-M3-102	STA	ubnt	NanoStation M3	v5.5.8	192.168.1.102
DC:9F:DB:6E:62:A0	W2LNX-NS-M3-103	AP	ubnt	NanoStation M3	v5.5.8	192.168.1.103
DC:9F:DB:6E:62:FF	W2LNX-NS-M3-104	STA	ubnt	NanoStation M3	v5.5.8	192.168.1.104

Showing 1 to 4 of 4 entries
 << < 1 > >>

Figure 5 — The airOS device tool displays the device names with call signs and IP addresses of every data radio on the network.

connected with an Ethernet cable to the main Ethernet port of the third NanoStation M3. These two NanoStation M3 devices form a network relay station. Functionally, a network relay station is the same as a human-operated relay station, reminiscent of the original mission of the American Radio Relay League as founded over 100 years ago, except that today it is automatic, smaller, uses less power, operates at much higher frequencies, is more reliable, and is less expensive. It is truly a relay station, because all traffic is exchanged between the two wireless links.

Figure 5 shows another view of the demonstration network. Select the DISCOVERY tool from the TOOLS drop-down menu list shown next to the airOS logo in Figure 3. The tool provides the DEVICE NAME and the IP address of every airMAX data radio station device on the network connected with a wireless link or by an Ethernet cable. In addition to the airOS DISCOVERY tool, Ubiquiti provides a standalone device discovery tool that is available for download (www.ubnt.com/download). A data radio station on the network can identify itself by setting its Amateur Radio call sign in the DEVICE NAME. In this example, the DEVICE NAME includes the call sign “W2LNX.”

More importantly, every station on the network can advertise its IP address. This provides the opportunity for a data radio station on a wireless network to select a unique IP address. We developed a simple scheme that encodes the latitude and longitude of a station within the contiguous 48 US States into a unique IP address for stations at least 4.8 km (3.0 miles) apart.⁷ This is valuable because it allows independent stations to announce their IP addresses without the need for a central

source on the network to assign them their IP addresses. This satisfies the distributed network design requirement of avoiding single points of failure.

Figure 6 shows two NanoStation M3 devices of the network relay station mounted back to back and connected with an Ethernet cable. There is no radio interference between them since they operate on frequencies 50 MHz apart. Optionally, an IP camera (see Figure 2) can be mounted on top of the network relay station and can be connected with an Ethernet cable to the secondary Ethernet port of the second NanoStation M3 device.

We discovered that a NanoStation M3 data radio can be conveniently powered by a 13 to 14 V power source using an inexpensive Tycon passive power over Ethernet (POE) device drawing about 0.5 A.⁸ The first NanoStation M3 of the relay station powered by the power source connected to an inexpensive wattmeter that allows us to monitor the voltage level of a 12 V AGM lead acid battery and the consumed energy in ampere-hours.⁹ We do not allow the voltage of a fully charged battery to drop below 12 V, and we do not consume more than half the ampere-hour rating of the battery. Two NanoStation M3 devices together (Figure 6) draw about 1 A. So an 18 Ah battery can provide about 8 hours of continuous operation. The network connection Ethernet cable between the two NanoStation M3 devices also provides POE power from the first to the second NanoStation M3 device.

Continuing Work

Many popular Amateur Radio applications currently running on the Internet can run on this high-speed wireless network. Our intention is not to replace the Internet with



Figure 6 — Two back-to-back NanoStation M3 stations connected by an Ethernet cable function as a wireless network relay station. The blue box at the bottom monitors voltage and current.

an Amateur Radio wireless network, but to extend the reach to the Internet on a selective basis. For example, the purpose of the Winlink e-mail system is to exchange e-mail over Amateur Radio with the Internet e-mail system.¹⁰ Currently, e-mail sent over Winlink requires a direct radio link between the Winlink user on HF or VHF to connect to a distant Winlink server on the Internet. By placing local Winlink servers

on the Amateur Radio wireless network, users can have additional access to the Winlink system.

Today, radio amateurs are building high-speed Amateur Radio wireless backbone networks all over the country using 2.4 GHz, 3.4 GHz, 5 GHz, and 900 MHz commercial wireless networking equipment. Some examples are listed in Table 1.

Ultimately, Amateur Radio users will want to *connect* over the high-speed Amateur Radio wireless backbone network. But not all users will have *direct access* to the high-speed backbone network. They will require radios in the 70 centimeter band that operate at slower speeds. New UHF data radio products are currently being developed such as in Table 2.

Building a nationwide Amateur Radio wireless network is a huge undertaking that requires many radio amateurs, groups, and clubs to collaborate and cooperate with each other. A project this size is not so daunting if it is organized into smaller projects.

Building a high-speed backbone network

Two groups of radio amateurs in neighboring communities can collaborate to create a high-speed wireless backbone link between their communities using high-speed wireless equipment in the microwave range. A pair of inexpensive Rocket M3 digital radios and their reflec-

tor dishes (see Figure 7) can provide a point-to-point link of at least 30 km (18.6 miles) according to Ubiquiti. The capability of this equipment is demonstrated by a 88 km (55 mile) 5 GHz link installed by Keith Elkin, KB3TCB, and Richard Hayman, WN3R. The link connects Gambrill Mountain, Maryland to the Red Lion, Pennsylvania network relay site of the Central Pennsylvania IP Network. Several point-to-multipoint wireless links can be established by using a Rocket M3 data radio configured as an access point along with a Ubiquiti 3.4 GHz 120 degree sector antenna (see Figure 8).

A station on the backbone network must be “confident” that network traffic originating from a neighboring backbone station can be trusted as coming from that neighbor and not from a bogus station. Likewise, only radio amateur users should be allowed access to the backbone network. Heikki “Hessu” Hannikainen, OH7LZB, discusses authentication protocols and use of ARRL Logbook of The World (LoTW) digital authentication certificates in his presentation at the 2013 Digital Communications Conference.¹¹ Network management software with authentication services will need to be provided.

Building local community wireless networks

Local radio amateur groups will need to build local area wireless networks at lower UHF frequencies to gain access to a high-

speed station on the backbone network. In addition to purchasing new UHF digital radios as mentioned above, what can we do with existing radio equipment that radio amateurs already own? For example, what can we do with the “9600 bps data ports” that are behind many VHF and UHF radios?¹² Can an inexpensive GMSK 9600 bps TNC be developed that can plug into these radios? The humble 1200 bps TNC many radio amateurs own can be used for low bit-rate text messaging on the wireless network.

Text messaging over cell phones and instant messaging over the Internet are probably the most popular form of personal wireless communications in the world today. What can we do with the robust data modes available in the *Fldigi* (and other) digital modem software programs for use in the VHF and UHF bands?¹³

Developing network applications

Internet applications such as text messaging, file transfer, VOIP (Voice Over Internet Protocol), e-mail, web services, and popular Amateur Radio Internet applications can run on the Amateur Radio wireless network. Such applications include Winlink, the APRS real-time tactical digital communication system, and the Echolink[®] voice system.^{14, 15} APRS text messaging can be supported by running an APRS to an Internet gateway program on the wireless network. Digital links between D-STAR[®] repeaters or between a D-STAR repeater and its remote D-STAR “hotspots” can also run on the wireless network. Can these applications be made to run without depending on the Internet to provide communication among users on the Amateur Radio wireless network? Even audio from remote receive sites of analog FM repeaters can be transmitted back to the main repeater site over the Amateur Radio wireless network. Inexpensive computers, such as a Raspberry Pi 2 (now just \$35), could be used to run such applications. It is up to the imagination and initiative of individual hams and groups of hams to migrate existing applications to the network and to develop new ones.

Testing and evaluating wireless networking equipment

We plan to continue testing Ubiquiti airMAX equipment to compare the link characteristics at 900 MHz, 3.4 GHz, and 5 GHz. We also plan to test and evaluate

**Table 1
Amateur Radio Wireless Networks**

Network	Information
Broadband-Hamnet HSMM-MESH network	www.broadband-hamnet.org/
British Columbia Wireless Amateur Radio Network	www.bcwarn.net
Seattle Area HamWAN network	https://www.hamwan.org/
Baltimore Radio Amateur Television Society 5 GHz network	bratsatv.org/repeaters
Additional Amateur Radio computer compatible networks	www.maijn.com

**Table 2
User Radios for Use Over Amateur Radio Wireless Networks**

Transceivers	Information
UDRX-440 Universal digital radio	nwdigitalradio.com/
CS7000 UHF data radio	www.connectsystems.com/products/top/radios%20CS7000.htm
Whitebox handheld SDR data radio	radio.testa.co



Figure 7 — A Rocket M3 data radio mounts behind this 3.4 GHz RocketDish point-to-point parabolic antenna (www.ubnt.com/airmax/rocketdish-antenna/).



Figure 8 — Point-to-multipoint wireless link can use a Rocket M3 data radio configured as an access point, and mounted behind this Ubiquiti 3.4 GHz 120 degree sector antenna (www.ubnt.com/airmax/airmax-sector-antenna/).

the new UHF data radio products as they become available. We will share our results with the Amateur Radio community. Please see www.maipn.com for the latest information about additions to the high-speed wireless network.

Acknowledgments

This article was adapted from the 2014 Digital Communications Conference paper and presentation.¹⁶ The video of the presentation is available on HamRadioNow.¹⁷

A project as large as this one benefits from the ideas and work of many people. I want to acknowledge my co-author Keith Elkin, KB3TCB, who is as enthusiastic as I am about building a national Amateur Radio high-speed wireless communications network. I want to especially acknowledge Phil Karn, KA9Q, who inspired me more than 25 years ago to learn about and experiment with Amateur Radio digital communications.

Notes

- ¹Edward F. Hare, Jr, W1RFI, "25 Years from now, Amateur Radio in the Next 25 Years," Jan 18, 2012, www.atldiv.org/training.htm, at time 1:02:11 – 1:35:12.
- ²Doodle Labs DL435-30 20 – 450 MHz Embedded COFDM Transceiver, www.doodlelabs.com/products/radio-transceivers/sub-ghz-range/420-450-mhz-dl435-30.
- ³David Bern, W2LNX, "Experimenting with High-Speed Wireless Networking in the 420 MHz Band," ARRL and TAPR Digital Communications Conference, Atlanta, GA, Sep 2012, www.tapr.org/pdf/DCC2012-High-SpeedWirelessNetworking_W2LNX_slides.pdf.
- ⁴David Bern, W2LNX, "Episode 41: Experimenting with High Speed Wireless Networking in the 420 MHz Band," HAM RADIO NOW, produced Dec 2012, arvideonews.com/hrn/HRN_Episode_0041.html.
- ⁵airOS™ Users Guide, dl.ubnt.com/guides/airOS/airOS_UG.pdf.
- ⁶Ubiquiti designates airMAX M family of products as M900, M2, M3, and M5 to indicate 900 MHz, 2.4 GHz, 3.4 GHz and 5 GHz frequency bands, respectively.
- ⁷David Bern, W2LNX, appendix of "High-Speed Wireless Networking in the UHF and Microwave Bands," ARRL and TAPR Digital Communications Conference, Austin, TX, Sep 2014, www.tapr.org/pdf/DCC2014-High-Speed-Wireless-Networking-UHF-Microwave-Bands-W2LNX.pdf.
- ⁸POE-INJ-LED-S Shielded POE Inserter w/ Power & Current LEDs, tycononline.com/poe-inj-led-s.html.
- ⁹AODE® LCD Digital 60V/100A Watt Meter Battery Balance Power Voltage Checker Analyzer, www.amazon.com/Digital-Battery-Balance-Voltage-Analyzer/dp/B00EYZS6R6.
- ¹⁰Victor Poor, W5SMM (SK), et al, "The Winlink radio email system," www.winlink.org.
- ¹¹Heikki Hannikainen, OH7LZB, "Authenticated Amateur Radio Services on the Internet," 2013 Digital Communications Conference, *Ham Radio Now*, produced Dec 2013, arvideonews.com/hrn/HRN_Episode_0113.html.
- ¹²These are not true 9600 bps data ports, they are raw audio connections to/from the FM modulator/demodulator stages. The digital data

- must be shaped into an appropriate waveform by digital modem software.
- ¹³*Fidigi* digital modem from Software by W1HKJ & Associates, www.w1hkj.com.
 - ¹⁴Bob Bruninga, WB4APR, "Automatic Packet Reporting System," www.aprs.org.
 - ¹⁵Introducing EchoLink, www.echolink.org.
 - ¹⁶David Bern, W2LNX, "High-Speed Wireless Networking in the UHF and Microwave Bands," ARRL and TAPR Digital Communications Conference, Austin, TX, Sep 2014, www.tapr.org/pdf/DCC2014-High-Speed-Wireless-Networking-UHF-Microwave-Bands-W2LNX-presentation.pdf.
 - ¹⁷David Bern, "Episode 176: High-Speed Wireless Networking in the UHF and Microwave Bands," HAM RADIO NOW, produced Dec 2014, arvideonews.com/hrn/HRN_Episode_0176.html.

Photos courtesy of the authors.

David Bern, W2LNX, was licensed in 1979 as N2AER with an Advanced class license and upgraded to Amateur Extra class in 2000. He obtained his W2LNX vanity call sign because he is a *Linux* enthusiast. He earned his First Class Radiotelephone Operator License with Ship Radar Endorsement while in high school. In 1977, he earned a BS in Computer Science from City College of New York and then an MS in Computer Science in 1983 from New York University. He was a professional software developer of large distributed network applications, then was an adjunct professor of engineering at Montgomery College, Rockville, Maryland. David enjoys experimenting with Amateur Radio digital communications, and operating HF QRP digital modes. He also serves on the education committee of the Montgomery Amateur Radio Club, Rockville, Maryland, organizing Amateur Radio licensing classes and volunteer examiner sessions. You can reach David at 8809 Cold Spring Road, Potomac, MD 20854-2430, or w2lnx@arri.net.

Keith Elkin, KB3TCB, earned his First Class Radio Telephone Operator License in 1969 and his Amateur Extra class license in 2009. He worked as an engineer at a Maryland radio station in his early years and received his BS in Computer Science from University of Maryland including studies at Uppsala University, Stockholm University, and University of Chicago. Keith is a veteran software developer, designer and entrepreneur and has a solid background in electronics and computers. He worked at the Karolinska Institute in Stockholm and as a consultant to Nokia in Finland. Keith started the largest Macintosh Users Group outside the US. He later founded two software development companies and sold one of the products to a well-known Silicon Valley company. Keith is presently promoting the development and deployment of Amateur Radio IP networks in the Washington, DC area and produces the website www.maipn.com. You can reach Keith at 601 Wilson Place, Frederick, MD 21702-4113 or mesh@kb3tcb.com.

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