High-Speed Wireless Networking in the UHF and Microwave Bands

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This paper discusses building an amateur radio wireless network using commercial off the shelf wireless networking equipment that is currently available. As an example, four Ubiquiti NanoStation M3 3.4 GHz digital radios are used to assemble a demonstration network of two wireless network links that operate on two different frequencies. In conclusion, the paper invites the amateur radio community to build a nationwide high-speed amateur radio wireless backbone network to connect local amateur radio area community wireless networks.

Keywords: airMAX®, airOS®, broadband, Ethernet, TCP/IP, Ubiquiti, wireless networking

Introduction

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 that will emerge in the next twenty five years [W1RFI]. This motivated me to action, to start thinking about and planning to build with fellow radio amateurs a national ham 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 [Doodle]. I purchased several several of these data radios to experiment with some members of Montgomery Amateur Radio Club (MARC) [MARC], my local amateur radio club. In addition, we experimented with wireless mesh networking on 2.4 GHz using Linksys WRT54GL Wi-Fi routers [WRT54GL] that we reprogrammed with Broadband-Hamnet™ firmware [BBHN 1]. In the September 2012 Digital Communications Conference (DCC), I presented our results of our experimentation with the Doodle Labs data radios [W2LNX 1]. At the end of 2013, Keith, KB3TCB contacted me after watching the HamRadioNow video of the 2012 DCC presentation [W2LNX 2] and, recently, we decided to collaborate on establishing a high-speed network link between locations in Frederick and Montgomery counties in Maryland. In early 2014, Bill, W3MSH contacting me after also watching that HamRadioNow video. We were inspired to take a look at the ARRL band plan [band plan] and we discovered that 3.3 GHz to 3.5 GHz is an amateur radio frequency allocation. So the question arose: is there any commercial off the shelf (COTS) wireless networking equipment that we can use? We discovered that Ubiquiti is manufacturing and selling their airMAX family of products [airMAX] and are selling 3.4 GHz to 3.7 GHz equipment for export from the United States. We realize that we can use airMAX NanoStation M3[1], NanoBridge M3 and Rocket M3 equipment in the 3.4 GHz to 3.5 GHz amateur radio frequency. I had decided to purchase airMAX M3 equipment since it is in the 3.4 GHz amateur radio frequency and it is not shared with unlicensed users such as in 2.4 GHz and 5 GHz bands. The challenge was to find one or more Ubiquiti dealers who

1 Ubiquiti designates their airMAX M family of equipment as M900, M2, M3 and M5 to indicate 900 MHz, 2.4 GHz, 3.4 GHz and 5 GHz frequency bands, respectively.

were willing to sell to US radio amateurs since the M3 is for foreign export. I was able to buy M3 equipment from Streakwave [Streakwave] after proving to them that I am a licensed US radio amateur and that US radio amateurs indeed have a frequency allocation at 3.4 GHz [FCC]. I also was able to buy M3 equipment from from Distriwave [Distriwave]. This was when we realized the possibilities of buying and using commercial off the shelf (COTS) wireless networking equipment for use on amateur radio frequencies. But more importantly, we realized just about everything that we learned about consumer 802.11 wireless networking has now become part of amateur radio. This is a big idea.

Another source of inspiration is the free book **Wireless Networking in the Developing World** [WNDW]. We discovered that there are large numbers of volunteers, not necessarily radio amateurs, who are actively installing high-speed wireless networks with inexpensive equipment all over the world and especially in the developing world. It is a practical handbook for installing commercial wireless networking equipment. It starts with the basics of radio science and then introduces basic networking. Then it follows with a practical guide on installation and deployment. The book also many references and several useful appendices. Much in this book is directly applicable to what US amateurs are trying to accomplish.

Demonstration 3.4 GHz wireless network

We set up a demonstration network with two wireless links using four NanoStation M3 data radios [NanoStation], two Grandstream GXP1105 IP phones [GXP1105] and one FOSCAM FI8910W IP camera [FI8910W], a Windows 7 netbook computer and a Windows 7 laptop computer.

Figure 1

Figure 1 shows a data radio station assembled with a NanoStation M3 and an inexpensive Grandstream GXP1105 IP phone. Note that red Ethernet cable is directly connected between the Secondary Ethernet port of the NanoStation M3 and the GXP1105 IP phone. A 24 volt power over Ethernet (POE) device powers the NanoStation M3 over an Ethernet cable. A computer is optionally connected to the

NanoStation M3 via the POE device with an Ethernet cable. Also, the GXP1105 is powered by 5 volts which is obtained with a 12 volt to 5 volt USB power adapter that provide a current of at least one-half an ampere. Two of these GXP1105 IP phones are configured with a unique IP address. One IP phone can call another IP phone on the same network by dialing the IP address of the other phone.

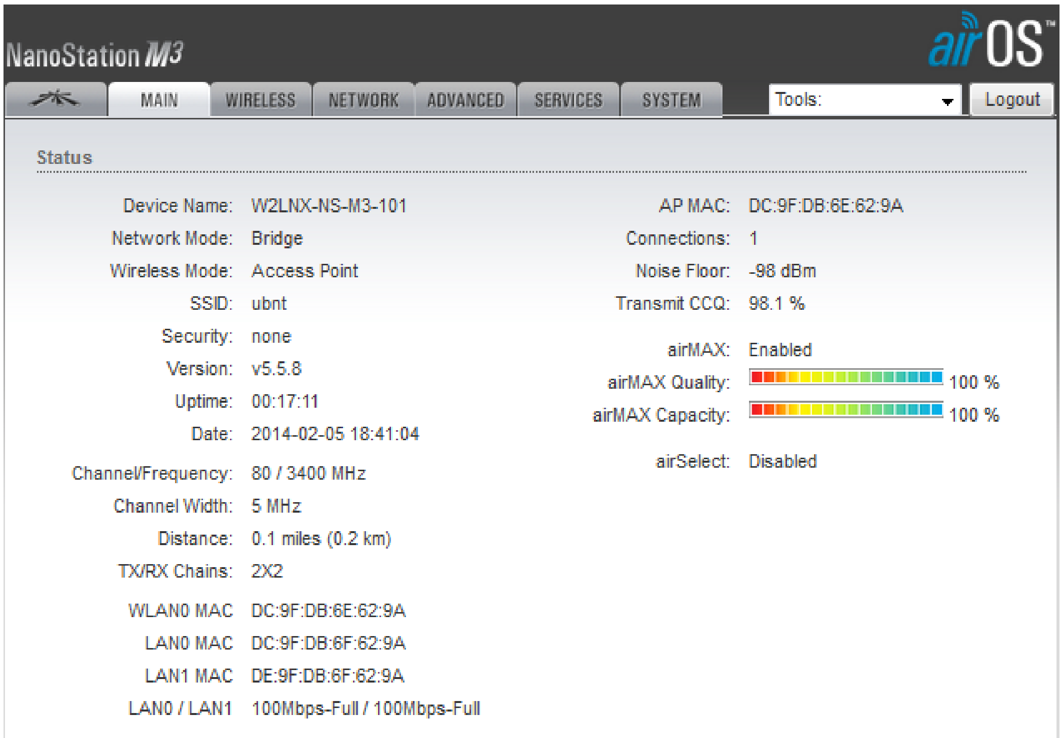

Figure 2

Figure 2 shows in greater detail how a NanoStation M3 is configured. The NanoStation M3 is configured as a bridge at the network layer by setting Network Mode to Bridge. This sets both Ethernet ports and wireless interface all have the same MAC address and the same IP address. This means that any packet that appears on any interface will appear nearly immediately on the other two interfaces. This is necessary for establishing a wireless data link between two NanoStation M3s. A NanoStation M3 needs to be configured as a station[2] (Wireless Mode: Station) so it can connect to another NanoStation M3 configured as an access point (Wireless Mode: Access Point). So, a **point-to-point wireless link** can be established using a Access Point and Station NanoStation M3 data radio pair. The wireless link acts as a wireless Ethernet cable: any data the enters an Ethernet port on one NanoStation M3 with appear on an Ethernet port of the other one. A NanoStation M3 provides a visual indication that a link has been established when one or more signal strength LEDs on its back light up.

The demonstration wireless network shown in Figure 3 consists of two wireless data links. Each NanoStation M3 in the network is assigned its own static IP address. The first link is configured to communicate at 3400 MHz and the second link is configured to communicate at 3450 MHz. The second and third NanoStation M3s are interconnected with an Ethernet cable. That Ethernet cable is connected between the Secondary Ethernet port of the first NanoStation M3 and the Main Ethernet port of the second NanoStation M3. So these two NanoStation M3s form a **network relay station**[3]. Functionally,

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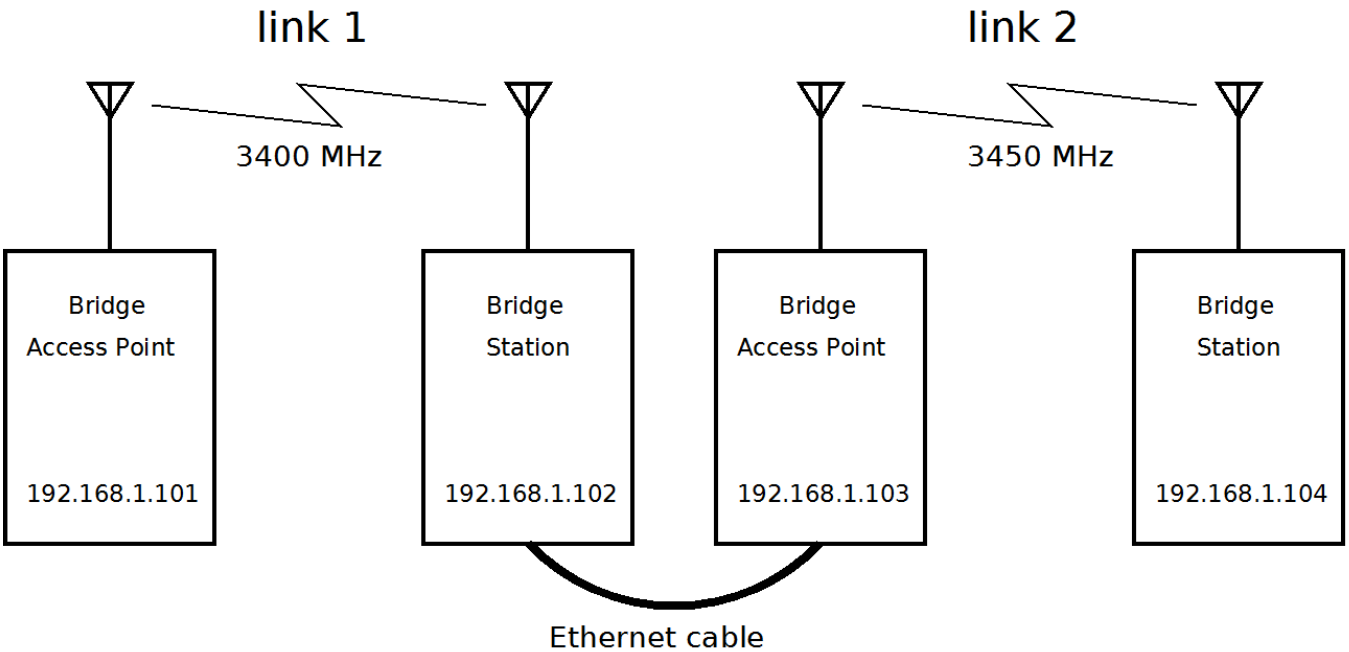
2 Ubiquiti uses the term “station” to indicate a wireless client that connects to a wireless access point.
3 This is in keeping with the spirit of the American Radio **Relay** League centennial celebration [Centennial].

a network relay station is the same as a human operated relay station from a century ago except that today it is automatic, is smaller, uses less power, operates at higher frequencies, is more reliable and is less expensive. It is truly a relay station since all packet traffic is exchanged between the two wireless



links.

Figure 3

Figure 4 shows another view of the demonstration network. This screen shot was obtained by selecting the Discovery tool from the Tools: drop-down menu list shown next to the airOS logo in Figure 2. It provides the Device Name and the IP address of every data radio station device on the network. In addition to airOS Discovery tool, Ubiquiti provides a stand-alone device discovery tool that is available for download [discover]. A data radio station on the network can identify itself by setting its amateur radio callsign in the initial part of the Device Name. In this example, the Device Name callsign is W2LNX.

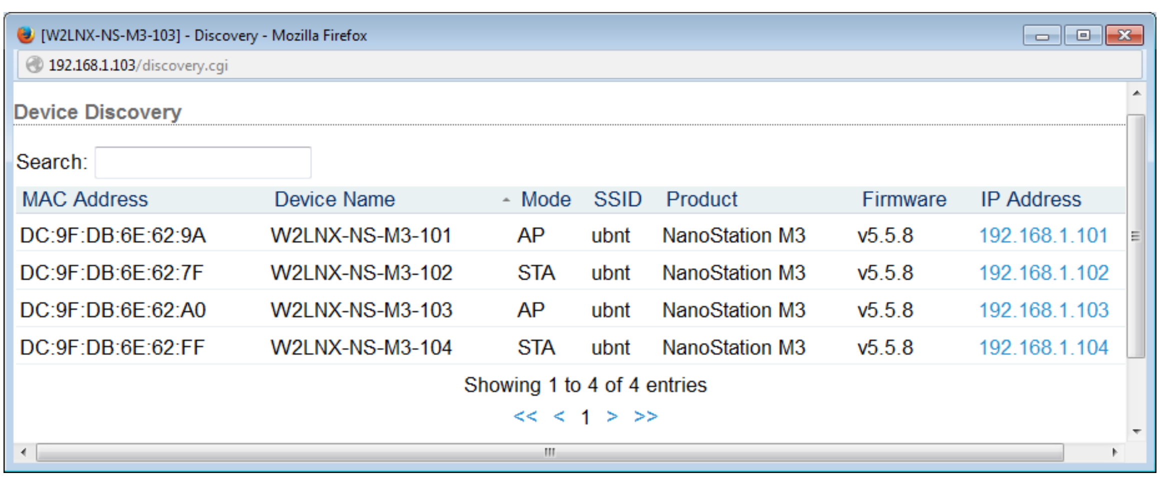


Figure 4

More importantly, every station on the network can announce its IP address. This provides us with the opportunity to let every data radio station on a wireless network to select its own unique 32-bit IP address. We developed a scheme shown below in the appendix that encodes the latitude and longitude of a station within the contiguous 48 states of the United States into a unique 32-bit IP address. Stations at least 4.8 km (3.0 miles) apart are guaranteed to have distinct IP addresses. This is important since it allows independent stations to announce their IP address without the need for a central source on the network to assign them an IP address. This is consistent with the important network design requirement of avoiding any single points of failure.

Figure 5

Figure 6

Figure 5 shows two NanoStation M3s of the network relay station mounted back-to-back with a red Ethernet cable connected between the two. There is no radio interference between them since they are on two different frequencies 50 MHz apart. As an option, an IP camera such as the FOSCAM FI8910W IP camera as shown in Figure 6 can be mounted on top of the relay station and connected directly to the network with an Ethernet cable. That Ethernet cable is connected between the Ethernet port of the IP camera and the Secondary Ethernet port of the second NanoStation M3 of the network relay station.

We discovered that a NanoStation M3 data radio can be conveniently powered by a 12 volt power source using an inexpensive Tycon passive POE device [TYCON] with a current of about one-half an ampere. The first NanoStation M3 of the relay station powered by the 12 volt power source is connected to an inexpensive Watt Meter [Meter]. This meter is important since it allows us to monitor the voltage level of a 12 volt lead-acid AGM battery and the consumed energy in ampere-hours. The rule that we follow is that we do not permit the battery to deplete below 12.0 volts and we do not consume more than half the ampere-hour rating of the battery. For example, the two NanoStation M3s in Figure 5 together draw about one ampere. So an 18 ampere-hour battery can easily provide about eight hours of continuous operation. The red Ethernet cable, in addition to being a network connection between the two NanoStation M3s, powers the second NanoStation M3 with power from the first NanoStation M3 by enabling POE power on the Secondary Ethernet port of the first NanoStation M3.

Discussion

In many ways, the amateur radio hobby is a reflection of our society. Thirty, forty years ago radio stations on the broadcast and shortwave bands were huge and expensive systems and amateur radio operators reflected this by building smaller versions of these radios stations. Today, short distance high-speed commercial wireless networks have become available everywhere. It is available in our homes, passenger trains, passenger jets, public libraries, cafes and just about everywhere. Our personal telephones have become sophisticated pocket computers with attractive displays that are connected to a high-speed wireless networks. It has become part our modern society. Young people today have come to expect this and to make amateur radio attractive to these people, we need to provide a communications environment and platform that they would find familiar and that they would find attractive to learn more about so that they would want to get their amateur radio license. Their amateur radio license would permit them to experiment at the radio level and at the link level of the network. They would learn about networking by using it, learning how it works at as great a detail they wish but, more importantly, contribute to the network by extending the network and by developing applications that they can share with fellow radio amateurs. Today, we have the advantage of applying and adapting networking techniques and protocols that has been developed in the last 40 years to build an amateur radio wireless network and by taking advantage of inexpensive high quality commercially available wireless networking equipment.

So the question we get is: what is an amateur radio high-speed wireless network? The following quote explains this:

> The “hinternet”[4] can support most of the traffic that the Internet currently does, including video chat, voice, instant messaging, the Web (HTTP), file transfer (FTP), and forums. The only differences being that on the hinternet such services are community instead of commercially implemented and the “hinternet” is mostly wireless [HSMM].

Another question we are often asked is what can we with do with this network and our answer is, for starters, that many popular amateur radio applications currently running on the Internet can migrate to this high-speed wireless network. One example is digital repeater linking between D-STAR repeaters or D-STAR repeaters and their remote satellite D-STAR “hotspots”. Even for analog FM repeaters, audio from their remote repeater receiver sites can be brought back to the main repeater sites over the amateur radio wireless network.

We are also asked if our intent is to replace the Internet with an amateur radio wireless network and our

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4 The name *hinternet* comes from a combination of the words *ham* and *Internet* and can be used to refer to any high speed data network over amateur radio, not just 802.11 networks [HSMM].

answer is “no” and, in addition to providing amateur radio communication within the amateur radio wireless network, we can extend the reach to the Internet on a case-by-case basis. For example, the purpose of the Winlink email system is to send email over amateur radio to an Internet access point at a distant location. Currently, email sent over Winlink requires a direct radio link between the Winlink user on HF or VHF to a remote Winlink server. Using the amateur radio wireless network, a Winlink user can have an additional means to connect to a remote Winlink server to exchange email traffic with the Internet.

Today, radio amateur are building high speed amateur radio wireless backbone networks all over the country using 2.4 GHz, 3.4 GHz, 5 GHz, and even 900 MHz commercial wireless networking equipment. Some examples include the original Broadband-Hamnet mesh network [BBHN 2], British Columbia Wireless Amateur Radio Network [BCWARN], the Seattle area HamWAN network [HamWAN], [K0RET] and [AE7SJ], the Baltimore Radio Amateur Television Society 5 GHz network [BRATS] and the Central Pennsylvania IP Network [CPIN]. More examples are listed in Keith's **Amateur Radio computer compatible Networks** Website [KB3TCB] as they go into service.

Ultimately, amateur radio end users are going to communicate over the high-speed amateur radio wireless network. They will want to connect to that network and not all end user will have direct access to the high-speed backbone network. Some will require radios at lower UHF frequencies such as 70 cm that provide slower speeds. Such new UHF data radio products currently being developed include the UDRX-440 UHF digital radio [UDRX-440] and [K7UDR], the CS7000 UHF data radio [Wanger], and the Whitebox data radio [Whitebox] and [KD2BMH].

Continuing work

Building 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 to 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 locations using high-speed wireless equipment in the microwave range. For example, two inexpensive Rocket M3 digital radios [Rocket] and their reflector dishes [RocketDish] as shown in Figure 7 can provide at least a 30 km (18.6 mile) point-to-point link[5]. Several point-to-multipoint wireless links can be established by using a Ubiquiti 3 GHz 120 degree sector antenna [Sector] as shown in Figure 8 together with a Rocket M3 data radio configured as an Access Point.

  One of the requirements is that a station on the backbone network needs to have confidence that network traffic originating from a neighboring backbone station can be trusted to be in fact coming from that neighbor and not from some bogus station. What authentication protocols are available that can be used to authenticate neighboring backbone stations? How can the digital authentication certificates issued by the ARRL for their free Logbook of the World logging system [LOTW] be used to authenticate neighboring backbone stations? Heikki Hannikaninen,

5 This is about the distance between Braddock Heights, MD and Damascus, MD of a link using two 5 GHz RocketDishes [KB3TCB] with a speed test showing an average of 3.0 Mbps receive and transmit speeds.

OH7LZB discussed this in his presentation at the 2013 Digital Communications Conference [OH7LZB].

Figure 7

Figure 8

- building local area wireless community networks – local groups of radio amateurs will need to build local area wireless networks at lower UHF frequencies to be able to gain access to a high-speed station on the backbone network. In addition purchasing new UHF digital radios as mentioned above, what can we do with existing radio equipment that amateurs already own? For example, what can we do with the 9600 bps data ports that are in the back many VHF and UHF radios[6]? Can someone develop an inexpensive GMSK 9600 bps modem that can be plugged into these radios? What can we do can with 1200 bps TNCs that many hams own? What can we do with the robust data modes available in *fldigi* [fldigi]?

- developing network applications – existing Internet applications such as text messaging, file transfer, VOIP, email, and Web services can be migrated to the amateur radio wireless network. In addition, existing amateur radio Internet applications such as Winlink [Winlink] and APRS [APRS] can be migrated. It is up to the imagination and initiative of individual hams and groups of hams to migrate existing applications to the network and to invent new ones.

- testing and evaluating wireless networking equipment – we plan to do more range testing with Ubiquiti airMAX equipment that we have to collect data on the performance and the characteristics of 900 MHz, 3.4 GHz and 5 GHz. Also, we plan to test and evaluate the new UHF data radio products when they become available and share our results with the amateur radio community.

6 These are a not true 9600 bps data ports; they are raw audio connections before the FM modulator stage and after the FM demodulator stage. Digital data needs to shaped into an appropriate waveform such as GMSK before it is modulated.

Conclusions

Now is an exciting time in amateur radio. It is clear in our minds that a high-speed amateur radio wireless backbone network is being built today and local area community wireless networks are being built today or in the planning stages to be built. High-speed commercial wireless networking equipment is available today and the slower speed UHF data radio products and projects are actively being developed and will be available soon. We are inspired by the Winlink project since it is an example of a group of radio amateurs who working closely as a team over many years have built a remarkable amateur radio email system. Similarly, another inspiring example is the development of the Broadband-Hamnet mesh software system by a dedicated group of radio amateurs. In addition, to having fun learning, experimenting with and building this network, we will have more communications tools for emergency amateur radio communications from distressed areas.

Acknowledgments

A project as large as this one requires the ideas and work of many people. I especially want to acknowledge Keith, KB3TCB as my co-author of ideas who is equally as enthusiastic as I am about building a national amateur radio high-speed wireless communications network. I've enjoyed many hours with discussions and friendly arguments which helped me shape and clarify many ideas in this paper. I want to acknowledge Phil Karn, KA9Q, who inspired me over 25 years ago to learn and experiment with amateur radio digital communications. I want to also acknowledge Abbey Alpern, N3WKO, who put up with my ham radio networking equipment strewn all over the house for this project; Afy Shahidi, who keeps me healthy so I can work on ham radio projects; Bill Kisse, W3MSH, who suggested that we look for commercial wireless equipment in the 3.4 GHz ham radio frequency allocation; members of the HacDC Amateur Radio Club [HacDC:ARC] for their infectious enthusiasm and eagerness to learn; and Earl "Terry" Sharar, W3EDS, who is planning with us to establish high-speed network network links between the MARC repeater sites and and points beyond.

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corrected: September 4, 2014

Keith and I would like to hear from you about your wireless networking projects. Please email requests, questions, ideas, suggestions and comments to `w2lnx@arrl.net` or to `mesh@kb3tcb.com`

Appendix: Obtaining an IP Address from Latitude and Longitude

Unique to all amateur radio stations is their latitude and longitude of their location. Drawing inspiration from the Maidenhead Locator System, also known as grid locators or grid squares [grid squares], a scheme was devised to encode the latitude and longitude of a station into a number to form a 32-bit IP address.

Forty eight states of the United States

A map of the contiguous forty eight states of the United States is roughly rectangular where its width is roughly twice its height as shown in Figure 9. The two longitude lines are inclined to show that longitude lines converge at the North pole. Illustrating this is that the distance between the SW point and SE point on the map is about 5955 km (3700 miles) on 24 degree North latitude and that the distance between the NW point and the NE point is about 4104 km (2550 miles) on 50 degree North latitude.

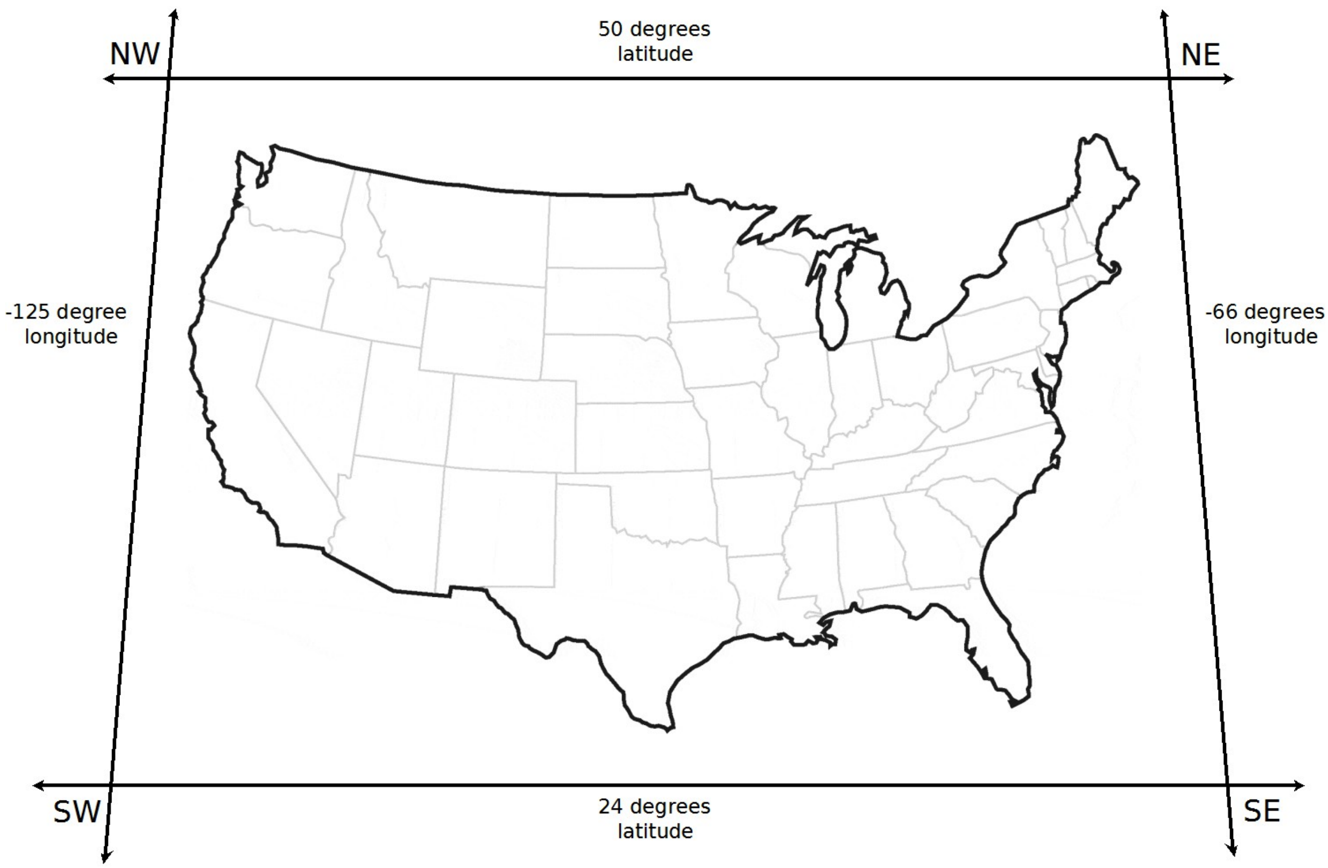

Figure 9

The latitude and longitude of a station are encoded into a number to form a 32-bit IP address. The 59 degrees between -125 and -66 degrees longitude are divided into 2048 units and, likewise, the 26 degrees between 24 and 50 degrees latitude is divided into 1024 units.

The bits in a 32-bit IP address are allocated as follows:

- 8 bits – reserved for a class A network address
- 21 bits – merged longitude and latitude bits:
  - 11 bits – the longitude of the station between -125 degrees West and -66 degree West starting from -66 degrees West
  - 10 bits – the latitude of the station between 24 degrees North and 50 degrees North starting from 24 degrees North
- 3 bits – 8 IP addresses for use at a station

The 10 latitude bits are interleaved between the 11 longitude bits giving a 21 bit number. The idea of interleaving the latitude and longitude bits is suggested by alternating the latitude and longitude codes in Maidenhead Locator System. This has the advantage that the 21 merged longitude and latitude bit values are numerically close for stations that geographically close. Stations at least 4.8 km (3.0 miles) apart are guaranteed to have distinct IP addresses [distance].

Example: Using Google Maps to obtain the latitude and longitude of Pike's Peak wireless network site:

latitude: 38.841780 N

$$round\left(\frac{38.841780-24}{50-24}1024\right) = 585 = 1001001001$$

longitude: -105.043821 W

$$round\left(\frac{105.043821-66}{125-66}2048\right) = 1355 = \mathbf{10101001011}$$

merging the latitude bits between the longitude bits yields

1 1**0**0**1** 0**0**1**1** 0**0**0**0** 1**1**0**0** 0**1**1**1**

shifting left three bits and subdividing into three decimal octets yields

11**0**0 **1**0**0**1 **1**0**0**0 **0**1**1**0 **0**0**1**1 **1**000 = 201.134.56

Hence, using the 10.X.X.X private network IPv4 address space, the eight IP addresses available at the Pike's Peak wireless network site are

10.201.134.56 to 10.201.134.63

The world

A similar scheme can be devised for the whole world assuming all all 32 bits are used in an IP address. Stations at least 4.0 km (2.5 miles) apart are guaranteed to have distinct IP addresses [distance].

The bits in a 32-bit IP address are allocated as follows:

- 2 bits – unused
- 27 bits – merged longitude and latitude bits:
    - 14 bits – the longitude of the station between -180 degrees West and 180 degree East starting from -180 degrees West
    - 13 bits – the latitude of the station between -90 degrees South and 90 degrees North starting from -90 degrees South
- 3 bits – 8 IP addresses for use at a station

Example: Using the latitude and longitude of Pike's Peak, the eight IP addresses available at the Pike's Peak wireless network site are

19.205.204.40 to 19.205.204.47

Python code implementing this scheme is available at the BOAR-net Web site [BOAR-net].

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