Recent Hubmaster Networking Progress in Northern California

Glenn Elmore N6GN
Kevin Rowett N6RCE

Abstract

This paper describes the authors' progress toward implementing a prototype digital amateur network in Northern California. A goal of the network is to provide network layer user access and high enough performance to allow a wide range of applications, both old and new, to coexist on a single network built and maintained by all users.

Papers in previous proceedings from this conference have addressed the implications,[1][2] portions of an implementation,[3][4] and a proposed protocol[4] of a higher speed wide area amateur radio network.

This paper is a brief description of some of our further progress towards implementing a prototype network in Northern California and of some of the practical issues which must be addressed when a wide area and medium performance amateur network is built.

"Coordination" is truly the key word with regard to building a significant and effective amateur radio network.

Our goal has been to prototype a network providing Layer 3 access by users and providing moderate performance, speed and latency for demonstration of concept and use by Northern California amateurs.

As we have written before, the task of coordinating a physically distributed and diverse group of resources is proving to be the most difficult aspect of developing a prototype network. As interesting and challenging as they are, the physical fundamentals, hardware design and communication protocols needed to build a network are only a part of the overall problem. Finding ways to coordinate at all levels and thereby optimally apply available resources is proving to be the common theme.

"Coordination" is truly the key word with regard to building a significant and effective amateur radio network. For this reason, examining the necessary aspects of coordination at various layers of the OSI networking model is useful for describing our progress locally as well as describing some of what others will need to do if the dream of a wide area moderate performance digital amateur network is to become a reality.

Physical Layer

Directional Antennas and Installation

A previous paper[2] has described why directive antennas and higher frequencies must be used to achieve our goals. Directional antennas are inherently a form of coordination since they must be pointed in the direction of the other end(s) of a communication link.

Since our last report we have put considerable effort into building and measuring radios and antennas for the 33 cm band. We have also made measurement of path loss over both line-of-sight (LOS) paths and paths obstructed by trees and other vegetation. The effect of obstruction on distortion of digital data streams has been observed.

Several of the 13 element yagi antennas previously described have been independently built by N6GN, N6RCE and N6OLD. The first design resulted in about the correct maximum gain, 15.3 dBi, but at approximately 2% lower than the desired frequency. The next version was modified to correct this and vector network analyzer measurement of an identical pair as well as remote measurement with a 10W transmitter, indicated greater than 15 dBi gain for each antenna.

A commercial colinear antenna was purchased for use at the center of one of the Hubmaster clusters. It was also measured and showed a gain of approximately 11 dBi which, while considerably less than the manufacturer’s published specification, is about correct for its size was as anticipated.

Measurements of our 10 watt transmitters over LOS paths, from 50 feet to 70 miles, has basically confirmed antenna gain measurements which were separately performed. In all cases the measured received signal strength was well within the measurement uncertainty of the value predicted by theory. Numbers within 3 dB of theoretical were always achieved even on the longest paths.

One of the results of these measurements was an emphasis on the importance of antenna mounting. In order to achieve expected antenna gains, the 900 MHz yagi antennas need to be positioned at least 10-15 feet above ground and nearby clutter such as roofs and trees. If this is not done, the main lobe can be deflected upward with a resultant reduction in gain in the direction of the horizon. The vertically polarized colinear needs to be similarly located and must not have clutter in its vicinity if best performance is to be obtained. Improper antenna mounting can easily result in the loss of several dB in received C/N.

Site Selection

Probably the most important lesson learned is the importance of locating antennas and sites to allow completely LOS paths. We found that even mild suburban clutter; trees, bushes and buildings, can degrade signal strength by 20 dB or more. Worse yet, it can contribute greatly to multipath distortion caused by differing wave arrival times which can create time jitter of the data edge and ultimately limit the maximum signalling rate (baud). With indirect paths we observed peak-peak variation of as much as 500 nanoseconds. These numbers are very much in agreement with published reports pertaining to cellular telephone systems operating between 800 MHz and 900 MHz[7].

Figure 1 illustrates the importance of obtaining a completely LOS path for each link. The effects translate directly to out-of-pocket expense for the user. It also

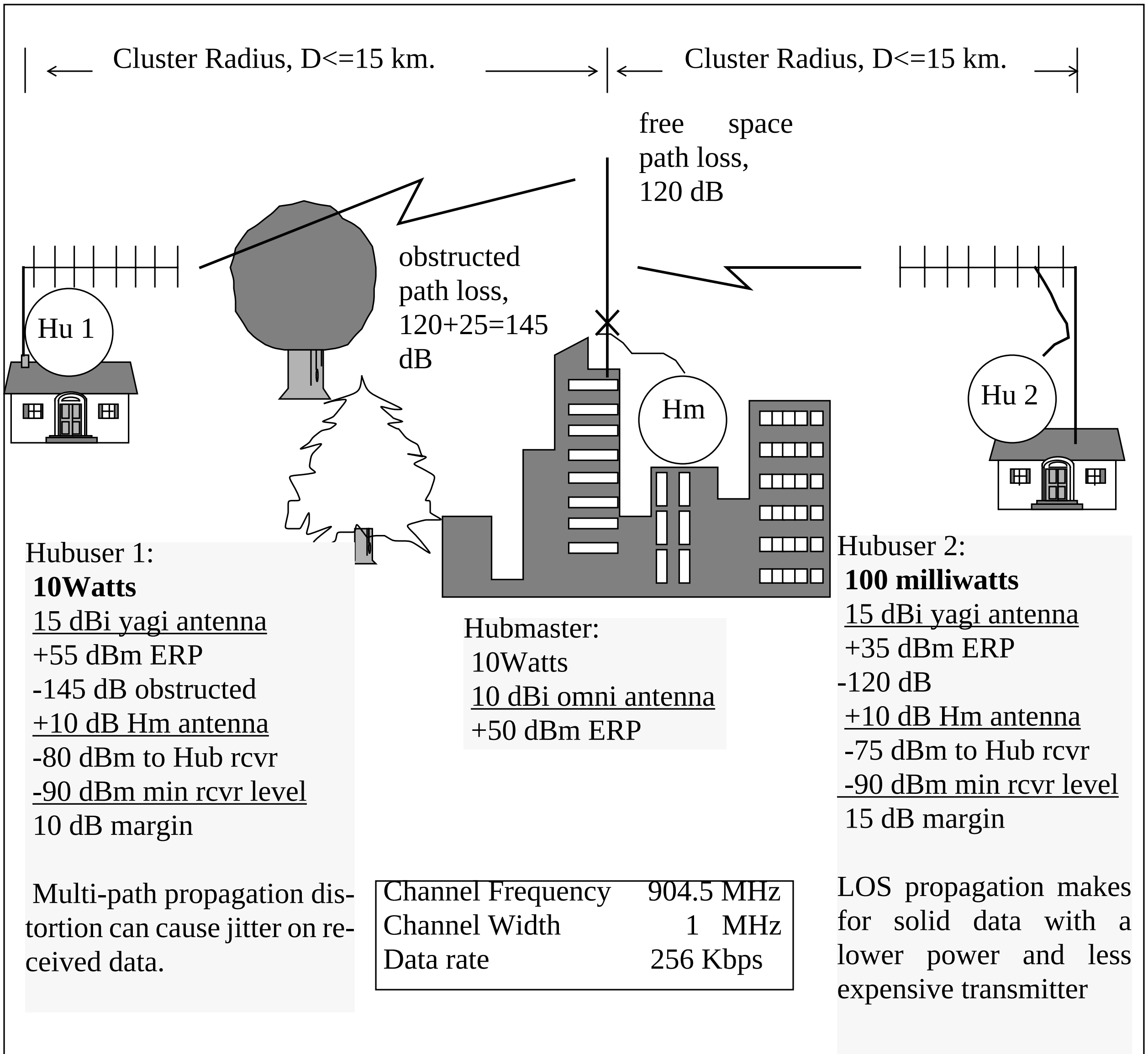

Figure 1. Good hub and user antenna site selection can translate directly to lower out-of-pocket radio expense as well as to higher data throughput.

indicates the importance of careful selection of the Hubmaster site. While the hub doesn't have to be and shouldn't be high level, it should be LOS to each of the anticipated users. It is not necessary that the hub be at the physical center of a group of users. A very viable alternative is to locate it outside the cluster of users and use an antenna with directivity in both azimuth and elevation instead of the colinear with its omni-pancake pattern. This alternative is shown in cluster 1 of Figure 2. The hub directional antenna should be chosen with a beamwidth just

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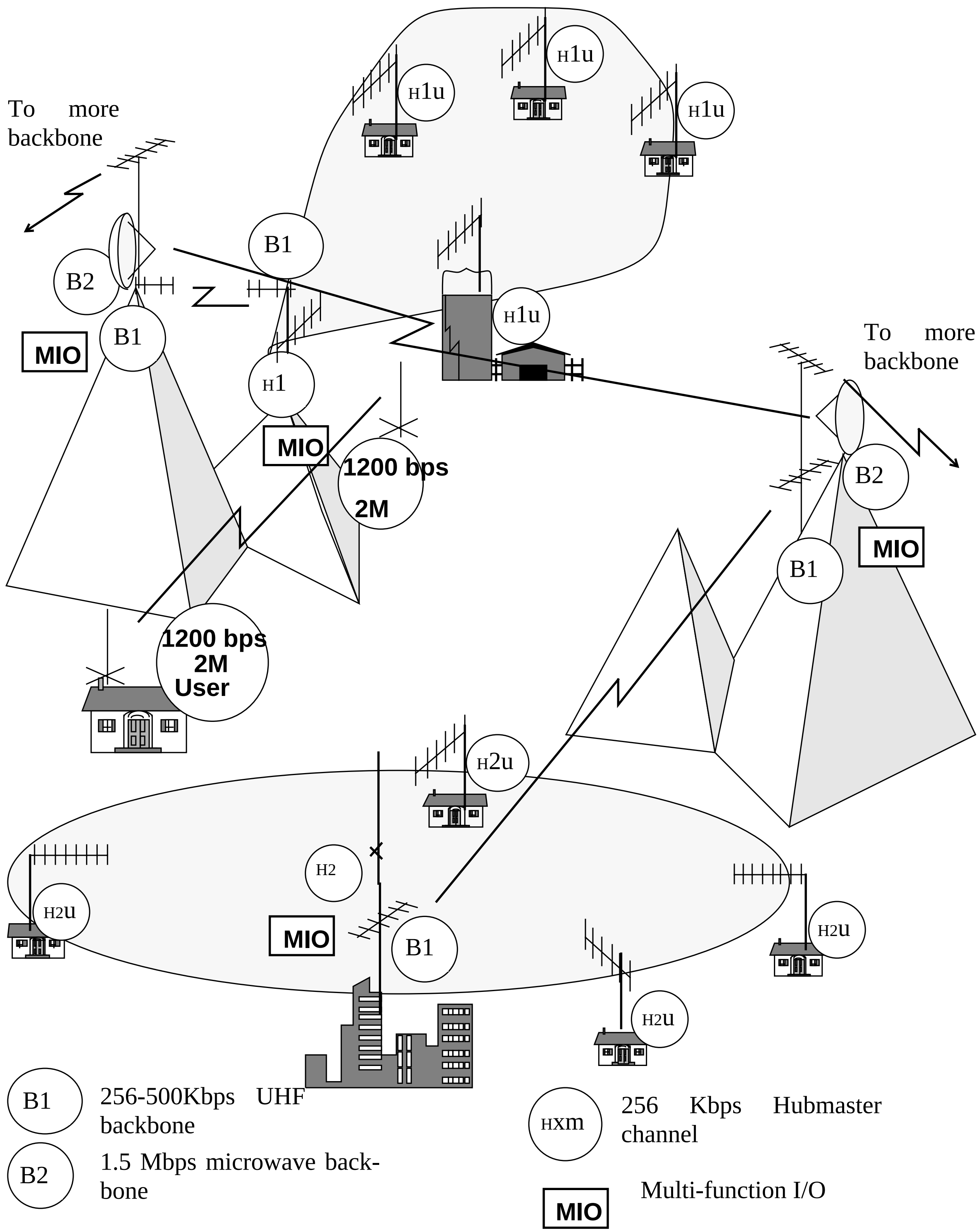

Figure 2. Common backbone and both high and low performance user access is provided in this example. LOS paths and directional antennas provide high performance with relatively inexpensive hardware.

sufficient to include the cluster members.

It is difficult to overstress the importance of carefully selecting the path and site although the results of not doing so are readily apparent. For a well located hub, tenth-watt radios appear to be very satisfactory for all users. This can result in excellent network performance with plenty of margin at minimum cost. If indirect paths are attempted even 10 watt or bigger transmitters may be insufficient and the accompanying distortion and path variations may make the resulting performance far from satisfactory even if higher gain antennas are used.

Getting good results from this higher speed network hardware will require special attention to the installation at each amateur's station. Instead of simply connecting a groundplane mounted on a window sill to an HT, as is commonly done now on the 2M band, the user will need to find a location with an unobstructed view towards the cluster server and mount a directional antenna. The directional antennas we have been using are homebrew yagis about 5 feet long but commercial antennas of similar performance should be just fine also. By working together with the other members of the local cluster to find a server site which is LOS to all members' antennas even inexpensive 100 milliwatt digital radios should be able to provide excellent results. Generally, mounting the antenna at least 10-15 feet above the ground and roof and in a position where it can "see" the hub server antenna combined with using good quality feedline like Belden 9913 works fine.

By keeping the total number of users of the cluster small, perhaps 6 - 10, each user can have a guarantee of high data rate and low delays for his communication. As other local amateurs see exciting new applications which higher speed networking can offer they may be encouraged to work together to add additional clusters. Adding well situated clusters instead of adding users to existing clusters can allow everyone to experience the same excellent service at the lowest cost. Adding a cluster does require additional hardware for the server but this cost can be shared among the users in the same way that repeater clubs share hardware expense. The benefits of maintaining small cluster size by limiting the maximum number of users and choosing a server site which is completely LOS to each member far outweigh the slight additional per-user cost of the extra server hardware.

Elevation Profiles

Site selection is just as important for inter-cluster (backbone) communications. In seeking optimum sites for backbone hardware we spent many hours with topographic maps trying to determine good potential sites. After much consideration and reducing the possibilities down to a small number of likely candidates an extremely useful tool was made available by Rich Biby of Communications Data Services Inc. He has made an elevation profile database available to radio amateurs for non-commercial use. We would like to thank him for the use of this database since we were able to very rapidly discover that several of the candidate paths and sites were in fact obstructed and *not* LOS. This prevented the expenditure of what would have been a lot of unproductive effort. Upon re-examination, the obstructions were visible on the topographic maps we used but were easily overlooked.

A graph of a path which did prove useful and was measured is shown in

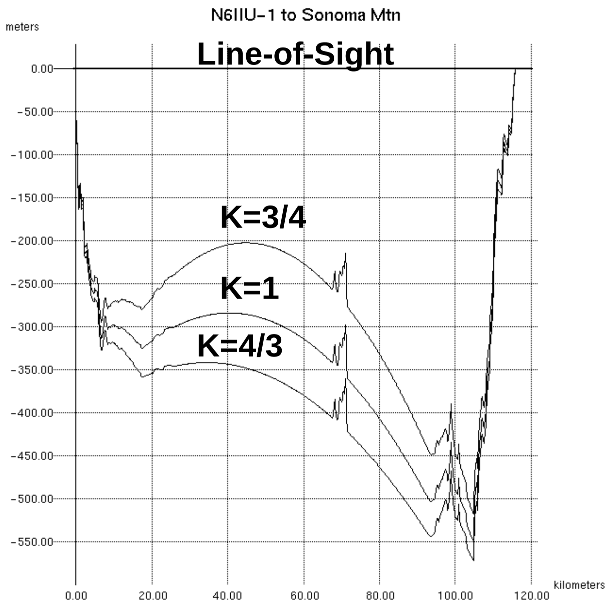

Figure 3. Elevation profile plot of a proposed N-S backbone path across the Golden Gate.

Figure 3. Three different K factors representing different effective earth radii are shown. Since this particular path is across the Golden Gate, the entrance to San Francisco Bay, it has moist marine air flowing in and out on a daily basis and may be a very difficult radio path. This movement can alter the refractive index and "de-steer" radio waves. For this reason earth curvature greater than actual (K < 1) is included. The K=4/3 value is a typical value to account for the nominal radio horizon being greater than the optical horizon. This is one of the paths actually measured and appears to have enough vertical clearance to promise communication unobstructed by terrain even in the worst of situations. By situating the ends at similar elevations we hope to minimize problems due to "layering" of air masses.

Spectrum Assignment

Since higher performance networking requires greater channel bandwidth, spectrum sharing is another form of necessary coordination. In Northern California the Northern California Packet Association is involved in coordinating amateur spectrum for packet use. By indicating our expected needs to the NCPA ahead of time, a few wider channels were allocated for higher speed networking use in both the 900 and 1200 MHz bands.

Modulation and Data Encoding

Because high speed digital radios are not presently common there hasn't yet been a great need to coordinate modulation schemes with other users. Although the radios we are presently building use FSK and operate at 256 Kbps, selection of modulation methods and coding schemes which are most economical and immune to multipath distortion is an area needing much further work. Certainly as the network grows it will be desirable for different radio hardware to be compatible.

In the same way that setting current NBFM radio deviation and frequency is important to achieve good performance it is also necessary that modulation levels and adjacent channel transmitter levels be controlled so that everyone can make good use of the amateur bands used for the network.

The present radios are being designed to fit into a 1 MHz channel with signals outside the band approximately 30 dB or more below the carrier. By operating the cluster and backbone radios with opposite antenna polarizations as well as using directional antennas, much greater isolation between channels is possible than would be afforded with only omnidirectional antennas.

Since prototyping and building two 10 watt 904.5 MHz digital radios with a "garage printed circuit board process",

Photo 1. The main board of one of the 10 watt 256 Kbps 904 MHz transceivers

twenty five sets of main and power amplifier boards have been commercially fabricated. Two 10 watt radios and two low power radios have been built from these newest boards. Several more 10 watt radios are currently in the process of construction and testing. A photograph of one of the 10 watt radios is shown in Photo 1.

The most recent radios have been redesigned slightly for operation in a 1 MHz instead of a 2 MHz wide channel using a lower first I-F at 29 MHz. They show good performance, BER below 1 x 10^{-6}, for signal levels greater than about -90 dBm.

Link Layer

As previously indicated, Hubmaster is a protocol designed as *a* solution to the problem of efficiently sharing a common channel by users using directional antennas and requiring LOS only to the hub. It is designed to be a useful solution for moderate speed networking, not as the only answer. Hubmaster is intended to give users equal access to the network and to provide throughput and latency performance sufficient to support a wide variety of amateur networking applications.

As amateurs seek even higher data communications speeds we anticipate a different link architecture and protocol to support full point-point physical layer hardware.

In order to develop the Hubmaster protocol as well as the simpler point-point communication for the backbone links we needed radios and antennas but also the digital hardware to control them. MIO is the platform we developed to provide this.

MIO features.

Multi-Function I/O adapter, or MIO,

Photo 2. Multifunction I/O, MIO, on the left with a 10 watt radio. The PC in the background is being used for software development.

was developed to provide the digital interfacing. MIO serves in the traditional TNC role of accepting data, getting them into the right link layer format and transmitted.

MIO is implemented as a full length ISA bus plug in card. MIO is actually a complete microcomputer system on a card including a NEC V40 microprocessor running at 8MHz, 768K of DRAM, two Enhanced Serial Communications Controllers (ESCC), up to 256K of EPROM (32 pin), and a shared memory interface to the ISA bus.

Programming and debugging software for MIO is done with the Borland BC++ V2.0 compiler and tools. These tools normally run on a PC and is the development environment presently in place for much of today's amateur radio software packages.

MIO will also function in a stand-alone or "hilltop" mode. The only necessary dependency MIO has on the ISA bus slot is for +5 VDC power. By supplying power and loading software into the EPROM, MIO can serve as a hilltop isolated packet switch. Software can also be loaded into DRAM over the air.

The serial ports in MIO consist of a pair of Zilog 85230 ESCCs. The 85230 is the next generation of the 8530 used in present TNCs. Four serial data channels are provided. Three of them are connected via direct memory access (DMA) to the V40 microprocessor (μP). One channel can provide full duplex at T1 (1.5 Mbps) serial data rates, two more can run half-duplex 256Kbps while the fourth is running in interrupt mode at 56Kbps.

The ESCC can provide full autovector capability to the V40 with hardware interrupt acknowledge. In most usages of SCCs, the device sends an interrupt to the µP which then begins to check each source of interrupt within the SCC to determine the cause. Autovectored interrupts allow the interrupt service routine to be specific to the cause of the interrupt. This saves machine instructions in interrupt processing allowing higher through-put at less overall system cost.

DMA data transfer can be programmed for three of the ESCC channels. In systems lacking DMA, transfers would be done via µP read/write to ESCC registers in an interrupt service routine. Hundreds of bus cycles would be required *per byte*. With DMA, only a few bus cycles are needed per byte transferred.

The connection to MIO for serial data is via a DB37 female connector on the end of the card. TTL logic levels are used. Normally TTL would not be a good choice for interfacing long, highspeed lines. However, this system is still in the experimentation phase and TTL used with external interface logic affords the most flexibility. +12 VDC at 500 ma from the PC bus is also available on the DB37 for powering interface conversion circuitry.

To date, interfacing has been built to support differential ECL to the microwave[5], and 900 MHz radios, an AM7910 for 1.2Kbps AFSK and high speed asynchronous serial RS232C for remote debugging.

The remainder of the logic on MIO consists of four PALs and eight MSI size gates all mounted on a four layer commercially produced PCB. It consumes 2.5 watts of power, similar to present TNCs.

The interface with the host PC is via one I/O-port control register, interrupts, and a shared memory window. The address of the shared memory window is set via the I/O-port control register. The size of the shared memory window can be set to either 8K or 64K. Future versions will be restricted to 8K. The idea of a 64K window was to minimize the move-in/ move-out nature of traffic, but MIO moves data across the bus at 97% of memory transfer rates, so that an extra copy was not too much of a performance problem relative to the line speeds of the serial ports. The I/O-port address is set via on-board jumpers.

The NEC V40 is an Intel-style architecture µP. Built into the µP are four DMA channels, an interrupt controller, three timers, bus interfacing logic, DRAM refresh, and external bus master control.

The V40 allows programming from a familiar environment with an existing set of tools. A PC can be used for development and code can be written in Borland C++. Stuart Phillips, N6TTO, in his usual get-the-job-done efficiency has developed a collection of tools which make programming and debugging MIO a dream[6]. First, one writes normal embedded C code with BC++. Then the code is TLINKed with a custom version of the BC++ startup file “C0”. TLINK produces the usual.exe file. The file is in normal.EXE format, with relocation items.

At this point N6TTO’s utilities really start to come into play. COMF takes the.EXE file produced by TLINK, fixes up all the relocation items and produces a.LOD file. The code file is now a memory image and is ready for loading onto MIO. Next a loader is supplied which will access the shared memory interface and load the file onto MIO so that execution can begin.

Debugging in an embedded environment is always a bit of a chore, since watching what happens can take expensive instruments. Again, N6TTO took on the task of developing special tools for MIO. BC++ is supplied with a graphic, screen oriented debugger called Turbo Debugger (TD). TD allows the developer to single step through a program in either assembler or C source lines. Break points can be planted for trapping. At the same time, the TD window displays the CPU registers, and data portions. Variables can be examined by name.

Borland supplies a version of TD called TDREMOTE that allows the target program to run in one PC while the debugger runs in another PC. The two PC's are linked via serial COM ports. N6TTO's MIOTDREM affords the same capabilities for debugging software on MIO.

A typical scenario would be MIO serving as a controlling point of a Hubmaster site. One serial port is connected to a 900MHz radio used to "poll" secondaries (users) in the cluster. Another port is hooked to a full-duplex microwave link (backbone) to other clusters. The third port could either serve as a connection to other clusters, or as a gateway port to 2M 1.2Kbps AFSK or a 56Kbps WA4DSY setup. The fourth port might be tied to a phone or leased line for non-RF access.

In this situation, the software on MIO would use the Hubmaster protocol to move traffic among the secondaries and to and from other clusters[4] as illustrated in Figure 2.

Progress to Date

To date, we've been able to get packets moving across the bench top by way of RF. On command from the PC, packets are sent out MIO via the ESCCs to a TTL/ECL interface and into one of the 904 MHz radios. Incoming packets from a second radio traverse the reverse of this setup and are examined on the target PC, which is the same PC as the source. This is simply back-to-back packets and something one could do with a null modem cable. In fact, that's how initial MIO testing started. Although this is a short RF path across a garage, signal strength and BER measurements over many different real paths give us confidence that these results will apply well to final installations into a network. During the first testing, software coding errors had the 256 Kbps radios running at something higher than the intended data rate; data was flowing at 624 Kbps!

At the time we write this the next task at hand is to reproduce this same test across a South Bay/North Bay RF path, with the data rate reduced to 256Kbps.

N6PLO is building a different I/O controller that will connect to any host with an ethernet port. Using a Zilog 16C50 DDPLL for decoding and clock recovery, he has developed an adapter for non-SCC serial interfaces, such as those provided by the Motorola 68302. Another short term goal is to demonstrate the interoperability of the two systems.

Network Layer

Amateur radio doesn't presently have an operational network layer. If amateur radio digital communications is to progress, a network layer needs to emerge. In this paper, we've detailed our progress in solving some of the physical and link layer issues. We've stressed the need for coordination and the direction technology must go to gain improvements in data throughput.

A network layer provides the "reachability" between two end points and the facility to extend communication beyond a single RF path. A network layer, if it's to serve the needs of all, must be transparent to the protocols above it, and needs to be able to maintain end-to-end "reachability", independent of the actions of the two communicating end-points.

The direction of amateur networking today is very much application specific. Operation is over connected mode AX.25. AX.25 is a link layer protocol which has been extended to function as a network and transport protocol all at the same time.

AX.25 is also a source routing protocol. Source routing presents the problem that the end points must get directly involved in how packets flow from end to end. Each end point must be prepared to deal with the dynamics of packet flow, including loss of various channels, congestion in a path, and path delay variances. Route discovery is complex as well. Multiple paths may exist between two end points. Which path is the best? Source routing makes end point nodes overly complex to manage and implement. This costs the end user money and performance.

AX.25 also lacks the necessary throughput algorithms to provide consistent service on faster links and diverse network paths. The AX.25 HDLC style go-back-N scheme doesn't have enough sequence space to keep faster pipes full. AX.25 could easily cause a 256Kbps channel to go as slow as today's 56Kbps or 1200 bps channels.

This paper is a progress report. Our previous papers give direction to a network layer. If you've read this far, you know we're barely past making link layer communications happen. The real point of our experiments is to provide amateur radio with a means to build a network layer. MIO is the first stop toward a network layer, layer three (L3), TNC.

A L3 TNC resides at the users location and serves as the connection point for end to end "reachability". The L3 TNC accepts packets containing transparent data and a destination address. It then uses the Hubmaster protocol to get the packet sent to the master. The master's routing table consists of entries with destinations or supersets of destinations, the next hop to the destination from this master and the number of hops from this master to the destination. When the layer 3 TNC frame arrives at the master this table is used to properly forward the packet.

Only master stations get involved in determining routes. The end point L3 TNC *and the users application* do not need to process routing information. Network operation will be transparent to the manner in which user applications access the network. User applications can be written without having to be tailored for each local network style.

Coordination Among Users

Perhaps the most difficult aspect of building a true amateur network relates to finding ways for the great number and diversity of amateurs to work together to achieve a common goal. In order for this common effort to occur, the many participants must be able to perceive and experience the benefits of network access. Each contributor must find a gain in his or her own area of interest.

Our desire is for users to view the network as a means of improving the quality and increasing the number of types of communication possible among all amateurs. The user's means of access, whether with conventional 1200 bps AFSK hardware or with much higher data rates supported with Hubmaster or other protocols, should not be connected with a particular service or application. Different amateurs interested in emergency communication, DX spotting sub-networks, experimenting with digital audio

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and those interested only in conventional electronic mail and BBS functions should each be able to pursue his own interests through identical connections to the network.

It is our desire that the connection of application with amateur band or frequency be eliminated. No longer would there need to be different frequencies for BBS traffic and access, keyboard-keyboard QSO and network experimentation. This will allow improvements in the network to be experienced by all. If a faster backbone is put into place, everyone can experience better performance. If previously unconnected subnetworks are bridged then everyone finds that their region of communication is increased. This commonality of resource provides the incentive for common effort towards implementation, support and improvement. Certainly for some applications higher performance user access will be required and higher frequencies will be necessary to support this but channelization based only on application can be eliminated. The idea of a channel "closed" to all but one kind of application can disappear.

Neither should the network be viewed as a particular set of protocols. Our desire is for an amateur network first not a TCP/IP or other particular protocol network. Nor is such a network just for "computerized" amateurs. We hope for information communications of all kinds, traditional and new, which can offer new relevance to all amateurs and new life and growth to the hobby as a whole.

References

[1] *The Implications of High Speed RF Networking,* Mike Chepponis, K3MC, Glenn Elmore, N6GN, Bdale Garbee, N3EUA, Phil Karn, KA9q, and Kevin Rowett, N6RCE, 8th ARRL CNC, 1989

[2] *Physical Layer Considerations in Building a High Speed Amateur Radio Network* Glenn Elmore, N6GN,. 9th ARRL CNC, 1990

[3] *Implementation of a 1 Mbps Packet Data Link,* Glenn Elmore, N6GN, and Kevin Rowett, N6RCE, 8th ARRL CNC, 1989

[4] *Hubmaster: Cluster-Based Access to High-Speed Networks,* Glenn Elmore, N6GN, Kevin Rowett, N6RCE, and Ed Satterthwaite, N6PLO. 9th ARRL CNC, 1990

[5] *A 2-Mbit/s Microwave Data Link,* ARRL Handbook for Radio Amateurs, 1991, 32-65

[6] *C++ for Embedded Systems,* Stuart Phillips, N6TTO, Dr.Dobb's Journal, 1991

[7] *IEEE Journal on Selected Area in Communications,* Vol. SAC-5, No. 2, February 1987