RF, RF, WHERE IS MY HIGH SPEED RF?

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Abstract

This paper presents some thoughts of where we are now and where we are heading in the RF hardware evolution of Amateur packet radio. It may be a disappointment to some in that it raises more questions than it answers. I feel it is vital ot raise these questions now, since this is where we need the most work.

Amateur Radio is a hobby for 'Radio' operators. It seems that a lot of us (myself included) have either forgotten that, or aren't willing to spend the time in RF design any more. Even when we try to work on RF problems (such as channel congestion) we tend to try clever 'digital tricks" rather than look at the basic problem. Boy have we become spoiled! While we have advanced greatly in a short time in the digital end of packet radio, our RF technology lags further and further behind (Just by staying at the same place). There have been only one or two contributions made in the last year or so.

This is particularly bad when one looks at the overall picture of the Amateur Packet Radio Network. For the last six months all I have heard is the same question: 'Where is the Network Layer?" I hate to be the bearer of bad news, but that isn't where our efforts should be concentrated. The Network Layer camps are progressing fine, which just adds to the problem. How can this be? The answer is in the term "'overhead". It doesn't matter if Virtual Circuits or Datagrams are used, both will add a lot of data that must be passed over the same already crowded RF paths. This means either more packets or longer packets will be flying through our RF. If you think our channels are congested now, just wait until the packet switches come on-line!

My answer to the question of where do we need the most work in packet radio right now is therefore simple, ALL PHASES OF THE RF WE USE! Having said that, I must now back down and admit that I cannot/will not alter my own course and proceed into the RF domain, I am too involved in the Network Layer development. The above comments are meant as a challenge to all those who do have the expertise to work in RF. WE DO NEED YOUR HELP! We need newer and faster radio and modem designs, NOW.

HF Packet Operation

In the last year there has been a large growth in the amount of HF packet operation. Almost all of this operation has been centered around the frequency of 14.103 mHz. The present technology being used is 200 Hz shift AFSK 300 bps lower sideband. Since this one frequency is being used both in the U.S. and Europe, it has become quite crowded most of the time. To add to the problem, some complaints have been surfacing about interference from the packet operation to nearby DX beacons operating on 14.100 mHz, which are used to detect band openings.

Bob Bruninga, WB4APR has been operating an HF station/gateway on 10.147 (USB) for over a year now. As more equipment is becoming available to operate 30 meters, it might be time to move some 0f the auto-forwarding stations from 20 meters-to 30 meters. This might help reduce the congestion on 14.103, show more activity on 30 meters, and help the DX amateurs all at the same time. I would hope to see more operation on 10.147 mHz over the next year.

As far as technological improvements on HF goes, I haven't heard of much lately. Paul Rinaldo still has a couple of Packet Adaptive Modem (PAM) prototypes built, but no one has done any serious experiments with them. These modem devices were described in the Second ARRL Computer Networking Conference Proceedings and are a first step toward minimum-shift-keying (MSK) operation on HF. We need someone to pick up the ball and test these devices, or alternatively come up with some other scheme of increasing the data speed on HF packet.

VHF/UHF Packet Operation

Amateur packet radio is really taking off on VHF and UHF. Some of the common bands and frequencies of use are as follows:

Two Meters (These are fairly standard nation-wide):

145.010 mHz (mostly National Backbone).
145.030 mHz (some local net operations).
145.050 mHz (mostly local net operation)
145.070 mHz (some local net operation).
145.090 mHz (some local net operation).

220 mHz, Low speed channels (1200 bps): (these have been requested from T-Marc in the D.C. area, the last five may have other services on them by now).

221.010 mHz (some east-coast backbone).
221.030 mHz
221.050 mHz
221.070 mHz
221.090 mHz
221.110 mHz
221.130 mHz
221.150 mHz
221.170 mHz
221.190 mHz

220 mHz wide-band channels (100 kHz channels centered around the following freq): (again specifically requested of T-Marc in D.C.)

220.550 mHz
220.650 mHz
220.750 mHz
220.850 mHz
220.950 mHz

440 mHz narrow-band channel (1200 bps): (again, requested of T-Marc in the D.C. area>

441.000 mHz

440 mHz wide-band channels (100 kHz bandwidth centered around the following freq.): (requested of T-Marc in the D.C. area)

430.050 mHz
430.150 mHz
430.250 mHz
430.350 mHz
430.450 mHz
430.550 mHz
430.650 mHz
430.850 mHz
430.950 mHz

I should point out that the above frequencies have NOT been set aside specifically for packet radio at this point, but rather maybe available for use IF WE NEED THEM.

They were requested to be set aside for packet use by one of the local Washington D.C. clubs (Tri-State Amateur Radio Club). We need to get some radios up on these frequencies before yet another voice repeater uses them up, or they are given to some other spectrum-starved service.

At this time there has not been much work in trying to get frequencies assigned to packet radio in either the 900 mHz band or the 1215 mHz band (in the Washington D.C. area at least).

Michigan Packet Radio Frequency Plan

Another packet radio frequency plan surfaced recently from Michigan. Apparently there was a state-wide meeting in mid-November of 1985, the results of which are as follows:

144-148 mHz

Apparently the Michigan Repeater Council does not coordinate packet channels on two meters, so the following is by "gentleman's agreement" rather than an official coordination:

144.910 mHz (Experimantal and QRP)
144.930 mHz (Local Area Network)
144.950 mHz (Local Area Network)
144.970 mHz (Local Area Network)
144.990 mHz (Non-Digipeated simplex)
145.010 mHz (Inter-Lan & Forwarding)
145.030 mHz (Local Area Network)
145.050 mHz (Local Area Network)
1451070 mHz (Local Area Network)
145.090 mHz (Experimental and QRP)

The Michigan group took a different approach for 220 mHz. They reserved several frequencies for full-duplex low-speed repeaters and simplex digipeaters, and four freqs for 9600 bps test channels, but pushed the higher speed packet operation up to 430 mHz, with only 50 kHz channels even there. The rest of their bandplan is as follows:

220 mHz low-speed (1200bps) full-duplex repeater channels:

OUT	IN	OUT	IN
220.52 mHz/	222.12 mHz	220.64 mHz	222.24 mHz
220.54 mHz/	222.14 mHz	220.66 mHz	222.26 mHz
220.56 mHz/	222.16 mHz	220.68 mHz	222.28 mHz
220.58 mHz/	222.18 mHz	220.70 mHz	222.30 mHz
220.60 mHz/	222.20 mHz	220.72 mHz	222.32 mHz
220.62 mHz/	222.22 mHz		

220 mHz simplex low-speed channels:

220.74 mHz, 220.76 mHz, and 220.78 mHz

220 mHz 9600 bps channels (uncoordinated):

220.825 mHz, 220.875 mHz, 220.925 mHz, 220.975 mHz

There would be nineteen coordinated 50 kHz channels for linking in the 430-431 mHz band segment as follows:

430.025 mHz	430.275 mHz	430.525 mHz	430.775 mHz
430.075 mHz	430.325 mHz	430.575 mHz	430.825 mHz
430.125 mHz	430.375 mHz	430.625 mHz	430.875 mHz
430.175 mHz	430.425 mHz	430.675 mHz	430.925 mHz
430.225 mHz	430.475 mHz	430.725 mHz	

The above information is being given here primarily to show that there are frequencies out there (for most of the country at least), and that the packet community IS being recognized and served by the frequency coordinating bodies. It is also being given to (hopefully) aid in the development of RF equipment for these bands.

Simplex vs Full-Duplex Digipeater Operation

Way back when, when packet radio was still mainly in Vancouver, I was pushing the use of full-duplex repeaters. At the time I was convinced of the error of my ways (at K8MMO's house one night, I remember). A simplex digipeater is MUCH easier and cheaper to put up. With just a TNC and a radio you too can put up a simplex digipeater. The only disadvantage of a simplex digipeater is the lower throughput. Is the loss of throughput made up by the cheaper cost of simplex digipeaters? Well, I'm not sure, but I feel it is time once again to look at repeater operation.

Some of the advantages of simplex digipeaters are:

A. The cost of a simplex digipeater is MUCH smaller than that of a full-duplex one.

B. The complexity of a simplex digipeater is also much less, especially in the RF plumbing required (ie. filters).

C. A simplex digipeater is also physically smaller, allowing it to be placed in remote areas more easily.

D. Since there is less equipment, it is less likely to require maintenance, and less control circuitry may be needed.

E. In order to use full-duplex to full advantage, user radios should also be capable of full duplex operation, driving the user cost up drastically.

The only real disadvantage to simplex digipeaters is that it has less throughput than a full-duplex type repeater. Some of the reasons for this reduced throughput follow.

One reason often mentioned for reduced throughput of a simplex digipeater is that it time-shares the same frequency for both receive and transmit, thus reducing the throughput by at least 50%. Actually, this is not completely true when one considers that full-duplex operation uses two frequencies. If two separate simplex digipeaters were put on the frequencies used by a full-duplex digipeaters, almost all of the channel capability can be recovered. The only amount of channel capability still lost would be the receive/transmit turn-around time, both at the individual stations and at the digipeater.

The other major loss of channel throughput in a simplex digipeater system is due to the hidden station syndrome. Since stations using the same digipeater may not be able to hear each other, one station may start transmitting a packet to the digipeater while another station was already sending a packet to the digipeater, or some other station on the same frequency, causing a collision and possible loss of data. In full-duplex digipeater operation this would be much less likely to happen, since all other stations would hear any station that starts to transmit on the repeater input (except for the small transition time between receive and transmit at the individual stations) on the repeater output.

Cross-Band Operation

Some hams have suggested that in order to reduce the amount of plumbing needed at digipeaters that the digipeaters receive on one band and transmit on another band. This cross-band operation would allow full-duplex operation at reduced cost and size.

Channel Access Methods

How stations gain access to the RF channel to pass data is another descision that must be made. Some of the different systems to chose from are listed below.

Aloha Type Channel Access Method

The first major packet radio network was the Aloha Network built in Hawaii. The Aloha Network used the RF channel by having a station immediately transmit data whenever it had some to send. Collisions of transmissions were detected by not receiving an acknowledgement of the data by a certain time. The theoretical maximum channel utilitization using pure Aloha is 18%.

Slotted Aloha Channel Access Method

One of the prolblems with pure Aloha is that anyone can transmit packets at any time. One method to increase channel utilitization is to divide the potential transmit time into discrete time-slices or slots, each of which is slightly longer than the time it takes to send a packet.

Once the stations are synchronized (usually by having a master station transmit a short clock pulse), a station will only transmit at the beginning of a slot. This reduces the amount of collisions, since stations will no longer accidentally transmit part-way through another stations packet transmission. Packets either make it through fully, or are fully destroyed. Using Slotted Aloha just about doubles the channel throughput to about 37%.

Reservation Aloha Channel Access Method

Another method used to improve channel utilitization over pure Aloha is to reserve specific time slots for each station to transmit data. There are several different schemes as to how these reservations are made and maintained, but basically they all assign times for stations to transmit, thereby greatly reducing collisions.

Token-Type Channel Access Method

Yet another method of controlling access to the data channel is to allow transmissions by a station only when it has "permission". This permission is usually in the form of a "token". This token is passed back and forth by all the stations on the channel. When a station receives the token, it checks to see if it has data to send. If it does, it sends the data, then passes on the token to the next station. If it has no data, it immediately passes on the token to the next station.

Among the disadvantages to token type access methods is that they must be carefully supervised. In order for additional stations to be accepted onto the channel, they must somehow be added to the token-passing list. The easiest way to have this function properly is to have a master station monitor the token passing and allow new station(s) in whenever it has the token.

Carrier-Sense Multiple Access (CSMA)

The method we Amateurs presently use to gain access to the RF channel is through a system called Carrier-Sense Multiple Access, or CSMA. CSMA is a fancy term for how we hams have shared our spectrum space all these years. Basically it means you are supposed to listen for others before you transmit. If you hear someone else on the channel, you wait until they are done before you start transmitting. With many people competing for the same channel, CSMA is a good method to control channel access.

The biggest problem associated with simple CSMA is what is called the "hidden transmitter" situation. There is a possibility that whenever a half-duplex channel is used, not all stations can hear all other stations. In fact, with the Amateur Packet Network of today with simplex digipeaters, this is quite likely. Whenever a station is hidden from another station, the possibility of both of them transmitting at the same time exists, since they cannot sense each other. The possibility of collisions expands greatly with the addition of each station that cannot hear another station. The degradation of the channel quickly reaches the point where there are more collisions than normal transmissions. Several schemes have been devised to overcome this situation.

One system for recovering from collisions in a CSMA enviroment involves "persistence". Persistence has to do with how a station handles access to a busy channel when it has data to send. Suppose a station has data to send, but detects the channel is busy. One method of handling this situation is for the station to transmit its data as soon as it thinks the channel is free. This is called 1-persistence because the probability of the station transmitting when detecting the idle channel is 1.

The other extreme in persistence is called nonpersistent CSMA. In this case, when the station detects the busy channel, it doesn't wait for the channel to become free and immediately transmit.. Rather, it waits a random amount of time and then tests the channel again. If the channel is free, it will transmit. If the channel is still busy, the station repeats the wait and test cycle until the channel becomes free.

A third persistence scheme is called p-persistent CSMA. This is a compromise between the above two systems. When a station has data to send, it will first check for an idle channel condition. If' the channel is free, it will transmit its data with a probability of p. If the channel is busy, the station will wait until the channel is idle before invoking the probability test for transmission. If the value of p is different for each station, this can reduce the potential for collisions of transmissions.

CSMA with Collision Detect

A modification to the basic CSMA operation involves monitoring the channel while transmitting. This means a full-duplex channel is being used. If, while transmitting data, a station detects that its data is not what's on the channel, another station has taken over the channel and the monitoring station should stop transmitting. Since all stations can now hear all other stations, the hidden station problem is almost completely eliminated. This collision detection can help reduce the number of collisions, at the cost of all stations being required to operate in full-duplex mode. If full-duplex capability is possible, CSMA-CD can be the most effective use of a channel.

Busy-Tone CSMA System

Another method of reducing collisions on a CSMA channel is to use a busy-tone to indicate when the channel is being used. This requires that the channel is being controlled by a master station with which the individual stations communicate. It also requires that a secondary channel be available to transmit a busy signal. This secondary channel does not have to be a full data type channel as the presence or absence of a busy signal is the only information carried on the secondary channel. Whenever the master station is receiving data from a station, it sends out the busy-signal on the secondary channel. Once the main data channel is free, the master drops the busy-signal. The individual stations monitor the channel for the busy-signal before transmitting data. This system also helps reduce the amount of collisions due to hidden stations, although not as effectively as the collision detect mechanism described above.

While this busy-signal system does improve channel access, it is not as effective as the CSMA-CD system mentioned above, for about the same complexity. This busy-signal system has been tried on the Amateur bands, and it is more effective than the simple CSMA we presently use.

With the above in mind, lets look at how these trade-offs are made in two different parts of the packet radio network.

Individual User/Local Network Operation

We are using simplex digipeaters almost exclusively at this point. I believe this is the best use of the RF channels we use at this point. Full-duplex repeater operation is not feasible on two meters with our present allocation, since the five main channels are right next to each other In frequency. In some areas, full-duplex (voice type) repeater assignments may be available, but are the users willing to pay the added costs to put up a full-duplex digipeaters? From what I have seen, the answer is no. It appears that a more palatable solution to channel congestion is to put up more digipeaters. Brian, WB6RQN tried to run an experiment by putting his Unix system on the AMRAD voice repeater (147.81/21 mHz). This test was met with a great yawn. Admittedly, the repeater lost some coverage part of the way into the experiment due to loss of antenna height at the repeater. I don't think this was the main reason for the lack of interest. I think that most everybody has accepted simplex digipeater operation for packet use for now.

Cross-band operation is not a viable option for the user/Local net due to its added expense for a second rig and antenna system at every location.

I mentioned that some hams have used a busy-signal system with digipeaters to reduce collisions. If the users are willing to pay for another receiver (or be lucky enough to find a repeater pair to use), this system may be a viable alternative. It does greatly reduce the hidden station problem, without requiring full-duplex operation at all locations, as CSMA-CD would.

My conclusion however, is that at this time simplex repeater operation is still the best way to go for Local Network operation. In the future this may change, especially if the Local Network becomes more of a cellular type operation at 900 mHz. For now, if a channel get too congested, it is easy enough to put up another simplex digipeater (ala FM voice repeater growth).

Local Network vs Backbone Network

I wanted to mention briefly that there should be a re-thinking of how our packet channels are being used. Both the Michigan Bandplan and the Tri-State frequency requests indicate the use of some frequencies for "local networks", while other frequencies have been set aside for "network backbone" operation. This is a very important point. We should start using the "local network" frequencies for small areas, such as small towns, or one part of a metropolitan area. These local network frequencies would be re-used by other small groups far enough away to avoid complete RF overlap (if we use-simplex digipeaters, the occasional overlap won't affect operation much). The local networks would then have access to the backbone via dual-port digipeaters or multi-port packet switches. A local area digipeater or packet switch should only cover as much as it needs to for the local group. This frequency re-use works almost like the cellular system, where each local network is a "cell" and the cells are hooked together by the backbone.

The main idea I want to get across is that putting up a super-digipeater for a "local" network can be counter-productive. The super-digipeaters work best for-the backbone, where they need to reach as far as possible (remember, we can only chain eight of them together). Keep the "local network" digipeater coverage within the "local" area.

Network Backbone RF Operation

There have been many different suggestions for how we should construct the RF part of the network backbone. Presently, we are using simplex digipeaters here also. Once again, I think this is mainly because they are cheap to put up. Another reason is that up until recently, if a digipeater was to use something other than the main frequency, it would it have to use two TNCs and two radios.

One of the common suggestions made for use of our frequencies for the network backbone is to imply direction by frequency. For example, if a packet is to be routed south from a switch, the packet would be sent on one frequency. Packets going north would be sent on a different frequency. East and West bound packets would be sent on still different frequncies.

This idea requires a lot of smarts in the switch, so it can control which radio channel to send the data, and therefore which radio. We should be able to do this someday, but it may be beyond our reach in the near future. In addition, this adds a lot to the cost, size, and antenna requirements of the digipeater or switch.

What's Happening Now?

Present packet operation is still mostly on two meters at 1200 bps using Bell 202 type modems. As an example, almost all of the east-coast backbone operation is still on 145.010 mHz.

One improvement is that some local areas have begun using the other two meter packet channels as local networks as suggested above. These local networks are usually concentrating around a local packet bulletin board (PBBS). In the Washington D.C. area for example there are at least two different groups using 145.050 mHz for local network traffic. The use of "Super-Digipeaters" seems to be fading, except for the backbone. In order to reduce the channel congestion (especially while using half-duplex digipeaters) this trend to localized networking will be very beneficial.

At the Fourth ARRL Computer Network Conference (March 30, 1985 in San Francisco) Steve Goode, K9NG described a method of modifying the Hamtronics FM-5 220 mHz tranceiver for 9600 bps operation. Since then TAPR has made boards available for this modification, and some hams around the country have tried this mod on various rigs, with different degrees of success. Unfortunately, I have heard some negative comments about the use of these "off-the-shelf" rigs when modified for high-speed packet operation, especially in uncontrolled enviroments (such as one might expect at a digipeater like WB4JFI-5).

One suggested method of curing some of the problems encountered is to replace the standard IF filter(s) in the modified radios with slightly wider ones, allowing more "slop" in the IF bandwidth.

Moving to 220 mHz, The First Step

In order to reduce the amount of traffic on the network backbone, I propose that we make the first step to 220 mHz operation. This step is fairly simple, we just add a 220 mHz 1200 bps digipeater wherever there is a two meter digipeater in the backbone. This parallel path can be enchanced at various points by installing a dual-port digipeater (ala Jon Bloom, KE3Z and a Xerox 820 board) instead of the normal TNC type digipeater. This parallel path will allow us to check the RF paths and also provide more data throughput on the network. Heavy users of the backbone (PBBS's) could then use one path while the other path could be used for lighter traffic. Another advantage of going to 220 mHz even at 1200 bps is that it reduces the number of stations that have access to the backbone directly, thereby reducing channel occupancy, since not as many hams have 220 mHz capability.

AMRAD should be making this first step about the time of this conference. We are improving WB4JFI-5 to a dual-port digipeater with access on both 145.010 mHz and 221.010 mHz, both at 1200 bps for now.

9600 bps on 220 mHz

As mentioned earlier, some effort has been made to design higher speed radios at 220 mHz. Steve Goode, K9NG did a good job on his "modem" modification to the Hamtronics FM-5. Even so, some hams have found that they have to continually fight the rig to keep it operating properly. I feel that this is at least partially due to the fact that the FM-5 is still basically a voice type radio, optimized for voice operation (especially in the bandwidth department). What we really need is a radio that was designed from the ground-up as an "RF-Modem" rather than a voice rig.

Another person that has felt that way is Gary Fields of Boston, Mass. He has been working for a while now on a complete 220 mHz radio that is designed to be an RF modem. While he hasn't finished it yet (last I heard) it sounds promising.

Another effort being made on the 9600 bps 220 mHz front is being done by the AMRAD crowd. Chuck Phillips, N4EZV (of spread spectrum fame) and Andre Kestloot, N4ICK are working on a 220 mHz RF-Modem design. It is suprising how much like a modem it looks. They are presenting a paper on their design ideas elsewhere in these proceeding so I will not steal their thunder here.

I hope 1986 will be the year for 9600 bps 220 mHz packet radio, its overdue and needed desperately.

56kbps Design Request by ARRL Digital Committee

The ARRL Digital Committee met last December at Newington, CT and one of the items on the agenda was (suprise!) higher speed radios. The committee came up with a wish list for the design of a digital radio for high-speed data. The basic design involves the use of a data interface/IF modem followed by a transverter to the band of choice. The IF frequency in/out of the data/IF interface should be 28 mHz with RF levels to match standard transverters (around 10 mw?). The data interface should accept standard serial data signals at either TTL or RS-422 levels. The data signals should be as follows:

Signal	Data/IF	TNC
RxData		--->
TxData		<---
RxClock (X1 speed)		--->
TxClock (X1 speed)		--->
Data Carrier Detect		--->
Request-to-Send		<---

The signalling speed of the complete data/IF/transverter chain should be at least 56 kbps, preferably using standard FSK FM modulation. The bands of operation should include 220 mHz, 440 mHz, and possibly 900 and 1215 mHz. It should operate in a 100 kHz channel, and should provide a clean RF output. Full duplex operation of the Data/IF interface should be possible, and the Rx/Tx switching speed should be extremely fast.

Anyone wishing a nice RF challenge should look no further. A radio that meets the above specs would be very welcome indeed!

Conclusion

Unfortunately, we have not progressed in the RF portion of packet radio development as quickly as we need to. There is still a lot of room to experiment with radio designs. The should be a welcome challenge to some enthusiastic Amateur out there who knows RF, and wants to learn about digital transmission methods and packet radio.

There is a world of variations available for the RF digital designer. Just tell us what you need, and we will supply the bits! If this sounds a bit like I am begging, I am. I WANT FASTER RADIOS!!

References

Rinaldo, P. L., "Introducing: the Packet Adaptive Modem (PAM)", Second ARRL Amateur Radio Computer Networking Conference, ARRL, 1983

Brooker, J., et al, "Michigan Packet Radio Frequency Plan", Packet Radio in Southern Michigan (PRISM), Nov. 17, 1985

Tanenbaum, A. S., "Computer Networks", Prentice Hall, 1981

Goode, S. "Modifying the Hamtronics 'FM-5 for 9600 bps Packet Operation"', Fourth ARRL Amateur Radio Computer Networking Conference, ARRL, 1985

Phillips, C. and Kesteloot, A. "A High Speed R.F Modem", Fifth ARRL Amateur Radio Computer Networking Conference, ARRL, 1986

Kesteloot, A., "An Application Note Describing A High-Speed Phase-Coherent FSK Generator", Fifth ARRL Amateur Radio Computer Networking Conference, ARRL, 1986