PACKET RADIO TIMING CONSIDERATIONS

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ABSTRACT

This Paper presents an analysis of existing packet radio systems and equipment (2 Meter AFSK). Both dual and single frequency repeater efficiencies are analyzed. The results demonstrate the relative inefficiencies of the existing networks. These inefficiencies reduce the effective capacity of a 1200 baud channel to 300-500 baud. In order to correct some of these inefficiencies a few suggestions are offered.

INTRODUCTION

A packet radio network stat ion in switching from receive mode to transmit mode passes through several processes that consume significant periods of time. These losses are due to inefficiencies contributed by the sending station, the repeater, and the protocol utilized. In order to establish a basis for further investigation, these time consuming processes and activities are explained here:

1. Send process time -- The time the sending station's central processor (cpu) takes to assemble and dispatch the packet. This is the terminal node controller (TNC) processing time. The time consumed is approximately .250 milliseconds. This time is relatively insignificant (in proportion to the other processes) and for all practical purposes can be ignored.

2. Transmitter turn-on time -- The time the sending packet radio stat ion takes to turn on it's carrier (and/or switch to transmit from receive). This activity is often overlooked in the analysis of packet radio systems. It is the single largest piece of dead time in the packet transmission process. This time is not of any great concern in a voice system and is not generally not iced for what it is. However, it can be recognized sometimes on voice as an operator chops off his call sign announcement at the beginning of each transmission (Sound familiar? You always thought he started talking before he pushed the PTT button). The amount of time consumed by this activity can vary significantly. A transmitter altered specifically for packet radio service can come on line in several milliseconds (e.g., like CW break-in keying). Most amateurs are using commercial two meter equipment. Unfortunately, most twc meter equipment is not made for break-in keying and suffers from the following list of delays:

   a. Synthesized rigs have to allow time for the phase lock loop to acquire the transmit frequency when switching from receive to transmit. Experience has shown some rigs to require 500 milliseconds for this function.

   b. Older rigs with sol id state receivers and tube transmitters have to allow time for the transmit power supply to come on line. This act ion can take as little as 100-200 milliseconds but 500 milliseconds is more realistic.

   c. Older rigs with relay switching of the antenna can use up to 200 milliseconds to accomplish T-R switching. The time is used in circuit delays, transmit recovery and relay movement time.

   d Low powered rigs usually use a solid state in-line amplifier (brick). These units switch from receive (bypass mode) to transmit by sensing for RF energy. Upon detection of RF from the rig the PA unit switches in the high power amplifier. The time for this function to take place has been found to require about 200 milliseconds.

3. Modem turn on time -- The time a modem takes to enable and stabilize the initial tone. Most commercial units allow 50 milliseconds for this event. The time consumed by this event is usually masked by the transmitter turn on time, so it can

be ignored in most cases. However, if the system waits for clear to send (CTS) to be returned from the modem before turning on the transmitter, this unnecessary delay will be introduced. Each packet radio stat ion should be checked to insure the modem and transmitters are turned on simultaneously. A modem constructed specifically for packet radio use can eliminate this time.

4. Propagation time -- The time it takes the radio signal traveling at the speed of light to arrive at the receiver. A nominal distance of 30 miles will take .03 milliseconds to traverse. For all practical purposes this time can be ignored.

5. Receive process time -- The time it takes the receiving station to process the packet and pass it on to the next stage (e.g., operators terminal). An allowance of .25 milliseconds should take care of this function. Once again for all practical purposes this time can be ignored.

6. Data receipt allowance -- At the end of transmitting a data packet the transmitter and modem do not turn off coincident with the last bit. Commercial modems cont inue to transmit the final tone for 10-20 milliseconds after the last bit. This is to allow the receiver clocking mechanism time to move out the last character received prior to the introduction of line noise that will occur with the removal of the carrier.

7. Transmitter turn off time -- Some hand held transceivers do not stop transmitting with release of the "PTT". They hang for a short time. While not a common occurrence it can prevent TNCs with carrier detect from accessing the channel. Thus, ack packets could be delayed. Reports of this happening have been seen on the UNIX USENET. This has not been seen the S.F. Bay Area and isn't included in the following analysis.

These are the inefficiencies introduced by the packet boards, modems and RF equipment into a packet radio network.

Another class of inefficiencies are introduced into the network by the AX25/HDLC protocol utilized by the network. They are:

1. Protocol overhead -- The HDLC and AX25 sync, control, address, and checksum bytes add an additional 20 or 27 bytes to each packet. They are: one sync byte (beginning), 14 or 21 bytes of address (14 for simplex, 21 for repeater), two control bytes, two checksum bytes, one sync byte (end).

2. Bit stuffing -- Bit stuffing required by the HDLC protocol requires that a "0" bit be inserted each time five "1" bits are encountered. The random probability of this occurring is 1 in 32 or 3.125%. This means that the data stream will be expanded approximately 3%. Table 1 includes transmit times for 3 packet sizes adjusted for bit stuffing.

3. Acknowledge packet -- Each message is usually acked. A receiving station sends back to the sender an ok to proceed packet of 20 or 27 bytes (20 for simplex, 27 for repeater).

The protocol itself introduces a quantity of bytes and an additional 3% of overhead (delay) into the system.

REPEATERS

The key to any packet radio system is the repeater. There are two types of repeaters in general use, single frequency and dual frequency repeaters. On a single frequency repeater (a digipeater), the repeater receives the entire packet, makes sure the packet is valid, and retransmits the packet on the same frequency. A dual frequency repeater listens on one frequency and retransmits the packet on another frequency. It does this with no delay and thus no packet validity check. Each approach has its merits and detract ions. On the surface it appears as though a single frequency repeater utilizes half the bandwidth of a dual frequency repeater but takes twice as long to complete a transaction. However, the inefficiencies described above cloud the issue and the merits are not as clear as they seem.

Another point of concern in a packet radio system is the amount of data to be allowed in the packets i.e., the packet size. With a given amount of data to send a few large packets would be more efficient than many small packets. But if you have a small amount of data to send then you are wasting the capacity of a large packet. The solution appears to be to use variable size packets. Then a maximum packet size has to be agreed upon, as all members of a local packet community have to be able to receive that maximum size packet.

It should be noted that Abramson and Ferguson have theoretically shown that mixed packet sizes decreases the throughput capacity of a contention packet system. However, for better or worse the current packet radio systems allow mixed packet sizes. As some packet systems are now running close to their capacity this effect is now being realized. Mixed packet sizes and the relative decrease in channel capacity is an effect that should be investigated.

INVESTIGATION

In order to determine the effect of these inefficiencies on packet radio transactions a few types of transact ions are examined. They are for: a simplex connection, a connection through a Dual Frequency (DF) repeater and a connection through a Single Frequency Repeater (SF). Packet sizes examined are a 64, 128, and 256 bytes of data on an Amateur radio packet system operating on a typical two meter AFSK FM carrier utilizing 1200 baud AT&T type 202 modems. The data packets conform to the AX-25 protocol. Each data packet is individually acknowledged and the ack packet is a minimum packet of 20 or 27 bytes. The times are based on the actual measured times of the KE6ZE & KA6M stat ions and the KA6M repeater. These delays are depicted in Figure 1 and Table 2.

Utilizing the data in Tables 1 and 2 the efficiencies can be computed. The results are presented in table 3 and summarized in Table 4. The efficiency is the time consumed by the actual data packet (of 64, 128, 256 Bytes) divided by the time utilized for each transaction. (Example for a single frequency repeater and 64 bytes of data: 1781.62 + 439 + 439 = 2659.62, 439 / 2659.62 = .16506 or 17%. Have to add two 64 byte transmission times because the data was sent twice, once to repeater, then repeater to destination (see Figure 2). Note: Table 3 accounts for the other multiple hop times.) Notice the the two dual frequency efficiencies. The first is calculated on an elapsed tine basis, the second on a spectral density time basis. This is to relate the two repeater types on an equal basis. i.e.: if a single frequency transmitter utilized twice the data rate and thus twice the bandwidth then the two would be equal in spectral density.

Note the decreased efficiency of the smaller packets. This is one case where bigger is better. Also, both repeater types are relatively inefficient at the small packet sizes utilized in most packet radio systems at the present. It appears as though we have considerable room for improvement in our systems. Note the advantage a single frequency repeater system offers in its ability to allow users to direct connect. At 25% efficiency a 1200 baud system will have the throughput rate of 300 baud.

CURES AND FIXES

What can be done to reduce some of these inefficiencies? One thing is to improve the data stream transmitted over the ether. A single frequency repeater can offer efficient use direct connects to its users, while having the repeater available should it be required. Make bigger packets where possible. But not too big, there will be both rag chewing traffic and computer traffic, each at opposite ends of the packet size needs. Attention to modem timing can increase efficiency also.

Another opportunity is to improve the rig for packet radio. The choice is to either make or buy a rig, but believe it or not the best may be to buy a used rig. There are old mobile FM voice rigs that are suitable for 2 meter packet radio service. They are generally available used at reduced prices and should have the following characteristics:

1. Crystal controlled receiver with another crystal for control of the transmitter frequency.

2. All solid state unit with an integrated single power supply. Although some hybrid rigs with solid state receivers and tube transmitters are more likely to be found. These have been found to come on in about 200-300 milliseconds. An all sol id state can be cut down to less than 100 milliseconds for turn on.

3. Moderate power RF amplifier contained within the rig. i.e., try to keep from using an external amplifier.

4. Antenna switching handled by a reed relay or PIN diode blocking (PIN diode is the best of the two).

Fortunately enough there are older (obsolete ?) rigs with most of these characteristics. They are crystal controlled mobile rigs. Progress in technology for voice rigs has relegated these units to the storage shelf and/or flea market sales. If you are looking to buy a rig and devote it to packet radio at your next flea market look for an all sol id state, crystal, mobile rig. For packet radio you rarely need more than several frequencies. So, the limited channel selection should not be a disadvantage. They are small and can be easy to shoe horn into a mountain top site. However, they have moderate power output (10 watts or so>. If they can be used bare-foot they make a fine packet station.

There are also lots of handy-talky (HT) units available at flea markets. Generally HTs have disadvantages of not having enough power and/or being synthesized. If your repeater or stat ion is operating simplex then the PLL lock time may not effect transmitter turn on time.

It depends on whether or not the unit always waits for a time to lock or senses. PLL lock. The lock time in addition to an outboard linear switching time was enough to require the first KA6M repeater 500 milliseconds for transmitter turn on time. The temptation to make a small packet station using an HT is great. If you build a repeater (or station) with a low powered HT or mobile rig and a linear, be sure to key the linear from the TNC PTT. Don't use RF sensing to switch the linear.

Also available at Flea Markets are older commercial mobile rigs (e.g., Motorola Motrac). These hybrid (solid state receiver, tube transmitter) rigs can be utilized in packet service if one gives consideration to the power supply turn on time required by them. Careful attention and adjustment can get them down to 150-250 millisecond turn on time. They have the advantage of 25-50 watts of power and good reliability. The lack of more than a dual frequency control may hamper versatility at home but for a bulletin board system they may be ideal.

CONCLUSION

A packet radio system has delay introduced by all its component parts: the originator, the repeater, and the recipient. The key item is the repeater. The repeater should have the most attention given to it in elimination of dead time. Practices incorporated into repeaters as a result of voice techniques should be re-examined. As the transmissions are not intended for the human ear the repeater can be tailored for efficiency. These tailorings are:

1. Eliminate the squelch tail on a two frequency repeater. Holding the carrier on may keep other transmitters from utilizing that time.

2. Key the transmitter on a two frequency unit from a tone detection on the receiver side. This will keep intermodulation product interference down and also drive the kerchunkers crazy.

3. In a two frequency repeater key the transmitter immediately upon tone detection. Or upon carrier detection if tone detection is not used. Some voice repeaters require a signal be present for a short time prior to keying the transmitter. For digital use this should be eliminated.

4. Strive to incorporate as many as possible of the previously described transmitter features into the repeater.

5. Turn the squelch up on the receive system. The data will be lost on a noisy signal anyway.

6. Have the CW IDer use one of the modem tone frequencies. This will allow channel busy detection schemes using tone detect rather than carrier detect from having data collisions.

7. Have the CW IDer come on at the end of a transmission in a two frequency system. This will keep from clobbering a data packet transmission on a start up after 5 minutes has elapsed.

Paying attention to the repeater can reap significant benefits to all the participants in a packet radio system. Elimination of a unit of time from the repeater will save two units of time on a transaction: once on the data packet, and again on the acknowledgement packet.

Round up an oscilloscope and check your packet radio system. After gathering measurements on your system run through a calculation set as done here. Doing this you will probably find out what it is that is causing your 1200 baud system to act like a 300-400 baud system. Don't think that other digital communication schemes are much better at efficiencies either. AMTOR Baudot RTTY communication starts off at 63% efficiency (5 data bits and 3 overhead bits for each element) then the AMTOR overhead starts wearing that down.

CLOSING COMMENTS

Finally, in closing, there are numerous theoretical studies of packet radio systems in various technical journals. These studies in general do not account for all of the delay types listed in this paper. When analyzing your packet radio system by these studies don't ignore these practical effects. In particular, transmitter turn-on time can cause difficulty in carrier detect protocols such as utilized on the VADGC and TAPR boards. The value of the carrier detect is somewhat diminished by the time it takes to turn on a carrier e.g., after a station senses the medium for carriers and prior to turning on its carrier a significant amount of time can pass, during which another (undetected) carrier may appear. Analyses of system stability, bandwidth capacity and packet delay should take this factor into account.

64 Bytes	=	439 milliseconds
128 Bytes	=	879 milliseconds
256 Bytes	=	1758 milliseconds

Table 1
Time to Transmit Data
Includes 3% Bit Stuffing

Simplex Direct Connect	Dual Freq Repeater A	Single Freq Repeater	
.25	.25	.25	Transmit Process Time
-		.25	Repeater Process Time
-			Modem Turn On Time (masked by next item)
250	250	250	Transmitter Turn On Time
-	500	250	Repeater Transmitter Turn On Time
133	133	180	AX25 Overhead (20/20/27 bytes @ 1200 baud)
-		180	Repeater AX25 Overhead (27 bytes again)
-			Data Transmission (see table 2)
-			Data Bit Stuffing 3% (see table 2)
15	15	15	Data Receipt Allowance (carrier hang on)
-		15	Data Receipt Allowance for Repeater
.03	.03	.03	Propagation Delay
-	.03	.03	Propagation Delay for Repeater
.25	.25	.25	Receiver Processing Time
398.53	898.56	890.81 =	Time to transmit an empty (or control) packet from source to destination.
x2	x2	x2	
797.06	1797.12	1781.62 =	Time to transmit an empty packet (source to destination) and ack it (destination to source)

Table 2
Times of the component parts of packet transmissions.
Times in Milliseconds

Simplex, Direct Connect

64	128	256	
1236	2555	1676	= Milliseconds
36%	69%	52%	= Efficiency

Dual Frequency (Voice) Repeater

64	128	256 = Bytes of data
2236	2676	3555 = Milliseconds
20%	33%	49% = Efficiency

Single Frequency (Digital) Repeater

64	128	256 = Bytes of data
2660	3540	5278 = Milliseconds
17%	25%	33% = Efficiency

Table 3
Complete Transactions of Varying Packet Sizes
Times In Milliseconds

64	128	256 = Packet size
17%	25%	33% = Single frequency efficiency
20%	33%	49% = Dual frequency efficiency
10%	16%	25% = Dual frequency spectral efficiency
36%	52%	69% = No repeater direct connect efficiency

Table 4
Channel Data Rate Effective Utilization Efficiency

```
I-I--+---------------I---+------------+---I-------I--I--I
 | |  |               |   |            |   |       |  |
 | |  -transmitter    |   -data        |   |       |  -receive process
 | |   turn on time   -AX25 header     |   |       -propagation
 | -modem turn on time                 |   -data receipt allowance
 -transmit process time                -AX25 trailer
```

Figure 1
Time Delay Accumulations

```
 Hop 1          Hop 2          Hop 3          Hop 4
+--------------+--------------+--------------+--------------+
|              |              |              |
-data packet   -data packet   -ack packet    -ack packet
 src to rpt     rpt to dest    dest to rpt    rpt to src
```

Figure 2
Dual Frequency Repeater Packet Transmissions

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