Packet-radio networks

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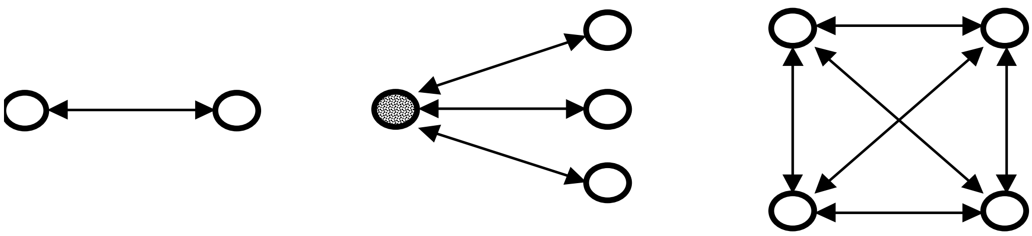
Abstract

Packet Radio (PR) represents the digital communications that use radio channels allocated to the amateur services. The name comes from the format in witch the data are send, called packets.
This technology can be used to create inexpensive experimental radio networks. This paper presents the techniques utilized in packet-radio networks and the ways in witch this techniques are used in commercial communications by wires and wireless.

Physical layer

Networks architectures
Because of the limitations imposed by the transmission medium only the followings networks architectures could be encountered in packet-radio networks:

Tipical Architectures for packet-radio networks



Point to point
-half duplex
-full duplex

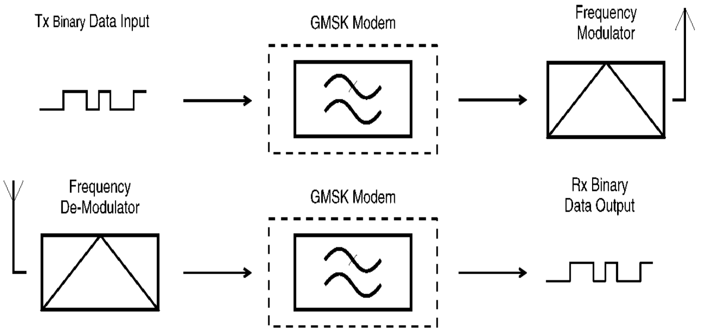
Point to multi-point
-half duplex
-full duplex

Mesh
-half duplex

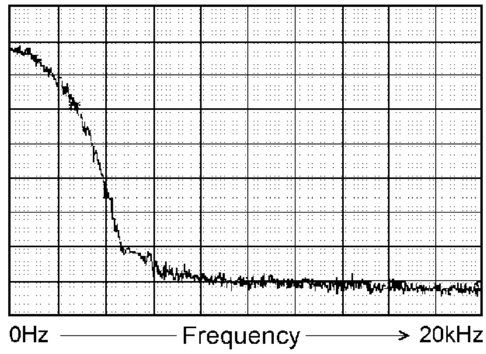
The main problem is that the network is not homogenous and even more it has an unpredictable character, that why the most used type of architecture is the "Mesh".
The "Point to Point" type of networks could be encountered at the high-speed links that work at frequency higher than 432MHz.
Only in the last period, the "Point to multi-point" architecture become widely used, mostly on links between Internet and packet-radio. This lead to the need of changing the medium access method, how will be reveled later in this document.

Modulations techniques
AFSK (Audio Frequency Shift Keying) is used at low speed (300bps-1200bps). The AFSK modulation is obtained by applying two tones, first one with a frequency for "0" logic and the second with another frequency for "1", at the microphone input of an ordinary radio transceiver. The received signal is obtained from speaker output of the radio transceiver. The main advantage of the AFSK consist of its simplicity and the main disadvantages are the very low speed and the high bandwidth, both caused by the double modulation.
GMSK (Gaussian Minimum Shift Keying). In a GMSK system, the bit stream to be transmitted is passed through a Gaussian low pass filter. A Gaussian filter is a filter which, when excited by an impulse, outputs a Gaussian shaped output pulse. This type of modulation is used in GSM system, and offers the best ratio performance complexity.

The main advantages are simplicity of implementation, efficient bandwidth utilization, and the possibility to use a common FM transmitter technique as well as a traditional FM discriminator based receiver.



Data Flow in a GMSK FM Radio System



4800bits/sec "Gaussian" filtered random data

PSK (Phase Shift Keying) is used at high communication speeds (mainly beyond 100Kbps).
This type of modulation is more difficult to implement and the phase errors have a grater impact over transmission. The transmission chain must be linear. In this case power amplifiers working in class C are not accepted.
Because of their complexity, other types of modulations, like **QAM** (Quadrature Amplitude Modulation), are less used.

Data link layer

Packet-radio networks use the AX25 protocol at the data link layer. This protocol conforms to the International Standards Organization (ISO) Information Standards (IS) 3309, 4335 and 7809 High-level Data Link Control (HDLC) and uses terminology found in these documents. It also follows the principles of the International Telegraph and Telephone Consultative Committee (CCITT) Recommendation Q.920 and Q.921 (LAP-D) in using of multiple links, distinguished by the address field, on a single shared channel. Parameter negotiation was extracted from ISO IS 8885. The data-link service definitions were extracted from ISO IS 8886.

Layer	Functions	
Data Link	Segmenter	Management
	Data Link	Data Link
	Link Multiplexer	
Physical	Physical	
	Silicon/Radio	

AX25 frame structure:

Flag	Address	Control	PID	Info	FCS	Flag
01111110	**112/224 Bits**	**8/16 Bits**	**8 Bits**	**N*8 Bits**	**16 Bits**	**01111110**

AX25 standard

AX25 standard is a "GO BACK N" type of protocol with the window size between 1 and 7 packets. Because the packet length is only 256 bytes, at speeds greater that 1200bps the data transfer efficiency is seriously affected by the transmission delay.
For a reasonable efficiency, the transmission delay must not exceed 10% of the transmission time. So one station must transmit enough data to stay on the air for 1.3 seconds, because the transmission delays could be up to 300ms. For instance, if the data speed is 9600bps, 24 packets must be sent, in order to maintain the station on air approximately 1 second.

Extended AX25

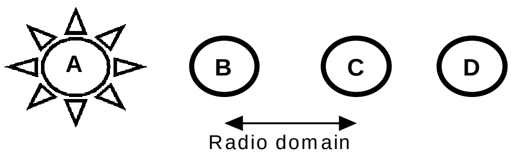
Because "standard AX25" uses 3 bits for packet labeling, the maximum number of packets that could be transmitted at one time must be above 7. To pass this obstacle, in "extended AX25" the number of bits used for packet labeling is increased to 7 (modulo 128).
The extended version is fully compatible with the old version. At the connection initialization, the "extended AX25" running station emits a special packet with a SABME field in the head. If the correspondent knows "extended AX25", it will respond with a similar packet. The protocol is no longer "GO BACK N", but Selective Repeat Protocol (SRP).

Medium access methods

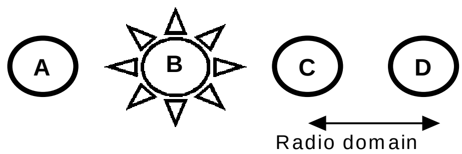
Network architecture	Connection type	Medium access method	Observations
Point to Point	full-duplex	CSMA	High speed links
	half-duplex	CSMA	
Point to Multipoint	full-duplex	DAMA	
	half-duplex	DAMA	preferred
		CSMA	
Mesh	half-duplex	CSMA	

ALOHA is the oldest access methods used in data radio networks. The very small efficiency, above 18%, forced the users to avoid it. The working principle is very simple: the users could send data any time they wish to. The collisions will destroy the data packets. Tanks to the confirmation of reception mechanism, the lost packets are retransmitted.
ALOHA is manly used in satellite networks, but even here, other medium access methods are preferred (like DAMA).

CSMA (Carrier Sense Multiple Access) is the most used medium access protocol. When a station needs to send data it will listen the channel first to see if is not busy. If the channel is free, it sends a data packet. After a collision, the involved stations wait a random time interval before starting all over again. Is obvious that CSMA works only on half-duplex links. Because of the propagation time and the time needed to switch from reception to transmission there is a non-negligible chance that a collision could occur. If the signal from the first station has not reached yet the second station, it will consider that the channel is free and will transmit, so a collision will occur. By increasing the delays times, the probability of collision increases and the efficiency of CSMA decreases. Even with great delays CSMA is more efficient compared to ALOHA.
Current version allows the user to modify the persistence factor of the protocol. Another problem in radio networks comes from the distribution of radio coverage areas. For CSMA protocol to work properly all the stations on the network must hear when somebody transmit data.
Unfortunately, because of the uncontrollable way in witch the network is build, not all the stations can listen each other, like in the next drawings. Station **C** can’t detect when station **A** is sending data, but could “hear” the **B** station. This phenomenon, called "hidden station problem", impose the network to act like pure ALOHA.
There is an opposite problem as well, called "the exposed station problem", but his importance is smaller in our case.
DAMA (Demand Allocated Multiple Access) is used mainly because of the problems previously exposed. Only one station



Hidden station problem



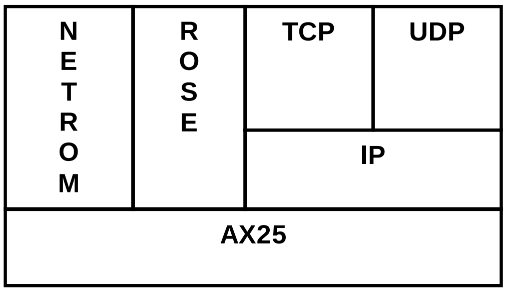
Exposed station problem

is a DAMA master, all others are DAMA slaves.
Once a connect request is recognized by the master, the connecting stations identification is added to the polling list and from this point on the master controls all connected stations. Permission to send data is granted by means of polls which might be included in ACK packets or even in transferred data frames. Therefore, in this case, a user will only be allowed to transmit after receiving "permission" in the form of a poll sent by the master station. Once permission is granted, several frames might be transmitted in a block. However, if the user does not respond within a given time frame (say around 1/2

second) then the master assumes that the poll got clobbered or the user never received it for some reason. The master then passes permission to transmit to all other active stations and, when completed, comes back to the first user and gives him another chance.
On the other hand, if the user (slave) actually receives the poll and replies with sent “I” (information) frames, the master will not acknowledge them until the next time around after serving all the other active stations. If when polled by the master, the user responds with an empty frame (Receive Ready/Final), then the master will reduce the user in polling priority and will skip him on the next time around.
As the activity on the frequency increases, the polling priority of inactive users might be further decreased, but when these stations respond with an I-frame they will again regain their original priority.
One advantage is the avoidance of system breakdown, which occurs with channel overload. Using DAMA, the throughput will increase continuously up to its maximum. The “Point to multipoint” network uses this type of medium access method, because the slave stations receive only the downlink channel and therefore they cannot know when the uplink channel is busy.
DAMA protocol is very new, so the implementations are rare at this time. One advantage of the DAMA method is that it does not require everybody to change everything all at once, the network with CSMA could use the same channel as a temporarily situation.

Network and transport layers

Over AX25 there are NET-ROM, ROSE and TCP/IP. The first two protocols have been used at the beginning of packet-radio networks. Meantime TCP/IP has become the standard, grace of his superior capabilities (see 4). To AMPRNet has been given a special group of Internet addresses of class A 44.0.0.0. In Romania the PR address are 44.182.x.x. The Computer Science Department of "Politehnica University" has the address: 44.182.5.1.



A difficult problem emerges in using TCP over radio links. TCP doesn't work well with packet loss rates more than a few percent, because it treats every packet loss as congestion and backs off. This is a good approach in cable networks in witch packets are lost due to congestion, but in radio networks the packets are lost because of the noise. If the link layer queue backs up too far, then the TCP layer, may expire their own retry timers. On the other hand, the UDP oriented applications works are not affected.

AX25 implementations

DOS and Windows
There are a number of DOS programs for packet-radio communications. Unfortunately, these programs use ROSE and NETROM protocols.
For Windows the software support is offered by FlexNet group and consists of:
- a DOS TSR program which handles the modem;
- a DOS TSR flexnet, which implements AX25 layer;
- a pseudo-driver for Windows95 witch emulates a network card and sends the data to flexnet.

Linux
The kernel of Linux operating system, from the first version, supports the AX25 protocol. Linux supports almost all of the PR hardware interfaces, including the soundcard modem interface. In addition to that, there are several tests programs available under Linux

Software module diagram of Linux Network Implementation

<table>
<tr><td>User</td><td>Programs</td><td colspan="2">Call node
Pms mheard</td><td>Daemons</td><td>ax25d mheardd
inetd netromd</td></tr>
<tr><td rowspan="5">Kernel</td><td rowspan="2">Sockets</td><td colspan="4">open(), close(), listen(), read(), write(), connect()</td></tr>
<tr><td>AF_AX25</td><td>AF_NETROM</td><td>AF_ROSE</td><td>AF_INET</td></tr>
<tr><td>Protocols</td><td>AX.25</td><td>NetRom</td><td>Rose</td><td>IP/TCP/UDP</td></tr>
<tr><td>Devices</td><td>Ax0,ax1</td><td>Nr0,nr1</td><td>rose0,rose1</td><td>eth0,ppp0</td></tr>
<tr><td>Drivers</td><td colspan="3">Kiss PI2 PacketTwin SCC BPQ
Soundmodem Baycom</td><td>slip ppp
ethernet</td></tr>
<tr><td>Hardware</td><td colspan="5">PI2 Card, PacketTwin Card, SCC card, Serial port, Ethernet Card</td></tr>
</table>

Like any UNIX system, TCP/IP support is complete, advanced networks operations like routing, packet filtering etc. are naturally implemented. Even more, a highly evolved access control and authentification system comes as a standard component on Linux. User may change every parameter of AX25 and even may change the operating system itself.
Any program that works on TCP/IP will transparently use the packet-radio interface. The IP address selects the interface that will carry data, packet-radio interface or Ethernet interface.

Experimental results

The possibly of building a packet-radio network with TCP/IP on upper levels has been studied by the author. The used hardware consisted of two PC-s with soundcards as modems. Maximum speed in this configuration is 9600Bps, limited by the sampling frequency of soundcards. For higher speeds other devices could be used, like the XILINX FPGA based modem build by Thomas M. Sailer, HB9JNX. This modem allows speeds up to 100Kbps full duplex.
As operating system Linux has been used for the reasons detailed in previous paragraph.
The tested kernel versions were linux-2.0.36, linux-2.2.0, linux-2.2.1, linux-2.2.2 and linux-2.2.3.
The additional programs come in a package called "ax25-utils". The tests were done using the last version, available: "ax25-utils-2.1.42a".
After the kernel was compiled and installed, with AX25 enabled, the radio interface is either a KISS interface, or a kernel network interface,"/dev/sm0" in our case.
This device looks like an ordinary Ethernet card:

```
lo      Link encap:Local Loopback
        inet addr:127.0.0.1  Bcast:0.0.0.0  Mask:255.0.0.0
        UP LOOPBACK RUNNING  MTU:3924  Metric:1
        RX packets:0 errors:0 dropped:0 overruns:0 frame:0
        TX packets:0 errors:0 dropped:0 overruns:0 carrier:0 coll:0

sm0   Link encap:AMPR AX.25  HWaddr YO3KXI
        inet addr:44.182.5.1  Bcast:44.182.255.255  Mask:255.255.255.0
        UP RUNNING  MTU:256  Metric:1
        RX packets:1119 errors:0 dropped:0 overruns:0 frame:0
        TX packets:0 errors:0 dropped:623 overruns:0 carrier:0 coll:0
        Interrupt:5 Base address:0x220 DMA chan:1
```

Linux allows changes of the data link level parameters through some files located in: /proc/sys/net/ax25/sm0. Parameters like AX25 timers, extended or standard AX25, etc. could be manually changed online.
A very important parameter is "ip_default_mode" that could be set in one of the tree values: "Virtual Circuit", "Datagram" or "both".
In **"Virtual Circuit"** mode, the system acts like a bits pipe. This behavior is very important if the packets have to pass a long chain of radio connected computers. Each frame is sent in the expectation that it will be correctly received and acknowledged afterwards.
In **"Datagram"** mode, each frame must be sent and acknowledged before the next frame can be sent, if they are confirmed the TCP increases de window size and the speed of packet generation. However, if they are lost TCP, decreases the window size, speed and this could even lead to "connection lost".

Because the TCP implementation is optimized for cable networks, it works on the premise that the drooped packets are caused by congestion. However, in radio networks this is not the case, packets are lost naturally because of the noise which is much higher on the air compared to cable.
AX25 retransmit the lost frames and if the link queue backs up too far, then the transport layer (TCP), may expire its own retry timers. The effect of this is that more stuff is put into the queue to cross the bad link, but now it will be totally redundant and useless. If TCP is expiring its retry timers quickly enough, relative to the link queue depth, then the link queue will grow indefinitely until buffers fill up, a condition called "secondary avalanche".
Experimentally we observed, at 10-15% loss rate, an unacceptable slow down of TCP transfers. In packet-radio systems, a loss rate above 5% is very difficult to obtain. The TCP based programs will not work on a radio chain configured in the "Datagram" mode, with 3-5% loss rate.
However, UDP applications work very well in all IP modes because AX25 guarantees deliverance.

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7. 9600 BAUD PACKET HANDBOOK - K9NG http://www.tapr.org/packet
8. AX.25 Link Access Protocol for Amateur Packet Radio Version 2.2 Nov. 1997
9. Extended AX25 Rob, PE1CHL Mar. 4, 1995
10. Useful Web addresses :

- Physical layer
  - http://www.ife.ee.ethz.ch/~sailer/ Thomas M. Sailer, HB9JNX HOMEPAGE
  - http://www.hamradio.si/ S5 Radioamateurs home page
  - http://www.wa4dsy.radio.org/ WA4DSY 56KB RF Modem
  - http://www.baycom.de/ Bavarian Packet-Radio Group

- AX25 protocol and upper layers
  - http://sunsite.unc.edu/LDP/HOWTO/AX25-HOWTO.html
  - http://www.tapr.org/packet/
  - http://www.th-darmstadt.de/diverses/afthd/flexnet/ Flexnet software