Thoughts on an Adaptive Link Level Protocol

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ABSTRACT

A look at HF channel conditions and historic Amateur radio practice reveals weaknesses in current packet radio link level protocol implementations. In line with the author's views of how protocols should work (see Level 8 Protocols elsewhere in these Proceedings), some features of ALink90, an experimental link-level protocol, are described.

CHANNEL CONDITIONS FOR AMATEUR PACKET ACTIVITY

Amateur rf paths for data have a number of departures from the ideal. The characteristics noted below are aggravated on HF, but they are generally true on VHF channels as well.

Low Speed / Narrow Bandwidth,

Most Amateur packet activity occurs at 300 bps on HF channels, 1200 bps on VHF/UHF channels.

Shared Channel

The Amateur service denies the luxury of individual users "owning" specific frequencies. Except for coordinated repeaters, everyone has an equal right to available frequencies. As a result, frequencies must be shared. Packet is one of the few digital modes which allows such sharing.

Hidden Transmitters

Along with shared channels, most Amateur packet activity occurs on channels with hidden transmitters. This means that not all stations can hear all other stations. This may be due to range, shadowing, differing power levels or other reasons.

Noise

Amateur frequencies are typically noisy. Weak signals, combined with multipath distortion, are common on HF as well as VHF/UHF.

Half-Duplex

Amateur gear is almost exclusively half-duplex. Amateur operations are almost exclusively half-duplex. This simply means that you cannot normally receive at the same time you are transmitting.

HISTORIC AMATEUR OPERATING PATTERNS

Radio is often used for roundtable discussions. Voice and CW nets with designated control stations and a variable number of check-ins is another common Amateur use. Of course, Amateurs also engage in one-on-one conversations by radio. Many times, an Amateur station does not previously know the station contacted (calling CQ).

Telephones are used for one-on-one conversations. The calling party deliberately dials the called party. The called party is usually known in advance of the call to the calling party.

As a result of these differences, telephone-based protocols may not be optimum for radio usage.

AX.25 LINK LEVEL PROTOCOL LIMITATIONS

The AX.25 Level Two protocols (versions 1, 2.0 and 2.1) provide reliable information transfer between two stations when signal levels are good and there are no hidden terminals.

A number of the deficiencies in versions 1 and 2.0 have been addressed in version 2.1.

Still, point-to-multi-point communications are not provided for. Retries are handled by pinging the other station before resending the data. Multiple frames are used for lengthy transmissions, adding overhead. There is no automatic methodology specified for tailoring the various protocol timers and variables to the RF path in use, placing a large technical burden on often naive users. And the protocol specifications are lengthy and complex.

Recognizing that AX.25 Level Two is not a panacea for all situations, the ARRL and others are actively working on developing a suite of protocols to handle various media (HF, satellites, etc.).

ALink90 PROTOCOL FEATURES

ALink90 seeks to resolve many of the deficiencies of current Amateur HF protocols. ALink90 provides the following features:

Protocol Timers Gated with DCD

The only timers used are for retry. If the channel is occupied, you shouldn't transmit. Your re-transmit timer shouldn't run, either! This requires the TNC modem to provide a data carrier detect (DCD) signal only when it senses other stations' signals.

Unconnected Mode Operation

ALink90 supports acknowledgments, but not connections, Connected mode operation is possible, however, when running higher level protocols.

No Digipeaters

A link protocol should only operate between stations in the same RF domain. Range extension should be handled as a Level 3 function. ALink90 is concerned with the task of getting chunks of information from one station to another (or others) in a single hop.

ARQ Operation

ALink90 doesn't incorporate forward error correction techniques. Instead, it relies on the receiving station(s) to send explicit acknowledgment (ACK) upon receipt of uncorrupted data.

HDLC Format

ALink90 would be useless if it couldn't run on existing hardware. Thus, it uses standard HDLC techniques for operation.

Prioritized Ack

If a data transmission occurs, the destination station(s) will send an ACK immediately. The sending station will then have the best opportunity to determine if the frame just sent was received.

Stop-and-Wait

ALink90 allows only a single frame in flight between stations. Another frame will not be sent until the current one is ACKed. This simplifies the protocol, minimizing memory and processor requirements.

Data ACKs Must be ACKed

The station sending data will respond to a received ACK by either sending more data (if more data is presently available) or an ACK-ACK.

Data is allowed to flow only one way at a time in ALink90. Thus, the ACK-ACK is a way of automatically turning the link around in a similar fashion to manually sending +? in AMTOR.

P-Persistence for Channel Access

Since the channel must support multiple QSOs, p-persistence is used to socially balance the users. If a station has data to send and detects the channel is clear, the station won't necessarily send the data immediately. This allows other stations that may be waiting to have a chance at accessing the channel to send their data.

Persistence Value Dynamically Adjusted

The number of users on a channel varies. For example, at 7 P.M. on a Sunday night, the local VHF channel may be very busy, but become very quiet by 3 A.M. ALink90 dynamically adjusts the probability of accessing the channel based on measured channel occupancy.

Frame Length Dynamically Adjusted

Although ALink90 allows only one frame in flight between stations, it tailors the maximum allowed length of the frame based on the path between the stations (not on channel occupancy). A fast-attack, slow-decay algorithm is used to adjust the maximum allowed frame size. In order to support reducing the length of a frame already sent but not acknowledged, automatic fragmentation is included in the down-sizing of the frame length. Fragmentation is a part of the retry process, so no data need be lost while the protocol adjusts to path conditions.

Multi-Way Connects

ALink90 allows as many as nine (9) stations to participate in a multi-way QSO. If the paths are good, data need only be sent once for guaranteed delivery to all other stations. If conditions deteriorate, or if one or more links are marginal, data may have to be re-sent. A slotted acknowledgment scheme minimizes the channel bandwidth needed to support multi-way QSOs.

Existing schemes for packet roundtables either assume all stations can copy all others at all times and go "UNPROTO" mode (utopian conditions), or the data is sent to each individual station and acknowledged (extremely wasteful of channel bandwidth).

Callsign is Address

Callsigns of up to 15 characters are allowed. There are no restrictions on the characters that may be used in the callsign field.

Multiple "Connects" Allowed

There is no restriction on implementations to allow a given station to participate in more than one QSO at a time. This is a function of a higher level than the link. However, ALink90 still requires that a station may only send data to one station (or group in the case of a multi-way QSO) during any data transmission sequence, This is for social balance -- no station should be allowed to "hog" a channel.

STRUCTURE OF A FRAME

The byte order of the various fields sent in a frame is:

SYNC FLAG HASH LID SRC DEST CNTL FID FRAG NID DATA FCS FLAG

The meaning of each field will now be explained.

SYNC

Preframe sync consists of a stream of zeroes during this station's transmit keyup delay time. These synchronizing zeroes will speed lockup of the receiving station(s) demodulator clock recovery circuits.

FLAG

The flag is the standard HDLC value of 7E hex, with no bit stuffing. This flag marks the beginning of a frame.

HASH

For point-to-point links, this is an 8-bit value corresponding to the encoded callsign of the destination station. For multi-point QSOs, the value is set to FF hex to exploit the use of hardware HDLC controllers with address recognition capabilities.

The algorithm used is a simple 8-bit summation of the callsign field, excluding -length byte:

[SUM(n) = sum(n-1) + byte(n)]

LID

The Link ID is used to identify the link level protocol in use. A value of 02H is initially being used to identify ALink90.

SRC

This is the callsign of the sending station. It is prefixed with an eight-bit character count which serves as a pointer to the next address in the queue. While 15 characters are allowed in this field, it may be as short as a single character (plus character-count).

Character encoding may be arbitrary. It is recommended that ASCII encoding be used, and that upper case characters be used, along with numerals and the "/" character.

There is no bit shifting. Further, the callsign field is simply an address list. There are no command or response bits, no digipeater bits and no other control bits buried in it.

DEST

This is a list of callsigns of the destination station(s). It may be a minimum of one (1) callsign field and a maximum of eight (8) callsign fields. The callsigns are encoded as in SRC, above.

CNTL

The control byte is used to control the information flow on the data link. It presently allows two types of data frames and four types of supervisory frames.

Data frames are used to frames convey information to the other station(s). These frames may or may not require an acknowledgment.

Supervisory frames indicate data frame acknowledgments, acknowledgments to data frame acknowledgments, error recovery and TNC busy.

A simplified control field structure allows simple bit masking or shifting instructions to be used in software to determine frame types and actions required.

FID

The Frame ID is an eight-bit value which changes when a frame is being sent that is different than the last one. It remains constant throughout a frame fragmentation/de-fragmentation procedure.

There is no requirement that FIDs be consecutive, only that an FID be different than the last one originated from this station in a particular QSO.

FRAG

The fragmentation field indicates the size of the frame length allowed and where in the possible frame space of 4096 bytes the present fragment fits. This field is a single byte, and is always sent.

NID

The Network ID byte is used to indicate the next higher level of protocol being used, if any. If none is used, a value to be negotiated with the ARRL Digital Committee will be sent. Initial experiments use a value of FO hex to indicate no higher layer.

DATA

This is a field of an arbitrary number of bytes. The only limitation is that it must not exceed the currently allowed maximum frame length.

FCS

This is a 16-bit CRC based on IS0 3309.

FLAG

This flag is identical to the one which marks the beginning of a frame. This one marks the end of the frame. The station transmitter should shut down immediately after sending this flag. Trailing bits after this flag will be ignored by the receiving station(s).

Since there is only one frame allowed per transmission, a single flag byte cannot mark the end of one frame the the beginning of a following frame.

CHANNEL ADJUSTMENT

ALink90 incorporates a number of special features to dynamically "tune" its operation to channel conditions. It carefully differentiates between channel occupancy and channel quality. These features, and the algorithms to implement them, are described below.

DYNAMIC FRAME SIZING

Overview

A QSO is initiated with a frame length allowed of 128 bytes. Fragmentation allows reducing this size without losing data being transferred between stations.

The maximum frame length allowed is 32 bytes at the low end, 4096 bytes at the high end.

If the channel can support longer frames, it is allowed to do so. If the path becomes noisy, frame length collapses rapidly and fragmentation occurs quickly for this frame.

Algorithm

The permitted frame length increases and collapses according to the following rules:

NOTE: Nlo is the retry count for the station originating (sending) the current frame.

1) Start with frame length = 128 bytes. This is a reasonable frame length to start with under typical 1989 operating conditions.

2) If data flows to other station(s) with no more than two frames retried and no frame retried more than once during the last eight frames, and if at least two of the last eight frames were longer than 50% of the allowed frame length, double the allowed frame length.

   This means that if the channel quality is good and there is sufficient data in the queue to warrant attempting it, cautiously increase the frame length.

3) Repeat step 2 until allowed frame length = 4096,

4) If retry for a given frame is two (Nlo = 2), divide frame length by four (but the value must not be less than 32), fragment this frame and try again. Do not clear Nlo.

   If retries are beginning to build up, aggressively back off the maximum allowed frame length.

5) If Nlo = 4, divide allowed frame length by four (but the value must not be less than 32), refragment this frame and try again. Do not clear Nlo.

6) If Nlo = 6, set allowed frame length to 32, refragment this frame and try again. Do not clear Nlo.

FRAGMENTATION

Overview

If the frame being sent is too long for the path to support, it must be fragmented into smaller frames at the sending end, and properly sequenced at the receiving end. In some cases, the frame must be reconstructed into a single, larger frame at the receiving end for proper operation of a higher-level protocol.

ALink90 provides both a frame ID and a fragmentation byte to allow this to happen automatically and transparently.

Algorithm and Control Field

The fragmentation byte is encoded to show the level of fragmentation (maximum frame length versus 4096 bytes allowed by the protocol) and the location within in the 4096 byte possible frame that the fragment fills. This encoding technique allows dynamic frame sizing to occur during the transfer of the fragmented frame.

The fragmentation byte is encoded as follows:

Bit 7 6 5 4	3 2 1 0	Frame Length
0 n n n	n n n n	32
1 0 n n	n n n n	64
1 1 0 n	n n n n	128
1 1 1 0	n n n n	256
1 1 1 1	0 n n n	512
1 1 1 1	1 0 n n	1024
1 1 1 1	1 1 0 n	2048
1 1 1 1	1 1 1 0	4096
1 1 1 1	1 1 1 1	Frame not fragmented

The "walking 0" is used as demarcation of the size information (high order ones) and the pointer to the start of the current frame's information field within the 4096 byte possible frame (values of n).

The receiving station places the data field received in the 4096 byte frame being reconstructed at the location specified by n. This is done even if this field has already been received at a different size level for this frame ID. This method allows dynamic frame sizing to occur even while sending a fragmented frame.

DYNAMIC PROTOCOL TIMERS

Overview

The only protocol timer used in ALink90 is T1, the retry timer. There are two Tls - Tlo for the _originator (sender) of the current data stream and Tld for the destination (recipient) of the data stream.

The timers are gated with DCD from the modem. Therefore, the TNC won't be counting time when other stations are using the channel. This automatically "backs-off" the rate of introduction of data to the channel by this station when the channel load increases. This is not enough, however, to maximize the efficiency of the channel.

ALink90 assumes there are other stations using the channel. Further, it assumes that any particular station will <u>not</u> be able to hear all the other users of the channel, but that one (or more) of the stations in the current QSO <u>may</u> hear some of these "hidden transmitters."

The protocol makes a further assumption that the hidden stations, with whom the rf domain of the present QSO may overlap, find their paths to be about as good as this station finds its path(s).

Algorithm

Tlo allows at least two other stations to be hidden and send data frames with frame lengths as long as this station allows. Therefore,

Tlo = bit_time * 8 * (frame_length_allowed t overhead) * 2

A maximum length overhead is 9 call signs of up to 15 characters plus 9 byte counts, a two-byte FCS, two flag bytes, an LID byte, an NID byte, an FID byte, a fragmentation byte, a control byte and a hashing byte, for a total of 54 bytes. A typical overhead byte count for a point-to-point QSO between two stations with 6 byte callsigns is 24 bytes. Current AX.25 usage is 20 bytes under the same circumstances.

Hidden transmitters may disrupt an incoming ACK. Since ACKs will usually take much less time to send than data, Tld is set to a value of Tlo/4. This means that, on average, four (4) ACKs will have to be missed by the originating station before it re-sends the data (and increments its retry counter).

Since the fragmentation byte of the received frame tells the receiving station the frame_length_allowed by the sender, it is a simple matter for the receiver to set its Tld to the appropriate value.

Finally, since a prioritized ACK scheme is implemented, the sending station will <u>usually</u> not have to wait to receive an ACK. Thus, when conditions are good, data will flow rapidly.

DYNAMIC P-PERSISTENCE SELECTION

<u>Overview</u>

Channel access probability should be based solely on channel occupancy by other users, It should not be based on channel propagation efficiency (noise) or other path-related concerns.

Current approaches to addressing congested channels cause the retry timer (T1) to rapidly increase in value, reducing offered load to the channel, if an ACK isn't received when expected. This has the undesirable effect of reducing load to a channel that is not occupied, but merely noisy. Still, it is the correct approach if round-trip time is the only criterion upon which offered load is based,

ALink90 gates Tl with DCD, so Tl is effectively backed off as a result of channel occupancy, not channel quality. Prioritized ACK has the effect of usually telling the originating station immediately if the frame got through.

Dynamic updating of the persistence parameter, p, based on channel loading can help reduce retries based on channel congestion.

If there are no other users on the channel, the persistence value selected should approach 0.9. A value of 1.0 would either prohibit other users from accessing the channel, or ensure collisions and retries if they attempt to. If there are many other users on the channel, the persistence value selected should approach 0.1. If it needs to be less than this, there are too many QSOs on this channel!

Algorithm

The probability of accessing the channel to send data is expressed as p. If p = 1, the TNC will send if the channel is clear. If p = 0, the TNC will never send. ALink90 allows p to range from 0.125 to 0.875, based on channel occupancy.

A 7-minute moving average, updated every 25.5 seconds, is maintained of detected channel use. This is done by gating a 100 mSec sampling counter with DCD. P is then (one minus the measured channel activity), limited at the busy case to 0.125 and limited to 0.875 if the channel appears unused.

MULTI-WAY STREAMS

Overview

ALink90 allows multi-point conferencing, or roundtable discussion, for up to nine stations without individually sending the data to each station. This multi-way system is especially suitable for group QSOs, small nets (DX alerts and so forth) and for inter-BBS forwarding of bulletins and other targeted information dissemination.

Implementation and Algorithm

The address field can contain up to nine stations. The first field is the sending station. The second through ninth are the destination stations,

A slotted, prioritized ACK scheme is employed, with additional ACKs sent as needed based on expiry of each station's Tld timer.

The prioritized ACKs are sent by the destination stations in their order of appearance in the address field. The algorithm used is:

1) Delay (Position in address field - 1) * (TXD t ACKTIME)
2) Send ACK, start Tld.

Where: TXD is xmtr keyup time, defaulted to 50 mSec.
ACKTIME is 35 * 8 * bit_time.

Subsequent ACKS, based on expiry of Tld, follow normal channel access procedures.

Other stations on the channel, upon decoding any information frame, will wait this amount of time before attempting to access the channel. Thus, even if a station can't hear all the ACKs, it will refrain from colliding with any of the ACKs (assuming it hears the data frame). Further, if a station hears any decodable frame, it will wait at least one ACK time before attempting channel access.

CONCLUSION

A straightforward, adaptive link-level protocol tailored for the Amateur packet radio environment has been outlined. Although not compatible with current versions of AX.25, a number of the ideas presented here could be incorporated in other link level protocols, perhaps even in AX.25 version 3.0.

ALink90 is not intended to supplant AX.25. Rather, it is an experimental protocol for further investigation into automating link-level and media-access decisions. The goal is optimizing the efficiency of limited bandwidth, multi-user packet radio channels.

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