On-air Measurements of MIL-STD-188-141A ALE Data Text Message Throughput over Short Links

Ken Wickwire
kwick@mitre.org

For the past six months a colleague W 1IMM and I have conducted automated measurements of throughput when ASCII text files are sent over short or "tactical" HF paths using the ALE Data Text Message (DTM) engineering orderwire (EOW). This is a preview of our results

Tactical HF links generally use either surfacewave or near-vertical-incidence skywave (NVIS). Surfacewave works out to about 50 miles and NVIS to about 300 miles. Multipath, D-layer absorption and interference usually affect NVIS, which usually has lower throughput than communications over "standard" (i.e., long) one-hop skywave paths.

ALE systems' ability to measure channel quality, and use it to make choices of good channels, now offers improved performance over tactical paths. ALE systems employ a slow but robust waveform that uses interleaving and two kinds of forward error correction (FEC) to combat the fading, noise and interference of HF channels.

ALE standards prescribe three engineering orderwire protocols for half-duplex data transfer: the Automatic Message Display (AMD) mode, the Data Text Message (DTM) mode and the Data Block Message (DBM) mode. DTMs can transfer ASCII text using the ALE waveform and an ARQ protocol.

We have carried out more than 200 measurements of throughput (in char/s and char/s/Hz) using DTMs on a 35-mile path. We have used 125-watt Harris RF5022 ALE radios, which implement DTMs of constant size (300 bytes) and "memory ARQ," in which up to six erroneous repeats of a message segment sent as a DTM are stored and compared when necessary in an attempt to construct an error-free segment. The RF5022's ALE firmware segments messages longer than 300 bytes into 300-byte DTMs. These DTM-segments are ACKed one at a time. Experiments suggest that messages 300 to 1000 characters long produce the highest throughput consistent with shortest run time.

Our two stations used broadband sloping longwires that allowed the radios to drive the antennas without tuners. The antennas have both vertical and horizontal components, so that they can launch both surfacewave and NVIS signals.

The ALE modems were programmed to try frequencies between 2 and 16 MHz. (IONCAP runs suggested that any link above 8 or 9 MHz probably used surfacewaves, which were chosen frequently at night, when interference was heavy.) The tests covered seven months from September, 1995, when the average sunspot number was near the bottom of its cycle.

Our measurements were automated by two C-programs. The first runs throughput tests. At the start of a test, and between DTM transfers, the receiving station is scanning the set of programmed frequencies and will stop upon hearing a call. If a link occurs, the calling and receiving stations negotiate a DTM transfer and the sender begins sending the DTM.

The program usually starts by performing a link qual.ity assessment (LQA) exchange, which gives both stations up-to-date info on channel quality. After the exchange, the calling radio links with the receiving one. When the calling radio informs the program that a link has been established, the program commands the local radio to list the channel number and the corresponding LQA scores for later analysis.

When the LQA scores for the linking channel have been logged, the program prepares the local radio to send an orderwire. It then uploads a standard English ASCII text file for transfer. After sending commands that require a particular response, the program invokes a function called `chkresponse ()` that scans the serial-port input from the local radio for the appropriate response ("LINKED", "MESSAGE RECEIVED", etc.).

As the program runs, timers set by the computer's clock measure "link time" and "message transfer time." Message transfer time is the time between start of character-by-character uploading of the file to the local radio and receipt of the MESSAGE RECEIVED notification. Transfer time does not include link time. The program calculates throughput by dividing the number of characters sent by the message transfer time. Since the message transfer time includes the few seconds needed for the receiving station to send the MESSAGE RECEIVED frame, the throughput measurements are slightly pessimistic.

The throughput-measuring program writes its results to an archive file. The archive file stores appended, time-stamped data in abbreviated format that can be analyzed off-line by a statistics program. Here is abbreviated statistical output for all the tests run up to 6 May 1996:

```
no_ALE_links = 235
E(link_time_ALE) = 25.96 s, sd(link_time_ALE) = 21.42 s
E(transfer_time_ALE) = 139.9 s, sd(transfer_time_ALE) = 98.7 s
E(no_file_chars_ALE) = 770.4, sd(no_file_chars_ALE) = 615.1
E(tput_ALE) = 5.21 cps, sd(tput_ALE) = 1.16 cps, sd(mean_tput_ALE) = 0.08 cps
max_thruput_ALE = 6. 60 cps, E(thruput_ALE/Hz) = 0.003 cps/Hz

Linking histogram:
Channel 1 (2.394 MHz):   1  link
Channel 2 (2.824 MHz):   70 links
channel 3 (3.166 MHz):   29 links
Channel 4 (4.565 MHz):   8  links
Channel 5 (5.031 MHz):   56 links
Channel 6 (6.870 MHz):   4  links
Channel 8 (7.850 MHz):   1  link
Channel 9 (9.305 MHz):   7  links
Channel 10 (10.330 MHz): 3  links
Channel 11 (10.523 MHz): 5  links
Channel 12 (13.692 MHz): 45 links
Channel 13 (15.487 MHz): 6  links
```

E() and sd() stand for the expectation (average) and standard deviation of a measurement. About two-thirds of a set of measurements will be within one standard deviation of their mean and over 90% will be within two. The `sd (mean_tput_ALE)` here suggests that our sample sizes are big enough to give us high confidence that if we collected more throughput measurements under roughly the same conditions, we would not get average throughputs that differed from the one above by more than a tenth of a character per second. One should keep in mind that our "conditions" correspond to winter and spring operations at low sunspot numbers. Average throughput in other seasons and at much higher sunspot numbers will probably be different.

To calculate the average throughputs per Hertz [`E ( thruput-ALE/Hz )`], we divided the average throughput by the ALE signaling bandwidth. For the latter we used the formula for "necessary telegraphy bandwidth" (from the 1992 Dept. of Commerce *RF Management Handbook):*

$$BW = R / \log_2(N_T) + f_{\max} - f_{\min},$$

where R (= 375 bits/s) is the channel rate, N_T (= 8) is the number of MFSK tones in the ALE waveform, f_{max} (= 2500 Hz) is the highest tone and f_{min} (= 750 Hz) is the lowest tone. For these values, the signaling bandwidth is 1875 Hz. At the end of its output, the statistics program prints histogram values of the frequencies chosen for linking by the sending ALE radio (more on these below).

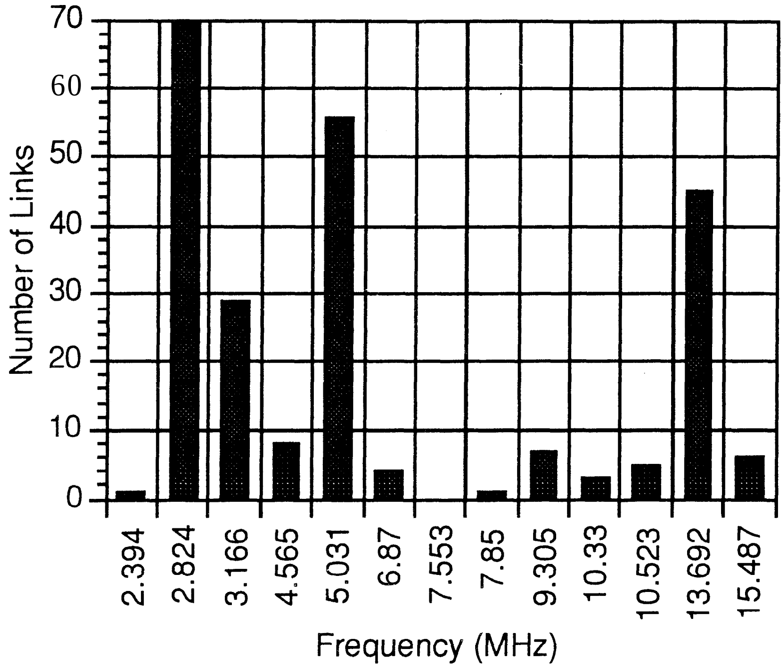
Because of the relatively low channel rate used by the ALE waveform (375 bits/s or 125 symbols/s), and the high overhead used to provide the waveform's robust forward error correction (about five-sixths of the channel rate), average DTM throughput (about 5 char/s) is modest. What distinguishes ALE DTM transfers from ASCII transfers using several other ARQ protocols, like the AMTOR, PacTOR, GTOR and AX.25 packet protocols, is the fact that on tactical links, DTM transfers are much more frequently successful, especially at night. The main reason for this is ALE's ability to look for another frequency for linking if the previously tried frequency fails. File transfers were successful on roughly 90% of the automated attempts.

Our ALE systems have probably often linked on surfacewave and possibly E-layer frequencies rather than on NVIS frequencies, which lie near the bottom of the HF band. Surfacewave frequencies appear to have been chosen often at night. (Most traditional propagation prediction programs do not suggest surfacewave frequencies for night time or any other operation.) One reason for avoiding NVIS communications at night is that there is almost always more interference on NVIS frequencies at night than during the day. For short-range communications, it is important to use antennas that can launch both NVIS and surfacewave signals; that is, antennas with both vertical and horizontal components.

The relatively small standard deviation of DTM throughput reflects the DTM protocol's restricted ability to adapt to changing conditions. The low variability of throughput over short paths and the reliability of transfer are also reflected in the fairly small difference between average and maximum (6.6 cps) observed throughput.

Average link time was about 26 seconds, with a standard deviation of about 21 s. This standard deviation implies that establishing a link required at least two attempts fairly often during our tests. (A single successful link handshake takes about 20 seconds.)

The histogram data produced by the statistics program are graphed below. The histogram shows that most DTMs were transferred at 2.824, 3.166, 5.03 1 and 13.692 Mhz. The middle two frequencies were chosen mostly during the day and probably supported only NVIS. The 2.824 MHz frequency appears to support both surfacewave and NVIS. (2.394 MHz may have had antenna-matching problems that caused its poor performance.) The transfers on 13.692 MHz were mostly at night and were probably by surfacewave. It is unlikely that an inexperienced communicator would have tried 13 MHz for night-time operation over this link.



These on-air results suggest that although the ALE DTM engineering orderwire mode is relatively slow, on tactical links it can perform ASCII file transfers more reliably than several other ARQ systems in current use.

Acknowledgments.

I am grateful to John Morgan of the Harris Corporation for providing the Harris RF5022 radio systems with which these measurements were made, and to Bob Levreault (W 1 IMM) for maintaining one of the ALE stations used for the tests.