On-air Measurements of CLOVER II and CLOVER 2000 Throughput

Ken Wickwire (KB1JY), Mike Bernock (KB1PZ) and Bob Levreault (W1IMM)

1. Introduction

This paper is one of a series treating on-air measurement of throughput in eight-bit characters per second (cps) for various HF data-transmission protocols of interest to amateurs (see the references to our other reports at the end of the paper). Here we describe an extensive set of measurements of throughput for compressed and uncompressed text files sent over near-vertical-incidence-skywave (NVIS) and one-hop skywave (OHS) paths. The on-air tests used the CLOVER II and CLOVER 2000 waveforms and the file transfer protocols implemented in the HAL CLOVER terminal packages.

NVIS paths, which often experience relatively difficult channel conditions characterized by multipath interference, high noise and QRM, are used to communicate over 20- to 300-mile ground distances using antennas that can launch energy at high takeoff angles. OHS paths need antennas that launch at low takeoff angles. These paths are many hundreds or thousands of miles long and are often easier to communicate over than NVIS paths.

Several versions of the CLOVER modem are available (the PCI4000, DSP4100, P38, and others). They are distinguished mainly by the size of their modulation constellations (number of different possible data symbols) and by the resulting maximum speed of data transmission. The number of symbols used by a modulation scheme affects not only throughput but also dictates the processing power required of the associated hardware (computer or modem or both).

CLOVER II and CLOVER 2000, which run on the HAL PC14000 and DSP4100 hardware platforms, were designed to process received signals in the BPSM ("binary phase-shift modulation"), QPSM (4-ary phase), 8PSM (8-ary phase), 8P2A (S-phase, 2-amplitude) and 16P4A (16-phase, 4-amplitude) modulation modes. (Because of the fact that CLOVER uses a non-standard multi-tone signaling scheme, HAL has chosen not to call the phase-shift modulations "PSK.") In ARQ (connected) operation, CLOVER chooses among these modulation modes in response to changing channel conditions.

CLOVER II, developed primarily for amateur radio applications, modulates four tones separated by 125 Hz and occupying a 500-Hz bandwidth. The faster CLOVER 2000 waveform modulates eight tones separated by 250 Hz and occupying 2000 Hertz. CLOVER 2000 was developed mainly for commercial applications but with the movement in HF from voice to data communications it may eventually be authorized for amateur use.

All of the CLOVER modems come with software (including a DOS-based GUI) that performs uncompressed and compressed file transfers using the CLOVER automatic repeat request (ARQ) protocol. Using the compressed mode, one can send graphics and other " binary" (eight-bit-character) file data, in addition to text files. The uncompressed mode is generally used for chat sessions and text-file transfers.

The CLOVER II data-transmission protocol changes its modulation mode (varying the number of bits per symbol while keeping the symbol rate fixed at 3 1.25 symbols per second). (This means that the shape of the CLOVER II signal spectrum stays the same as the modulation adapts itself to the channel, a property of all the CLOVER versions.) The four "tone pulses" of the waveform are transmitted in numerical order, with 32 milliseconds between occurrences of the same tone pulse. The CLOVER II CCIR emission designation is 500H J2 DEN or 500H J2 BEN and its maximum uncompressed throughput in the ARQ mode is 69.6 characters (8-bit bytes) per second.

CLOVER 2000 runs on special versions of the PC14000 and DSP4100 modem platforms (it cannot run on the P38 card). Its CCIR emission designation is 2KOH J2 DEN or 2KOH J2 BEN. Although similar to CLOVER II, CLOVER 2000 operates with eight tone pulses at twice the fixed CLOVER II rate, or 62.5 symbols per second, and the order of its transmitted frequencies (tone-pulses), separated by 250 Hz, is scrambled to reduce adjacent-tone interference. CLOVER 2000 changes its modulation mode (and thus the number of bits per symbol) in a way similar to that of CLOVER II: if BPSM is chosen as the modulation (typical of a poor channel, and always used for control frames), only one bit per symbol (tone pulse) is sent and received (for a total data rate without overhead of 8 x 62.5 = 500 bits per second). If 16P4A is chosen (only on extremely good channels, with high SNRs and almost no multipath), the effective data rate without error-coding and other overhead is 3000 bits per second. The maximum uncompressed throughput in the ARQ mode for CLOVER 2000 is 249.3 characters (8-bit bytes) per second.

The CLOVER system assesses channel conditions (at receivers) by measuring the amount of error-correcting capacity [ECC] used to remove data errors, the number of erroneous data blocks and the phase dispersion [PHS, related to multipath], among other things. Receivers send this information to transmitters at turnarounds, and transmitters change their modes according to the most current channel information sent to them by receivers. This adaptability to the constantly changing channels, combined with the underlying Reed-Solomon FEC coding, and, when necessary, retransmission of erroneous frames, is the key to CLOVER's reputation as one of the two fastest and most reliable HF data communication protocols available to hams. (The other is the PacTOR II system, which we plan to test later.)

For further details on how CLOVER works, see the HAL documentation supplied with the various versions and the descriptions published by Ray Petit and Bill Henry in the *RTTY Journal, QST*, *QEX* and elsewhere between 1990 and 1994.

The NVIS paths we have studied, which are 25 to 140 miles long, frequently display strong multipath, high local and propagated noise, D-layer absorption at mid-day and occasionally strong interference from other stations operating in both voice and digital modes. (Horizontal antenna polarization at all our NVIS stations allowed us to be fairly certain we were using NVIS rather than surfacewave propagation, and this was confirmed by the fading we observed during many file transfers.)
We measured one-hop skywave throughput on 1000-mile paths from Massachusetts and New Hampshire to Illinois. These paths produced less multipath interference than our five NVIS links and therefore in some cases somewhat higher throughput.

We tested CLOVER II in the ham bands and on assigned frequencies outside the ham bands. CLOVER 2000 was tested only on assigned frequencies. The majority of NVIS measurements were at 3.2 and 3.6 MHz, with a few at somewhat higher (up to 5 MHz) and lower (down to 2 MHz) frequencies. The OHS measurements were made at 10.3, 10.5, 12.2 and 15.7 MHz. (Amateur frequencies usually had too much QRM for CLOVER II OHS tests, and the legality of using CLOVER 2000 in the amateur bands is unclear to us.) For the OHS tests we normally avoided mid-day testing on frequencies far below the MUF. (On such frequencies there are two "windows of good performance" in the morning and evening when the MUF is either rising or falling through the operating frequency. We did most of our testing in such windows.) Output power (about 100 watts) and antennas at all stations were typical of those used by hams.

Daytime was defined to occur between the fixed times of 1000 and 2200 GMT (about 5:00 AM to 5:00 PM local time). Note that because our measurements were made over the course of nearly nine months, "nighttime" (roughly 5 :00 PM to 5 :00 AM local time) was not always associated with darkness at the path midpoint. Nevertheless, most nighttime measurements were taken in conditions that characterize conventional nighttime HF propagation: high noise and increased interference.

Since we achieved the goal of working near the MUF only approximately with our available frequency set (especially for daytime CLOVER II tests), our results are conservative. A properly set up adaptive automatic link establishment (ALE) system that used quasi-real-time channel assessments to choose the best operating channel for the CLOVER waveform would have allowed us to avoid a lot of the interference and " far-from-the-MUF" conditions that we occasionally tested in over OHS paths.

The NVIS tests covered the six-month period from September 1997 to February 1998. The OHS tests covered parts of the eight-month period from January 1998 to July 1998, with most of the OHS CLOVER II tests toward the end of that period. The average sunspot number during these periods was between about 20 and 70, so MUFs were in the lower half of their eleven-year up and down cycle.

The rest of the paper describes the paths between stations and layout of antennas, the HAL CLOVER interface and our file-transfer operations, the files sent, the recorded data format, statistical analysis software, a statistical summary of the data, a discussion of the statistical results and concluding remarks.

2. Layout of Paths and Discussion of Antennas

The stations used for the NVIS tests are in Bedford, Mass. (KB 1 JY), Norfolk, Mass. (W1IMM), Derry, N.H. (KB1PZ) and Portland, Maine (KB 1 JY-1). Bedford used an 80m dipole up 30 feet for NVIS tests, and a terminated, bottom-fed 125-ft longwire pointing southwest for OHS tests. Norfolk used an 80m dipole up 40 feet for NVIS tests. Derry used an off-center-fed 80m dipole up 30 feet for NVIS and OHS tests. Portland used an end-fed 100-foot unterminated longwire pointed west for NVIS links. The stations in the OHS tests are in Bedford, Mass. (KB 1 JY), Derry, N.H. (KB1PZ), and Urbana, Illinois (W9KVF). In the OHS tests Bedford used the resistively terminated sloping longwire running southwest, Derry the off-center-fed 80m dipole and Urbana a KLM-7 seven-element log-periodic up 75 feet. The links (followed by lengths and rough estimates of the percentage of data collected over each link) are:

NVIS

Bedford-Derry (25 miles, 25%)
Bedford-Norfolk (35 miles, 25%)
Derry-Norfolk (60 miles, 25%)
Portland-Derry (60 miles, 10%)
Portland-Norfolk (140 miles, 15%)

OHS

Bedford-Urbana (1000 miles, 70%)
Derry-Urbana (1000 miles, 30%)

The NVIS links run more or less north-south and the OHS links east-west. At least 100 transfers were conducted in each throughput category.

3. The HAL CLOVER User Interface and CLOVER File Transfer Protocol

Although there are graphical user interfaces (GUIs) for running CLOVER that may be more sophisticated than the DOS-based one provided by HAL (Express, XPWIN and others), the HAL GUI is presently the best one to use for making throughput measurements because it gives the transfer time of compressed file transfers. During the course of our tests we moved through several versions of the CLOVER firmware. Some of the firmware upgrades made improvements in CLOVER's ARQ scheme. The improvements appear to have been in the nature of fine-tuning since we did not notice large increases in performance.

To send a file with the HAL GUI, one first establishes a CLOVER ARQ link with the receiving station by selecting (or entering) the callsign of the station and sending a carriage return.

Once the link is established (which is usually confirmed in a few seconds by a LINKED message on the GUI and the appearance of "HIS" channel statistics on the display), one can enter the name of a file to be transferred. The HAL software allows one to view and record channel statistics (signal-to-noise ratios, phase dispersion, etc.) during file transfers and chat sessions. These statistics allow one to make changes (between links) in the operating parameters (via the "BIAS" setting) in response to assessed channel state. They can also provide fascinating insight into the workings of a file transfer (see the references at the end for our paper on CLOVER channel statistics).

After the filename has been entered, one has a choice of sending a text file from the TX Buffer in uncompressed mode or sending any file (" Send from Disk") in compressed mode. Only generic text can be sent in uncompressed mode; files with control characters in them will abort a transfer attempt. Files sent in compressed mode can have any format, although some files may not benefit from compression, and may even be expanded slightly by the compression process. Conventional text files always benefit from compression.

Some people view the throughput of uncompressed files as the inherent, or "true" performance of a waveform, error-control scheme and file-transfer system. Others consider compression to be part of a protocol if it is provided as a constituent of the "common" interface provided with a modem's hardware. To satisfy both camps, we have measured throughput in these tests of both compressed and uncompressed text files.

To measure the throughput of uncompressed (text) files, we had to record transfer time in our transfer-data files by hand, since the HAL software does not display transfer times of data sent from the text buffer. This was not as onerous as it sounds since once we decided on a recording format we were able copy, paste and edit with a text editor to speed up data recording.

All of the files sent for this report consisted of readable text. To measure the throughput of compressed text files, we took advantage of the HAL software's calculation and display of file transfer time on the GUI screen. Through experimentation we deduced that the optimal file size (highest throughput with smallest test time) for throughput assessment of CLOVER was between 10 and 40k bytes, and most of our files had sizes in that range.

Files already compressed by other applications (for example, GZIP-ed files) may get sent via the HAL CLOVER GUI in even smaller form than those compressed only by the PKWARE algorithm used by HAL, but we did not do this in our tests. Precompression in HF data communication is nevertheless a useful technique that deserves further study.

4. Recorded Throughput-Data Format

The data archive file into which the results of each transfer were entered contains the date-time group at the time (GMT) of the transfer, callsign of receiving station, callsign of sender, the CLOVER interface (for these tests, that of the HAL DSP4100), uncompressed file size in bytes, compressed file size in bytes, transfer time in seconds, predominant waveform used by CLOVER during the transfer (AUTO = set adaptively by the HAL software), HF frequency in megahertz, observed channel condition (Q = quiet, N = noisy, etc.), the power adjustment mode (usually F = fixed), the BIAS (F = FAST, N = NORMAL, R = ROBUST) and the hand-calculated throughput in characters per second (cps). The latter doesn't have to be accurate, or even recorded, since it's calculated later by the analysis software. In the case of uncompressed files sent from the TX buffer, the transfer time is read from the computer clock and may therefore be off by a second or two. This makes little difference to throughput calculations for files that take several minutes to send.

The BIAS is a parameter that describes the error-correcting overhead (and thus the number of data-bytes per ARQ block) chosen by the transmitting station's operator for a communications session. Robust bias is usually chosen when the channel appears bad (noisy, low signal-to-noise ratios, interference) and fast bias when it appears to be good.

Here's an excerpt from the NVIS transfer-data file for CLOVER II tests run from KB1PZ to W1IMM and KB1JY in October 1997:

```
04.10.97 01:04:00 WlIMM KBlPZ 4100 20000 10176 363  AUTO  3.6155   N   F   F   55
04.10.97 01:12:00 WlIMM KBlPZ 4100 20000 10176 375  AUTO  3.6155   N   F   F   53
04.10.97 01:19:00 WlIMM KBlPZ 4100 20000 10176 548  AUTO  3.6155   N   F   R   36
04.10.97 01:30:00 KBlJY KBlPZ 4100 20000 10176 433  AUTO  3.6155   N   F   N   46
04.10.97 01:37:00 KBlJY KBlPZ 4100 20000 10176 480  AUTO  3.6155   N   F   N   42
04.10.97 01:46:00 KBlJY KBlPZ 4100 20000 10176 384  AUTO  3.6155   N   F   F   52
```

Files like this are opened and analyzed by a data-analysis program described in the next section.

5. The Data-analysis Software

The results in the data archive were analyzed off-line by a program called summary clo.c. This program reads the archive file line-by-line looking for various strings. As it moves through the file to the end-of-file indicator, the program keeps running totals of throughput and other data corresponding to the strings, from which it calculates statistics such as the average and standard deviation of the throughput. The statistics are written to a summary file after the pass through the archive file. Switches in the summary code are set before each run to pick out specific data (corresponding to various string combinations) for analysis. For example, we select lines with differing actual and compressed file sizes to pick out compressed file transfers, and use the date-time group to distinguish daytime from nighttime transfers. Since the summary program was written to analyze archive files of fixed format but arbitrary length, summaries of the data collected so far can be made at any time.

Shown below is the output of the summary program for all CLOVER-II one-hop skywave (OHS) tests run from March 1998 to mid-July, 1998 (a subset of all such data). For this output we set the software switches to compute throughput statistics for *nighttime compressed text files*.

```
Statistical Summary of CLOVER Throughput Tests:
16.07.98 17:20:01 CLOVER-II NIGHTTIME COMPRESSED

NUMBER OF CLOVER XFERS IN SAMPLE = 80,  CLOVER BW = 500 Hz
E(FILE_SIZE) = 22500.0 bytes, E(COMPRESSED_SIZE) = 11490.9 bytes
E(TRANSFER TIME) =  674.2 s, sd(TRANSFER TIME) =  393.0 s
E(THRUPUT) = 36.60 cps, sd(THRUPUT) = 12.44 cps, sd(mean_THRUPUT) = 1.391 cps
MAXIMUM THRUPUT = 63.90 cps, E(THRUPUT/Hz) = 0.073 cps/Hz
E(COMPRESSION RATIO) = 50.99%, sd(COMPRESSION RATIO) = 0.20%
Lowest compression ratio = 50.83%; Compressed_size:File_size = 5083:10000
Highest compression ratio = 51.39%; Compressed_size:File_size = 20557:40000
NUMBER OF UNCOMPRESSED TRANSFERS IN SAMPLE = 0
7 transfer failures; P(transfer success) = 80/87 = 0.92
```

The output shows that the average throughput for 80 uncompressed-text-file transfers was about 37 characters per second (cps) and that the largest observed throughput in this mode was about 64 cps. The sd(THRUPUT) reflects the spread of the throughput measurements about their average. Roughly speaking, about two-thirds of a set of measurements will be within one standard deviation (here 12.4 cps) of their mean and over 90% will be within two standard deviations of their mean.

We also calculate the " standard deviation of the mean throughput" [sd(mean THRUPUT)] in characters per second and the average throughput per Hertz of signaling bandwidth. The standard deviation of the **mean throughput (equal to the standard deviation of the throughput divided by the** square root of the sample size) is an assessment of the variability of the mean itself (which has its own statistical variability). The sd(mean) above suggests that our sample size in this case is big enough to make us confident that if we collected many more throughput measurements under roughly the same conditions, we would not get an average throughput that differed from the one above by more than about 1.4 characters per second.

To estimate the average throughput per Hertz [E(THRUPUT/Hz)], we divide the average throughput by the average signaling bandwidth. For CLOVER II, the signaling bandwidth is 500 Hz and for CLOVER 2000 it's 2000 Hz (see the Clover documentation).

The compression ratio is defined as the ratio of compressed size in bytes to uncompressed size in bytes. A ratio of 100% therefore means no compression.

For the tests analyzed here we also kept track of the number of failed transfers and calculated the percentage of successful file transfers. Unsuccessful transfers occurred when, after a successful link, the number of times the modem tried to send a data frame exceeded a GUI-programmable limit of 20, causing the modem to terminate the link. We did not include failures to link in our transfer success ratios. In the excerpt given above, 87 transfer attempts resulted in ARQ links, seven of which were terminated by the modem when the link timed out before the file got through. This led to a transfer success ratio of 80/87 or approximaely 92%.

6 . Statistical Summary of Throughput Results

The results of our NVIS and OHS tests of CLOVER II and CLOVER 2000 (as of August 1998) are summarized in Tables 1 through 4 below. They correspond to CLOVER II NVIS and OHS transfers and CLOVER 2000 NVIS and OHS transfers in that order. The first column in each table gives the average throughput and its standard deviation, the average throughput per Hertz, the standard deviation of the mean throughput and the maximum observed throughput. The second column gives the number of transfers and the probability in percent of successful transfer [P(good xfer)] in each case. The third column gives the mean and standard deviation of the compression ratio for compressed transfers (100% means no compression). The fourth column gives the mean and standard deviation of the transfer time in seconds and the fifth column the average number of bytes in the original, uncompressed files.

Table 1. Statistical Summary of CLOVER II NVIS Throughput Data

File Type & Time	E(thruput) sd(thruput) E(tput/Hz) sd_mn(tput) max tput	No. Xfers P(good xfer)	E(Compr. Ratio) (CR) sd(CR)	E(xfer_tm) sd(xfer_tm)	E(No_char)
Uncompr. Text Day	34.3 cps 11.8 cps 0.07 cps/Hz 0.77 cps 69.0 cps	239 98%	—	980 s 522 s	31346
Compr. Text Day	52.1 cps 19.9 cps 0.10 cps/Hz 1.52 cps 127.5 cps	172 98%	51.4% 1.8%	704 s 360 s	33986
Uncompr. Text Night	23.8 cps 8.2 cps 0.05 cps/Hz 0.74 cps 45.7 cps	125 93%	—	1080 s 558 s	24259
Compr. Text Night	37.2 cps 12.3 cps 0.07 cps/Hz 1.15 cps 61.9 cps	115 98%	51.0% 0.3%	781 s 564 s	26977

Table 2. Statistical Summary of CLOVER II OHS Throughput Data

File Type & Time	E(thruput) sd(thruput) E(tput/Hz) sd_mn(tput) max tput	No. Xfers P(good xfer)	E(Compr. Ratio) (CR) sd(CR)	E(xfer_tm) sd(xfer_tm)	E(No_char)
Uncompr. Text Day	24.3 cps 7.7 cps 0.05 cps/Hz 0.67 cps 54.6 cps	131 90%	—	1049 s 461 s	24626
Compr. Text Day	42.3 cps 14.6 cps 0.08 cps/Hz 1.26 cps 87.2 cps	134 94%	51.1% 0.2%	668 s 322 s	25373
Uncompr. Text Night	21.3 cps 7.2 cps 0.04 cps/Hz 0.68 cps 36.5 cps	113 97%	—	864 s 517 s	16637
Compr. Text Night	38.3 cps 12.1 cps 0.08 cps/Hz 1.08 cps 63.9 cps	125 94%	51.0% 0.2%	615 s 347 s	21760

Table 3. Statistical Summary of CLOVER 2000 NVIS Throughput Data

File Type & Time	E(thruput) sd(thruput) E(tput/Hz) sd_mn(tput) max tput	No. Xfers P(good xfer)	E(Compr. Ratio) (CR) sd(CR)	E(xfer_tm) sd(xfer_tm)	E(No_char)
Uncompr. Text Day	91.2 cps 32.6 cps 0.05 cps/Hz 1.82 cps 186.7 cps	321 95%	—	527 s 345 s	45964
Compr. Text Day	166.2 cps 67.8 cps 0.08 cps/Hz 5.11 cps 333.3 cps	176 94%	5 1.4% 0.3%	308 s 189 s	43454
Uncompr. Text Night	58.6 cps 25.9 cps 0.03 cps/Hz 1.89 cps 148.2 cps	188 88%		625 s 295 s	32584
Compr. Text Night	93.3 cps 39.0 cps 0.05 cps/Hz 2.77 cps 242.4 cps	199 95%	5 1.3% 0.3%	474 s 353 s	39156

Table 4. Statistical Summary of CLOVER 2000 OHS Throughput Data

File Type & Time	E(thruput) sd(thruput) E(tput/Hz) sd_mn(tput) max tput	No. Xfers P(good xfer)	E(Compr. Ratio) (CR) sd(CR)	E('xfer_tm) sd(xfer_tm)	E(No_char)
Uncompr. Text Day	117.2 cps 37.3 cps 0.06 cps/Hz 2.04 cps 208.3 cps	334 92%	—	377 s 388 s	36008
Compr. Text Day	180.9 cps 53.5 cps 0.09 cps/Hz 4.34 cps 288.2 cps	152 92%	51.4% 0.3%	319 s 203 s	53978
Uncompr. Text Night	82.8 cps 3 1 .o cps 0.04 cps/Hz 2.92 cps 154.4 cps	113 83%	—	478 s 287 s	34478
Compr. Text Night	163.6 cps 54.4 cps 0.08 cps/Hz 4.81 cps 248.8 cps	128 96%	5 1.4% 0.2%	299 s 130 s	44167

'. Discussion of Results

CLOVER II

'ables 1 and 2 show that the inherent (no compression used) over-the-air average throughput of CLOVER II on our links is around 34 characters per second (cps) on NVIS paths and 24 cps on OHS)aths for daytime operations. Nighttime NVIS and OHS throughput averages for uncompressed files ıre 24 and 21 cps. (The standard deviations of these mean throughputs are all about 0.7 cps, giving us ıigh confidence that additional measurements made under the same conditions would yield nearly the ame mean throughputs.)

\verage CLOVER II throughputs for compressed text files are 52 and 42 cps on our NVIS and OHS)aths during the day, and 37 and 38 cps at night, with standard deviations of mean throughput around 1 :ps. These average throughputs, and the average compression ratios of about 5 1% given in column 4)f the tables, show that the HAL GUI software's PKWARE compression is squeezing our text files lown to about half their original size. This, of course, roughly doubles text-file throughput. That :ompressed throughputs are in fact slightly less than twice the corresponding uncompressed ones is lue probably to a combination of slight differences in the times files were sent (and hence channel :onditions) and the additional time needed to compress and decompress the files.

\t first glance, the fact that average OHS throughputs for CLOVER II are in some cases smaller than ıverage NVIS throughputs is surprising, since our and many others' experience with these and other)rotocols has shown that NVIS conditions for data transmission are generally worse than OHS :onditions. On NVIS paths there is *usually* more multipath, noise and interference on the band of iequencies that lie below the MUF than on OHS paths, even when comparisons are made in different ;easons. However, seasonal and frequency-dependent effects of noise and interference on HF channels)ften overturn common experience.

n our tests, CLOVER II NVIS data were collected in fall and winter on mostly amateur frequencies hat were unusually quiet during the day. However, scheduling forced us to gather our OHS data (on amateur and non-amateur frequencies) in spring and summer, when lightning noise was a feature of a ong period of rainy weather in the eastern half of the country. Several of the OHS frequencies we had ıvailable in the spring were also affected by powerful broadcast stations located only a few kilohertz 'rom our carriers. This unlucky but all-too-realistic combination of bad conditions was the reason why)ur CLOVER II OHS throughputs were lower than their NVIS counterparts. Experience suggests that f we had been able to collect our CLOVER II OHS data on frequencies with amounts of burst noise ınd interference similar to those on our NVIS frequencies, CLOVER II OHS throughputs would have)een twenty to thirty percent higher than NVIS throughputs.

Given enough frequency choices, an automatic link establishment (ALE) system, such as prescribed in MIL-STD- 188- 14 1 A, and now widely available, can almost always find useful, interference-free 'requencies that lie below the MUF. The next generation of ALE systems, being developed now, may ılso do a better job than the current generation of predicting the performance of non-FSK waveforms ike CLOVER.

n all cases the probability of successful file transfer with CLOVER II was 90% or higher (with the lefault maximum number of retries of 20). This suggests that if CLOVER II can establish a link it can ılmost always (even at night) complete a file transfer. (The transfer success rate given a link can be ● aised to almost 100% by raising the retry limit, at the expense of wear and tear on radios and ımplifiers.) Although we were usually successful in choosing frequencies that supported linking, we sometimes had to give up when the MUF dropped below our set of available operating frequencies and inking became impossible. (This phenomenon can be observed clearly in CLOVER channel statistics.) It was during transits of the MUF through our operating frequencies that we logged most of :he failed transfers that figured in our success-probability calculations.

CLOVER 2000

Tables 3 and 4 show that the uncompressed over-the-air average throughput of CLOVER 2000 for text files on our links is around 91 cps on NVIS paths and 117 cps on OHS paths for daytime operations. These are about four times the corresponding CLOVER II throughputs. Nighttime NVIS and OHS throughput averages for uncompressed files are 59 and 83 cps, three to four times the corresponding CLOVER II throughputs. (The standard deviations of these average throughputs are all under 3 cps, making us confident that additional measurements made under the same conditions would yield similar mean throughputs.)

Average CLOVER 2000 throughputs for compressed text files are 166 and 18 1 cps on our NVIS and OHS paths during the day, and 93 and 164 cps at night, with standard deviations of mean throughput 5 cps or less. Compressed throughputs are again somewhat less than twice the corresponding uncompressed ones.

For the CLOVER 2000 transfers, average OHS throughputs are 20 or more percent larger than average NVIS throughputs, confirming expectations. This is no doubt the result of running the CLOVER 2000 NVIS and OHS tests on frequencies that had similar amounts of interference and lightning-induced noise.

Except for uncompressed nighttime OHS transfers, the probability of successful file transfer with CLOVER 2000 was 88% or higher (with the default maximum number of retries again set at 20). Uncompressed nighttime OHS transfers were successful 83% of the time. With a sample size of 113, this may merely reflect statistical variation. If not, it may be related to higher signal-to-noise-ratio requirements for the 2K-bandwidth CLOVER 2000 modulation than for the CLOVER II modulation, which had a somewhat higher transfer percentage (88%) in this case. An ALE system would probably also raise transfer success probabilities with CLOVER 2000.

The relatively large standard deviations of uncompressed and compressed file throughput for CLOVER II and 2000 (the standard deviations range from about ten to several tens of cps for one to two hundred transfers) reflect, in part, CLOVER's ability to adapt itself to changing channel conditions (see Sec. 1). However, these standard deviations are also affected by variability of file size, so channel adaptation should not be viewed as the sole source of throughput spread.

8. Comparison with PacTOR, GTOR and the HAL P38

In contrast to the daytime CLOVER II and CLOVER 2000 throughputs in Tables 1-4, PacTOR (with Huffman compression on) and GTOR (with its built-in compression) achieved average throughputs for text files of about 18 and 24 cps on our daytime NVIS links and 20 and 32 cps over daytime OHS links (data taken two or three years ago; see Ref. 4. We did not collect enough PacTOR, GTOR or P38 data for a comparison with their nighttime throughput.) Corresponding uncompressed throughputs would be about half of these values. Thus, if data compression is viewed as an intrinsic part of what we have called (Ref. 4) the "common" implementation of PacTOR and GTOR, then the HAL GUI software in its PKWARE-compression mode produces about twice the average throughput of PacTOR and GTOR for text-file transfers. CLOVER 2000, with four times the bandwidth of PacTOR and GTOR, has six to seven times the uncompressed throughput of PacTOR and GTOR and eight to ten times the compressed throughput.

The P38 achieved daytime NVIS throughputs for uncompressed and compressed text files of 24 and 43 cps. These are 20-30% lower than corresponding CLOVER II throughputs, as might be expected. Daytime P38 OHS throughputs were 29 and 50 cps for uncompressed and compressed text files, about 25% *higher* than the corresponding CLOVER II OHS throughputs. The reasons for this otherwise surprising result are the same as those for the reverse ordering of CLOVER II NVIS and OHS throughputs: unavoidably high levels of noise and interference during the CLOVER II OHS tests that vere not present during the CLOVER II and P38 NVIS tests. Against similar amounts of noise and nterference, P38 NVIS throughputs would have been well below CLOVER II OHS throughputs. P38 naximum throughputs were about half those of CLOVER II.

'. CLOVER and File Encryption

'o see if CLOVER file compression interferes with off-line file encryption (of interest in certain nilitary and commercial applications), we encrypted and compressed several large (I 0-40k) text files vith the commercial, Fortezza-based, LJLCryptoLib " LJLCryptor" application and sent them in ompressed binary mode over a non-amateur CLOVER II NVIS link. Although the HAL GUI's 'KWARE compression attempt produced, as expected, slightly larger versions of the already ompressed and encrypted files, LJL decryption of the results restored the files to their original form as ıncompressed text. CLOVER binary transfers thus appear to pass files encrypted by this approach ransparently.

0. Concluding Remarks

Ve hope that our data will aid understanding of CLOVER file transfer over HF and perhaps serve as a ıseful introduction to how CLOVER works. CLOVER is now used all over the world by amateurs (in ɪarticular, for BBS mail forwarding). A number of international aid and other communications-ɪroviding organizations also use CLOVER to send information across parts of Africa and Australia, vhere alternative means of long-haul communication are not available, or too expensive. CLOVER nodems are also used for at least two special-purpose e-mail systems (one used by private boating and hipping operators). Our data may shed light on why this inexpensive, amateur-developed modem and ts protocols have become **so** popular.

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Ɛmail: kwick@mitre.org. Packet radio: KB 1 JY@W 1 ON.