THE CLOVER-II COMMUNICATION PROTOCOL

TECHNICAL OVERVIEW

Raymond C. Petit, W7GHM

ABSTRACT This paper describes the CLOVER-II adaptive modulation controller, Reed-Solomon error-correcting coder, and selective-repeat ARQ algorithm. These operations are coordinated to obtain high-performance narrowband data communication over HF radio paths.

INTRODUCTION

The CLOVER-II strategy for sending data over the non-ideal HF radio path is to:

1. Adaptively adjust the modulation format. Slow rate modes are used to pass data in poor conditions, and high rate modes take advantage of good conditions. The channel capacity estimator provides automatic and dynamic adjustment of the modulation format for best performance in changing conditions.

2. Correct errors when possible. The large block Reed-Solomon coding system corrects errors and repairs data blocks which have been damaged by noise and signal dropouts. A finite number of errors are corrected without requiring repeat transmissions.

3. Repeat only the lost data blocks. ARQ mode only repeats those data blocks whose errors exceed the capacity of the Reed-Solomon encoder. Correctly recovered data blocks are not repeated.

The CLOVER-II carrier waveform is a composite of four tone pulses which are interleaved in time and isolated from each other in frequency. The pulse envelopes are Dolph-Chebychev functions which provide an exceptionally compact frequency spectra. The -50 dB bandwidth of a CLOVER-II signal is 500 Hz.

Data is transmitted by changing the phase and, in some modes, the amplitude of successive tone pulses. Depending on the data speed chosen, phase changes are multiples of 180 degrees (BPSM), 90 degrees (QPSM), 45 degrees (8PSM) or 22.5 degrees (16PSM). Amplitude changes are either in steps of 8 dB (8P2A) or 4 dB (16P4A).

The Reed-Solomon coder produces code blocks of size 17, 51, 85, and 255 bytes Only the 17- and 255- length blocks are used in the ARQ protocol. A selectable parameter, code rate, sets the tradeoff between maximum number of correctable errors in a block and the overhead cost of this capacity. Higher code rates produce blocks containing larger numbers of data bytes yielding higher throughput, and fewer coder check bytes for error correction. For each block received, the coder reports the percentage of its error-correcting capacity that was required to rebuild a block or if it was overwhelmed by errors.

DATA AND CONTROL BLOCK STRUCTURE

For link maintenance, **CLOVER-II** modems exchange 17-byte bursts, called **"CLOVER** Control Blocks" or "CCB's". These are always sent in **BPSM,** the slowest and most robust of the modulation formats used in the ARQ protocol. Eight of the seventeen bytes are required for coding and checksum overhead for the 60% code rate. The remaining nine bytes contain control bytes, call signs, signal reports and two-way "CCB-Chat" data. A single exchange of CCB's takes exactly 2.784 seconds and is referred to as a CCB FRAME **TIME,** as shown at the top of Figure 1.

When a sending station presents a large volume of data to be transmitted, the protocol controller switches into block transfer mode. After confirmation via a CCB exchange between stations, the sending station's next CCB is preceded by a stream of one or more 255-length code blocks. The time duration of the set of 255-length data blocks is always **16.704** seconds, exactly 6 times the time required for one CCB frame (2.784 seconds). Including the CCB exchange and transmitted data blocks, each **CLOVER-II ARQ** frame has a length of **19.488** seconds as shown in Figure 1.

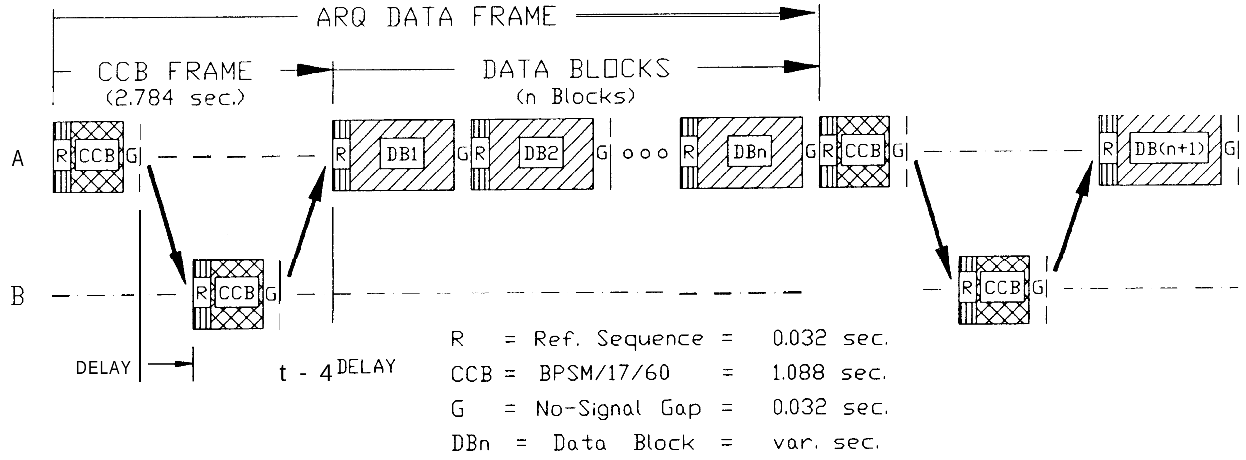
The number of code blocks sent varies with the modulation format selected by the adaptive controller. Multiple blocks are sent when fast rates are used - fewer blocks are used in slow rate mode (e.g., 6 data blocks in 16P4A format and 1 block in BPSM). The amount of data sent in each code block and the error correction capacity of the Reed-Solomon coder are set by the ARQ "Bias" parameter. The "ROBUST" bias setting (60% efficiency) provides the greatest forward error correction, but lowest total data throughput. The "FAST" bias setting (90% efficiency) provides high throughput but limited error correction. The **"NORMAL"** bias setting (75% efficiency) provides a compromise balance between high throughput and forward error correction. The timing and throughput of each ARQ bias setting are shown in the three tables of Figure 1 .

ADAPTIVE FORMAT ADJUST

Test data has shown that measurement of the average phase dispersion of a CLOVER pulse provides a very accurate indicator of the capacity of the radio channel. While modulation produces changes in the phase of the entire CLOVER pulse, phase deviations within a pulse indicate path instability. Measurement of the detected signal-to-noise ratio (S/N) provides a secondary indicator of radio channel conditions. In typical multi-path channels, the phase dispersion can vary over several powers of 2 during intervals as short as 10 to 15 seconds. Further, it is generally the condition that S/N and therefore transmitted power is much greater than is actually required for data recovery in CLOVER.

CLOVER's estimate of current channel conditions is obtained by a process that is separate from demodulation of the data itself and is thus independent of the modulation mode in use. The phase dispersion averages are obtained over approximately 1 second samples during CCB's and 2 second samples near the end of each data block. Figure 1 shows "No-Signal Gap" (G) and "Reference Sequence" (R) portions of the CLOVER transmissions. Comparison of the receive amplitude data at these times provides a dynamic measurement of received signal-to-noise ratio (S/N = R/G) that is not affected by operation of radio's receiver AGC system.

CLOVER-II MULTI-BLOCK ARQ DATA FRAME



ROBUST

ROBUST BIAS (60%) RATE	MOD	BLOCK	BYTES/ FRAME	MAX ERRORS	BLOCK TIME	BLKS/ FRAME	ARQ FRAME TIME	THRU-PUT BYTES/SEC
					sec	6	19.488 sec	46.2
30	16PSM	255	600	200	4.080 sec	4	19.488 sec	30.8
30	8P2A	255	600	200	4.080 sec	4	19.488 sec	30.8
23	8PSM	255	450	150	5.440 sec	3	19.488 sec	23.0
15	QPSM	255	300	100	8.160 sec	2	19.488 sec	15.4
46 8	BPSM 16P4A	255 255	150 900	50 300	16.320 sec 2.720	1	19.488 sec	7.7

NORMAL

NORMAL BIAS (75%) RATE	MOD	BLOCK	BYTES/ FRAME	MAX ERRORS	BLOCK TIME	BLKS/ FRAME	ARQ FRAME TIME	THRU-PUT BYTES/SEC
58	16P4A	255	1128	186	2.720 sec	6	19.488 sec	57.9
39	16PSM	255	752	124	4.080 sec	4	19.488 sec	38.6
39	8P2A	255	752	124	4.080 sec	4	19.488 sec	38.6
19	QPSM	255	376	62	8.160 sec	2	19.488 sec	19.3
10 29	BPSM 8PSM	255 255	188 564	31 93	16.320 sec 5.440 sec	1 3	19.488 sec 19.488 sec	9.7 28.9

FAST

FAST BIAS (90%) RATE	MOD	BLOCK	BYTES/ FRAME	MAX ERRORS	BLOCK TIME	BLKS/ FRAME	ARQ FRAME TIME	THRU-PUT BYTES/SEC
70	16P4A	255	1356	72	2.720 sec	6	19.488 sec	69.6
46	16PSM	255	904	48	4.080 sec	4	19.488 sec	46.4
46	8P2A	255	904	48	4.080 sec	4	19.488 sec	46.4
35	8PSM	255	678	36	5.440 sec	3	19.488 sec	34.8
23	QPSM	255	452	24	8.160 sec	2	19.488 sec	23.2
12	BPSM	255	226	12	16.320 sec	1	19.488 sec	11.6

Figure 1. CLOVER-II ARQ Data Block Timing

Under very stable conditions on an operating radio frequency that is near the MUF, measured phase dispersion is well correlated to the signal/noise ratio, and to laboratory measurements for constant signals in additive white Gaussian noise (AWGN). In this case, adaptive mode selection is made by comparing measured phase dispersion with mode threshold values obtained from laboratory measurements under controlled S/N conditions.

When HF path parameters are “less-than-ideal” and vary widely and rapidly, the adaptive adjustment algorithm uses a more cautious approach. Although the goal is always to maximize data throughput, parameter settings which may be “optimum” at one instant may become totally unsuitable only a few seconds later. Adaptive changes may be made rapidly over several modes when path variations are well behaved. However, a less aggressive approach is required under less stable conditions. The CLOVER bias command sets three different levels of adaptive control. The bias settings are called FAST, NORMAL, and ROBUST. BIAS affects the following **parameters:**

1. Reed-Solomon coder “efficiency”:
   FAST = 90% for high throughput but low correction capacity
   NORMAL = 75% for moderate throughput and correction
   ROBUST = 60% for high correction but low throughput

2. Phase dispersion averaging period:
   FAST = short period average for fast response
   NORMAL = moderate averaging period
   ROBUST = long averaging period to smooth wide variations

3. Modulation format selection criteria:
   FAST = favors high data rates for a given amount of phase dispersion
   NORMAL = standard mode vs phase dispersion relationship
   ROBUST **= favors lower data rates for a given amount of phase dispersion**

SELECTIVE REPEAT

Although CLOVER-II includes Reed-Solomon forward error correction, there are of course finite limits to the number of errors that may be corrected by the coder. In this case, CLOVER uses ARQ repeat transmission of the damaged data blocks in a similar manner to that used in AMTOR and packet radio. In the simplest form (e.g., AMTOR or packet with MAXFRAME = **I),** no new data is sent until the defective block has been successfully relayed and acknowledged. This imposes no special flow management problems at either the transmitter or receiver.

The disadvantage of this scheme is that the ARQ link must be turned around after every block to obtain the acknowledgement and this imposes a high overhead cost in throughput. When conditions are good, the throughput can be increased significantly in packet radio by setting MAXFRAME to values higher then 1. The problem is that a checksum failure in an early block of the transmission will force repeat of that block ***and all following*** blocks of that transmission in accordance with AX.25 protocol.

Like packet, the CLOVER-II system sends multiple data blocks, but also allows *selective repeat of only the damaged data blocks*. This avoids the inefficient repeat transmission of data blocks which have already been successfully received, Adding selective repeat also increases the complexity of both transmit and receive data buffers. In CLOVER, it is further complicated by the necessity to encode all transmit data in finite sized Reed-Solomon data blocks.

The CLOVER selective repeat algorithm:

1. Buffers seven data blocks of data to be sent
2. Sending station announces data blocks to be sent
3. Receiving station acknowledges announcement
4. Sending station transmits data blocks (6 for 16P4A to 1 for BPSM)
5. Receiver buffers received data blocks, noting failures
6. Receiver passes to PC successful blocks up to 1st failure
7. Receiver requests repeat of failed block(s)
8. Transmitter clears TX buffer of successful blocks
9. Transmitter shifts blocks to be repeated to top of queue
10. Transmitter loads new data into balance of TX buffer
11. Return to step 2 and continue until complete message is sent

ON THE AIR PERFORMANCE

A few preliminary tests of the above-described protocol have been made on the air at the time of this writing. File transfers were made between AKOX and W7GHM (Boulder, Colorado to Oak Harbor, Washington, about 1508 miles) at speeds ranging from 20 to 40 bytes per second depending on conditions, in the 40, 30 and 20 meter bands. Details of subsequent testing will be given in the verbal presentation of this paper.