A Proposed Wideband (24kHz) HF Data Modem Standard

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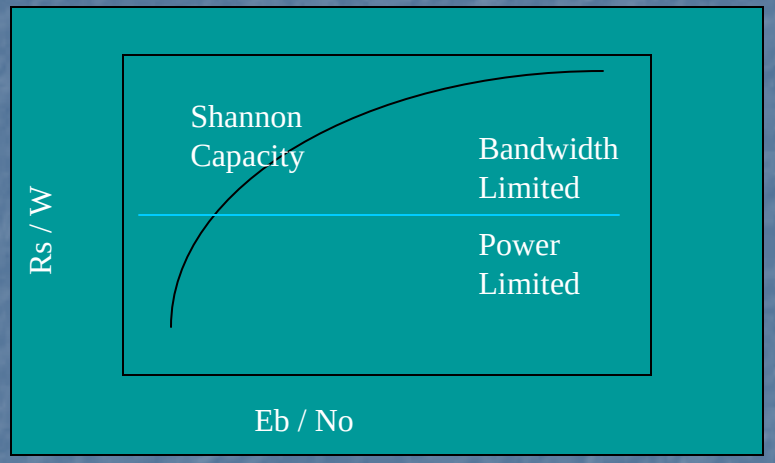
Overview

- Background / Basic Design Philosophy / Features (Jorgenson)
- Waveform format and FEC (Nieto)
- Proposed Preamble Design (Furman)
- A Way Ahead (Johnson)

Achieving higher data rates ...

- Data rate evolution
  - FSK 75 bps – 0.025 b/s/Hz
  - Kineplex 1200 bps – 0.4 b/s/Hz
  - Serial Tone
    - PSK 2400 bps – 1 b/s/Hz
    - QAM 9600 bps – 4 b/s/Hz
    - Actually using 64QAM 6 b/s/Hz
- Increasing data rates costs exponentially more power to achieve
  - Now well into the bandwidth constrained portion of Shannon's capacity curve



Motivation for Wideband HF Standardization

- Higher HF data rates becoming important
  - Digitization of the battlefield means low rates are extremely limited in the services that they can support
  - Concern about operation in Satellite denied environment has led to a resurgence in interest in data over HF
- Harris and Rockwell Collins had both commenced independent efforts to achieve higher rates at HF
  - Both approaches assumed availability of higher bandwidths and used a serial tone approach to achieve the highest data rates
  - Eric Johnson of NMSU facilitated cooperative meetings to see if Rockwell Collins and Harris could work together to standardize a next generation wideband HF waveform to be included in the revision of Mil-Std 188-110

Basic Design Philosophy

- Waveform set for every bandwidth multiple of 3 kHz up to 24 kHz
  - Bandwidth to be used is specified in advance
- As in Mil-Std 188-110B, data rate and interleaver are autobaud capable
- Delay spread, Doppler spread and SNR capabilities improve monotonically as data rate is reduced
- Highest data rates for each bandwidth intended for surface wave usage (256 QAM)
- Lower PSK data rates to support at least 6.6 ms of delay spread
- Lowest rate for every bandwidth is based on a Walsh modulation

Features

- Autobaud preamble selects from
  - 16 possible modulation/code rate/known-unknown data combinations
    - Currently ~12 serial-tone PSK/QAM data rates defined for every bandwidth
    - One combination for every data rate
    - Lowest data rate to be provided by a Walsh modulation
  - 4 interleaver lengths
  - 2 code lengths
- No reinserted preamble
  - Broadcast transmissions supported by providing for synchronization of any interleaver on the long interleaver boundary

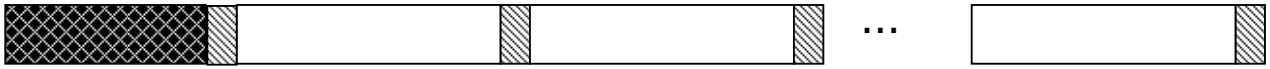
More Features ...

- Preamble length is selectable
  - Shortest preamble for every data rate is approximately 0.12 ms
  - Better support for services requiring low-latency (voice)
- Better support for TDMA services
  - Mil-Std 188-110B specified transmission length feature maintained
  - EOT indicator in the mini-probe allows rapid return to acquisition following receipt of a transmission

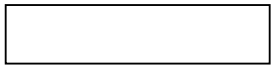
Waveform Format

- Proposed Format .. Not Official !!
- Similar to US MIL-STD-188-110B Appendix C waveforms
  - Initial preamble
    - Provides auto-baud capability
  - Mini-probe (known symbols)
    - Used for channel estimation
  - Unknown symbol portion
    - Data symbols

Waveform Format



Synchronization Preamble



Data Block - U symbols

Mini-probe – K symbol sequence

Waveform Format

Number of Unknown Symbols (Data) in Frame

Waveform Number	0 Walsh	1 BPSK	2 BPSK	3 BPSK	4 BPSK	5 BPSK	6 QPSK	7 8-PSK	8 16-QAM	9 32-QAM	10 64-QAM	11 64-QAM	12 256-QAM
Bandwidth													
3000	N/A	48	48	96	96	256	256	256	256	256	256	360	360
6000	N/A	96	96	192	192	512	512	512	512	512	512	540	540
9000	N/A	288	288	288	-	768	768	768	768	768	768	960	960
12000	N/A	192	192	384	384	1024	1024	1024	1024	1024	1024	1080	1080
15000	N/A	288	288	288	288	1280	1280	1280	1280	1280	1280	1152	1152
18000	N/A	448	448	448	-	1536	1536	1536	1536	1536	1536	1920	1920
21000	N/A	320	320	320	320	1344	1344	1344	1344	1344	1344	2560	2560
24000	N/A	272	272	816	816	2176	2176	2176	2176	2176	2176	1920	1920

Waveform Format

Number of Known Symbols (Mini-Probe) in Frame

Waveform Number	0 Walsh	1 BPSK	2 BPSK	3 BPSK	4 BPSK	5 BPSK	6 QPSK	7 8-PSK	8 16-QAM	9 32-QAM	10 64-QAM	11 64-QAM	12 256-QAM
Bandwidth													
3000	N/A	48	48	32	32	32	32	32	32	32	32	24	24
6000	N/A	96	96	64	64	64	64	64	64	64	64	36	36
9000	N/A	144	144	144	-	96	96	96	96	96	96	64	64
12000	N/A	192	192	128	128	128	128	128	128	128	128	72	72
15000	N/A	192	192	192	192	160	160	160	160	160	160	128	128
18000	N/A	224	224	224	-	192	192	192	192	192	192	128	128
21000	N/A	240	240	240	240	224	224	224	224	224	224	128	128
24000	N/A	272	272	272	272	272	272	272	272	272	272	128	128

Waveform Format

- Modulation used for Preamble
  - Walsh based
- Modulation used for Mini-Probe
  - Phase Shift Keying (PSK) based
- Modulations used for Data
  - Walsh modulation similar to 75 bps
    - Actual details TBD
  - M-ary-PSK (M-PSK)
    - BPSK, QPSK, 8-PSK
  - M-ary Quadrature Amplitude Modulation (M-QAM)
    - Non-standard “Rounded” Constellations
      - Lower peak-power to average-power ratio
    - 16-QAM, 32-QAM, 64-QAM, 256-QAM

Waveform Format

- 8 Bandwidths
  - 3, 6, 9, 12, 15, 18, 21, 24 kHz
- 13 Data Rates defined for each bandwidth

Waveform Format

Symbol Rates and Sub-Carrier for each Bandwidth

Bandwidth (kHz)	Symbol Rate (Sym/sec)	Sub-Carrier (Hz)
3	2400	1800
6	4800	3300
9	7200	4800
12	9600	6300
15	12000	7800
18	14000	9300
21	16800	10800
24	19200	12300

Waveform Format

Modulation and Data Rate for Each Bandwidth

Waveform Number	0 Walsh	1 BPSK	2 BPSK	3 BPSK	4 BPSK	5 BPSK	6 QPSK	7 8-PSK	8 16-QAM	9 32-QAM	10 64-QAM	11 64-QAM	12 256-QAM
Bandwidth													
3000	tbd	150	300	600	1200	1600	3200	4800	6400	8000	9600	12000	16000
6000	tbd	300	600	1200	2400	3200	6400	9600	12800	16000	19200	24000	32000
9000	tbd	600	1200	2400	-	4800	9600	14400	19200	24000	28800	36000	45000
12000	tbd	600	1200	2400	4800	6400	12800	19200	25600	32000	38400	48000	64000
15000	tbd	600	1200	2400	4800	8000	16000	24000	32000	40000	48000	57600	76800
18000	tbd	1200	2400	4800	-	9600	19200	28800	38400	48000	57600	72000	90000
21000	tbd	600	1200	2400	4800	9600	19200	28800	38400	48000	57600	76800	115200
24000	tbd	1200	2400	4800	9600	12800	25600	38400	51200	64000	76800	96000	120000

Waveform Format

- 14 Different Mini-Probe Sequences
  - 11 Different base sequences used to generate the mini-probe sequences
  - Mini-probes are cyclic extensions of base sequence
- Cyclic shift of mini-probe used to indicate end of long interleaver block boundary

Waveform Format

Base Sequence and Cyclic Shift used for each Mini-probe

Mini-Probe Length	Base Sequence	Cyclic Shift for Interleaver Boundary
24	13	6
32	16	8
36	19	9
48	25	12
64	36	18
72	36	18
96	49	24
128	64	32
144	81	40
160	81	40
192	100	50
224	121	60
240	121	60
272	144	72

Waveform Format

- 4 different interleaver sizes
  - Ultrashort (approximately 0.12 secs)
  - Short (approximately 0.48 secs)
  - Medium (approximately 1.92 secs)
  - Long (approximately 7.68 secs)

Waveform Format

- 2 different Convolutional Codes
  - rate ½ constraint length 7
  - rate ½ constraint length 9
- Repetition and Puncturing used to generate following code rates
  - 1/16, 1/12, 1/8, 1/6, 1/4, 1/3, 1/2, 2/3, 3/4, 5/6, 8/10, 8/9, 9/10

Waveform Format

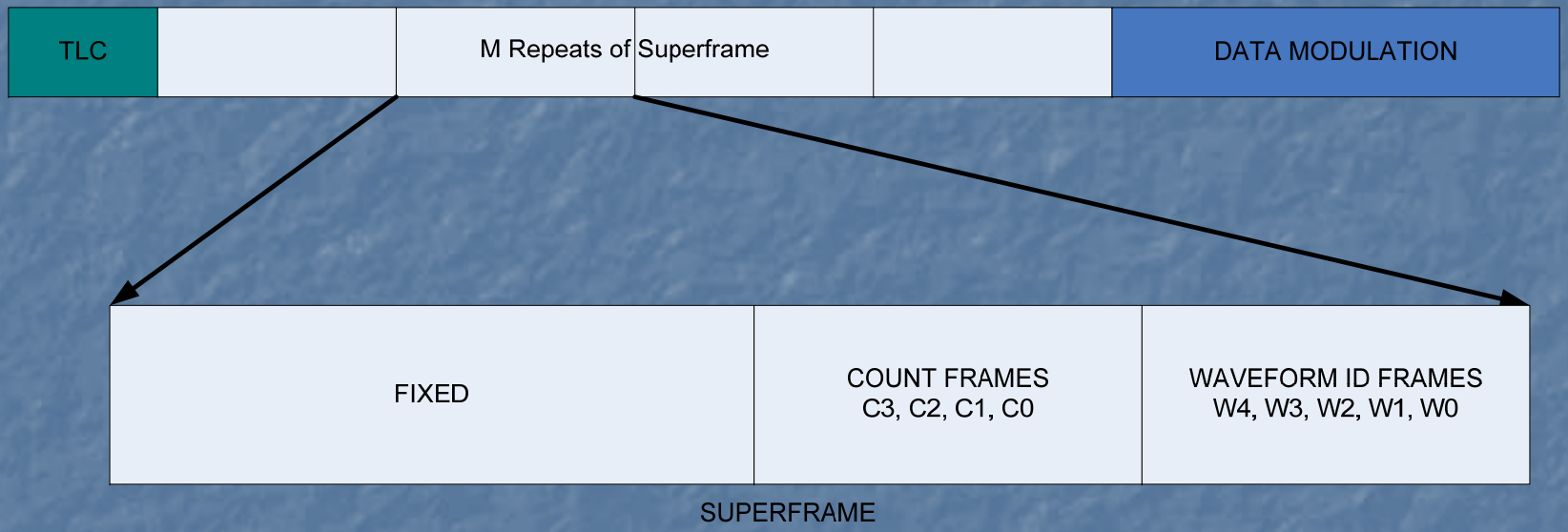
Code Rate and Modulation for Each Bandwidth

Waveform Number	0 Walsh	1 BPSK	2 BPSK	3 BPSK	4 BPSK	5 BPSK	6 QPSK	7 8-PSK	8 16-QAM	9 32-QAM	10 64-QAM	11 64-QAM	12 256-QAM
Bandwidth													
3000	tbd	1/8	1/4	1/3	2/3	3/4	3/4	3/4	3/4	3/4	3/4	8/9	8/9
6000	tbd	1/8	1/4	1/3	2/3	3/4	3/4	3/4	3/4	3/4	3/4	8/9	8/9
9000	tbd	1/8	1/4	1/2	-	3/4	3/4	3/4	3/4	3/4	3/4	8/9	5/6
12000	tbd	1/8	1/4	1/3	2/3	3/4	3/4	3/4	3/4	3/4	3/4	8/9	8/9
15000	tbd	1/12	1/6	1/3	2/3	3/4	3/4	3/4	3/4	3/4	3/4	8/9	8/9
18000	tbd	1/12	1/6	1/3	-	3/4	3/4	3/4	3/4	3/4	3/4	8/9	5/6
21000	tbd	1/16	1/8	1/4	1/2	2/3	2/3	2/3	2/3	2/3	2/3	8/10	9/10
24000	tbd	1/8	1/4	1/3	2/3	3/4	3/4	3/4	3/4	3/4	3/4	8/9	5/6

Proposed Preamble Design

- Sent at beginning of each transmission
- Transmitted at same symbol rate / Bandwidth as the following data
- Provides a mechanism to align time and frequency at the receiver
- Identifies the waveform ID – bit rate, code length, interleaver setting.

Preamble Format



- TLC section for TGC / AGC settling
- Preamble consists of M repeats of the preamble Superframe
- Each Superframe contains fixed modulation, followed by frames containing count, followed by frames containing Waveform ID

Preamble Superframe Format

- FIXED SECTION
  - Consists of L repetitions of a 128 symbol frame.
  - Symbols are 8PSK, m*PI/4 {m 0-7}
  - 128 symbols selected via computer simulation for code cross correlation properties
  - Processing provides time alignment and frequency offset estimates

Orthogonal Walsh Modulation

- Count and Waveform ID sections convey data by Orthogonal Walsh Modulation
- Each Frame consists of a 32 element 8PSK sequence chosen for good correlation properties.
- A dibit (2 bits) of information are conveyed by each frame by modulating the 32 element 8PSK sequence by one of 4 Walsh sequences.

Orthogonal Walsh Modulation

di-bit	Walsh Sequence
00	0000
01	0404
10	0044
11	0440

- Example:
  - 32 Element Sequence { 01365275416724262763252201754231}
  - Dibit of 01 selects Walsh sequence 0404 which is repeated 8 times { 04040404040404040404040404040404}
  - Resulting in 05325671456320223672126057146 35}

Preamble Superframe Format

- Count
  - 8 bit count represented as 4 dibits
  - C3,C2,C1,C0 represent count MSB to LSB
  - Count starts at (M-1) where M is the number of superframe repeats
  - Example: Count of 33 would be represented as 00 10 00 01, C3=00,C2=10,C1=00,C0=01

Preamble Superframe Format

- Waveform ID
  - 10 bit count represented as 5 dibits W4,W3,W2,W1,W0
  - W0 provides a parity of W1-W4

Waveform Number	W4	W3	Waveform Number	W4	W3
0	00	00	8	10	00
1	00	01	9	10	01
2	00	10	10	10	10
3	00	11	11	10	11
4	01	00	12	11	00
5	01	01	13	11	01
6	01	10	14	11	10
7	01	11	15	11	11

Interleaver	W2
Ultra Short	00
Short	01
Medium	10
Long	11

Constraint Length	W1
7	00
9	01

A Way Ahead

- Specify radio passbands in -141C
- Specify waveforms in -110C
- WBHF channel simulator specs in -110C
- Demonstrate viability to user community
- Demonstrate demand to spectrum managers

Questions?