Extension of Wideband HF Capabilities

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Overview of Extended Wideband HF Capabilities

- Motivation of extending HF bandwidths: viable mitigation of SATCOM Denied Environment (SDE) Anti Access, Area Denial (A2AD) threats
- Description of Extended Wideband HF (EWBHF) waveform architecture
  - EWBHF signal structure, modulations, bandwidth, data rates, interleaving
- Bandwidth adaptation and dial frequency offset
- Bandwidth availability for North American mid-latitude links
- EWBHF Over-the-Air performance
- Opportunities for IP based networks over HF links

Why Wideband HF?

- Satellite Denied Environments (SDE) and Anti Access, Area Denial (A2AD) threats are an important driver for consideration of Beyond-Line-Of-Sight (BLOS) alternatives

- HF offers a viable solution for SDE or A2AD, but higher than 9600 bps data throughput capabilities will be required

- WBHF enables extended range over Line-Of-Sight (LOS) circuits (Naval Battlegroup) with comparable data rates; extended range enhances Subnet Relaying (MARLIN) and HFIP performance utilizing higher HF data rates

- WBHF data rates will not match wide-band satellite rates, but will enable reasonable throughput for BLOS communications

So What?

- What can you do with WBHF, that couldn't be done with 3 kHz?

- Pass data at rates about 8x faster (16x faster with EWBHF)
  - An image that required 2 minutes to send would be down to less than 20 seconds (10 seconds)

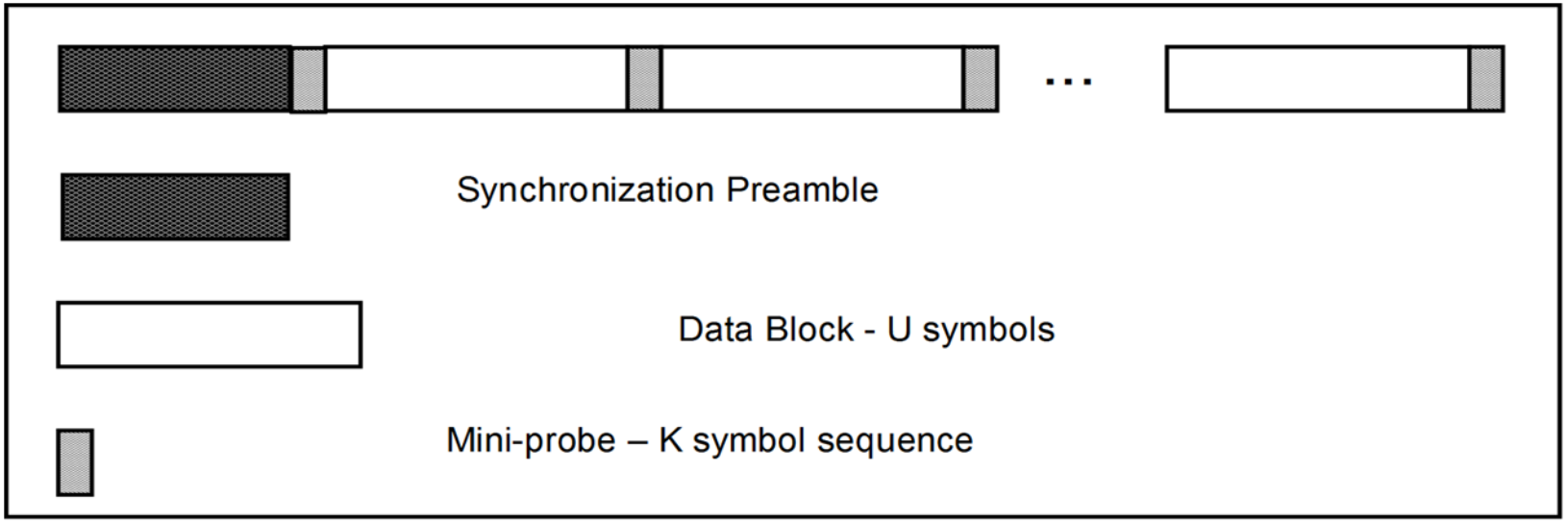
- Pass data much more reliably at moderately high rates
  - Lowering modulation complexity provides much larger gains than the loss due to noise in the additional bandwidth

- Support services that intrinsically require higher rates
  - Video
  - IP Networking

Why Extended Wideband HF?

- Motivation of extending HF bandwidths for viable mitigation of narrowband SATCOM denied environment, A2AD threats, day without space
  - Satellite time cost a factor for many users, HF recurring costs very low
- Wideband HF, utilizing increased contiguous bandwidth, first suggested in 2007 as alternative to narrowband SATCOM
  - Led to ratification of MIL-STD-188-110C App D in 2011 defining bands to 24 kHz
  - Spectral mask definition ratified in 2010, MIL-STD-188-141C
- Office of Naval Research (ONR) sponsored research of expanding HF bandwidths up to 48 kHz for yet higher throughput, up to 240 kbps, contract N00014-12-C-0363
- ONR EWBHF R&D project is focus of the presentation

Extended Wideband HF Waveform Structure



- Robust synchronization preamble for signal detection
- Preamble provides signal's waveform ID, data rate, interleaver length, constraint length information
- Regularly inserted mini-probes (known symbols) for channel estimation & equalization aid
- Mini-probe symbols periodicity relative to unknown symbols controls Doppler spread tolerance
- Length of mini-probe symbols impacts delay spread threshold

MIL-STD-188-110C App D WF Characteristics

Modulation	Bandwidth (kHz)							
	3	*6*	*9*	*12*	*15*	*18*	*21*	*24*
Walsh	75	150	300	300	300	600	300	600
BPSK	150	300	600	600	600	1200	600	1200
BPSK	300	600	1200	1200	1200	2400	1200	2400
BPSK	600	1200	2400	2400	2400	4800	2400	4800
BPSK	1200	2400	-	4800	4800	-	4800	9600
BPSK	1600	3200	4800	6400	8000	9600	9600	12800
QPSK	3200	6400	9600	12800	16000	19200	19200	25600
8PSK	4800	9600	14400	19200	24000	28800	28800	38400
16QAM	6400	12800	19200	25600	32000	38400	38400	51200
32QAM	8000	16000	24000	32000	40000	48000	48000	64000
64QAM	9600	19200	28800	38400	48000	57600	57600	76800
64QAM	12000	24000	36000	48000	57600	72000	76800	96000
256QAM	16000	32000	48000	64000	76800	90000	115200	120000

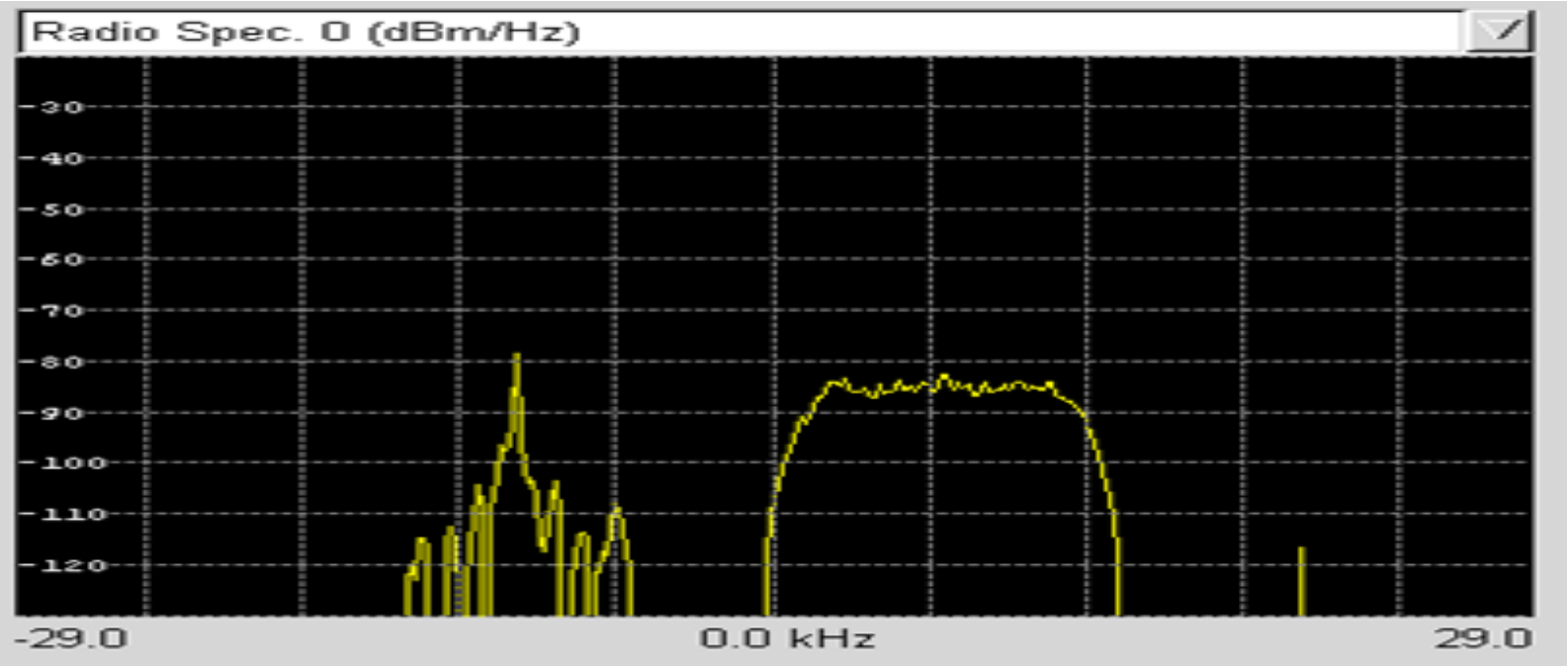
- Eight bandwidths in integer multiples of 3 kHz, to 24 kHz
- Modulations range from very robust, Walsh, to high rate QAM constellations
- Four interleaver options ranging from 0.12 to 7.68 seconds
- Lower PSK rates employ repetition , varying code rates
- Higher rates utilize puncturing to decrease code rate

Extended Wideband HF Waveform Characteristics

Modulation	Bandwidth (kHz)			
	30	36	42	48
Walsh	600	1200	1200	1200
BPSK	1200	2400	2400	2400
BPSK	2400	4800	4800	4800
BPSK	4800	9600	9600	9600
BPSK	9600	12800	14400	16000
BPSK	16000	19200	19200	24000
QPSK	32000	38400	38400	48000
8PSK	48000	57600	57600	72000
16QAM	64000	76800	76800	96000
32QAM	80000	96000	96000	120000
64QAM	96000	115200	115200	144000
64QAM	120000	144000	160000	192000
256QAM	160000	192000	192000	240000

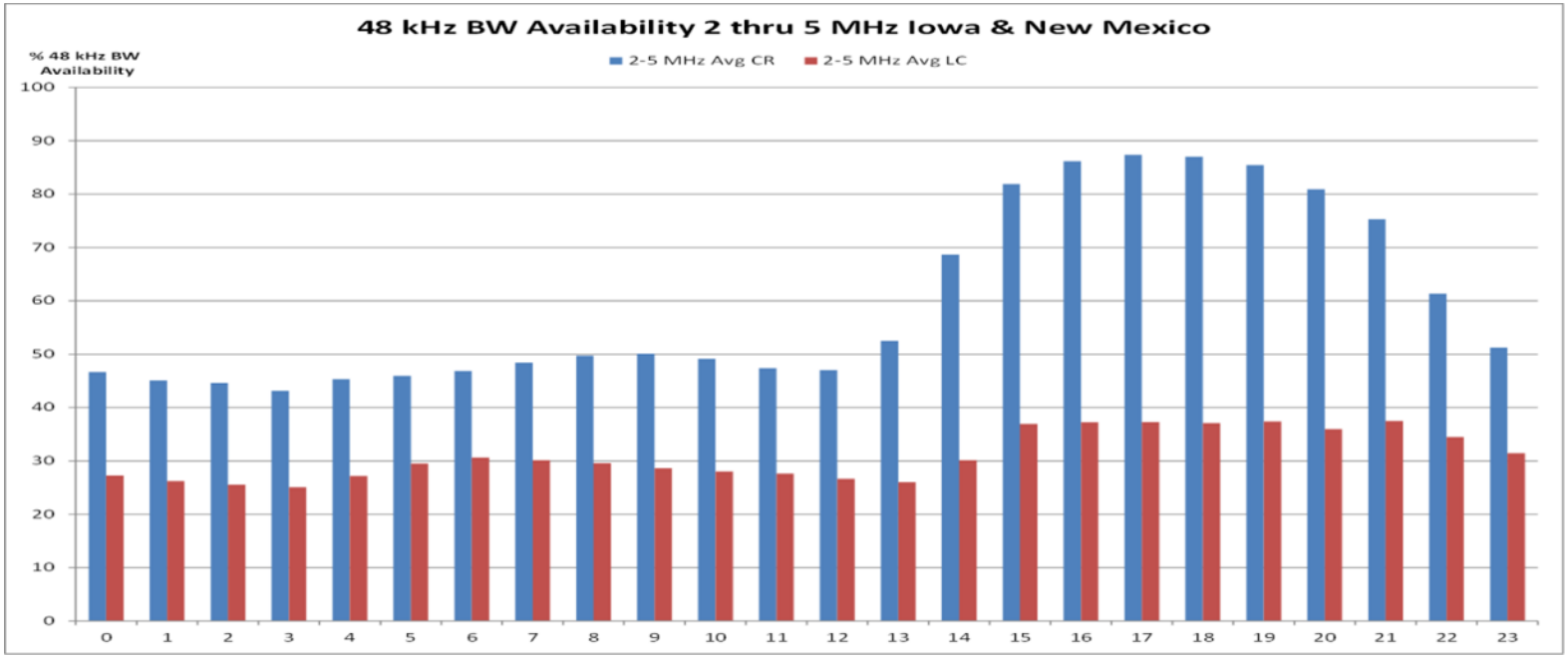
- Four bandwidths: 30 kHz, 36 kHz, 42 kHz & 48 kHz
- Interleaver lengths range for 0.08 seconds (48 kHz band) to 7.68 seconds
- Selectable constraint lengths, 7 and 9
- Code rates range from rate 1/12 to rate 8/9
- Wider bands provide more robust modulations for higher data rate in App D
- Example: 96 kbps in App D 24 kHz uses rate 8/9 64QAM, in 48 kHz, 96 kbps is rate ¾ 16QAM

Bandwidth Adaptation-Dial Frequency Offset



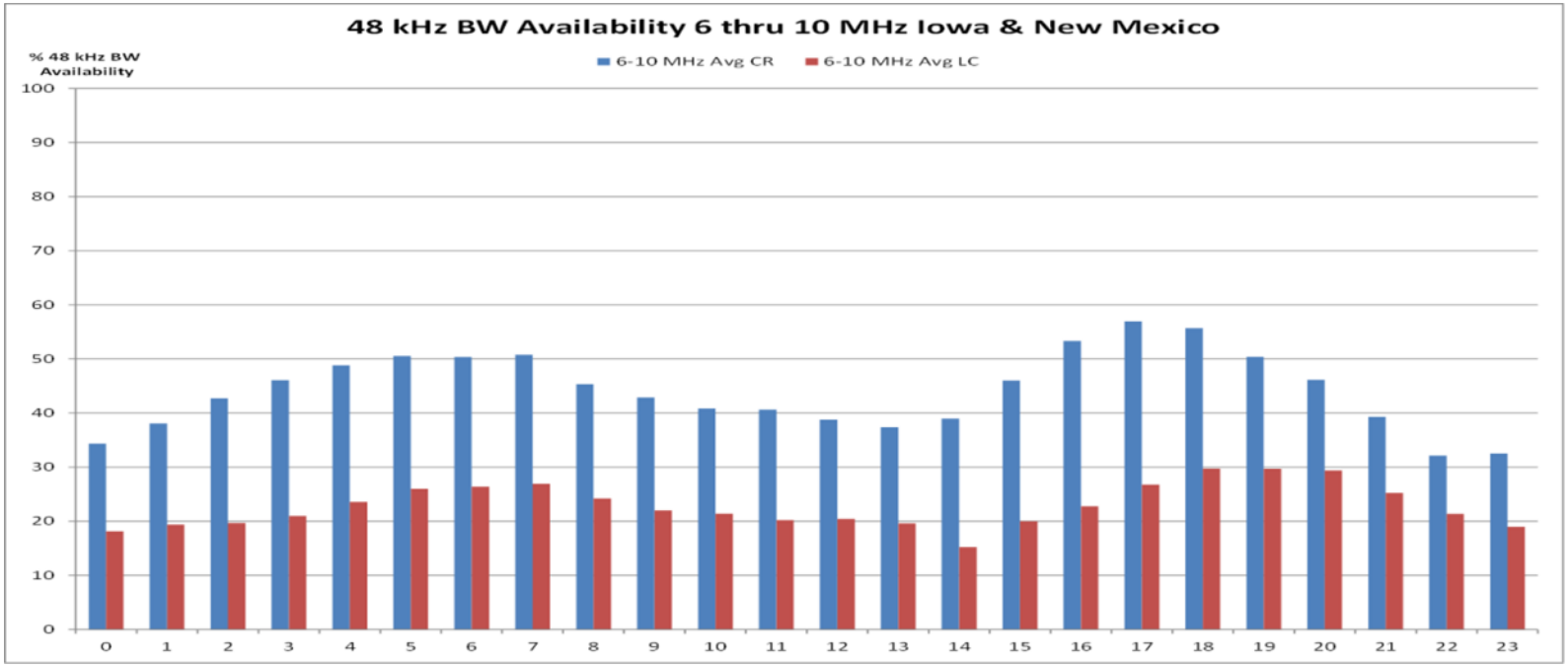
- Receiver scans spectrum for determining signal occupancy characteristics of authorized dial frequencies
- Occupancy history for channels of interest are stored for availability probability
- Graphic illustrates example of two persistent signals in desired channel, bandwidth is set to “fit” within open spectrum, dial frequency adjusted, transmission begins

Bandwidth Availability: 48 kHz in USA



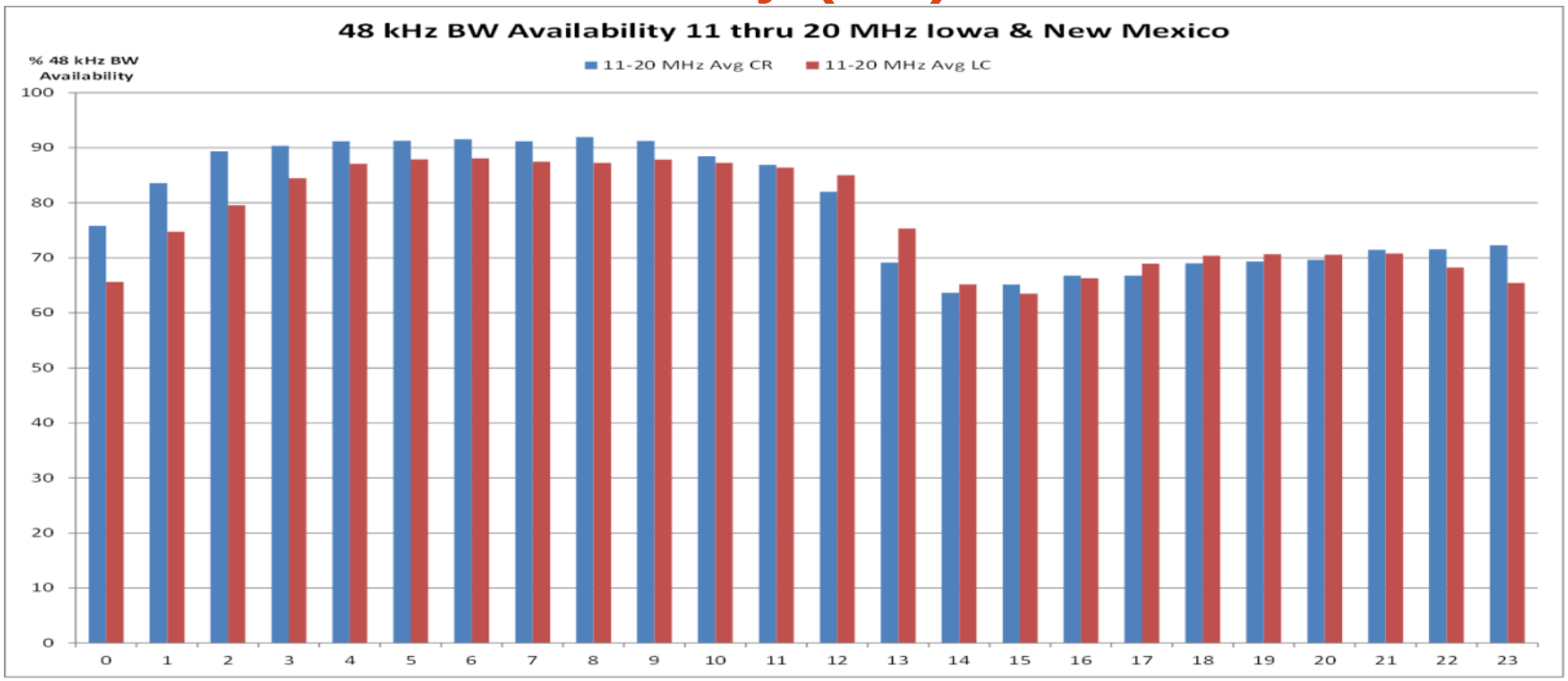
- 24/7 scanning campaign of HF spectrum over 8 months, 2012-13 in Las Cruces, NM & Cedar Rapids, IA
- Bar graph shows percentage of time 48 kHz channels available over one hour intervals from 2 through 5 MHz
    - Red bars are New Mexico, blue bars are Iowa
- Time of day where 2 to 5 MHz are useable (night) in left half of chart
- Probability of open 48 kHz bands in low HF frequency range twice as high in north central US versus US-Mexico border region

48 kHz Band Availability (US): 6 MHz - 10 MHz



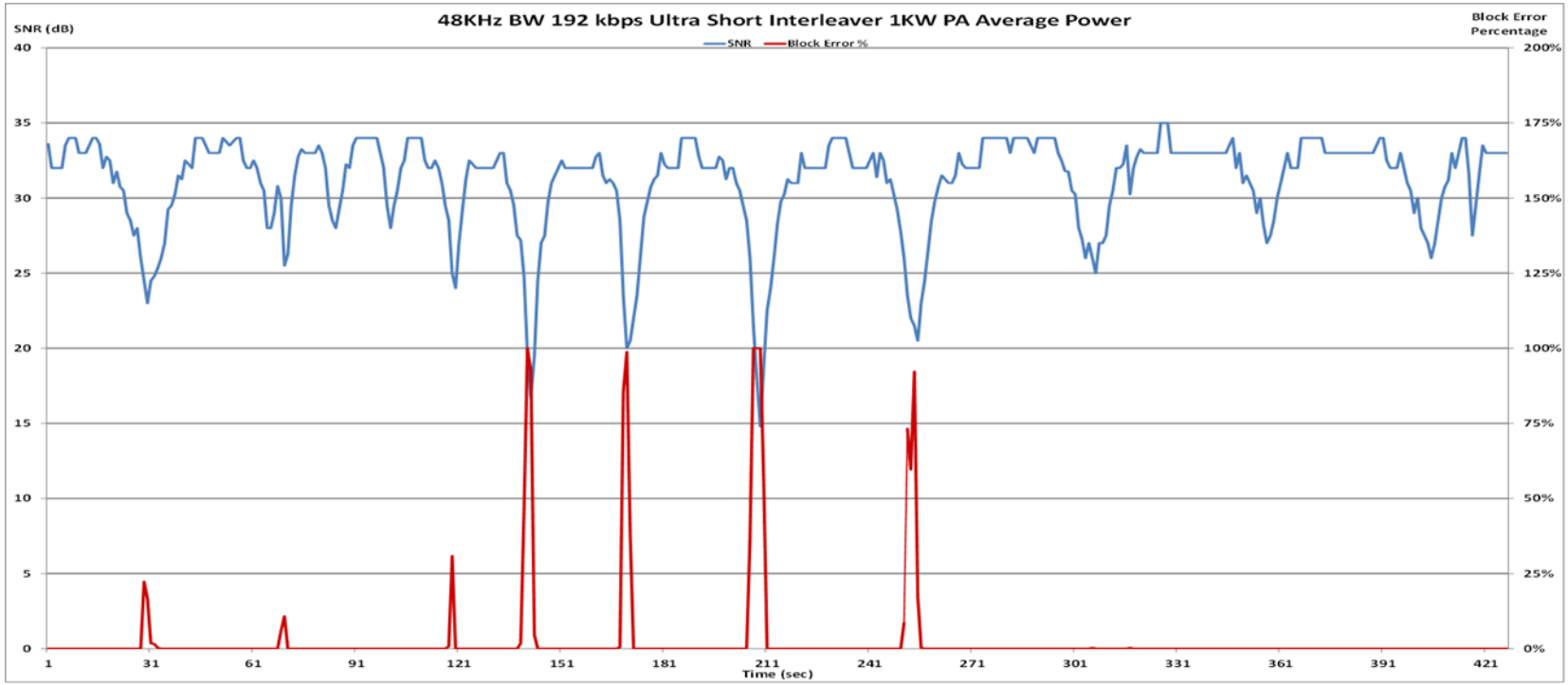
- Blue bars percentage of 48 kHz HF band availability in north central US, red bars US-Mexico border region
- 6 MHz to 10 MHz range typically shorter haul (< 600 miles) in daytime
- As with lowest range of HF spectrum, probability of open 48 kHz bands in North Central US nearly double of US-Mexico border region
- Signal strength 10 dB above the HF noise floor defines occupying signal

48 kHz Band Availability (US): 11 MHz - 20 MHz



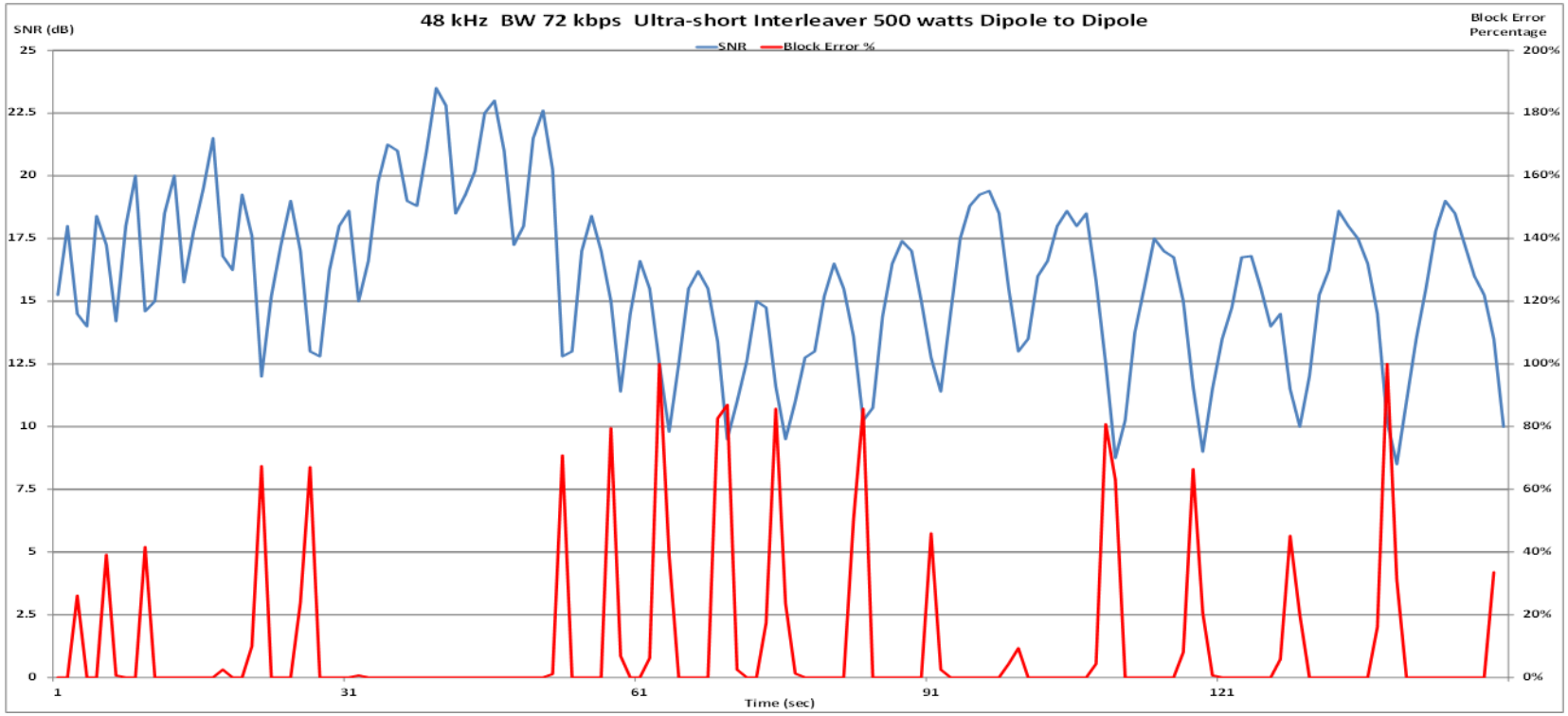
- 11 MHz through 20 MHz frequency range typically longer haul (> 600 miles) in daylight hours
- 48 kHz band availability over 60% of daylight hours both north & south US regions
- 48 kHz bandwidth availability for 21 MHz through 29 MHz frequency zones (not shown) are available over 80% of daylight hours
- Frequencies above 21 MHz, depending upon solar conditions, are suited for transmissions greater than 1000 miles

48 kHz Band OTA Trials: Ultra-Short Interleaver



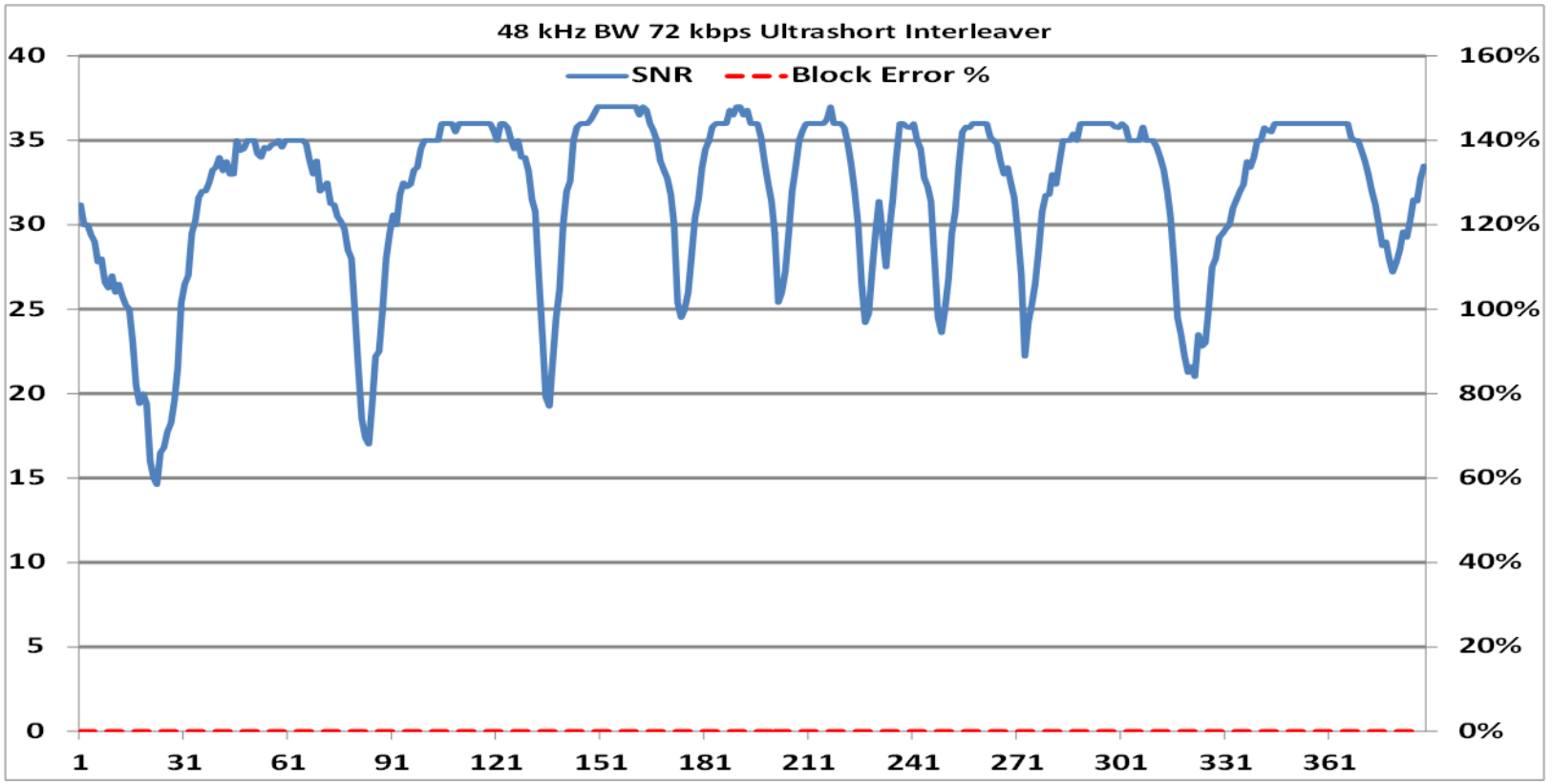
- Plots exhibit blue signal to noise ratio (SNR) curve versus percentage of block error rate (BLER) between Iowa-New Mexico
- Data rate 192 kbps, rate 8/9 coding, 0.08 second interleaver
- 0.08 second interleaver provides low latency for TCP and ARQ based links
- Link is fixed site to fixed site, 1 KW average power
- Majority of block error events when SNR faded below 20 dB

48 kHz Band OTA Trials: 500W, Dipole Antennas



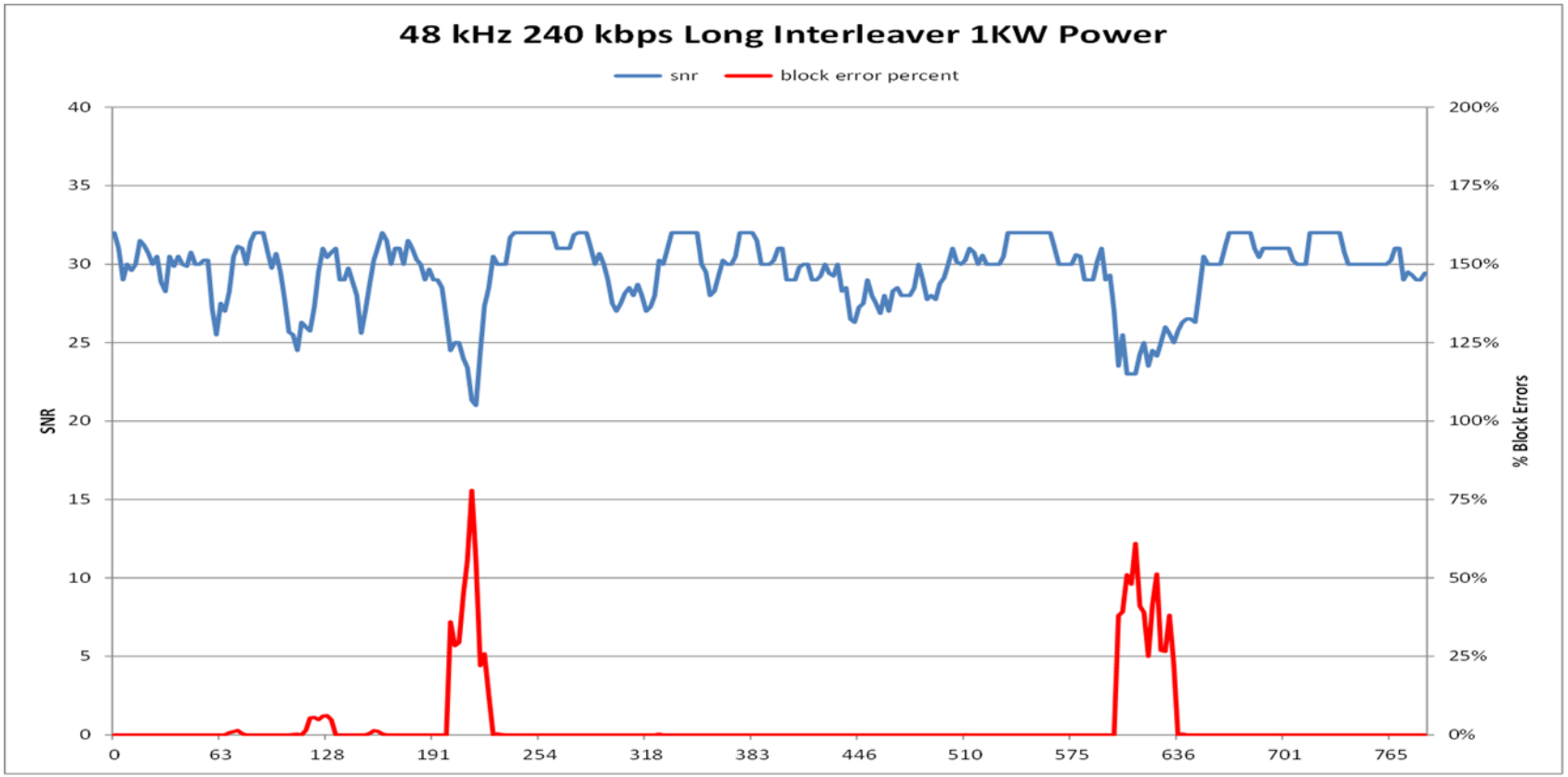
- Link between Iowa-New Mexico with dipole antennas, 500W power
- Data rate 72 kbps, 8PSK rate 3/4 coding, 0.08 second interleaver
- SNR samples are polled at 0.5 second intervals.
- SNR samples smoothed with a four polling moving average (MA), with MA captured every 2 seconds
- Majority of block error events occur when SNR fades are below 13 dB

48 kHz Band OTA Trials: 1 KW, Dipole Antennas



- Link between Iowa-New Mexico, dipole antennas, 1 KW power (3 dB power increase over previous slide)
- Data rate (72 kbps) and interleaver (0.08 sec) ~ 1 hour after slide 12
- No block errors during 6.5 minute reception, SNR breached 15 dB only once
- Note cyclical nature of fading patterns with shorter cycles as SNR troughs rise

48 kHz Band OTA Trials: 1 KW, LP Antenna



- Link between Iowa-New Mexico, dipole antennas,1 KW power with 6 dB gain log periodic antennas
- 240 kbps, rate 5/6 256-QAM, throughput with 7.68 second interleaver
- Long interleavers suitable for broadcast transmissions such as streaming video
- Reception ~ 15 minutes with shallower fading cycles
- Block error events when 25 dB SNR level violated

Summary

- EWBHF channels up to 48 kHz are feasible, with good results using fixed site ground stations and limited maritime platforms
  - Future OTA tests will include NVIS links less than 250 miles with compact antennas and varying transmission power
  - Challenges include feasibility for tactical platforms: airborne and ground mobile
  - Rockwell Collins FY14 effort underway for evaluating use on aircraft
  - Trident Warrior ship-to-shore reachback
- Initial testing using ad-hoc networking protocols such as HF-IP (STANAG 5066 Annex L) and MARLIN (STANAG 4691) show promise for IP based HF
  - IP based protocols demand shortest interleaver lengths suggesting mid range data throughput, 50 kbps to 100 kbps range for 48 kHz channels are feasible for skywave links
- Work ongoing to agree on a wideband HF automatic link establishment (ALE) capability

Special Thanks…

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