Design concepts for a Wideband HF ALE capability

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Presentation overview

- Background
- Wideband ALE design considerations
- Provisional design decisions
- Spectrum sensing
  - Capability overview
  - Wideband Availability Experiment
- Harris Prototype WBHF ALE System
- Conclusions and future work

Background: new wideband waveforms

- MIL-STD-188-110C includes a new Appendix C defining a new family of data waveforms having bandwidths of 3.0 to 24.0 kHz, and data rates from 75 to 120,000 bits per second.
- Compared to the 3.0 kHz waveforms of MIL-STD-188-110B, the new waveforms offer new possibilities:
  – Much higher data rates at the highest bandwidths, when channel conditions are favorable
  – Under unfavorable channel conditions, using increased bandwidth at the same data rate offers greater reliability: acceptably low Bit Error Rate (BER) at lower Signal to Noise Ratio (SNR), with no additional transmit power
- The higher data throughputs made possible by these waveforms hold promise to enable HF to support a new range of missions and applications (Network Centric Warfare).

Background: Wideband HF implications

- Many options, requiring many choices:
  - Bandwidth and frequency offset
  - Data rate: modulation format, code rate
  - Interleaver depth
  - Code constraint length
- Manual selection of these would be prohibitively complex: intelligent automation is required
- Use of wider bandwidths results in a greater likelihood of suffering interference
- Above factors create requirements for a new *wideband ALE* capability:
  - <u>Frequency management</u>: provisioning and allocation of wider-bandwidth channels
  - <u>Channel selection</u>: select both channel and *sub-channel* to use, in a manner cognizant of both propagation and interference
  - <u>Link establishment</u>: coordinate link establishment on a *sub-channel* determined dynamically rather than *a priori*
  - <u>Link maintenance</u>: detect changing propagation and/or interference conditions once link is established; potentially modify bandwidth and/or offset to adapt

Wideband ALE design considerations

- Bandwidth must be considered in frequency allocation, management, and selection
- System must estimate the propagation characteristics of wider-bandwidth channels
  - Propagation (unlike interference) is believed to be mostly uniform across channels of up to 24 kHz
  - 3 kHz probing waveforms should be suitable for measuring propagation
- Increased bandwidth results in a greater likelihood of interference
  - System requires capabilities to detect, and avoid interfering signals
  - A key requisite for such capabilities is *spectrum sensing*
- New potential applications with distinctive requirements
- Practical issues: implementation complexity, transition, coexistence

Provisional design decisions (1)

Design decision	Rationale
WBALE will coexist with STANAG 4538 FLSU; stations can operate simultaneously in both kinds of networks. • Same synchronous scanning procedure and timing as FLSU • Similar burst waveform design for calling and linking (like BW5), facilitating simultaneous search • Compatible frequency usage: same frequency can be used for FLSU and for WBALE calling and linking (within a wider channel). Station can be participating simultaneously in both kinds of networks.	• Facilitates adoption of WBHF capabilities including WBALE, especially by organizations already making heavy use of S4538 FLSU • STANAG 4538 burst waveforms, scanning, calling mechanisms are field-proven and widely deployed

Provisional design decisions (2)

Design decision	Rationale
WBALE stations will use a spectrum sensing capability to sense and avoid interference within a channel of width up to 24 kHz. • Waveform family provides waveforms of 3, 6, 9, 12, …, 24 kHz bandwidth • WBALE link set-up determines bandwidth and offset to be used, based on spectrum sense data	• Receiving a wideband frequency allocation provides no guarantee that it's not occupied – many will be, at least partially • A partially-occupied or –blocked 24 kHz allocation can still accommodate useful communications at bandwidths in excess of 3 kHz • Frequent spectrum sensing will be required to detect intermittent interference

Provisional design decisions (3)

Design decision	Rationale
WBALE will contain specific design features aimed at supporting IP-over-HF traffic. • Minimum latency required in addition to high throughput • Wideband data transfer mechanisms tailored to IP traffic • QoS mechanisms along the lines of *Diffserv* • Compatible with TCP performance enhancing proxies and similar mechanisms	• IP-based applications are a crucial underpinning to Network Centric Warfare • Wideband HF has the potential to revolutionize HF's ability to support such applications • Increased bandwidth doesn't inherently eliminate some of the challenges that have hindered past uses of IP over HF

Spectrum sensing

- Calculate spectral profile of an entire wideband channel of up to 24.0 kHz
- Inspect profile to identify usable portion of channel (usable ‘sub-channel’)
- Observation interval short enough to permit sensing within FLSU dwell period (analogous to ‘Listen-Before-Transmit’)
- Includes method for aggregating multiple observations on a single channel at different times, to recognize sources of intermittent interference, etc.

Spectrum sensing examples

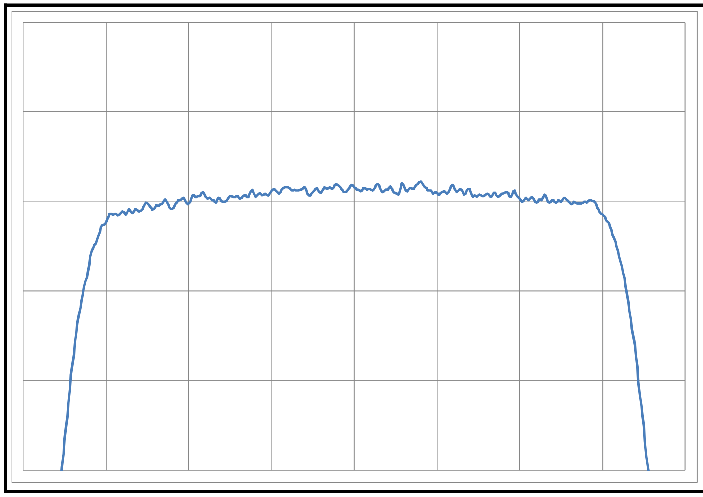


Figure 1. No signal

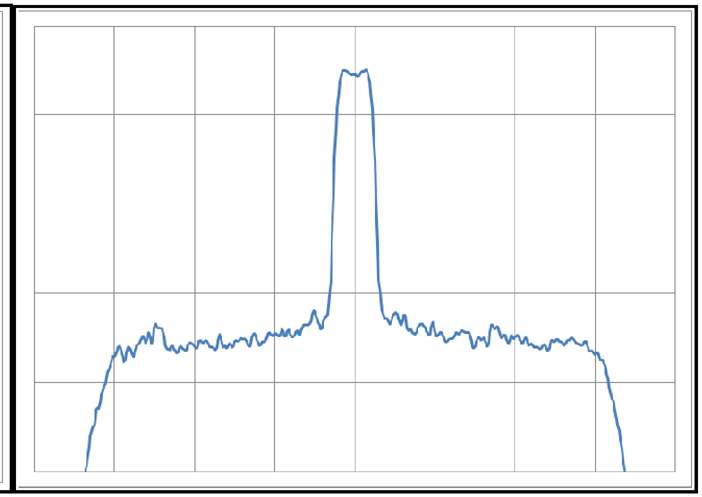


Figure 2. 3 kHz probe

- Figure 1 depicts the spectral profile of a channel from which interference is absent: a mostly flat spectrum of the local noise floor
- Spectrum sensing can also be performed while receiving a known signal – in this case, a 3 kHz probe signal

Use of spectrum sensing

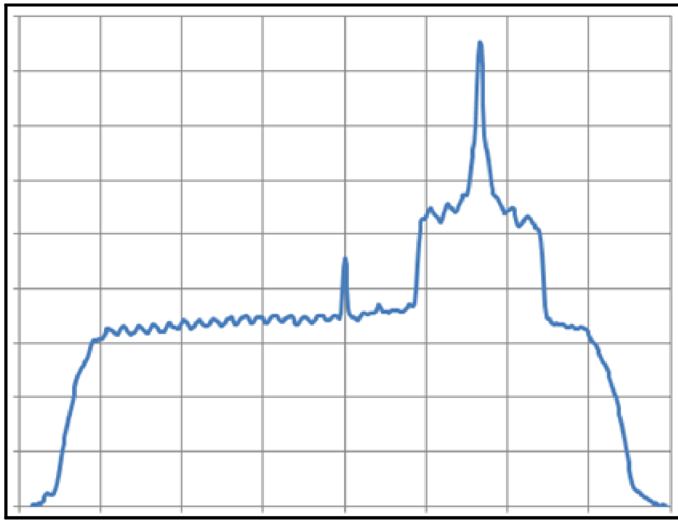


Figure 3. AM interferer

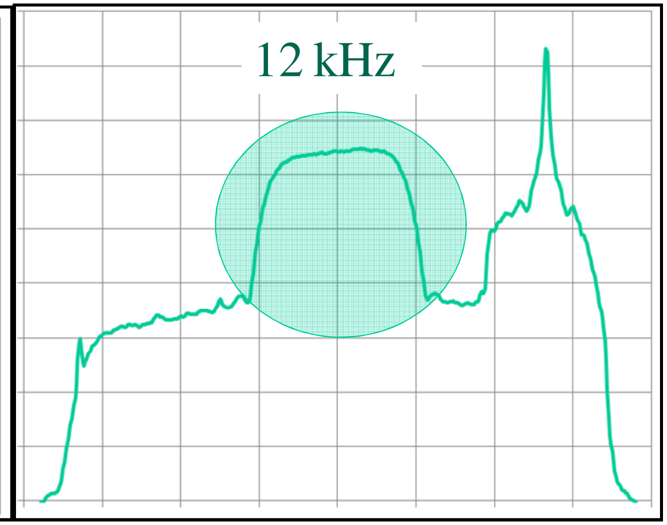
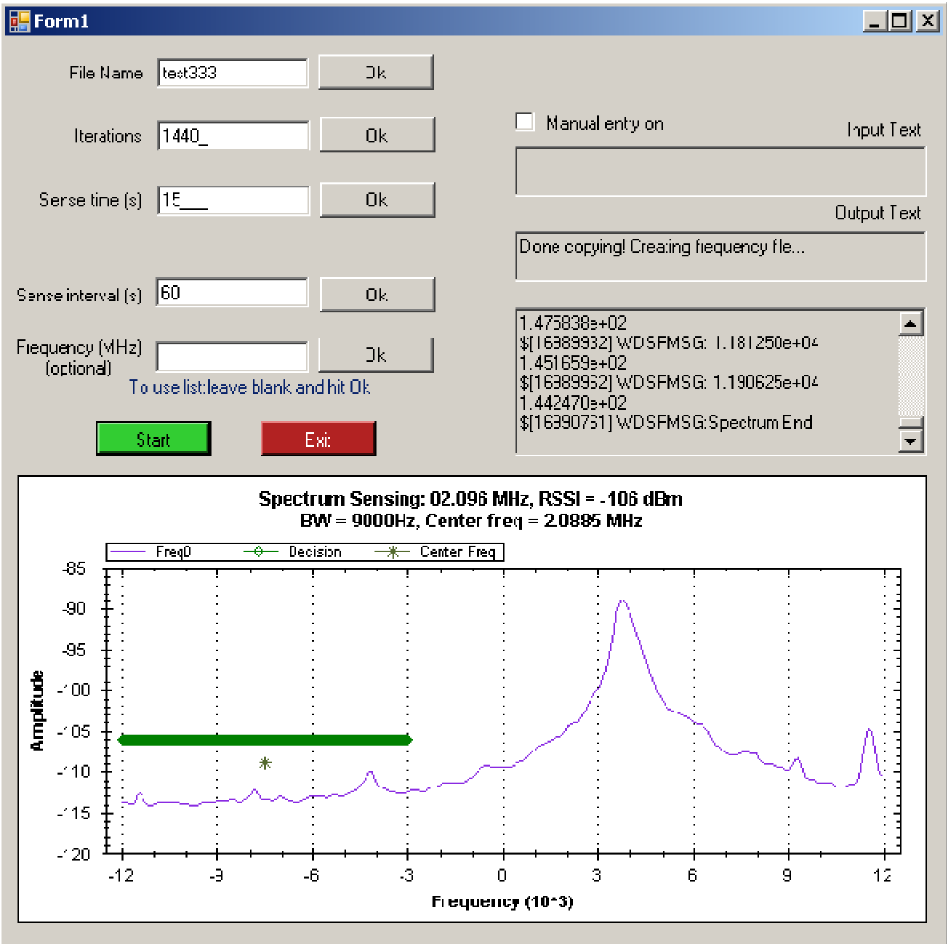


Figure 4. Interference avoided

- Figure 3 shows a spectral profile containing a prominent interfering signal: in this case, an AM broadcast signal
  - Attempted to pass data at 64 kbps, 24 kHz bandwidth: 50% BER
- In Figure 4, we see that the transmitter has limited its bandwidth to 12 kHz and added a frequency offset
  - By sidestepping the interference, was able to pass data error-free at 32 kbps

Automated spectrum sensing tool

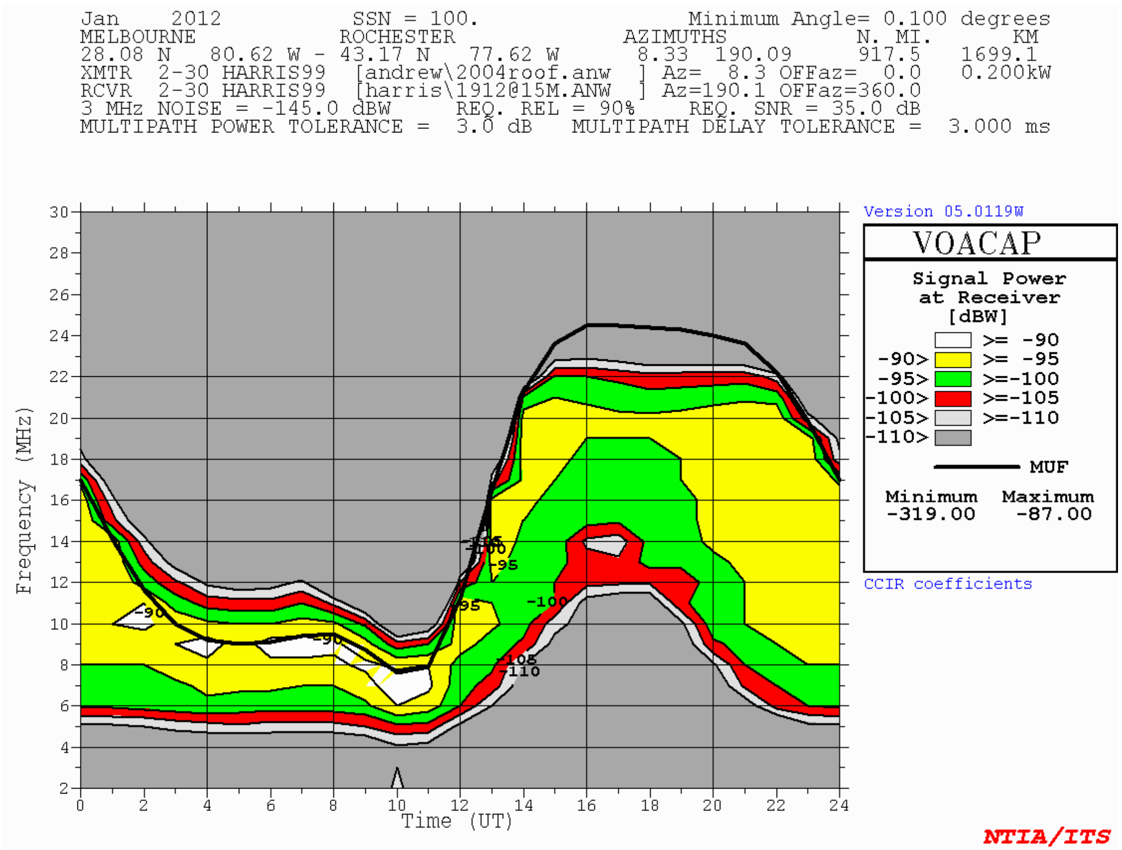


- PC based application which interfaces with a prototype wideband receiver
- User inputs file name, number of senses, duration of sense, and interval time
- User can specify single frequency or run from a list of frequencies
- All data logged to PC
- For each spectrum sense a plot of received signal density (dBm/Hz) versus frequency is calculated, displayed, logged

Wideband Availability Experiment

- The spectrum sensing tool was used to perform an experiment examining wideband HF channel availability and achievable performance gains:
  - Use VOACAP to predict the usable frequency range and received signal levels on a specific link at various times of day
  - Perform spectrum sensing at the receive site on observation frequencies randomly selected from the usable frequency range predicted by VOACAP, at one-minute intervals
  - Use measured noise/interference levels from spectrum sensing and VOACAP predictions of received signal strength to estimate SNR for each candidate bandwidth and offset
  - Select bandwidth and offset yielding the highest possible data rate with BER of 10^{-5} or less; record data rate
- The series of achievable data rates enables us to predict, in a rough way, the aggregate data throughput that could be achieved through the use of Wideband HF *including WBALE*

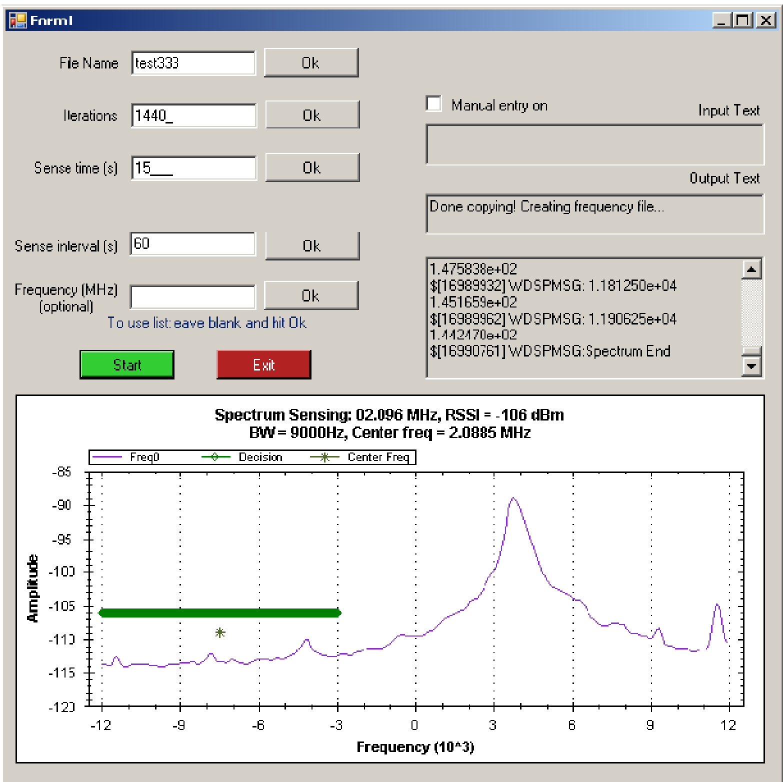
WB Availability Experiment: frequencies

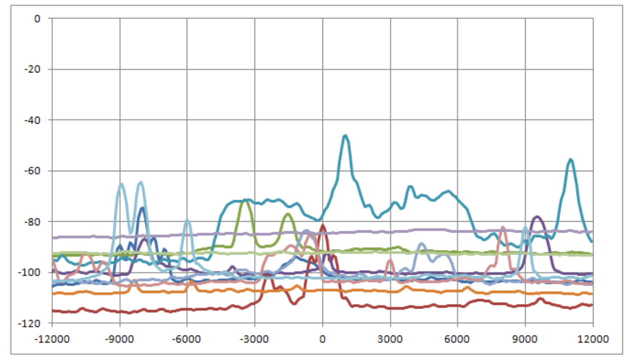


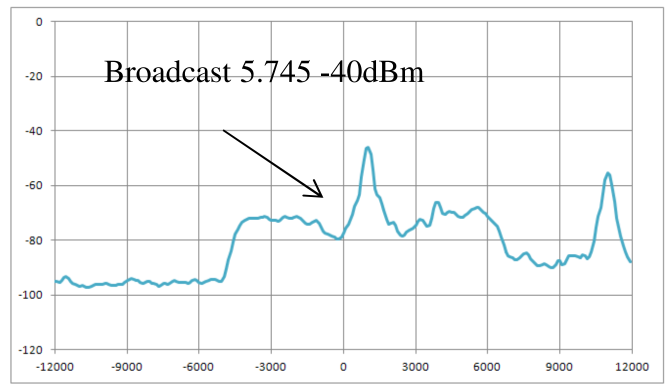
UTC	Min	Max	dBM
0	9	17	-60
1	9	14	-60
2	9	11	-60
3	8	10	-60
4	8	10	-60
5	8	10	-60
6	8	10	-60
7	8	10	-60
8	8	10	-60
9	7	9	-60
10	7	9	-60
11	7	9	-65
12	9	13	-65
13	10	16	-65
14	12	22	-65
15	14	22	-65
16	14	22	-65
17	14	22	-65
18	14	22	-65
19	14	22	-60
20	14	22	-60
21	9	22	-60
22	9	20	-60
23	9	18	-60

- Step 1 – VOACAP used to estimate usable frequency range and received signal strength in dBm

WB Availability Experiment: spectrum sensing



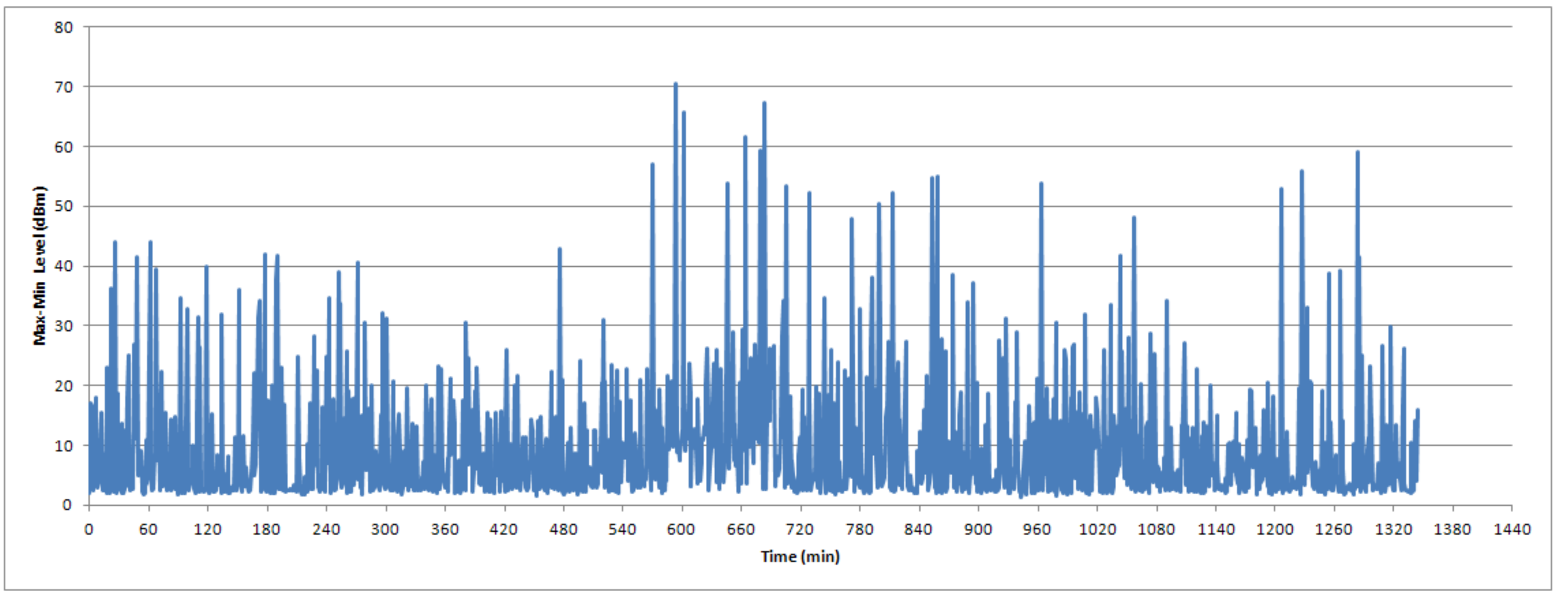




- Step 2 – Program the Spectrum Sense application to collect 24 kHz channel spectra once per minute, on randomly-selected frequencies between the estimated min and max. Frequency limits are changed each hour based on VOACAP predictions

WB Availability Experiment: observations

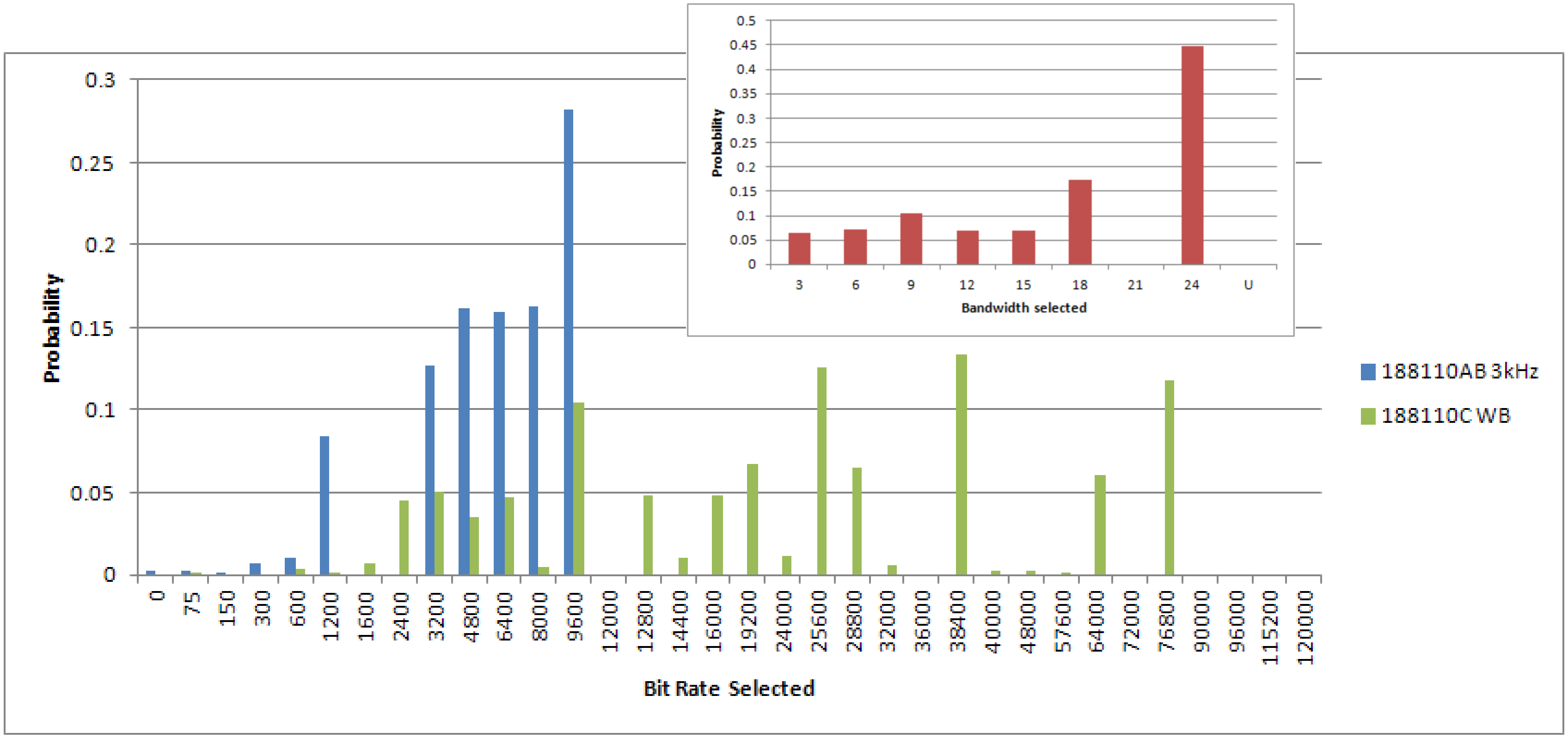
- 24-hour experiment
- Transmitter at Melbourne FL: 200 watts, log-periodic antenna (assumed in VOACAP predictions)
- Receiver in Rochester NY: broadband dipole antenna (used for spectrum sensing)
- Interference present on a large fraction of the observed 24 kHz channels



WB Availability Experiment: results

- Step 3: Data Analysis
  - Data are post-processed. Based on predicted Rx signal power and measured interference power a received SNR is estimated, assuming constant Rx power and accounting for varying noise+interference bandwidth
  - Received SNR is compared against AWGN and ITU-R Mid-Latitude Disturbed channel SNR thresholds for a 10^{-5} BER at each bit rate, to determine maximum bit rate supported using:
    - 188-110A/B 3 kHz signaling, fixed alignment
    - 188-110C Wideband: bandwidth and alignment are chosen so as to maximize data rate (with BER no worse than 10^{-5}) across all available bandwidths and offsets
  - Total throughput is calculated by integrating bit rate selected for each minute over the 24 hour test duration

Wideband Availability Experiment: results

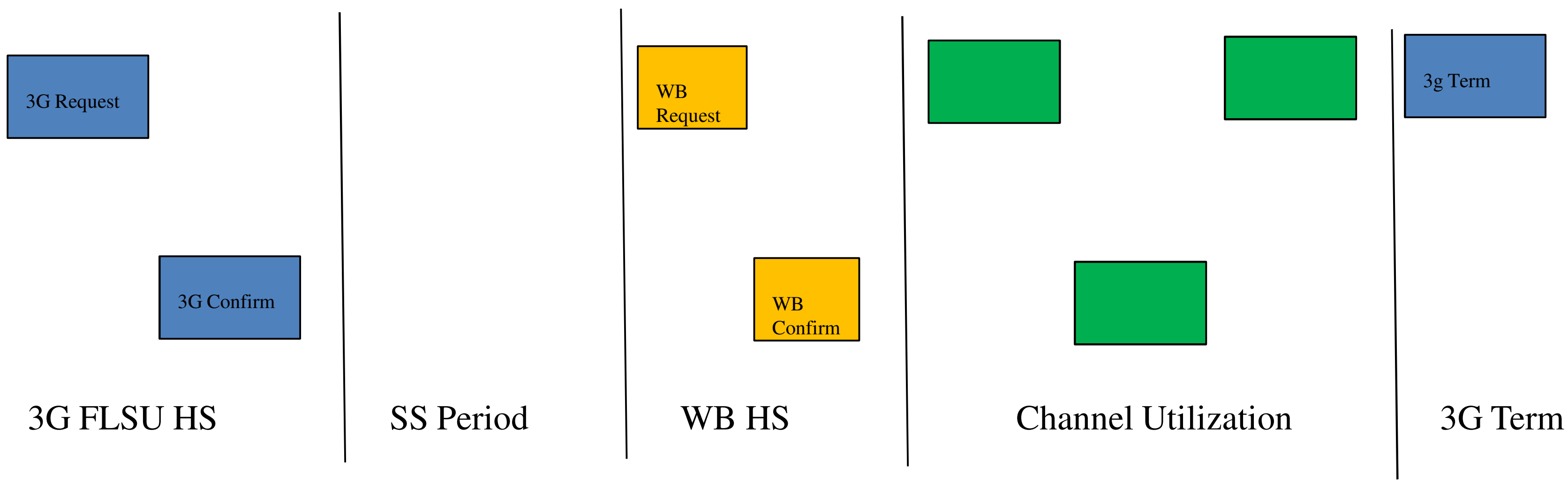


- Total throughput
  - AWGN: 85MB (3kHz), 505MB (Adaptive Wideband)
  - ITU-R MLD: 65MB (3kHz), 294MB (Adaptive Wideband)
- At least 50% of channels contained potential interference avoided through the use of spectrum sensing

Harris Prototype WB ALE System

- Uses STANAG 4538 FLSU for link setup
- Uses spectrum sensing to measure interference within the selected wideband channel
- New burst handshake exchanges spectrum sense measurements
- Available bandwidth and offset are determined by the called station and the decision conveyed in the handshake

Harris Prototype WB ALE System



Timing not to scale

Harris Prototype WB ALE System

- Initial testing and evaluation underway
- Testing based in Rochester NY
- Both fixed and mobile platforms under test
- Results are promising; optimizations and enhancements underway

Harris Prototype WB ALE System On-Air Testing

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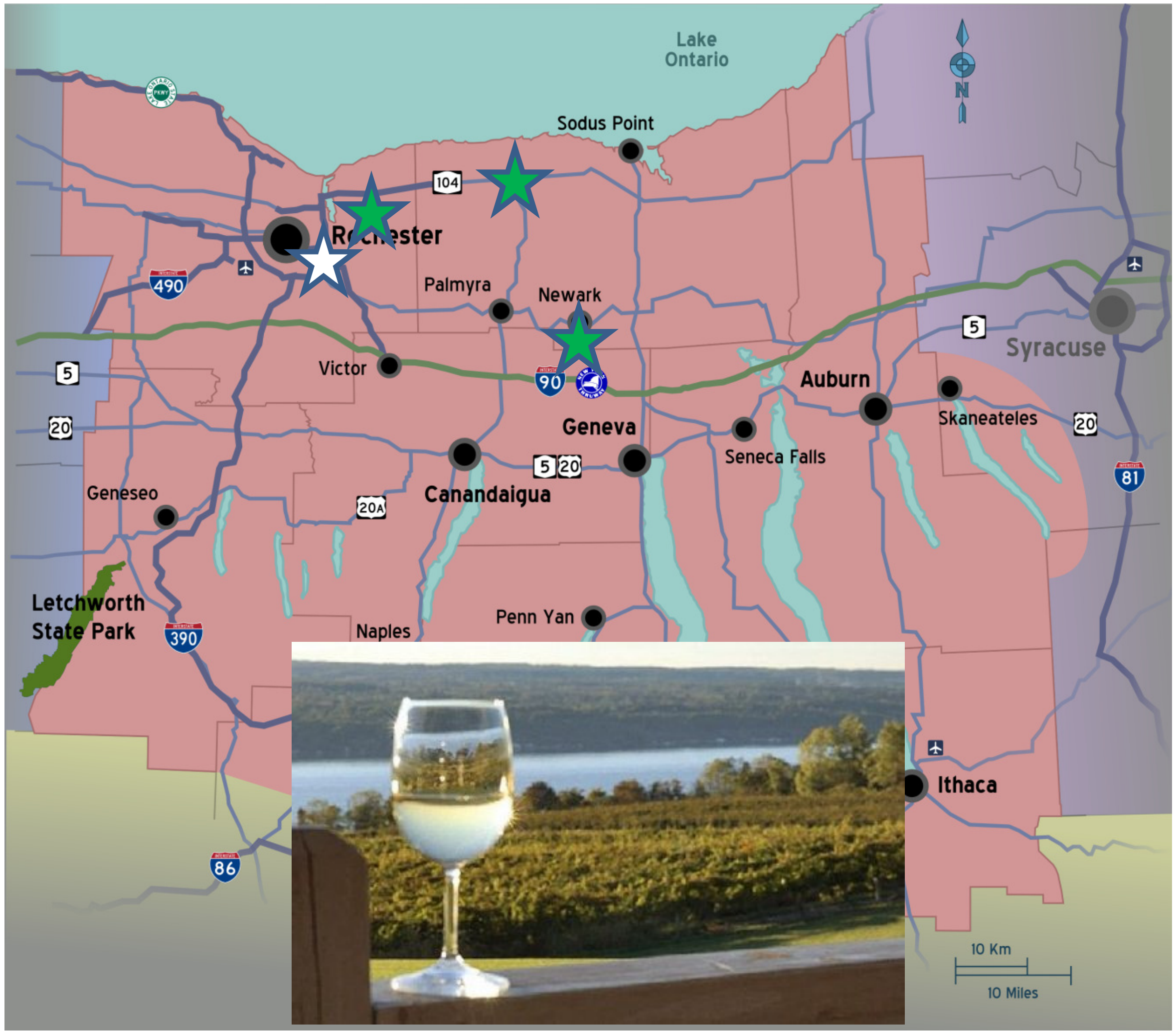
- H1
- Ford Econoline
- Diesel Generator
- RF-5800H
- Proto WB
- 5m Vertical Monopole
- Inverted V Dipole 10m legs, 6M apex (stationary) Primary
- 150 Watt PA



- HMMWV
- M998
- Diesel Generator
- RF-5800H
- Proto WB
- 5m Tilt Whip
- RF-3134 Full loop antenna
- Inverted V Dipole 10m legs, 6M apex (stationary)
- 150 Watt PA

Conclusions and future work

- The new wideband HF waveforms defined by MIL-STD-188-110C promise to revolutionize HF communications through dramatic improvements in throughput and robustness
- Due to the flexibility and complexity of these waveforms, automated adaptive or ‘cognitive’ techniques will be required – a new ALE solution, a ‘Wideband (4G) ALE’ – in order to fully realize their potential
- A Wideband Availability Experiment based on a prototype spectrum sensing capability has demonstrated the capability of a Wideband HF solution to achieve dramatic gains in throughput compared to existing 3 kHz waveforms and protocols
- Harris has implemented a Wideband HF ALE prototype and is in the process of on-air testing and optimizing.