Wideband High Frequency (WBHF) for Anti-Access Area-Denial (A2AD) Environments

James A. Stevens PhD, Lizy Paul, Timothy E. Snodgrass, Randy W. Nelson
Rockwell Collins Government Systems

United States of America

james.a.stevens | lizy.paul | timothy.snodgrass | randy.nelson @ rockwellcollins.com

***Abstract*— This paper describes the applicability of High Frequency (HF) infrastructure and standards to provide robust and satellite-alternative communications for the Anti-Access Area-Denial (A2AD) environment. Recent Wideband High Frequency (WBHF) over-the-air demonstrations are described.**

Keywords—HF, WBHF, A2AD

I. High Frequency and A2AD Introduction

High Frequency (HF) wireless communications became important for beyond line of sight (BLOS) communications in the 1920s and was critical for long distance command and control in World War II and the early part of the Cold War. HF became less important during the 1960s and 1970s with the advent of satellite communications (SATCOM) due to SATCOM's greater throughput and ease of use.

Electronic warfare (EW) and satellite denied environment (SDE) threats create Anti-Access Area Denial (A2AD) environments that are difficult to communicate and operate within. Advancements in HF technologies over the past two decades, especially automatic link establishment (ALE) and wideband HF (WBHF), improve the ease of use and capacity of HF communications. By upgrading to these latest HF standards and leveraging existing infrastructure, the US can cost effectively provide robust and satellite-alternative communications for the A2AD environment.

II. HF Propagation

HF operates BLOS in the 2 to 30 MHz frequency band by either reflecting off the ionosphere (called Skywave) or refracting off the surface of the earth (called Surface Wave).

Different frequencies will reflect off the ionized layers depending upon their height and ionization density which varies depending upon time of day and solar activity. Thus, multiple HF frequency assignments are required to ensure 24/7/365 reliable communications.

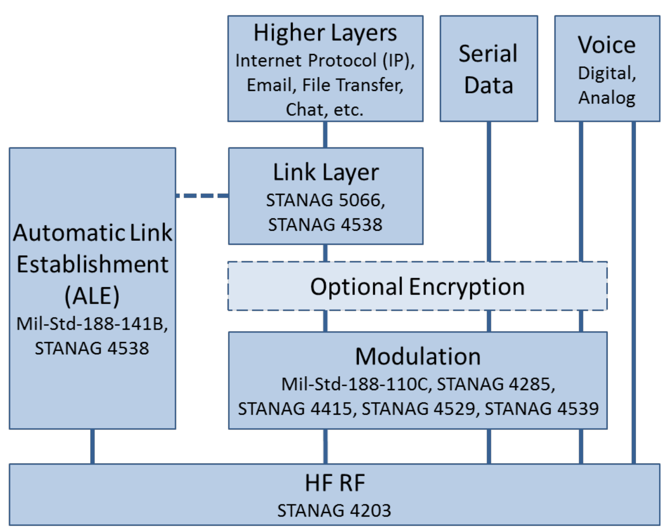
It is possible to predict which frequencies will be propagating based upon time of day and solar conditions as well as physical measurement of the ionosphere layers via sounding stations. However, actual propagation performance for frequency channels will often be better or worse than expected. Thus, automatic protocols are required to determine which frequencies are propagating and adapt the waveform modulation and coding to actual channel conditions.

III. Currently Fielded HF Waveform Standards

There are a variety of HF waveform standards currently fielded today. The US military standards (MIL-STDs) and NATO Standardization Agreements (STANAGs) define standardized HF protocols for the physical and link layers. Fig. 1 shows currently fielded HF waveform standards.

Automatic Link Establishment (ALE) protocols probe (sound) HF frequencies to identify good propagating channels to setup a link. In the past, successful HF communications required skilled operators to know when to manually switch frequencies to obtain or maintain good links to exchange voice or data. ALE enables radios to automatically determine which links are propagating and use those links.

Fig. 1. Current HF waveform standards.



Single sideband (up to 3 kHz bandwidths) channel modulations support data rates up to 9.6 kbps and independent sideband (6 kHz bandwidth) channel modulations support data rates up to 19.2 kbps. The serial tone data waveform modulations feature an "autobaud" capability that enables the receiver to automatically adapt the transmitter's data rate and interleaver configuration without operator intervention.

HF link layer protocols dynamically adapt data rate to channel conditions and improve reliability through acknowledgement and retransmissions. These link layer protocols support higher layer applications including email, chat, and file transfer.

IV. CURRENT HF SYSTEMS

The US has a large installed base of HF radios for ground, maritime, and airborne operations. For example, there are more than 4000 fixed and rotary wing airborne platforms with HF radios installed. Fig. 2 shows some of the HF capable airborne platforms.

Some of these aircraft do not include ALE and some only support analog voice. Thus, a platform may have HF, but rarely if ever use it because of the steep training curve required to manually operate HF without ALE or the poor quality of analog voice. Upgrading the radios on these platforms (without having to replace antennas) would improve the HF reliability and operational effectiveness.

The US uses HF to communicate directly from platform to platform, such as air-to-ship communications. The US also has fixed and deployable HF entry station infrastructure for connectivity from deployed platforms to the Global Grid. Fig. 3 shows locations of the HF Global Communications System (HFGCS) ground entry stations [1].

HFGCS operates as a worldwide cellular-like system. A user radio sends an ALE request to HFGCS and HFGCS determines which entry station has the best link quality and responds to the user radio from that station. The spatial diversity of HFGCS provides operational flexibility and jam resistance compared to using a single entry station per radio.

Fig. 2. Sample selection of aircraft with HF radios.

Fig. 3. HF Global Communications System (HFGCS) ground entry stations.

HFGCS provides secure and unsecure voice service and remote access for Secure Internet Protocol Router Network (SIPRNet) and Nonsecure Internet Protocol Router Network (NIPRNet).

V. NEW WIDEBAND HF (WBHF) STANDARD

In 2007, an HF standards Technical Advisory Committee (TAC) was formed to review, then update HF radio and modem standards. The TAC sponsor, US Air Force, expressed the desire for increasing data throughput over the HF medium for several obvious reasons, including mitigation against SATCOM denied and Anti Access, Area Denial (A2AD) threats.

A new MIL-STD-188-110C Appendix D WBHF waveform standard was ratified in 2011. Appendix D specifies waveform modulations with data rates from 75 bps to 120 kbps and channel bandwidths between 3 and 24 kHz [2]. The higher data rates supported by the Appendix D waveforms are sufficient to support services not previously practical over HF radio such as real-time video transmission.

In addition, an extension of WBHF has been designed and implemented to provide data rates up to 240 kbps using channel bandwidths between 30 and 48 kHz [3]. This work has been proposed to the HF TAC for consideration as another new appendix to MIL-STD-188-110C.

A. WBHF Propagation Tests and Demonstrations

Multiple propagation tests and demonstrations have been performed during development and subsequent standardization of WBHF to validate the WBHF design and usefulness.

<u>2010 Transatlantic Tests.</u> In November and December 2010, WBHF was tested over a transatlantic link between Cedar Rapids, Iowa in the US and Dongen in the Netherlands as shown in Fig. 4 [4]. This 6800 km link is sufficiently long that it had multiple earth to ionosphere back to earth bounces to close the link. Using different frequencies to track the predicted propagation by time of day, reliable communications with burst rates between 19.2 and 38.4 kbps were achieved in 12 kHz channel bandwidths.

Fig. 4. WBHF Transatlantic Demonstration.

2011 Four Node IP Network Trials. Trident Warrior WBHF trials in March 2011 demonstrated a successful four node, single frequency skywave HF-IP network between four North American fixed ground sites, illustrated in the Fig. 5 [5]. Links varied between 943 and 2245 km in length.

A sustained four node skywave network was established with burst data rates between 19.2 and 38.4 kbps, and a two node HF-IP skywave network was established with sustained burst rates up to 72 kbps. All networks used 18 kHz channel bandwidths.

2014 WBHF Surrogate Satellite JREAP Experiment. A demonstration of WBHF capabilities as an A2AD surrogate satellite mitigation solution took place in March 2014 as shown in Fig 6.

The demonstration featured a network joint fires mission with a notional Tactical Operations Center (TOC) in Cedar Rapids and the target in Virginia Beach, Virginia as in Fig 7. A Joint Terminal Attack Controller (JTAC), with a tablet JTAC Mobile system, obtained positioning, navigation, and timing (PNT) for offshore ships using a PLRF15C laser range finder.

The PNT data was automatically transmitted using variable message format (VMF) over line of sight (LOS) UHF to a Network Tactical Gateway (NTG). The NTG converted the VMF messages to Link-16 J-series message tracks and routed them over a Link-16 network to a notional Close Air Support (CAS) platform. Simultaneously, the NTG encapsulated the same J-series targeting data in Joint Range Extension Applications Protocol (JREAP)-C Internet Protocol (IP) messages and sent them over WBHF to the TOC. Two-way chat messages were also sent between the TOC, CAS, and JTAC using the J-series free-text message.

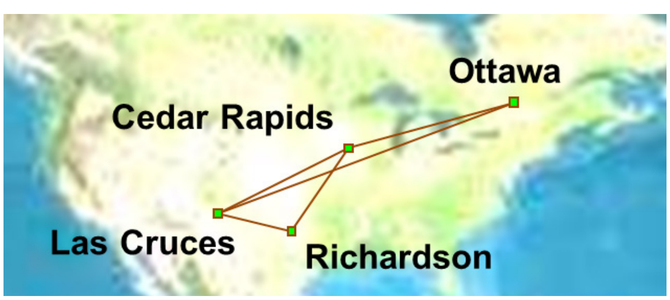


Fig. 5. Four Node WBHF IP network Demonstration.

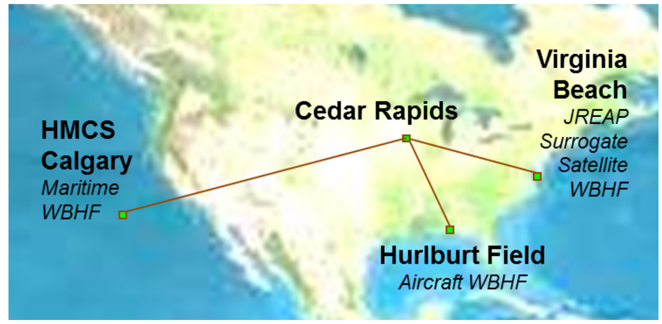


Fig. 6. 2014 WBHF Demonstrations and Experiments.

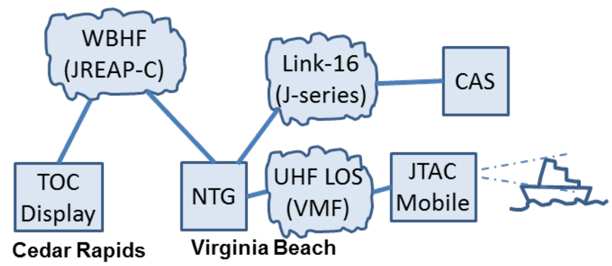


Fig. 7. WBHF Link 16 (JREAP) Surrogate Satellite Experiment.

This demonstration used the 30 kHz WBHF extension with a burst rate of 32 kbps and an effective net throughput of 22.4 kbps (after subtracting off link and network overhead). The elapsed time from lazing the offshore freighter to receiving the targeting data at the WBHF receiver in Iowa was five seconds.

Typically, JREAP messages are sent over satellite links; this demonstration showed WBHF use as a surrogate satellite link.

2014 WBHF Shipboard Demo. A one day June 2014 pre-Trident Warrior 2014 test demonstrated a WBHF link between a Canadian ship, HMCS Calgary (FFH 335), in the Pacific and Cedar Rapids, Iowa as shown in Fig. 6. Several 24 kHz wideband channels provided solid connectivity with data rates up 76.8 Kbps from the ship to Cedar Rapids and data rates up to 96 Kbps from Cedar Rapids back to the ship.

2014 WBHF Aircraft Experiment. Research has recently begun to determine WBHF data transport performance on military aircraft, with the initial investigation conducted on a C-130 transport aircraft parked on the flight line at Hurlburt Field, Florida as shown in Fig. 6. A proof of concept WBHF radio was installed on the C-130 and used the existing aircraft HF antenna and antenna coupler. The average power amplifier (PA) output power was at 100 watts. Over-the-air data transmissions between the aircraft and three fixed site ground stations within the US were conducted on August 12, 2014.

The existing antenna and coupler were able to support WBHF bandwidths up to 48 kHz with reliable data rates up to 72 Kbps. Full motion video was successfully transmitted from the aircraft to Cedar Rapids, IA, a distance of approximately 800 miles. The compatibility of legacy airborne PA, couplers,

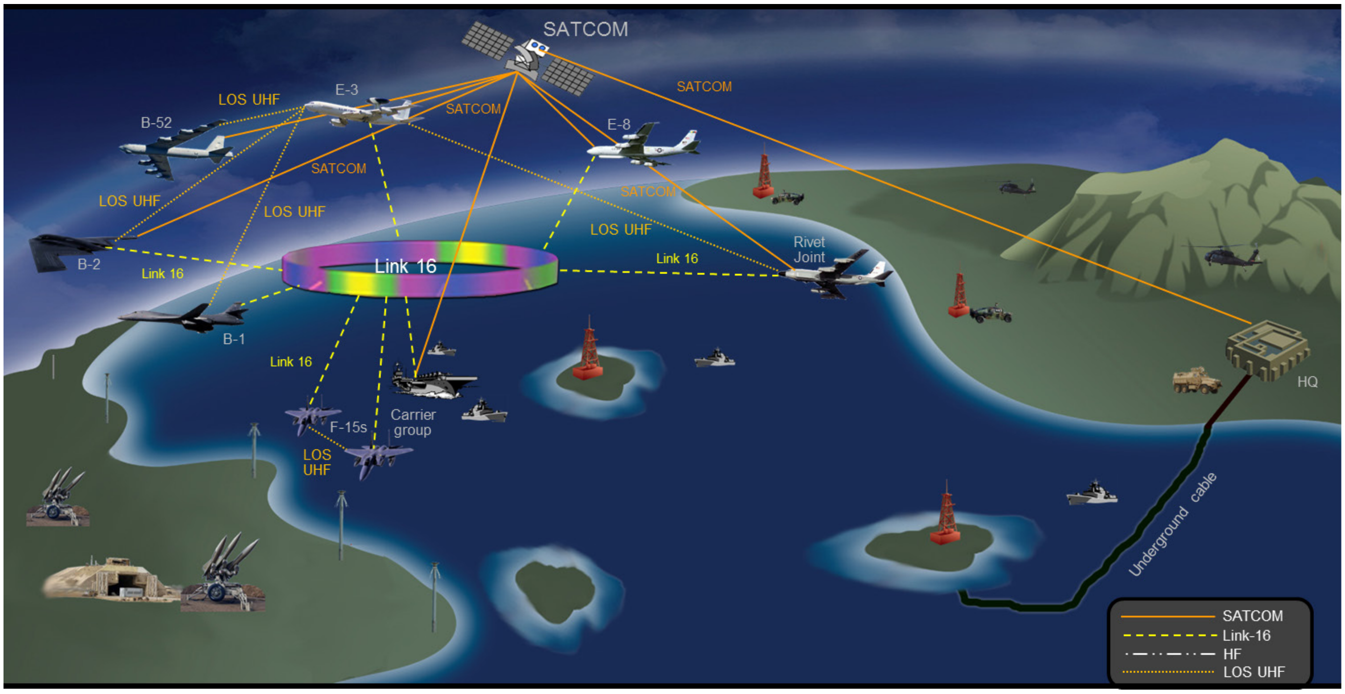


Fig. 7. Example communications in benign conditions.

and antennas with HF bandwidths up to 48 kHz enables the WBHF technology to be easily integrated into existing airborne systems. In the coming months, additional tests will be conducted with aircraft in flight to further validate the feasibility of WBHF migration into military aircraft providing an effective A2AD mitigation solution.

B. WBHF Spectrum Availability

An HF Industry Association (HFIA) subcommittee has been formed to measure HF spectrum availability worldwide, using common hardware, software, and antennas [6]. The spectrum sensing system scans the entire HF spectrum, 2 MHz to 30 MHz, each minute and collecting channel occupancy statistics by time of day and one MHz frequency bands. The collected data is processed to determine average hourly occupancy for 3 kHz up to 48 kHz bands.

Preliminary US and UK channel minute availability (CMA) data was obtained and analyzed for predicted propagating channels across the 24 hour day [7]. Overall availability was good in the US, with CMAs ranging from 85% for 3 kHz channels to 75% for 24 kHz channels. Overall availability was lower in the UK, though still quite useable with CMAs ranging from 71% for 3 kHz channels to 54% for 24 kHz channels.

VI. A2AD ENVIRONMENT

Anti-Access and Area Denial (A2AD) occurs when an enemy gains the ability to disrupt command and control to such an extent that friendly forces cannot control their assets nor risk sending assets to that region [8].

Example A2AD communications threats include:

- loss of communications through satellite denial,
- loss of communications through jamming,
- platform detection and location from communications transmissions, and
- loss of communications due to nuclear effects.

Fig. 7 shows example communications under benign conditions. Fig. 8 illustrates how line of sight (LOS) jamming and satellite-destruction threats can disrupt communications.

VII. WBHF USE IN A2AD ENVIRONMENTS

WBHF mitigates many of the A2AD environment threats, including jamming, detection, and satellite denial as illustrated in Fig 9.

The lowest data rate modulation for each WBHF channel bandwidth operates with a Signal to Noise Ratio (SNR) of about -9 dB for mid-latitude links. This provides data rates from 75 bps (3 kHz channel bandwidth) to 600 bps (24 kHz channel bandwidth). The latter is sufficient for the lowest data rate Mixed Excitation Linear Prediction - Enhanced (MELPe) vocoder and thus provides voice at significantly lower SNR than possible today.

The lowest data rate WBHF modulation is based upon Walsh codes that spread the transmitter power out in a wider channel than the information actually requires. This means that a transmitter has additional transmit power reserve

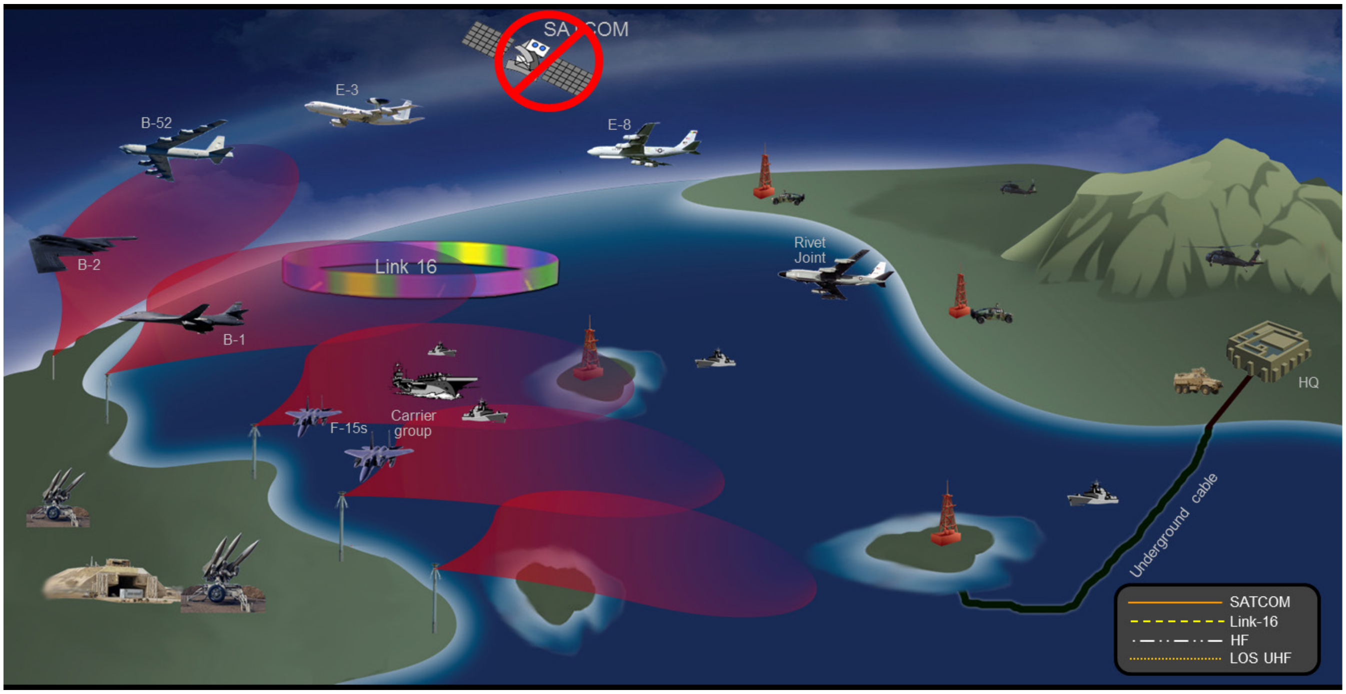


Fig. 8. Example loss of communications under A2AD jamming and satellite-denial threats.

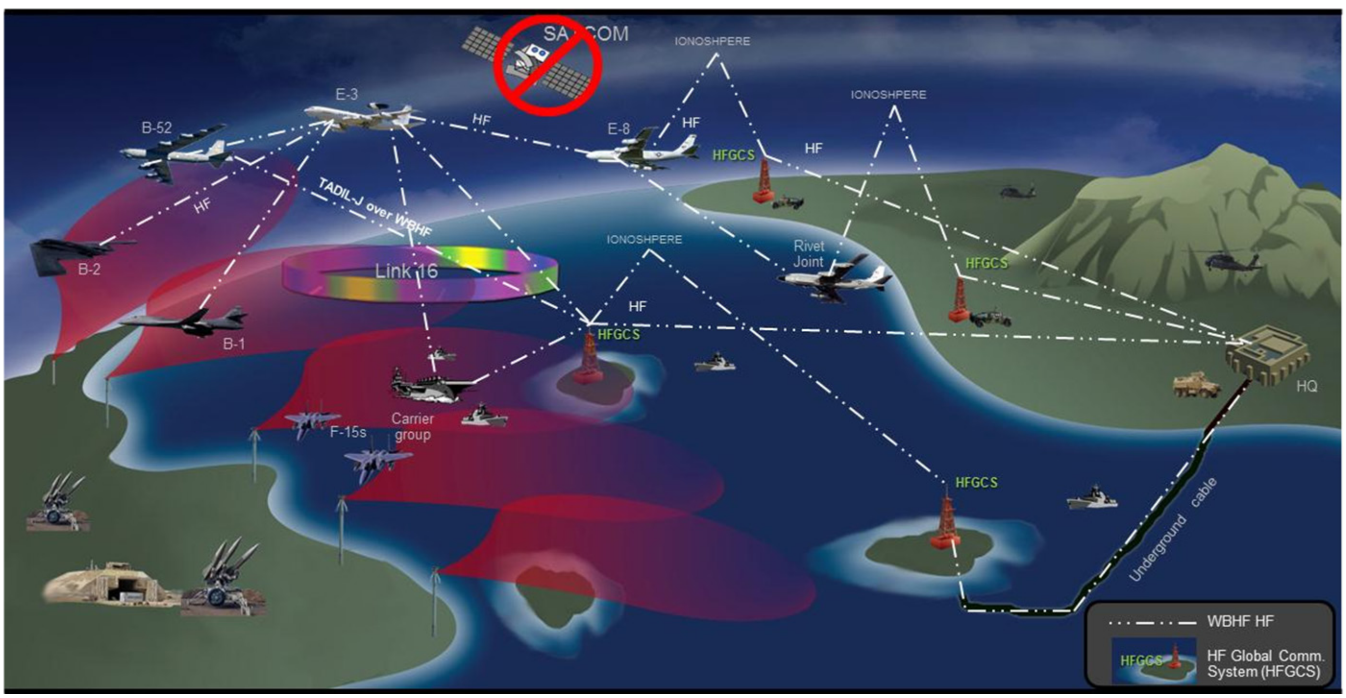


Fig. 9. Example recovery of communications in A2AD environment using WBHF.

available to bust through jamming signals. It also means that a transmitter can reduce its transmitted power to make its signal stealthier and harder to detect. This WBHF capability can be used to mitigate the jamming and/or detection threats in A2AD environments.

WBHF can be used to heal jammed LOS and SATCOM links in the A2AD area. Upon loss of connectivity, the forward deployed links use ALE and WBHF to reestablish communications via either HF skywave or surface wave links.

The HFGCS cellular HF network provides spatial diversity so that the best propagating channel is used to maximize transmitter power margin against jammers.

The HFGCS system can be used in an A2AD scenario to provide reachback connectivity if satellite communications are denied. HFGCS can also be used to heal jammed LOS links in the A2AD area by allowing forward deployed nodes to communicate via relay through the HFGCS.

WBHF's voice service can heal A2AD jammed voice nets like UHF SATCOM voice; WBHF's IP data service can heal A2AD jammed networks like SHF SATCOM; and WBHF, combined with JREAP, can heal A2AD jammed Link-16, Link-11, and VMF tactical data links.

Nuclear events disturb the ionosphere by increasing its electron density which increases the absorption of lower HF frequencies and the reflection of higher HF and VHF frequencies [9]. Combined with ALE and a suitably wide range of channel frequency allocations, an adaptive WBHF system could potentially operate through the changing RF environment during and after nuclear events.

VIII. Conclusion – WBHF is a Practical and Affordable Capability for A2AD Mitigation

The BLOS nature of HF coupled with the robustness and higher capacity of WBHF provide a viable, alternative communications for BLOS connectivity in A2AD environments.

A WBHF solution leverages existing DoD worldwide HF infrastructure and platforms with installed HF. Only the HF radios/modems would have to be upgraded to run the latest military standards, including ALE and WBHF. This means that airborne platforms with existing HF only have to upgrade their radios and could reuse their existing HF antennas without having to make costly modifications to the outside of the aircraft. WBHF, with its low SNR requirement, operates below the noise floor and can be used with lower transmit powers for lower detectability or with higher transmit powers for additional anti-jam margin.

In summary, the US investment in HF fielded platforms and ground entry infrastructure can be cost effectively upgraded to the latest HF standards to provide robust and satellite-alternative communications for A2AD environments.

Acknowledgements

The 2014 demonstrations and experiments were performed through Rockwell Collins internal WBHF funding in conjunction with Government facilities provided by USSOCOM (WBHF Surrogate Satellite JREAP Experiment), SPAWAR (WBHF Shipboard Demo), and AFSOC (WBHF Aircraft Experiment). Note that Government support does not imply endorsement of WBHF or Rockwell Collins products.

Reference

[1] Dwayne Harris, "HFGCS Status", Feb. 2010, HF Industry Association (HFIA) Conference.

[2] W. N. Furman, J. W Nieto, "Latest on-air testing of U.S. MIL-STD-188-110C appendix D wideband HF data waveforms", 2012, International Ionospheric Radio Systems Techniques Conference (IRST).

[3] M. B. Jorgenson, R.W Johnson, R. W Nelson, "An Extension of Wideband HF Capabilities," Nov. 2013, IEEE MILCOM.

[4] Jorgenson, Nelson, Doms, et al, "WBHF Testing over Transatlantic Link", Jan. 2011, HFIA Conference.

[5] James Mahan, et al, "Wideband HF IP Experimentation", Jan. 2012, HFIA Conference.

[6] William Furman, "Summary – Wideband HF Channel Availability Working Group", Feb. 2014, HFIA Conference.

[7] William Furman, John Nieto, Eric Koski, "Interference Environment and Wideband Channel Availability", Aug. 2013, HFIA Conference.

[8] "Air Sea Battle: Service Collaboration to Address Anti-Access & Area Denial Challenges", May 2013, Air-Sea Battle Office, http://www.defense.gov/pubs/ASB-ConceptImplementation-Summary-May-2013.pdf

[9] C. B. Gabbard, R. E. LeLevier, "Emerging HF and Related Radio Communications Concepts for Enduring C3I Roles in a Nuclear War Environment;" Jun. 1980; the referenced declassified, unlimited distribution version is at http://www.dtic.mil/dtic/tr/fulltext/u2/a209335.pdf.