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Network-Centric Maritime Radiation Awareness and Interdiction Experiments: C2 Experimentation

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Abstract

The paper addresses technological and operational challenges of developing a global plug-and-play Maritime Domain Security testbed for the Global War on Terrorism mission. This joint NPS-LLNL project is based on the NPS Tactical Network Topology (TNT) composed of long-haul OFDM networks combined with self-forming wireless mesh links to air, surface, ground, and underwater unmanned vehicles. This long-haul network is combined with ultra-wideband (UWB) communications systems for wireless communications in harsh radio propagation channels. LLNL's UWB communication prototypes are designed to overcome shortcomings of the present narrowband communications systems in heavy metallic and constricted corridors inside ships. In the center of our discussion are networking solutions for the Maritime Interdiction Operation (MIO) Experiments in which geographically distributed command centers and subject matter experts collaborate with the Boarding Party in real time to facilitate situational understanding and course of action selection. The most recent experiment conducted via the testbed extension to the Alameda Island exercised several key technologies aimed at improving MIO. These technologies included UWB communications from within the ship to Boarding Party leader sending data files and pictures, advanced radiation detection equipment for search and identification, biometric equipment to record and send fingerprint files to facilitate rapid positive identification of crew members, and the latest updates of the NPS Tactical Network Topology facilitating reachback to LLNL, Biometric Fusion Center, USCG, and DTRA experts.

1. Introduction

Civilian and naval vessels have long been potential targets for criminal and terrorism activities. There are concerns that terrorists can ship various types of weapons of mass destruction (WMD) to international ports using commercial ships and their cargos. One of the major steps in preparedness for such danger is reliable wireless communications both between the boarding party as well as effective ship-to-ship and ship-to-shore communications once the first sign of threat is detected. In addition, reliable wireless communication systems inside a ship provide situational awareness for boarding party at the time of maritime threat. Therefore, there is a critical need for a reliable wireless communications for transferring voice and images inside a ship and out to shore or other ships to ensure maritime domain awareness and safety.

Since 2004 a joint team of Naval Postgraduate School (NPS) and Lawrence Livermore National Laboratory (LLNL) researchers have been operating a plug-and-play testbed, which enables discovery, integration, and demonstration experiments for a broad range of Maritime Interdiction Operation (MIO) scenarios. The operational focus of NPS-LLNL experiments is on finding viable solutions for MIO connectivity and collaboration providing for rapid radiation detection, biometrics identification, non-proliferation machinery parts search, and explosive materials detection on board the target vessel during the boarding party search phase. The testbed includes mesh and long-haul wireless networking with radiation detection sensors, boarding party collaboration with remote expert teams, and reachback to different locations around the globe.

In this paper we present an overview of the NPS-LLNL experiments to find a feasible solution to MIO connectivity. The organization of the rest of this paper is as follows. Section 2 introduces the NPS-LLNL MIO testbed. Section 3 discusses a typical MIO scenario that was considered for NPS-LLNL experiments. Section 4 provides a brief description of the main MIO networking segments. Section 5 is dedicated to discuss the details of UWB communications used in NPS-LLNL testbed. Section 6 describes the radiation detection for search and identification. Finally, lessons learned and concluding remarks are summarized in section 7.

2. NPS-LLNL MIO Testbed

The testbed contains a tactical, OFDM 802.16 backbone, terminating in various locations within the 200 mi length in Northern California (Fig. 1), which provides for the ad hoc plug-in of UAVs, boats, ships, small SOF and Marine units, including airborne and ground self-forming mesh communications.

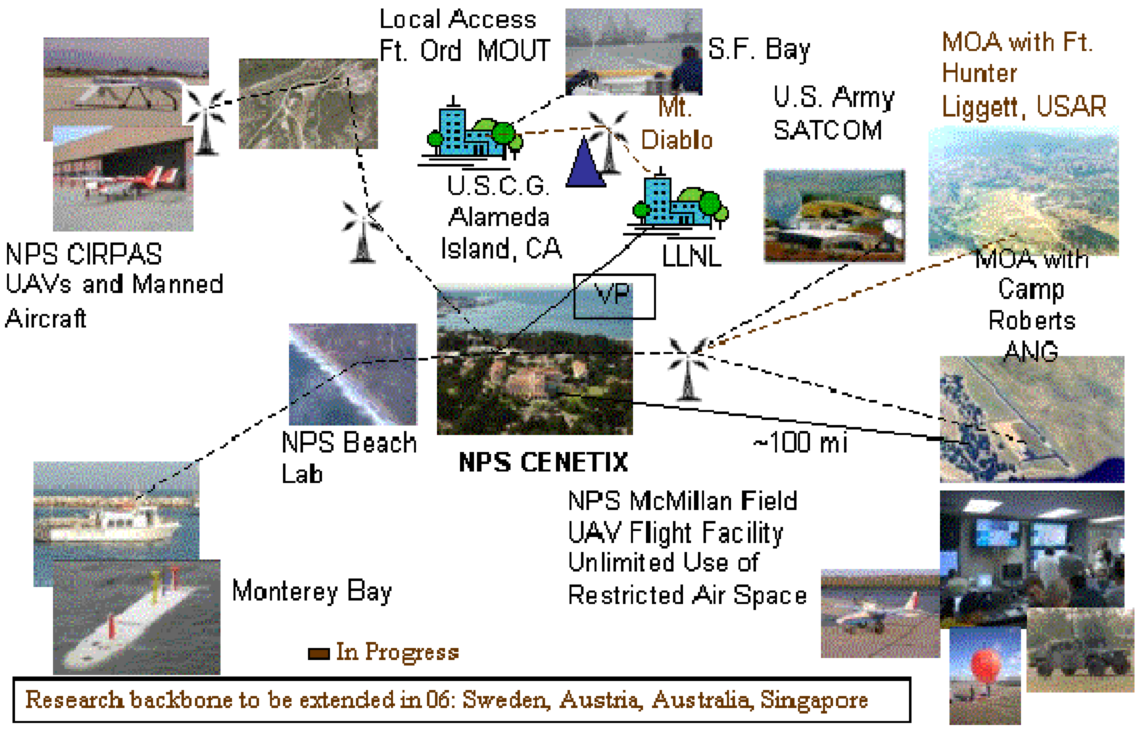

Figure 1. Plug-and-Play TNT MIO Networking Testbed

As shown in the above figure, the testbed contains an expanding set of domestic and overseas remote command and tactical centers with global reachback capabilities and rapidly deployable self-forming wireless clusters (including student network operation services 24/7). The Maritime component being developed jointly with the Lawrence Livermore National Laboratory extends the testbed capabilities to ship-to-shore, ship-to-ship, ship-UAV (Unmanned Aerial Vehicle)-ship, ship-USV (Unmanned Surface Vehicle)-ship, and ship-AUV (Autonomous Underwater Vehicle), sensor mesh mobile networks (Fig. 2).

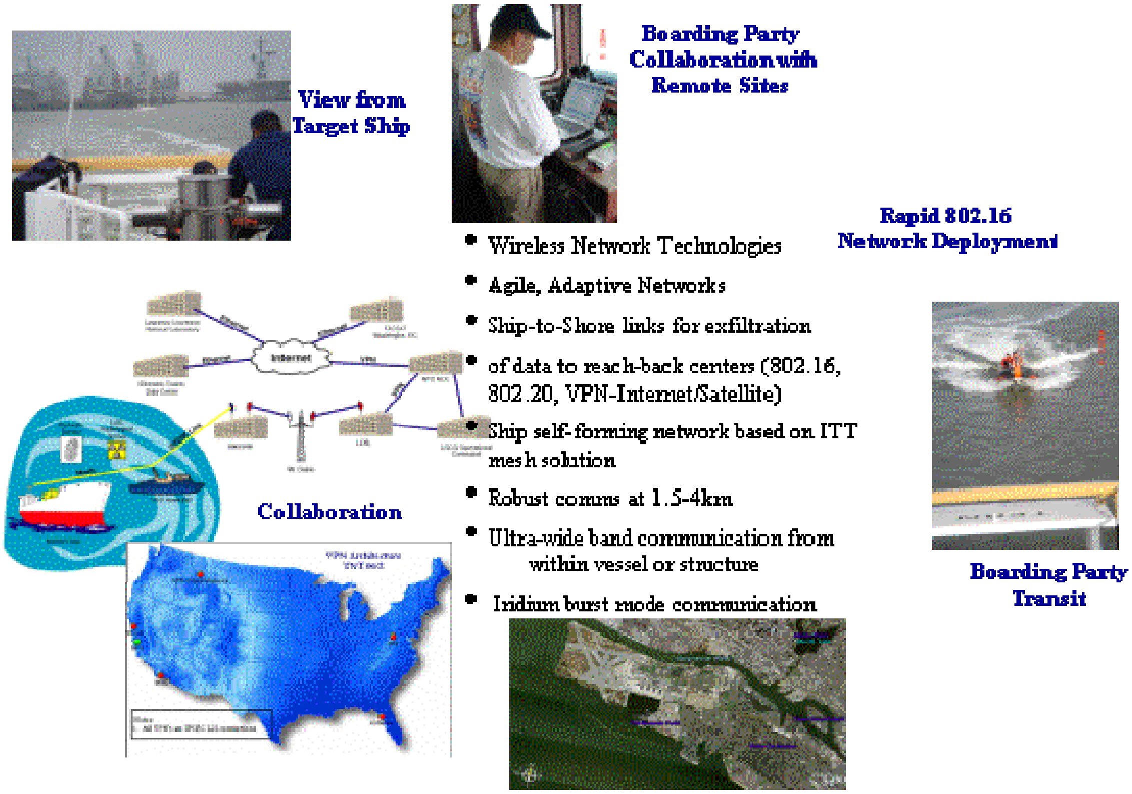

Figure 2. NPS-LLNL Testbed in Action During the MIO 06-2 Experiment

3. Typical MIO Scenario

Over the course of 6 consecutive discovery-and-demonstration experiments, the MIO scenario evolved into a script which employs coordinated actions of multiple agencies and institutions involved in homeland security operations and especially those related to maritime interdiction, interception and control:

> "According to intelligence, a cargo vessel that departed country X in early February is carrying a terrorist cell with hazardous (radiological) material and is attempting to enter the country via a West coast port. The Vessel's name and port of arrival are unknown. Multiple boarding operations are ongoing (and updates are posting to an operational command center E-Wall). Intel has updated information and has high confidence that a vessel entering Washington State has the terrorists onboard. Simulated deception

event is that USCG and NSWC are coordinating the vessel's takedown and that is happening with updates to E-wall.

Under that course of action, USCG has ordered one of its vessels (simulated by MARAD SS GEM STATE) to stop, board, and search a ship (simulated by USCG Tern) suspected of transporting radiological material as well as a terrorist cell. In order to do that, while the suspect vessel is underway, a RHIB with a boarding team is employed.

Level I boarding team has conducted a search of the vessel in a routine safety inspection. During the inspection, a neutron alarm was triggered on a portable radiation sensor. The alarm was a constant alarm, not spurious counts. The level I team secured the ship and called in a Level II team to resurvey the ship with their additional radiation detection equipment. This is now a law enforcement mission.

Therefore, in order to assist in locating suspects and possible contraband, the Operations Center has directed its Level II boarding team to employ radiation detection, explosives detection, and biometric equipment to help expedite this at-sea search. Since positive identification of the source in a short time is imperative, a network extension capability is utilized from the suspect vessel to the boarding team's launch vessel and ashore. This rapidly deployable, collaborative network is reaching back to LLNL to assist in identification of the suspect cargo. Support from the National Biometric Fusion Center (NBFC) must be used to quickly and accurately discriminate between actual vessel crewmembers and non-crew suspects.

The tasking for Level II boarding team is to conduct a radiation survey of the cargo ship and identify the source of the neutron readings. Also, using biometrics recording devices, fingerprint data from crew members will be sent to the NBFC.

The expected boarding scenario events are the following:

- Hidden neutron source in engine room and hidden gamma source as cargo.
- The neutron source is located by the Boarding Party. Gamma spectrum of neutron source and photos sent to Reachback (LLNL experts) and export control analysts (DTRA and LLNL experts) for identification.
- Fingerprint data taken of target ship captain and crew.
- The second (gamma) radiation source is located by the Boarding Party and a radiation spectrum is sent to Reachback. The first gamma spectrum sent to Reachback is incomplete. . (Reachback can ask for second spectrum for analysis).
- Once the identification of the items is passed to the boarding team and fed to the Operational Command Center, the cognitive process clock starts where the experts work in collaboration with the Operational Command Center and USCG support vessel to understand the situation and come up with a course of action to deal with the threat.
- Once the captain of the target ship is located, he can inform the boarding party that he had a soil density gauge that emitted neutrons (but only after the Boarding Party has sent the radiation spectra and photos of item for analysis and the export control analysts have identified it as a commercial soil density gauge.) Unfortunately it was stolen. The captain can't explain the gamma source- possible terrorist threat? Captain's fingerprints show him to be on a watch list.

4. Brief Description of Main MIO Networking Segments[1]

A. **<u>OFDM/802.16</u>** mobile man-portable network extension connecting USCG Island to GEM STATE (ship-to-ship) and GEM STATE to USCG Tern (ship-to-ship).

Short for ***O****rthogonal* ***F****requency* ***D****ivision* ***M****ultiplexing*, an FDM modulation technique for transmitting large amounts of digital data over a radio wave. OFDM works by splitting the radio signal into multiple smaller sub-signals that are then transmitted

[1] Compiled by LCDR George Stavroulakis, Naval Postgraduate School.

simultaneously at different frequencies to the receiver: multiple carrier waves take the place of and carry the data of one large wave. One of the key benefits of OFDM is that the multiple carrier waves overlap (as shown in Figure 3), which provides a very efficient use of the frequency bandwidth by packing more data into the bandwidth compared to what can be achieved with a single larger carrier wave spread across the same spectrum. Also, OFDM reduces the amount of crosstalk in signal transmissions. Among others, the IEEE 802.11a and 802.11g Wi-Fi standards also use OFDM as well as IEEE 802.16.

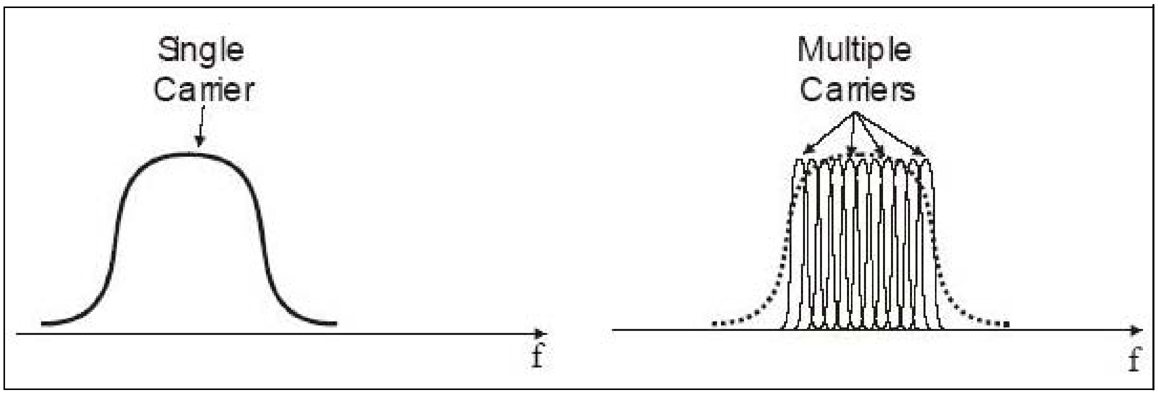

Figure 3: OFDM Modulation

IEEE 802.16 Wireless Communications Standard origins lie in recent years' increasing interest shown in wireless technologies for subscriber access, as an alternative to traditional twisted-pair local loop. These approaches are generally referred to as wireless local loop (WLL), or fixed-wireless access. Published on April 8, 2002, IEEE 802.16, commonly referred to as *WiMAX* (Worldwide Interoperability for Microwave Access), or less commonly as WirelessMAN™ or the Air *Interface* Standard, is a specification for fixed broadband wireless metropolitan area networks (MANs) that standardizes the air interface and related functions associated with WLL. The current 802.16 standard is IEEE Std 802.16-2004, approved in June 2004. It renders the previous (and 1st) version 802.16 obsolete, along with its amendments 802.16a and 802.16c.

WiMax has two main topologies – Point to Point for backhaul and Point to Multi Point Base station for Subscriber station. In each of these situations, MIMO antennas are used. 802.16 standard defines the use of bandwidth between the licensed 10GHz and 66GHz and between the 2GHZ and 11GHz (licensed and unlicensed) frequency ranges and defines a MAC layer that supports multiple physical layer specifications customized for the frequency band of use and their associated regulations. 802.16 supports very high bit rates in both uploading to and downloading from a base station up to a distance of 30 miles to handle such services as VoIP, IP connectivity and TDM voice and data.

The MAC is significantly different from that of Wi-Fi. In Wi-Fi, the MAC uses contention access—all subscriber stations wishing to pass data through an access point are competing for the AP's attention on a random basis (DCF). By contrast, the 802.16 MAC is a scheduling MAC and uses Time Division Multiple Access (TDMA) in which the subscriber station only has to compete once (for initial entry into the network). After that it is allocated a time slot by the base station. The time slot remains assigned to the subscriber station meaning that other subscribers are not supposed to use it but take their turn. This scheduling algorithm is stable under overload and oversubscription (unlike 802.11). It is also much more bandwidth efficient. The scheduling algorithm also allows the base station to control Quality of Service by balancing the assignments among the needs of the subscriber stations. Although there is more management overhead that must be broadcast and time synchronization is more critical, TDMA provides an excellent solution to WMANs that have nodes distributed over larger distances.

With a theoretical range of up to 30 miles, WiMAX outdistances WiFi by miles (WiFi's range outdoors is less than 1000 feet) and is supposed to provide connectivity between network endpoints without direct LOS in some circumstances although the details of performance under NLOS circumstances are still unclear. Practical limits from real world tests seem to be around "3 to 5 miles" (5 to 8 km).

The fastest WiFi connection can transmit up to 54 megabits per second under optimal conditions. WiMAX should be able to handle up to 70 Mbps. Real world tests, however, show significantly lower practical data rates, depending on conditions at a given site.

Under the aforementioned advantages the IEEE 802.16 can be used in many cases:

- ✓ To connect Wi-Fi hotspots with each other and to other parts of the Internet and provide a wireless alternative to cable and DSL for last mile (last km) connectivity.

- ✓ For countries that have skipped wired infrastructure as a result of inhibitive costs and unsympathetic geography, WiMAX can enhance wireless infrastructure in an inexpensive, decentralized, deployment-friendly and effective manner.
- ✓ WiMAX can boost Government Security. In an emergency, communication is crucial for government officials as they try to determine the cause of the problem, find out who may be injured and coordinate rescue efforts or cleanup operations. A gas-line explosion or terrorist attack could sever the cables that connect leaders and officials with their vital information networks.
- ✓ WiMAX could be used to set up a back-up (or even primary) communications system that would be difficult to destroy with a single, pinpoint attack.
- ✓ In military computer networks, providing the required range and throughput.

The current issue with IEEE Std 802.16-2004 for use in maritime communications is that it addresses only fixed systems. An amendment, IEEE 802.16-2005, approved on December, 2005, (formerly named **IEEE 802.16e**), the WiMAX mobility standard, is an improvement on the modulation schemes stipulated in the original WiMAX standard. It allows for fixed wireless and mobile Non Line of Sight (NLOS) applications primarily by enhancing the OFDMA (Orthogonal Frequency Division Multiplexing Access). That standard has not yet been in the market yet and therefore utilized in TNT experimentation.

A recent addition to the WiMAX standard is underway which will add full mesh networking capability by enabling WiMAX nodes to simultaneously operate in "subscriber station" and "base station" mode. This will blur that initial distinction and allow for widespread adoption of WiMAX based mesh networks.

In order to implement the 802.16 links, the TNT network uses the Redline Communications AN-50e 802.16 compliant Transceiver / wireless bridge for both fixed wireless backhaul and mobile broadband networks. AN-50e operates under the 802.16 in the frequency range of 5.4 to 5.8 GHz however North American regulations limit the frequency range from 5.735 to 5.815 GHz. The AN-50e radios are designed to operate in a point-to-point or point-to-multipoint configuration depending on the options code purchased with the radio and the firmware load out.

B. **<u>ITT Mesh</u>** connecting GEM STATE with the boarding party onboard the RHIB during their transition to USCG Cutter and on board the USCG Cutter providing wireless mesh capability to the boarding party members.

Not much data exists on the aforementioned wireless mesh technology that uses a center frequency of 900 MHz since it’s a proprietary technology of ITT (owned by Motorola).

C. **<u>802.20 FLASH OFDM</u>** (Fast, Low-Latency Access with Seamless Handoff Orthogonal Frequency Division Multiplexing)

Introduced by Flarion Technologies, Inc. (owned by QUALCOMM Incorporated) FLASH-OFDM utilized in the 802.20 standard is a direct competitor to the yet to arrive 802.16e mobile broadband standard. IEEE 802.20 standard is capable of providing connectivity to the BS of SS moving up to speeds of 200-300 knots. FLASH-OFDM differs from 802.16 OFDM applications, in that it is vertically layered across the network, link and physical layers of the OSI model. This implementation is possible because in an IP network, only the layers above the network layer need to be layered horizontally to ensure interoperability across multiple link layer technologies. The 802.16 standard utilizes multiple MACs for multiple Physical layers and has run into design challenges because of the large amount of internetworking needed between the 802.16 MAC and PHY layers. 802.20 on the other hand utilizes a non-contention MAC together with OFDM which allows for the support of many low bit rate dedicated control channels. Therefore, IEEE 802.20 standard isn’t subject to various performance variations and inefficiencies when dealing with mobile users like IEEE 802.16 because it provides a fully scheduled uplink and downlink air resource to the user while IEEE 802.16 MAC is provided primarily through a contention-based access scheme.

During the TNT 06-02 experiment the utilized frequency was approximately 700 MHz and the EIRP was 20 W. The 802.20 frame is 26 bytes, of which 2 bytes form the frame header.

D. **UWB** portable data communications equipment.

Since conventional wireless technologies face significant performance degradation in heavy metallic environments, UWB communications was considered as the technology of choice for shipboard communications in NPS-LLNL experiments. Using LLNL's UWB communication prototype in this boarding scenario, real time data was successfully transferred from the ship's *engine room* to *multiple levels of the vessel with all hatches closed*. Due to the importance of UWB communications in maritime applications as well as NPS-LLNL MIO testbed, the next section is devoted to describe the details UWB communications and LLNL's approach to improve the signal strength in harsh propagation channels.

5. Ultra-wideband (UWB) Communications

Ultra-wideband communications is fundamentally different from conventional communication techniques because it employs extremely narrow RF pulses (pico-seconds to nano-seconds) with low duty cycle to communicate between transmitters and receivers. Utilizing short-duration pulses in place of continuous waveforms as the building blocks for communications, directly generates a very wide bandwidth (several Giga-Hertz). A comparison of conventional narrowband and UWB communications is shown in Fig. 4.

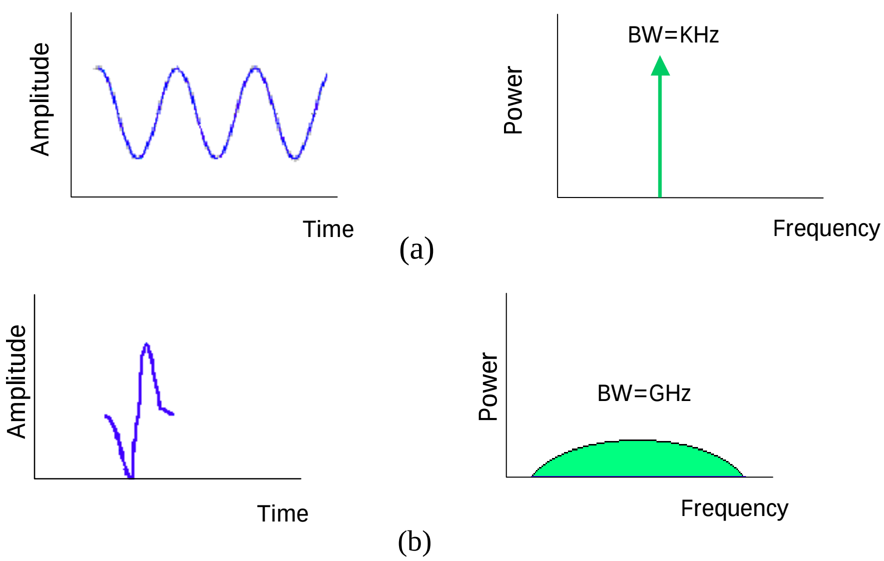

Figure 4. (a) Conventional narrowband communications send long continuous waveforms and generate very narrow frequencies. (b) UWB communications send extremely narrow pulses and generate very wide frequencies.

5.1 History of UWB Communications

Ultra-wideband communications is not a new technology; in fact, it was first employed by Guglielmo Marconi in 1901 to transmit Morse code sequences across the Atlantic Ocean using spark gap radio transmitters. However, the benefit of a large bandwidth and the capability of implementing multi-user systems provided by electromagnetic pulses were never considered at that time.

Approximately fifty years after Marconi, modern pulse-based transmission gained momentum in military applications in the form of impulse radars. From the 1960s to the 1990s, this technology was restricted to military and Department of Defense (DoD) applications under classified programs such as highly secure communications. However, the recent advancement in micro-processing and fast switching in semiconductor technology has made UWB ready for commercial applications. Therefore, it is more appropriate to consider UWB as a new name for a long existing technology.

In February 2002, the Federal Communications Commission (FCC) approved the first report and order (R&O) for commercial use of UWB technology under strict power emission limits for indoor and outdoor communications devices.

5.2 Advantages of UWB Communications

The nature of short duration pulses used in UWB technology offers several advantages over narrowband communication systems. Some of the key benefits that UWB brings to wireless communication systems are summarized below.

1) Sharing the Frequency Spectrum: The FCC's power requirement of –41.3 dBm/MHz (75 nano-Watts/MHz), allows the UWB signals to co-exist with the currently available radio services with minimal or no interference problems.

2) Large Channel Capacity: Due to the very large bandwidth, UWB pulses provide large channel capacity that can be translated to very high data rate or large number of users in the system.

3) Low Probability of Intercept and Detection (LPI/D): Because of having a low transmission average power, UWB communications systems have an inherent immunity to detection and intercept. In addition, UWB pulses are time modulated with codes unique to the transmitter/receiver pairs which makes them extremely difficult to detect.

4) <u>Resistance to Jamming:</u> The frequency diversity offered by GHz bandwidth, makes UWB signals relatively resistant to intentional and un-intentional jamming. The reason is that no jammer is capable of jamming all of the frequencies at once.

5) <u>High Performance in Multipath Channels:</u> Multipath phenomenon is caused by multiple reflections (Non-Line-of-Sight) of the transmitted signal (Line-of-Sight) from various surfaces, degrading the transmitted signal quality in conventional narrowband radio system significantly (Figure 5). On the other hand the very short duration of UWB pulses makes them less sensitive to multipath effect, since the reflected pulse has an extremely short window of opportunity to collide with the LOS pulse to cause signal degradation.

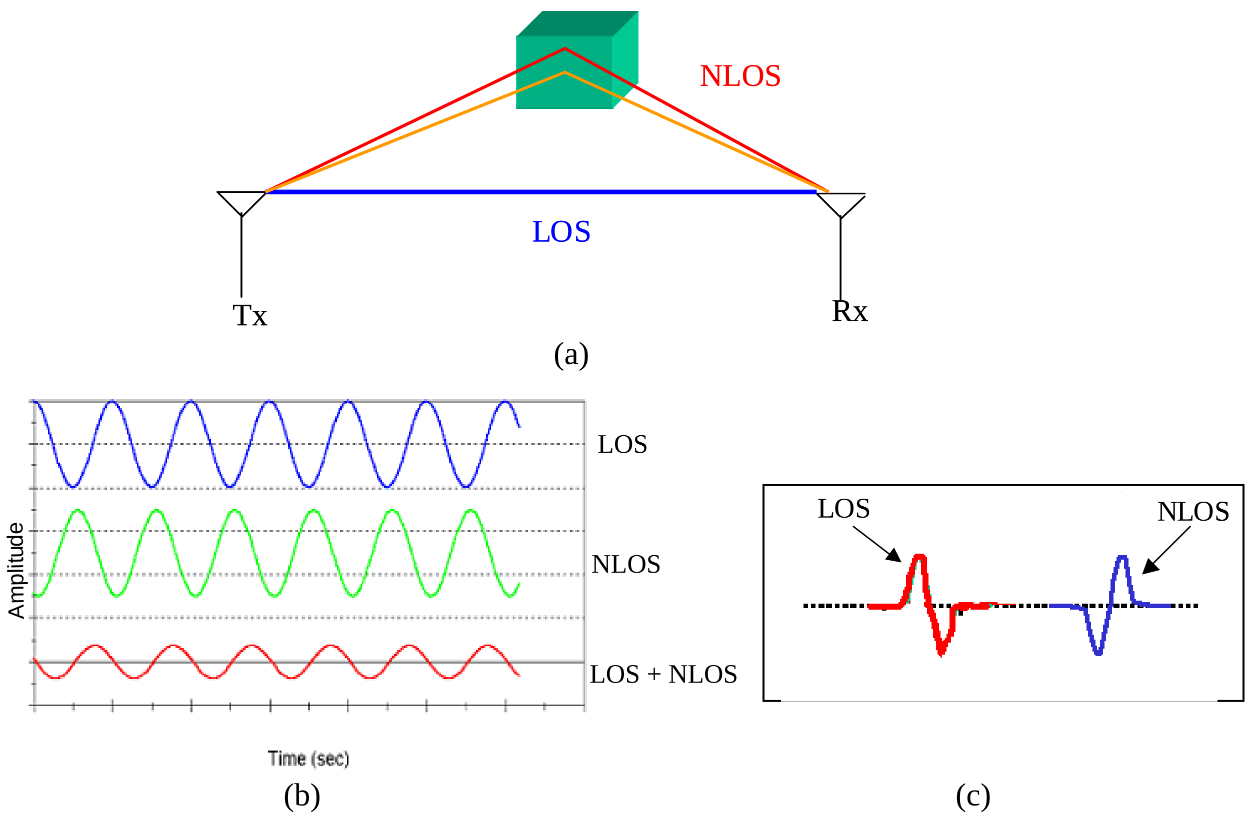

Figure 5. (a) Multipath phenomenon in wireless channels (b) Multipath effect on narrowband signals (c) multipath effect on ultra-wideband pulses

6) <u>Superior Penetration Properties:</u> Due to the long bandwidth of their pulses, UWB systems can penetrate effectively through different materials. This property makes UWB technology viable for through-the-wall communications.

<u>7) Simple Transceiver Architecture:</u> UWB transmission is carrierless, therefore it requires fewer RF components than carrier based transmission. For this reason UWB transceiver architecture is significantly less complicated than narrowband transceivers [1].

5.3 LLNL's UWB Communications Systems

LLNL's UWB communication systems are based on transmitted-reference (TR) modulation technique. This proprietary technique takes advantage of multiple signal reflections in multipath environments to improve the signal quality in UWB communications systems. Therefore, it adds another level of improvement to the inherent ability of UWB signals to tackle multipath problems. In TR modulation a pair of polarity modulated of pulses separated by a delay known to the receiver represents the transmitted data.

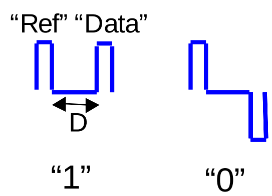

Figure 6. TR modulation technique

Unlike the conventional UWB receivers that correlate the received pulses (distorted in a wireless channel) with a clean and predefined pulse template, the TR receiver detects the data bits by correlating and finding the similarities between two transmitted pulses. Therefore, both pulses experience the same channel distortion and there is always high correlation between them that results in reliable detection. Furthermore, in heavy cluttered channels where multipath phenomenon introduces a longer duration in the signal component of the received signal, the overall signal energy is increased in TR receivers and provides higher detection quality compared to other UWB receivers (Figure 7).

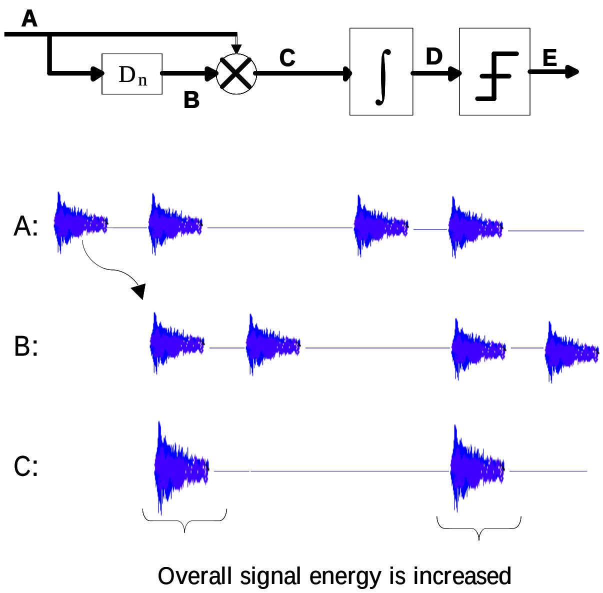

Figure 7. TR receiver diagram and its signal representation in a multipath propagation channel

Exploiting the multipath reflections to improve the received signal quality in harsh and cluttered propagation channels, makes them an ideal candidate for maritime wireless applications.

6. Radiation Detection for Search and Identification

Radiation detection is used on MIOs to search for illicit trafficking in nuclear materials. These materials can be weapon-usable materials such as plutonium or highly enriched uranium, or other radioactive materials, that could be used for radiological dispersal devices (RDDs). Likely candidates for RDDs are ^{60}Co, ^{137}Cs, ^{192}Ir and others which are widely available and heavily used in medicine and industry. All of these materials emit radiation in the form of gamma-rays and/or neutrons, which can be detected by radiation sensors.

The detection of illicit radioactive material is made difficult because there are environmental background radiation, naturally occurring radioactive materials (NORM), medical and industrial radiation sources. Background is a major signature interference, from signal intensity as well as shape (energy). A typical radiation spectrum of ^{60}Co and ^{137}Cs is shown in the following figure. Much of the gamma-ray background shown in the figure are from terrestrial sources. At sea, the terrestrial background is reduced; however cargo contains items derived from terrestrial sources and so the interferences will persist.

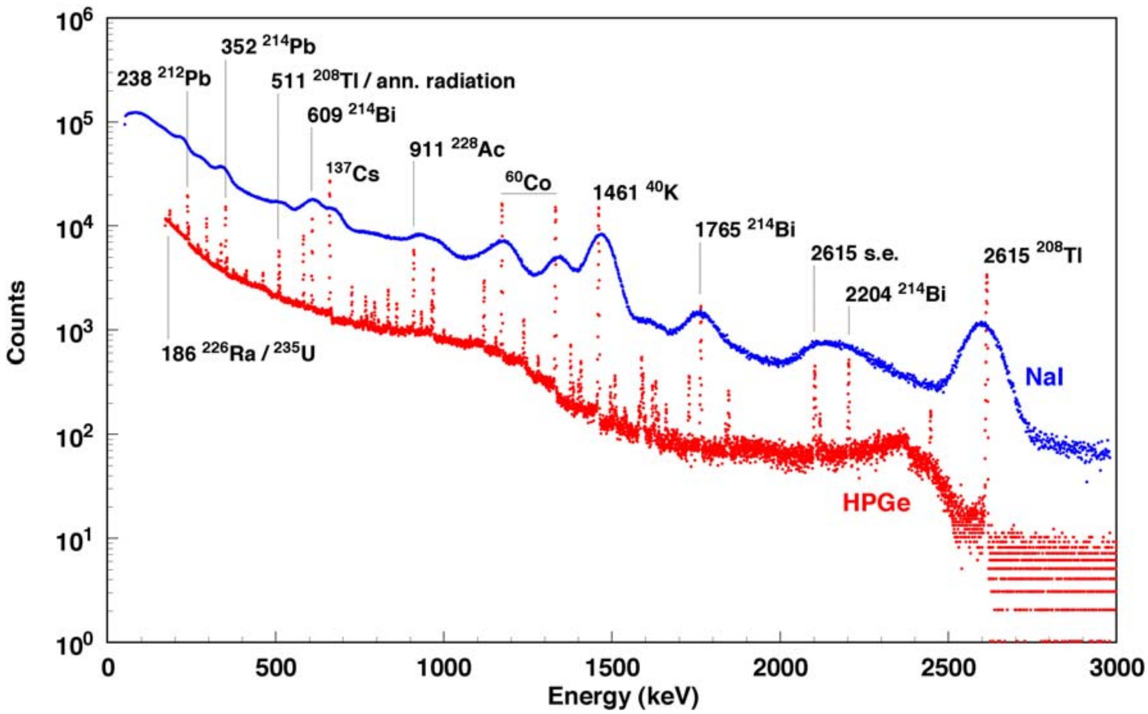

Figure 8. Typical radiation spectra ^{60}Co and ^{137}Cs using a sodium iodide (blue) and high purity germanium (red) detector. Other radioisopes noted in the photo are background radiation.

In our testbed, we have used a variety of commercial and prototype radiation sensors, to simulate the detectors in use by first responders. Typically a radiation pager is used to simply detect the presence of gamma-rays or neutrons. Once radiation is detected, it is important to identify the material that is emitting radiation. This identification is important so that the first responder can determine if the radioactive item is NORM, an illicit material, or whether it matches the manifest. For these detectors, sodium iodide detectors are typically used. These detectors have fairly low resolution and sophisticated software is used to analyze the data. Because of the difficulty in the analysis, the spectra can be sent to Reachback for further analysis.

High purity germanium (HPGe) detectors, which are most high resolution radiation sensors, are recently become commercially available with electromechanical coolers so that they can be transported to remote locations. We have used prototype HPGe detectors on our MIO experiments and find that even with HPGe detectors, advanced analysis software is critical and Reachback expertise is necessary to resolve some ambiguous identifications.

Reachback experts analyze the radiation spectra to determine the material emitting the radiation. This analysis takes time and requires experienced experts trained in nuclear detection. The MIO allows the Reachback experts to communicate directly with the Boarding Party, obtain and view photos and to take additional data when necessary.

7. Lessons learned and Concluding Remarks

One of the major lessons we learned along the course of several increasingly more advanced NPS-LLNL MIO experiments, conducted quarterly during 2005-2006, is understanding of most efficient self-forming wireless MIO network configuration for supporting the Boarding Party radiation awareness:

1. The OFDM 802.16 directional link provides efficient high-bandwidth mobile portable solution for Boarding Party reachback from target vessel to surface Command Post on the board of the Boarding Party deploying ship. This is a ship-to-ship segment of MIO network. The same OFDM 802.16 solution proven to be the best for high-bandwidth wireless communications between the boarding ship Command Post and Tactical Operations Center (TOC) ashore, the gateway to the rest of the wide area MIO network.

2. However, fixed OFDM 802.16 directional solution or its omni directional substitute are not sufficient for providing two-way communications between the Boarding Party high-speed boat, while in transit to Target Vessel, and the rest of the MIO network. The 802.20 or lower in bandwidth 900 Mhz radio communications perform better for two-way collaboration with transit boat crew,

but require additional study. The NPS is currently working on self-aligning directional OFDM solution, which could potentially solve the problem of high-bandwidth two-way communications with transit boat.

3. Once on the board of the target vessel the Boarding Party could stretch the network out for searching the deck, going around large size structures by using the ITT mesh.
4. The two-way communication between Reachback and the Boarding Party has eliminated confusion and increased the speed of analysis.
5. Inserting the UWB link into the mesh or as a final leg of it, allows to penetrate several decks and other metal structures for providing video and radiation detection feed from under the deck areas.
6. Although RF signals can adversely affect the radiation detection capability, in these set of experiments, no adverse effect such as spurious neutron or gamma counts were caused from UWB sources. This is due to the very low transmit power of UWB signals.
7. Although UWB communications system was capable of successful data transfer from engine room to multiple decks, forward error correction (FEC) algorithms can be added to the future designs to improve the quality of the received data.
8. An improved range and power in UWB communications can be achieved by future generations of the LLNL UWB-TR transceivers [2] , [3].

All together the described solutions provide MIO network-on-the-move capable of supporting real-time collaborative work with geographically distributed radiation detection experts, higher-level command centers, and situational awareness applications.

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