MIO TAR2HOST LASERCOMM EXPERIMENT IN TRIDENT WARRIOR 08

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ABSTRACT

The Naval Research Laboratory fielded a free space optical (FSO) communication system for use in Maritime Interdiction Operations (MIO) during the Trident Warrior 08 Sea Trial exercise in June, 2008. The system utilized the compact dual mode optical interrogator (compact - DMOI) developed by Novasol, Inc. to interrogate NRL developed modulating retro-reflectors (MRRs). The compact – DMOI was installed on the USS Comstock (LSD 45) and a portable MRR array was operated on the USNS Yukon. The main goal of this experiment was to investigate the capabilities of a short range FSO link to transmit data obtained during a MIO operation. The successful demonstration of FSO links for MIO operations will enable diversified communication paths that will allow operation in situations where RF sources are inoperable due to multiple possible causes – RF interference, jamming, spectrum allocation issues, lack of host nation approval, etc. Other potential applications for ship-to-ship communications will be investigated as well including data/voice/video communications during normal underway operations and during underway replenishment without the usage of SATCOM assets.

INTRODUCTION

Trident Warrior 08 is “the” major annual FORCEnet Sea Trial Event sponsored by NETWARCOM to: (1) Provide “Speed to Capability” a rapid fielding of improved FORCEnet Command and Control Warfighting capability to the Fleet, with full supportability and maintainability and (2) Develop supporting Tactics, Techniques, and Procedures on how best to use this new capability to optimize the execution of Naval operations.

The wireless optical communication system for the MIO Tar2Host initiative demonstrated a 2 megabit Ethernet link between a boarded vessel of interest (VOI, USNS Yukon) and a host ship (USS Comstock) at ranges from 0.07 to beyond 2 nautical miles. The system demonstrated in TW08 is an asymmetric system using a small (12”x12”x12”) gimbal mounted lasercomm transceiver from Novasol, Inc. mounted on the Host ship, and a very small battery powered modulating retro-reflector (MRR) array mounted to ship railings or other convenient mounting locations on the exercise VOI. Two stand-alone laptop computers were used to send data between the Host ship and the VOI over this link to demonstrate the performance of this system.

This technology provides an additional data link for MIO operations which can operate with no frequency allocation requirements and no interference with any RF sources (radars or communication systems) allowing operation in all national and international waters. Additionally, this technology has very low probabilities of detection and intercept and is extremely hard to jam (intentional or unintentional) due to the requirement of the jamming source being located within a very narrow cone (less than 1º full angle) around the optical communication beam.

The system was demonstrated during transit from San Diego to Honolulu between ships underway and during the approach for underway replenishment (Unrep). This underway operation of the system demonstrates the additional capability of the asymmetric optical communication system to transmit information to assist with Unrep and/or transmit data to update data bases, software, etc. without the need to transport removable media between the ships manually. Also demonstrated is the ability to enhance voice and video communications.

Demonstration of this system in an operational environment proves the usefulness of an asymmetric optical communication system for MIO in waters where frequency allocation, interference, jamming, LPI, and/or LPD are potential concerns.

LASERCOMM SYSTEM

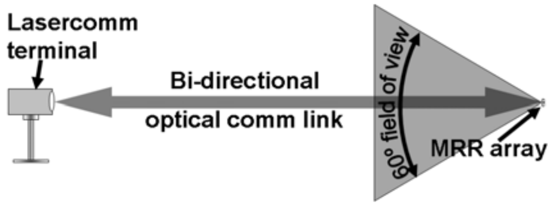

Figure 1: A lasercomm terminal interrogates an MRR array within the array's FOV and the modulated data is reflected back to the terminal

Free-space optical links (lasercomm) are finding increasing use for commercial systems and are being considered for military systems [1–5]. The Naval Research Laboratory has been studying lasercomm system performance for military applications in the maritime environment for the past several years [6-14]. The narrow divergence and high bandwidth of optical beams enable point-to-point data links at rates exceeding 1 Gbps. However, conventional free space links require terminals with telescopes, lasers, and highly accurate pointing systems at each end of the link. There are many situations in which one end of the link cannot accommodate the weight of a lasercomm terminal due to small platform size or man-portable requirements. These asymmetric links often have lower data requirements than a conventional lasercomm link because smaller and/or portable systems typically have the capacity for only a moderate (1 to 100 Mbps) data rate sensor. An optical link may still be desirable in these cases because RF terminals for these data rates would be larger, RF spectrum allocation may be limited, electromagnetic interference may be an issue, and optical links are more difficult to intercept. For this class of problems, a modulating retro-reflector (MRR) link is appropriate.

An MRR couples a passive optical retro-reflector such as a corner-cube or cat's eye with an electro-optic modulator. In a basic MRR link (see figure 1), a lasercomm terminal on one end interrogates an MRR on the other end of the link with a continuous wave laser beam. The MRR acts as a fast shutter which reflects the laser beam directly back at the lasercomm terminal with information encoded on the beam via on-off shuttering of the beam at the MRR (see figure 2). This return beam is focused on an optical receiver in the lasercomm terminal where the on/off light pulses are converted to an electrical binary data stream allowing digital communications (Ethernet, digital audio/video, etc.).

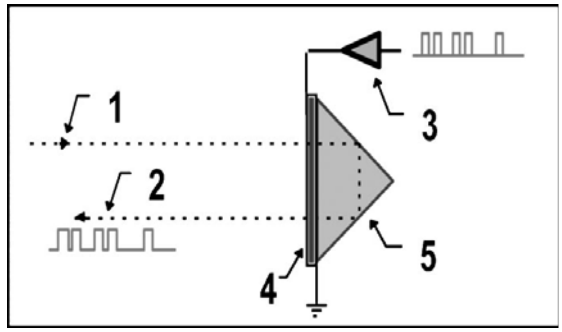

Fig. 2 Diagram of an MRR: 1, incoming beam; 2, outgoing, modulated beam; 3, data source; 4, multiple-quantum-well modulator; 5, corner-cube retro-reflector

Since 1998, the Naval Research Laboratory (NRL) has studied the performance of lasercomm beams in the maritime environment and developed MRR systems based on multiple-quantum-well (MQW) modulators [15,16]. MQW modulators are semiconductor *p-i-n* devices whose inherent switching rate exceeds 1 GHz. In practice, this switching rate is limited by the resistance-capacitance (RC) time constant of the device. We have developed two forms of MQW MRR. One is based on corner-cube retro-reflectors and is capable of data rates up to about 10 Mbits/s [17-19]. The other, based on cat's-eye retro-reflectors, is capable of rates up to hundreds of megabits per second [20-22].

The system used in Trident Warrior 08 (TW08) used a Novasol compact dual mode optical interrogator (DMOI) [23] as the lasercomm terminal and an array of five corner cube MQW MRRs. The lasercomm terminal, developed by Novasol in cooperation with NRL, is a bi-static lasercomm terminal with an inner and outer loop nested tracking system (see figure 3). The lasercomm terminal transmits the initial beam from a single mode fiber (SMF) which is reflected from a fast steering mirror (FSM) and collimated with a 4" diameter lens. A 4" aperture is used since this allows eye safe operation of the terminal at transmit powers up to 2 watts for the 1550 nm laser wavelength used by the system. The receive beam path uses an identical lens to the transmitter but uses a beam splitter to direct 20% of the beam to a quadrant detector for tracking and the remainder of the beam (80%) to a 100 micron core multi-mode fiber (MMF) which is coupled to an optical receiver for data reception.

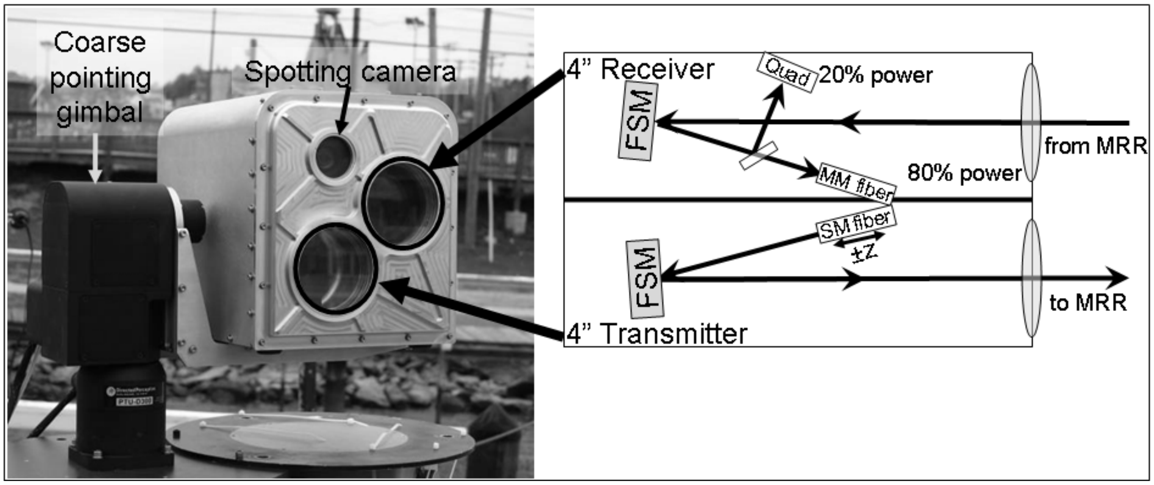

Figure 3: The DMOI uses fast steering mirrors (FSM) for high precision inner loop tracking and a gimbal for lower precision but larger range outer loop tracking of the opposite end of the lasercomm link.

To establish the data link between the DMOI and the MRR, the acquisition mode of the DMOI is activated and the terminal is pointed at the MRR to within approximately 1 degree using the spotting camera. The acquisition mode continuously scans the transmit beam FSM and monitors the quadrant detector for a return from the MRR. When a return signal is detected, the system “locks-on” and drives the receive beam to the center of the quadrant detector. Since the quadrant detector and receive MMF are co-bore sited, this tracking on the quadrant detector couples the received light to the MMF and attached optical detector to allow data transmission from the MRR to the DMOI. Additionally, as the system transitions from acquisition to tracking mode, the transmitter FSM exits scanning mode and becomes slaved to the receiver FSM pointing. This maintains pointing of the transmit beam at the MRR and closes the tracking loop. Any short disruptions to the link, such as obstructions passing through the beam, immediately drops the system back into acquisition mode and typically results in rapid (<<1 second) re-establishment of the link with negligible impact on system performance.

The MRR system used in TW08 consists of an array of 5 MRR corner-cube retro-reflector devices and 5 small optical receivers. This array results in a field of view (FOV) of the MRR system of 60 degrees requiring only coarse pointing of the system in the general direction of the DMOI to establish a link. Re-pointing of the array is only necessary for large course changes of the VOI or significant bearing changes due to large speed differentials between the host ship and the VOI. It should also be noted that the 60 degree FOV is more than sufficient to handle ship roll in all but the most severe sea states where MIO operations would not be possible.

The small optical receivers co-located with the MRR array are used to receive modulated data from the DMOI to allow two-way digital data transmission between the lasercomm terminal and the MRR. This configuration results in a half-duplex link since data cannot be sent from the MRR to the lasercomm terminal while modulated data is present on the terminal to MRR beam. The typical application of an MRR link, such as MIO, is highly asymmetric data exfiltration where half-duplex operation is sufficient for excellent performance of data transfer over the link.

The data transmitted and received by both the MRR and DMOI is interpreted in modems to establish a two-way Ethernet link. The link typically operates at a rate of 2 Mbps. Data is Manchester encoded to improve robustness of the link to the highly variable power levels received at each end of the link due to atmospheric scintillation of the laser beam. Packet error detection and positive packet acknowledgements are used for transmitting files over the link resulting in a high quality of service with no errors in received files.

INSTALLATION

The Novasol DMOI was installed on the O7 level (approximately 100 feet above the waterline) of the USS Comstock–LSD45 (host vessel) and used to interrogate the MRR system mounted on the signal bridge level (approximately 120 feet above the waterline) of the USNS Yukon (VOI). An existing signal light on the starboard side of the host vessel with an approximate field of regard from -90º to +150º from the forward direction was removed and its mount used for the DMOI. The MRR array was mounted to various railings on the VOI and pointed within ±30º of the host vessel to allow data communications. Figure 4 shows an overview of the demonstration configuration.

Figure 4: DMOI installed on the O7 level of the USS Comstock–LSD45 (host vessel) used to interrogate the MRR on the VOI.

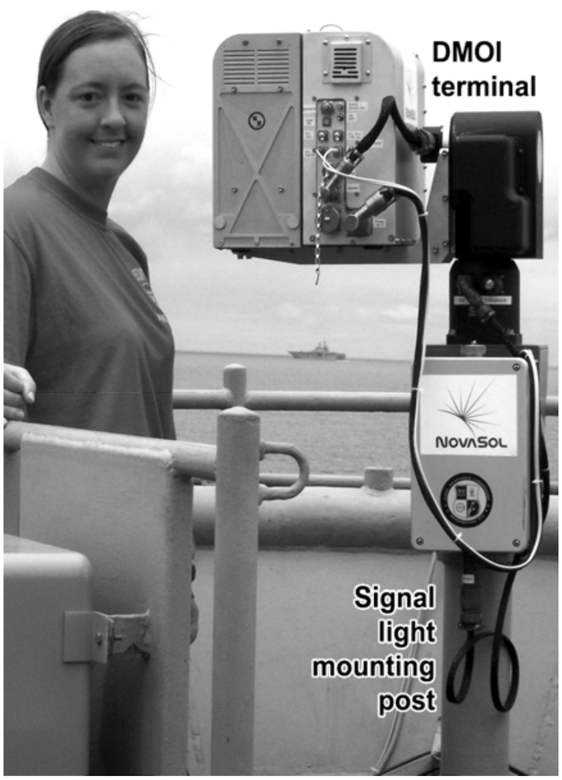

Figure 5: An existing signal light was removed and its mounting post used for installation of the DMOI terminal on the host vessel

A simple bracket was constructed to allow mounting of the DMOI terminal with no modifications to ship hardware. The mounting of the system to the signal light post is shown in Figure 5. This method allows for the possibility of direct transition of the DMOI from demonstration hardware to an operational system with minimal impact on ship's hardware. The minimal usage of signal lights and the ability to use hand held units instead in current Navy operations, could potentially allow permanent install of a DMOI or install of DMOI's as needed for operations.

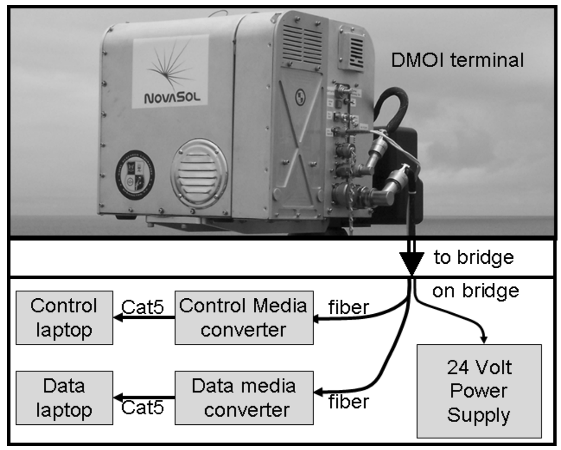

Figure 6: Connections from the DMOI terminal on the O7 level to electronics on the bridge are shown in the block diagram

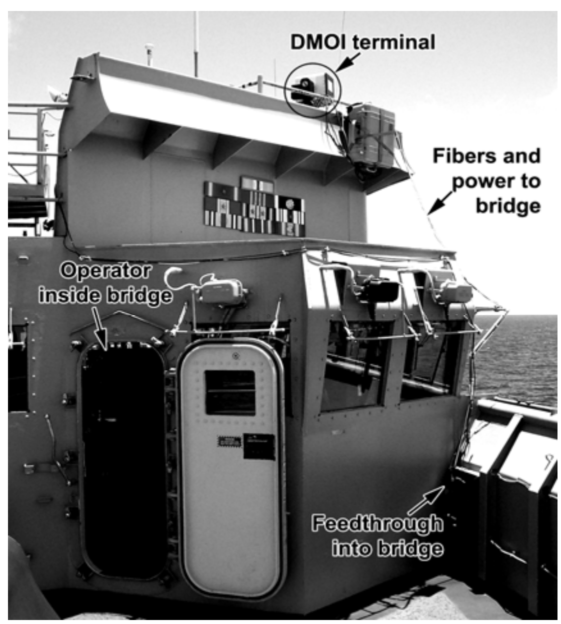

Figure 7: The DMOI terminal was installed on the O7 level of the host vessel with optical fiber and power routed to inside the bridge. The system was operated with two laptops on the starboard map table in the bridge.

The wiring and overall layout of the system installed on the Comstock is shown in Figure 6. Two optical fibers carrying Fast Ethernet (100 Mbps) and a shielded two conductor cable were routed from the DMOI on the O7 level to the starboard map table in the bridge (see figure 7). The shielded two conductor cable was connected to a small 24 Volt power supply at the base of the map table to provide power for the terminal (110 Watts). One of the fibers was connected to a control laptop in the bridge and used to operate the DMOI and maintain the lasercomm link. The second fiber carried Ethernet traffic transmitted and received through the lasercomm link and was connected to a data laptop for file transfers, Voice over IP, chat, and audio/video transfer between the VOI and the Host vessel.

No installation was required on the MRR end of the link. The MRR array was attached to a clamp which was mounted to a railing on the signal bridge level of the VOI (see figure 8). The MRR array was attached to a 12 volt battery through a shielded cable for power and to a laptop through a shielded Ethernet cable for data transfer. All components of the MRR system are battery powered and can operate for hours off a single charge.

Figure 8: MRR array, video camera, and control laptop installed and operated on USNS Yukon. Small 12V battery is not visible in photograph.

TEST PLAN

During the staged positioning of the host vessel and the VOI, two types of data were collected. The first was quantitative system performance data. Figure 9 shows the form that was used for this data collection. Data collection using this form continued in a loop where one form was filled out as quickly as possible and then the process was repeated.

TAR2HOST data logging form

Date ________________ Time____________ Dist(yds)___________
Bearing(°) ____________ Remote Ship___________ Remote#_________

Init with PER (remote⇒DMOI) and optimize:

P_{xmt}(W)________ Θ_{out}(μrad)_________ λ(nm)________ P_{rcv}(dBm)_______
P_{quad}(dBm)_________ σ_{rcv}(dBm)__________ σ_{quad}(dBm)_________

PER Testing (per loop 7 ms):
Remote⇒DMOI:
Time___________ Pckt size__________ PER ___________

DMOI⇒Remote:
Time___________ Pckt size__________ PER ___________

File Transfers (Dir, 1=Rem⇒DMOI, 2=DMOI⇒Rem):

Time______ Dir___ File________________________ Pckt size______
Δt(sec)________ Rate(kB/s)________ Retrans________ PER________
Time______ Dir___ File________________________ Pckt size______
Δt(sec)________ Rate(kB/s)________ Retrans________ PER________
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Time______ Dir___ File________________________ Pckt size______
Δt(sec)________ Rate(kB/s)________ Retrans________ PER________

Remote⇒DMOI Audio/Video transfer:

No. retrans ______ MRR Temp ____________ MRR Volt ____________
Data Qual _________ Stat Qual ___________ Frame/sec____________
Video record file(s)____
High speed record: Time ________________
Notes:____

Figure 9: Data collection form for quantitative link performance characterization.

Information collected on this form consists of data transfer metrics:

- Packet error rate (PER) testing
- File transfers performance
- Audio/Video transfer quality,

and laser propagation information. Laser propagation information is indicated in general by the laser power, standard deviation, etc. in the "Init with PER…" section. Quantitative system information on tracking performance and atmospheric conditions are recorded in the "High speed record" section where 10 kHz raw data readings on received laser power, quadrant detector readings, fast steering mirror positioning, etc. are recorded. These readings are useful for post-analysis of how well the tracking system worked to compensate for disturbances to the system (vibration, ship roll, bearing changes, atmospheric turbulence, etc.) as well as collection of scientific information on atmospheric conditions which are extremely useful for future engineering of shipboard lasercomm systems. Unfortunately, as will be described below, no high speed record data was taken due to a software error and the inability to correct this error due to cancellation of VOI participation in TW08 with no warning after only approximately 1½ hours of MIO TAR2HOST testing.

The second type of data collected is qualitative data based on surveys of observers from ship's company or other ship's riders. These surveys were conducted on both the USS Comstock and on the USNS Yukon. Survey questions typically involved multiple areas from opinions on observed link performance to general observations of the technology. For link performance evaluation, observers witnessed file transfers, two-way voice communications, and audio/video streams, and rated the performance in a number of categories. For general observations, observers evaluated the military utility of the system based on observations of system operation, applicability to MIO, advantages over existing technologies, etc.

RESULTS

The maritime interdiction operation (MIO) Target-to-host (TAR2HOST) demonstration during the Trident warrior 08 (TW08) exercise was performed to investigate the use of an all optical communication system as an alternative to MIO RF comms systems for use in RF denied environments. The TAR2HOST system used a Dual Mode Optical Interrogator (DMOI) on the MIO Host vessel (Host vessel) and a modulating retro-reflector (MRR) array remote unit on the vessel-of-interest (VOI) for the two ends of an optical data link. The DMOI was built by Novasol, Inc., which was developed in cooperation with the Naval Research Laboratory (NRL) as a "dual mode" system which could operate either as an interrogator of small SWAP & battery powered MRR array remote units, or as one end of a direct lasercomm link between two DMOI units as demonstrated in TW06 [24]. The DMOI units used in TW08 are prototype units (TRL7) that have greatly reduced SWAP and improved performance over the DMOI units used in TW06.

The Trident Warrior 08 exercise is a U.S. Navy exercise in which numerous communications related technologies were tested. To enable testing of these multiple technologies, testing times, ship maneuvering, test plans, etc. were developed well before the exercise to allow ample test time for all initiatives. Dedicated test time for the TAR2HOST initiative was planned for June 19th & 20th, 2008 when the USNS Yukon (VOI) would be maneuvered between 0.5 and 3 Nm off the starboard side of the USS Comstock (host vessel) to enable TAR2HOST communications. Due to no need for permissions to radiate of the 1550 nm laser radiation used by the DMOI (as opposed to spectrum allocation, EMCON, etc. necessary for all RF), the TAR2HOST was allowed to operate anytime the two ships were within range and in the FOR of the Comstock's DMOI terminal. This allowed two short windows of time (~10 minutes) on June 17th and June 18th where the VOI was within the range (~2 Nm) and the field of regard (FOR) of the DMOI. During these short windows of opportunity, the system was tested and proper performance of the system was confirmed in preparation for testing on the 19th and 20th. Unfortunately, testing on June 19th was cut short and further testing on June 20th was cancelled due to re-tasking of the VOI 1½ hours into the June 19th testing.

Despite this minimal testing time, less than 2 hours total for the entire exercise, the TAR2HOST initiative satisfied all of the objectives it was possible to satisfy during the experiment. Only objectives that required specific conditions (sea state and weather) that were not present during testing were unable to be satisfied.

Objective 1: Can Tar2Host Lasercomm provide high data rate (2Mbps) link beyond 1nm range?
Yes - Successfully transferred audio, video, and 39 files of various types (binary, biometrics files, jpeg image files, and PowerPoint file) over 2 Mbps link at ranges beyond 1 Nm. Actual range limit was between 2 and 2.5 Nm but this was not accurately determined due to cancellation of planned testing.

Objective 2a: Is data transmitted by Tar2Host Lasercomm sufficient?

Yes - Multiple surveys were completed on audio/video/file transfer quality. These surveys assessed different aspects of the data link with numerical quality scores between 1 and 5 with 1 being very poor and 5 being very good (voice quality, video quality, transfer speed, etc.). The averaged results from all of these surveys are shown in Table 1.

Survey question	**Average Score**
Please rate the audio quality	4.75
Please rate the video quality	4.50

Survey question	Average Score
Please rate the general quality of the transferred files	5.00
Please rate the file transfer speed	4.70

Table 1: Survey scores of audio, video, and file transfers by ships' company and riders during MIO TAR2HOST initiative in the TW08 exercise

Objective 2b: Is data transmitted by Tar2Host Lasercomm relevant?

Yes – General utility surveys were conducted with various types of responses as indicated below.

Numerically scored categories are shown in Table 2. The 1-5 scale used here was the same as above with 1 representing very poor satisfaction and 5 representing very good satisfaction of the survey question.

Survey question	Average Score
Does the system provide sufficient capability to perform MIO tasks?	4.67
Is the data transferred over the system (video, voice, scanned images, biometric data, etc.) of sufficient quality to meet the needs of MIO Operations?	4.92

Table 2: Survey scores of general utility by ships' company and riders during MIO TAR2HOST initiative in the TW08 exercise

Survey questions on general utility were also based on a strongly disagree/strongly agree scale with a 1 representing strongly disagree and a 5 representing strongly agree (a 3 represents a neutral opinion to the question). The scores for these types of questions are shown in Table 3.

Survey question	Average Score
I would take this technology to the field in its current configuration	3.67
If this system was available outside of TW08, I would use it in my regular job	4.80

Table 3: Agree/disagree ratings of various MIO TAR2HOST general utility assessments – 1 = strongly disagree and 5 = strongly agree.

Objective 3: Is Tar2Host system dependable (robust) to manage changes in environment such as sea state, visibility and noisy RF, with minimal loss of functionality or effectiveness?

Sea state: Yes/Unknown – Maximum sea state experienced during operations was a sea state 2. Testing of the system prior to TW08 demonstrated excellent operation with >20 degree rolls from a small boat. These rolls were typically larger and much higher frequency than experienced on large navy vessels indicating that the system will operate in high sea state but further testing is required at sea to verify this assertion.

Visibility: Unknown – Weather was typically clear during TW08 operations not allowing testing in a range of visibility conditions.

Noisy RF environment: Yes - Operated in shipboard RF environment with all RF systems active demonstrating non-interference of RF systems with TAR2HOST system and non-interference of TAR2HOST system with other shipboard systems. No spectrum allocation was necessary due to systems lack of RF emissions. At no time was TAR2HOST system affected by any RF emissions (from host vessel, VOI, or other ships in vicinity) or denied permission to operate.

Summary of data transferred during 1½ hour test on June 19th, 2008:
Ranges below in bold are range measurements, ranges not in bold are estimates accurate to ~100 yards. During this testing, the VOI approached from the host vessel's stern and took up station off the starboard side of the host vessel for 48 minutes at a range varying between 1400 and 2000 yards. After 48 minutes of being stationed off the starboard side of the host vessel, the VOI was called away from TW08 participation and rapidly accelerated and pulled away from the host vessel. Of particular note for this testing was the lack of use of any RF communications. The link was established without the use of any RF communications (radios, SATCOM, etc.) and all coordination of testing utilized VoIP communications over the TAR2HOST optical link.

For inbound track as the VOI closed with the Host vessel from behind at ~120-150 degree bearing:
-**4700 yards**: PER testing gave raw PER of 32% which sufficient for reliable file transfers
-3260 yards: 6.44 MB file transferred from the VIO to the host vessel in 47.8 seconds
-2780 yards: 6.44 MB file transferred from the host vessel to the VOI in 49.9 seconds

-**2300 yards**: 6.44 MB file transferred from the VOI to the host vessel in 47.3 seconds

VOI on station approx. 1400-2000 yards off starboard beam of Host vessel from 1322 to 1410:
-16 successful file transfers in both directions between the host vessel and VOI at ranges of 1400-2000 yards at an average transfer rate of 1.1 Mbps
-Audio/video link from video camera on VOI to the host vessel at a range of 1500 yards. Audio/Video successfully transferred and recorded at high sound and image quality.

As the VOI accelerated forward of the host vessel and left the TW08 group:
-**2100 yards**: 7 files with a total size of 7.1 MB transferred from the VOI to the host vessel in 52.95 seconds
-2200 yards: 3 files with a total size of 6 MB transferred from the host vessel to the VOI in 72 seconds
-2400 yards: 4 files with a total size of 8 MB transferred from the VOI to the host vessel in 108.275 seconds (this included an antenna blockage period which paused transfer for ~10 seconds and continued when link re-established)
-**2800 yards**: 3 files with a total size of 6 MB transferred from the host vessel to the VOI in 58.1 seconds
-3100 yards: 1 MB file transferred from VOI to the host vessel in 7.7 seconds
-3700 yards: 1 MB file transferred from host vessel to VOI in 26 seconds (included long blockage from VOI structure, transfer paused during blockage and finished after reestablished).
-**4000 yards**: 1 MB file transferred from VOI to host vessel in 7.65 seconds
-4900 yards: Tracking and voice comms lost

Blockages were a significant problem looking at stern of VOI and lost link multiple times as VOI pulled away beyond 4000 yards. These issues would have been easily solvable by a minor movement of the MRR but a lack of notification prior to ships' separation resulted in insufficient time to move MRR to better location.

During testing, laser parameters of the DMOI were logged to determine quantitative performance of the system. Results from these logs are shown in Table 4 and show good agreement between predicted link budget power (P_{Theory}) and observed power ($P_{observed}$) into the receive fiber in the DMOI.

Power (W)	Divergence (μradians)	Range (yds)	P_{Theory} (dBm)	$P_{Observed}$ (dBm)
0.45	600	1400	-30.8	-31
0.75	596	1486	-29.6	-30.89
0.75	500	1500	-28.3	-29.5
0.75	800	1600	-33.3	-33
1.5	200	3260	-32.8	-33
1.5	300	3455	-36.15	-36
1.5	200	4900	-40	-40

Table 4: Predicted (P_{Theory}) and observed ($P_{Observed}$) received powers for various DMOI laser transmitter powers, divergences and ranges.

Successful demonstration of the system at 200 microradian divergence for MRR links and verification of theoretical link margins, implies that the direct link mode of the **Dual mode** optical interrogator (DMOI) used in TW08 is capable of Fast Ethernet links (100 Mbps data rates) at ranges up to 80000 yards (40 Nm) with substantial link margin (>20 dB) between pairs of DMOIs (see Table 5). This would allow links to the horizon for ship-ship communications or to airborne platforms for over the horizon airborne relays.

Power (watts)	Divergence (μradians)	Range (yds)	P_{Theory} (dBm)	$P_{Required}$ (dBm)
1.5	200	80000	-21.7	-42

Table 5: Predicted (P_{Theory}) and required ($P_{Required}$) received powers for a long range direct link between a pair of DMOI terminals with transmit power and divergence demonstrated in TW08.

CONCLUSIONS

The MIO TAR2HOST lasercomm system demonstrated in TW08 to ranges beyond 2 Nm has great potential to diversify communication paths to non-RF communications for MIO. This diversification will allow MIO operations in more conditions reducing the risk of suspicious vessels operating with no interdiction. Additionally, the use of optical frequencies to transmit data is inherently LPI/LPD, will reduce congestion of the RF spectrum, and will allow operation in harsh RF environments where RF communication systems' functionality may be limited. Finally, verification of link budgets in TW08 demonstrates the capability for pairs of DMOI terminals to operate at ranges of 40 Nm or greater at fast Ethernet (100 Mbps) data rates. This further enhances the efficacy of this lasercomm system since with a simple installation of DMOI systems in existing signal light mounts, high data rate optical communications are possible for both MIO operations and ship-to-ship communications.

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