Free-Space Optical Communication Systems (FOCUS): An Army Overview

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ABSTRACT

The Army's objective is to design, develop and demonstrate its "ability to distribute information around the battlefield." Future Army systems will be based on a survivable, adaptable network capable of integrating commercial services and securely utilizing bandwidth for voice, data, and video applications. However, microwave bandwidth allocation has been a serious problem (given crosstalk, interference and frequency management) for a mobile, adaptive communication network. Because of the inherent advantages of the high data rate, crosstalk independence, jam - resistance, covertness and quick system setup time, the Army is looking into optical wireless communication as a means to address this communications requirement. However, development of a fielded laser communication system requires the development of enabling technologies, the understanding of physical limits and performance, and concept of operations (CONOPS).

1. INTRODUCTION

The future of battlefield communications will require a large amount of data that will support multimedia, imagery, video, mapping and other command and control functions. Laser communication is considered a viable option to address some of the future connectivity needs. Fixed site laser communication systems may be ideal for forward Army base communications infrastructure, upgrades of existing Army base communications systems, remoting of imagery from perimeter surveillance, and peacekeeping functions where a communication infrastructure may not be available.

However, the Army's communications objective will require a mobile communication system to emphasize mobility and agility. For laser communications to be viable, beam pointing, tracking and stabilization technologies, advanced protocol buffering as well as network topology issues move to the forefront of developmental needs. For a mobile network using laser communication systems, the links must be quickly established and maintained despite blockages, pointing errors and platform motion. Also, the network assets may be on a platform moving through a wide variety of terrains, weather conditions, and battlefield obscurants (natural and man-made) where intermittent link availability is the rule rather than exception.

A variety of system concerns must be addressed in order to make a laser communication node for the Army viable. Several general areas of relevant research include laser communication system's hardware and software, data coding systems, signal acquisition and tracking, network infrastructure, and predictive modeling. All these areas need to be addressed and successfully integrated in order to realize an operational system.

2. Army Laser Communication Systems Concept–of-Operations (CONOPS)

At present, no mobile platform – mounted laser communication system exists in the Army's communication infrastructure. The major difficulty lies in the availability of workable prototypes to test aspects of Army doctrine or CONOPS. Commercial interest in laser communication has only emerged recently for the use of last mile and fixed-site to fixed-site networking needs. However, these are systems designed with very limited tracking ability in order to

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mitigate building sway. The Army however, requires systems that can point and track over many tens of degrees at high control loop bandwidths. For communications purposes, such systems do not exist today. Thus, laser communication systems have not established a history of operation with the Army. Conversely, the Army has used RF communications systems for decades. In some aspects it takes the Army longer to mature the training, tactics and doctrine for laser communications than the time it take to mature the technology to a fieldable system.

Both the Air Force and the Navy have strong developmental programs for laser communication. The Army was one of the earlier pioneers for terrestrial crosslinks in the 1960's using CO^2 lasers. However, the main conclusion was that the atmospheric turbulence and scintillation prevented a long haul link (i.e. > 10 km range was not possible). Due to advances in technology and adaptive optic techniques, long haul links have become much more viable for terrestrial usage. Additionally, the availability of higher powered and high-reliability lasers at several key wavelengths has pushed the recent emergence of commercial investment for laser communication into the last-mile networking arena.

3. DOD Laser Communications Efforts

The emergence of more robust and higher powered lasers as well as advances in optical integration and ruggedization have made line-of-sight systems more realizable for Army applications. Commercial systems currently exceed the 4km range with a data rate of up to 2.5 Gbps.[1] Commercial capability trends have slowly moved toward the operational requirements of the Army, albeit whenever a commercial market is viable. Department of Defense technology efforts are currently underway to address many of these issues that commercial industry is presently not pursuing. In 2000, DARPA initiated a Steered Agile Beam Program called STAB, which has looked at the necessary technology components to develop non-mechanical pointing and tracking systems for mobile laser communications. Laser beam "agility" provided by eliminating large mechanical gimbals allows more effective means of improving the speed and stability of pointing the laser. Optical communication systems will be more robust because an agile beam can compensate more quickly for signal fades caused by atmospheric conditions and transceiver motion.

Most of the components developed under STAB have multifunctional aspects, which can be used in a variety of different applications. Advances from the program in areas such as Micro-Electro-Mechanical Systems (MEMS), liquid crystals materials, laser technology, optical phased arrays, and receiver systems may be critical for the development of future systems. STAB is developing very cutting edge technologies that have shown promise within the laboratory environment. For example, DARPA's STAB is developing a Steered Agile Laser Transceiver (SALT) Cube, with the goal of communications at a rate of 10 megabits per second over a distance of 10 km. As shown in Figure 1.0, the objective of the SALT Cube is to integrate a laser diode source, MEMS laser scanner, gyroscope, detector array, and control electronics into a volume of 1 cm^3.

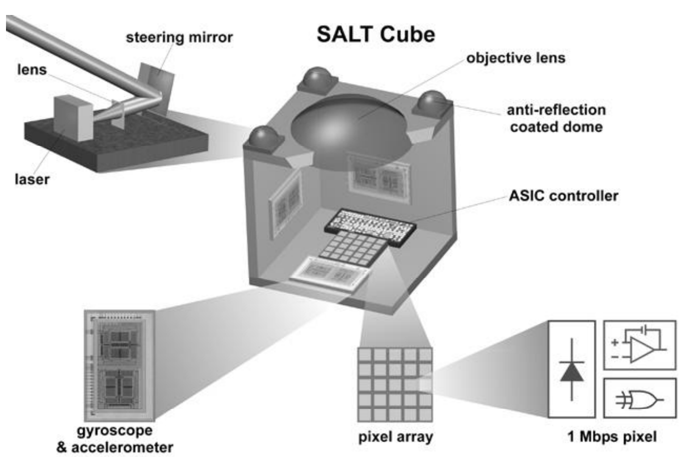

Figure 1.0 SALT Cube (Volume ~1cm^3)

Another new DARPA program takes more of an application specific approach by looking at developing advanced communication systems, which may be a critical force multiplier for the military. The DARPA Terahertz Operational Reachback (THOR) Program[2] (Figure 2.0) deals with the enabling technologies and systems concepts to realize a global encompassing laser communications network for both satellite, airborne, terrestrial and underwater links.

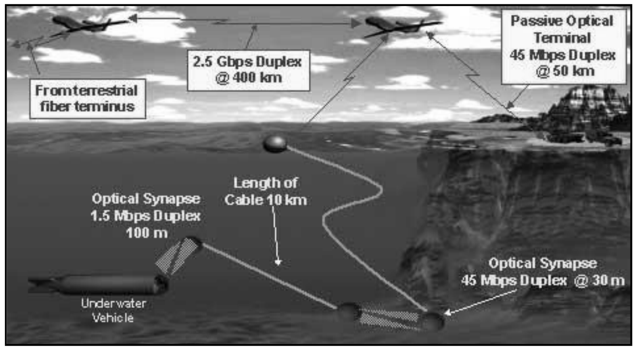

Fig. 2.0 DARPA THOR Operational Concept

The THOR concept covers a variety of Army, Navy, and Air Force applications and originated from the military's need to seamlessly communicate across the variety of different Tri-Service networks. Because of the various conditions intrinsic to each Service, the design of the laser communication system varies considerably for underwater, airborne, terrestrial, space usage.

4. Laser Technologies of Army Interest

The Army has looked at several potential candidates for suitable laser sources for laser communications. The current emphasis is on lasers whose output wavelength are 1.5 microns due to the commercial availability of both the lasers and receivers. However, other areas of Army interest are the 3.8 - 4.2 micron and the 9 - 11 micron regime. US Army STRICOM has developed a Multiple Integrated Laser Engagement System (MILES)[4] as a tactical engagement simulator that facilitates force-on-force training in realistic battlefield scenarios. MILES is a free-space communication transceiver that generates weapon codes that is characteristic of the weapon platform, ammunition features and user. Figure 3.0 shows tactical battlefield imagery transmitted through an obscurant on an optical carrier beam whose wavelength is 3.8 microns.

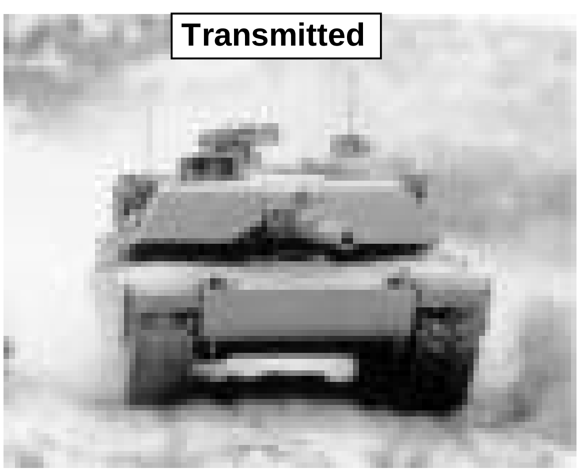

Figure 3.0 Digital image data transmission through smoke cloud with the mid-wavelength IR MILES unit

US Army CECOM is involved with collaborative efforts with industry/academia by investigating long IR sources due to the increased capability of transmission of long-IR radiation through the atmosphere. Stevens Institute of Technology and Lucent Technologies (Figure 4.0) have been developing long IR sources based on quantum cascade technologies.[3] While still in the research phase, advances indicate the potential for stable operation in a room temperature environment.

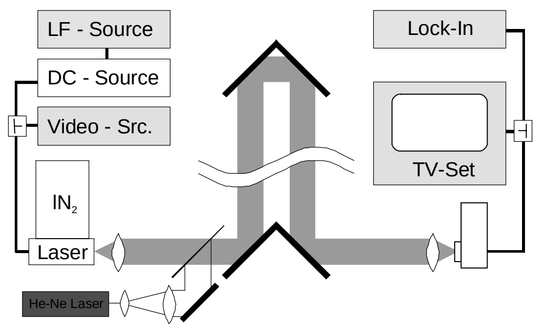

Figure 4.0 Video image data transmission via QC Laser (Stevens Institute of Technology/Lucent Technologies)

5. Signal Acquisition and Tracking

One of the most challenging problems for mobile laser communications is the issue of pointing and tracking. While the DARPA STAB and THOR programs address future technology issues, there is an immediate need to address the near term realizable solutions to demonstrate how the Army can benefit from an on-the-move laser communication system. There have been relevant areas of work on mechanical gimbals systems for other type of applications such as munitions, satellite tracking, and robotics; however, there has been very little experimental work on high – bandwidth pointing and tracking systems for terrestrial-based laser communication systems. Although some commercial venues are looking at finite pointing and tracking for fixed-site laser communication transceivers to account for building sway, this is by no means sufficient for a tactical battlefield type of scenario that the Army envisions.

Current steerable laser communication systems require either fixed site mounting or extensive hardware (CCIT camera systems, multiple corner cubes, etc.) to perform tracking between the transmitter and the receiver. Brute force tracking concepts in use have various detriments. They require either higher power lasers or significant support sensor systems to maintain the link. Tracking systems requiring infrared cameras for angle processing are expensive and narrow field of view frame stabilization becomes a problem in and of itself. For systems without fine pointing accuracy, a broad transmit beam dispersion requires high power laser components. Other systems used require multiple widely space detectors or corner cubes that are difficult to install and maintain on moving vehicles.

The main components for developing a mobile, agile and low - cost data transmission link include the use of a high performance scanning system coupled with smart information utilization that embeds position and pointing information into the data stream. There are a variety of different methods to accomplish the tracking: hemispheric scanning, Global Positioning System (GPS) assisted tracking, imaging cameras schemes, and optical retroreflectors, are some of the prevalent options that exist (Figure 5.0).

One current Army program[4,5] looks to develop a compact, hardened, high-speed laser communication system with fast tracking capability for use in all-terrain vehicles using micro-mirror or optical galvanometers (Figure 6.0).

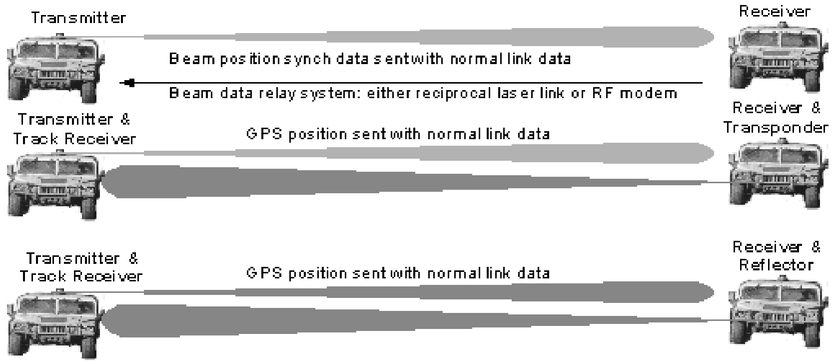

Figure 5.0 Basic Functional Diagram For Angle Tracking Data Link

This current Army effort utilizes fast, precision scanning systems at the transmitter to provide stable line of sight to the receiver in addition to providing closed loop tracking information to the data link transmitter. The common thread is the use of tracking related data transmitted along with normal communication data to assist in closing the data link. Furthermore, the tracking systems will utilize additional data to minimize the field of view that is required of the transmitting system. For all the systems, GPS data is used to assist in link acquisition and then either directly to improve tracking or track support functions. Using differential GPS with platform attitude data, the field-of-view (FOV) uncertainty is reduced to within a degree at a kilometer. This allows initial acquisition and subsequent tracking to be performed much more efficiently.

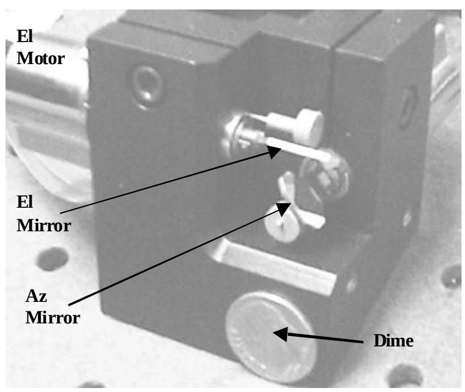

Figure 6.0 Galvanometer based precision fast scanning system

6. Modeling and Simulation

Though much work continues to be done in the area of modeling and simulation, a suitable communication link model usable to the Army is lacking. The user must be able to understand the limitations of a theoretical model in order to plan effective operational scenarios that are realistic in scope. Also, the model must closely predict the performance of current available laser communication systems. Finally, the model must be used to identify areas where further research is required. For example, one proposed method would have adaptive optics parameters and typical data communications metrics combined in a model that predicts performance depending on data encoding method and adaptive optics correction technique will be used (Figure 7.0).

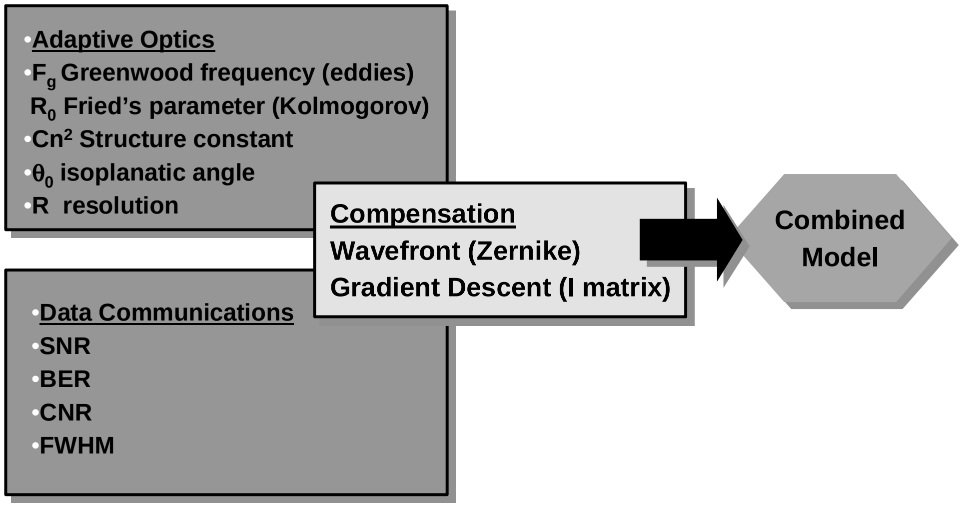

Figure 7.0 Laser communications system model incorporating communications metrics with adaptive beam correction parameters

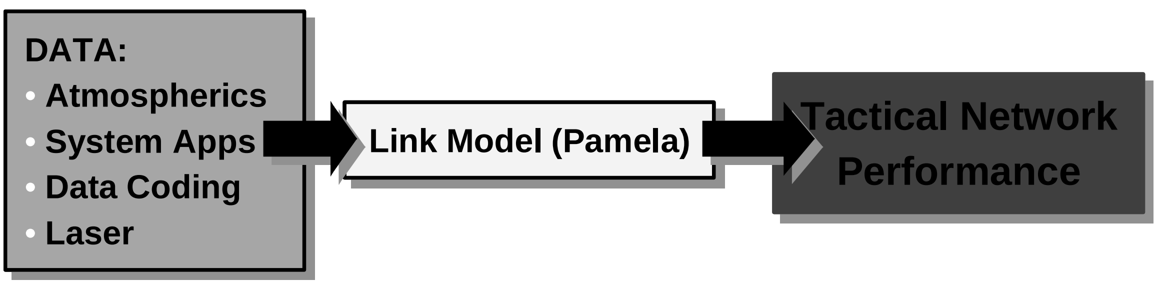

Figure 8.0 The Army's laser communications system model - PAMELA

The Army is currently developing a laser communications system model called PAMELA (Propagation and Modeling Analysis for Laser Applications) that will combine adaptive optics parameters with atmospheric effects in order to make the correlation to communications system design and performance metrics such as bit error rate, channel availability and achievable throughput (Figure 8.0).

7. Conclusions

Laser communications have an enormous potential to be an enabling technology that will allow the Army to provide a secure, jam-resistant, low detection probability, and high-bandwidth means of communications to its operational elements. There are a number of research programs currently undertaken by the DoD to tackle the issues that arise when laser communications is applied to the battlefield. Fortunately, many of the issues involving lasers have already been investigated for its uses in systems other than communications. These systems include: laser target designators, directed energy weapons, LADAR and others. The challenge then remains to transition that research and apply it to communications as well as to initiate new research programs for issues that pertain only to battlefield laser communication systems.

The aspects of mobility, range, security, and seamless data connectivity make a fieldable mobile laser communication a very challenging, yet attainable goal. With the advances in new technology, issues of tracking, data reliability, and packaging are continuously being improved. It is important to understand the current operational constraints and to clearly identify areas of future research which make a laser communication system more amenable asset for future military systems

References:

[1] FSONA SONAbeam™ OC-48 Family

[2] Terahertz Reachback (THOR), George Duchak

[3] R. Martini, C. Bethea, F. Capasso, C. Gmachl, R. Paiella, E.A. Whittaker, H.Y. Hwang, D.L. Sivco, J.N. Baillargeon and A.Y. Cho: Free-space optical transmission of multimedia satellite data streams using mid-infrared quantum cascade lasers, Electronic Letters, 14 Feb 02, Vol.38, No.4

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[5] Narasimha S. Prasad, Patrick T. Kratovil, "Laser Communication System With Spatial Tracking For Movable Platforms," Coherent Technologies, Phase I SBIR Contract # DAAB07-02-C-D406