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C2 and Agility

TNT Testbed for Self-Organizing Tactical Networking and Collaboration

Track 2: Network and Networking

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Introduction

Beginning in 2002, a team of Naval Postgraduate School researchers together with sponsors from USSOCOM, and later joined by the OSD and DHS S&T Programs, started a new campaign of discovery and constraints analysis experiments (Alberts and Hayes, 2007), which is now collectively known as Tactical Network Topology (TNT) Experiments. This campaign of experimentation, carried out under the USSOCOM-NPS Field Experimentation Cooperative program and OSD/ HLS S&T support unfolds in two major areas.

The first one involves quarterly field experiments with USSOCOM, in which NPS researchers and students as well as participants from other universities, government organizations, and industry investigate various topics related to tactical networking with sensors and unmanned aerial systems (UAS) as well collaboration between geographically distributed units with focus on high value target (HVT) tracking and surveillance missions. The TNT experimentation process with USSOCOM is focused on both technologies associated with networking and the human aspects of networked forms of organization. Technologies investigated have included network-controlled UASs, various forms of multiplatform wireless networking, mesh networked tactical vehicles, deployable operations centers, collaborative technologies, situational awareness systems, multi-agent architectures, and management of sensor-unmanned vehicle-decision maker self-organizing environments.

The second direction involves Maritime Interdiction Operation (MIO) experiments with Lawrence Livermore National Laboratory, USCG, First Responders (San Francisco Bay, New York/New Jersey) supported by HLD and HLS S&T Programs and DoE agencies. These experiments are conducted twice a year and are also supported by the overseas partners from Sweden, Germany, Denmark, and Singapore.

In all of these experiments, the focus has been on both adapting both emerging and commercially available technologies to military requirements and on investigating new social networking/collaboration elements associated with the addition of such technologies to the battlespace and maritime security operational scenarios.

In the core of TNT HVT and MIO experimentation is a unique testbed, which enables sustainability and evolution of the TNT experimentation campaign. It is based on the plug-and-play tacticalon-the-move sensor-unmanned systems networking capabilities combined with global reachback to the remote expert/command sites and augmented by rapid integration applied research services.

The goal for this paper is to describe the architecture of the TNT testbed environment and the potential for its application to studies of emerging self-organizing tactical networks.

1. Tactical Networking Testbed: Man-Machine Plug-and-Play Systems Enabling Sustainable Experimentation

Each quarter, the growing team of NPS researchers, USSOCOM operators, and commercial/academic partners get together on the grounds of Camp Roberts, California to explore synergy and impact of emerging sensor-unmanned systems-decision maker self-forming networks on to the HVT and ISR missions. Figures 1a and 1b illustrates the state of the experimentation team during FY2008.

Large Interdisciplinary NPS Team
27 Thesis Students
31 Faculty, 4 Staff; 9 Departments and Institutes
Includes 21 PhDs
Course Projects: IS, OR, MET
28 NPS Field Experimentation Projects

Programs Utilizing TNT Testbed	
AFRL JASMAD	JIEDDO
AFRL Marti	MCWL TW Radio
AFRL N-CET	Team TACLAN
AFSOC CP/BI	JFCOM EC-08

Participating Universities	
ASU	Univ. of Bundeswehr - Munich
Carnegie Mellon	Univ. of Florida
Case	Virginia Tech
JHU/APL	WPI
MIT	WVHTF
NDU	UM, Columbia, UCSD, UCCS
UC Berkeley	

Figure 1a. TNT Academic Participants for FY08

Foreign Country Participation in MIO

- Univ. of Bundeswehr at Munich
- Swedish Naval Warfare Center
- Turkish Air Force Academy
- Systematic/Danish Navy Training Center

National Guard

- West Virginia – Camp Dawson
- Indiana – Camp Atterbury

State and Local Government in MIO

- Alameda County Sheriff's Office
- Oakland Police Dept.
- San Francisco Police Dept.
- Port Authority of NY/NJ
- Fire Department New York
- California Office of Emergency Services
- California Dept. of Health
- U.S. Park Police

Broad DoD and Gov't. Participation and Support

- USSOCOM	- USASOC
- AFSOC	- NAVSOC
- MARSOC	- JSOC

Other Participating DoD and U.S. Gov't.

AFRL	LLNL	SPAWAR
ARL	NAWCWD	TSWG
BTF	NECC	USASMDC
DARPA	NIST	USCG/D-11
DHS/S&T	NRL	USCG-Staten Island
DNDO	NSA	USMC-HQMC
DOE RAP	NSWCCD	USMC-MSTSSA
DTRA	ONR	USMC-MCWL
JFCOM	ONR 113	USATC (Fort Eustis)
JIEDDO	OPNAV N8F	
JITC	OSD/HD	
LBNL	OSD/RRTO	

Figure 1b. TNT Testbed Federal, Local, and Foreign Participants in 2008

The TNT experiment members plug-in their sensors, networks, UASs, aerial balloons, ground vehicles, situational awareness systems, and operator units into the TNT testbed comprised of segments and layers.

These field experiments are then connected back to the Network Operations Center (NOC) at NPS via an 802.16 network link. All the network infrastructure involved is operated and maintained by students and is, itself, often the subject of some experimental activity. High-level network views of a few of these sites are given in Figures 2 and 3.

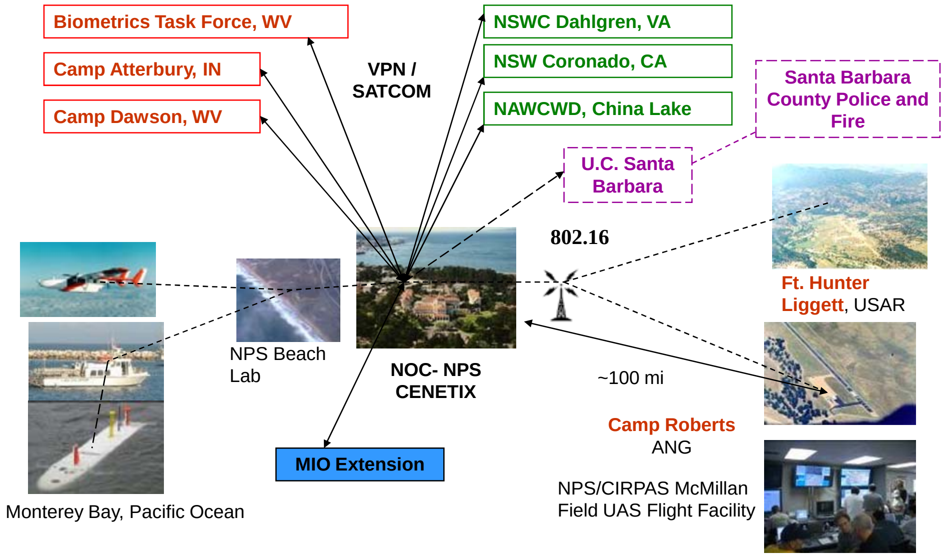

Figure 2. Plug-and-Play Testbed with Global Reachback: Camp Roberts segment with reachback to East Coast Centers

Figure 2 shows the fixed wireless 802.16 backbone connecting NPS with Camp Roberts. It reflects the complexity of the TNT network setup. The Light Reconnaissance Vehicle (LRV) in Fig. 3 is a mobile OFDM[1] node. Also visible are a number of remote field locations that have been used in past experiments. In addition to the locations at Camp Roberts and NPS, various remote sites are connected to the TNT infrastructure via an ever-changing set of Virtual Private Network (VPN) tunnels on top of satellite links or commercial IP cloud. As such, a large portion of each experiment is concerned with the collaboration and coordination necessary to integrate the large number of sites and interested parties into the ongoing activities.

For example, the Biometrics Fusion Center (BFC), located in West Virginia, has been a member of many of our experiments. They are concerned with our research as a way of connecting remote, tactical field users to biometrics databases removed from the battlefield. In this manner, field agents looking for suspected terrorists can take sensors (fingerprint, facial recognition, etc.) directly to the area of interest while drawing on the full (and likely updated) databases provided by the BFC. Conversely, information gained in the field can be immediately made available to analysts back at headquarters or located in other locations around the world. Figures 3 and 4 illustrate the self-forming mesh segments of TNT testbed at work with the UAS systems and different applications.

[1] Orthogonal Frequency Division Multiplexing — this is the technology that underlies 802.16.

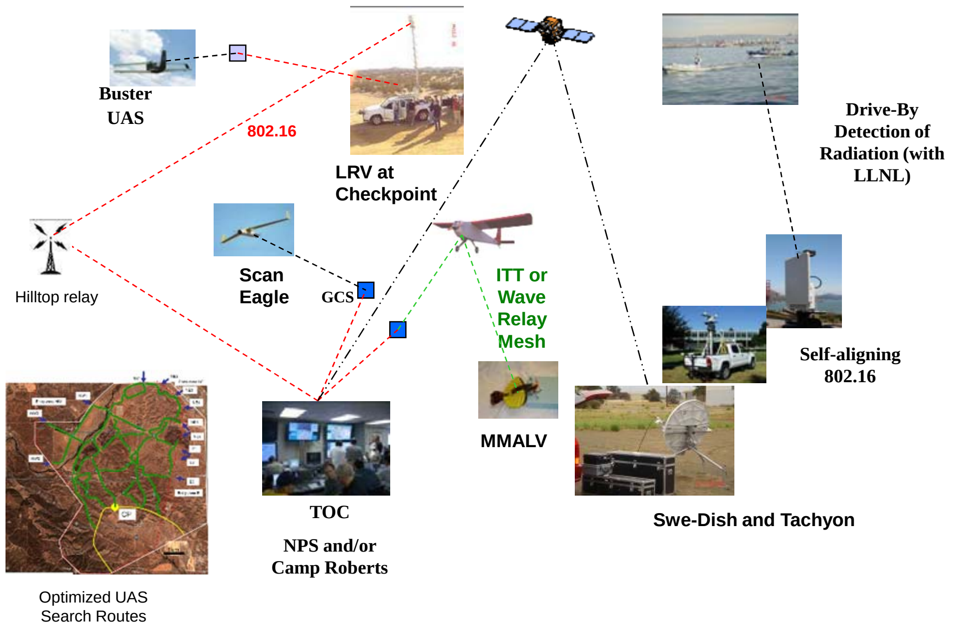

Figure 3. Typical self-forming mobile mesh segments of TNT testbed

Figure 4. Tactical applications enabled by self-forming segments of TNT testbed

The other part of the TNT experimentation not occurring at Camp Roberts is focused specifically on the Maritime Interdiction Operations (MIO), usually centered in the San Francisco Bay area with multiple support sites within the CONUS and overseas. However, it is not always the case. The last TNT MIO 08-4 was actually centered in Port Authority New York New Jersey (PANYNJ) area of Homeland Security activities with riverine operations component of the MIO scenario executed in Hampton Roads/Ft. Eustis area. The network infrastructure that supports the MIO segments of the TNT testbed are described in Figure 5.

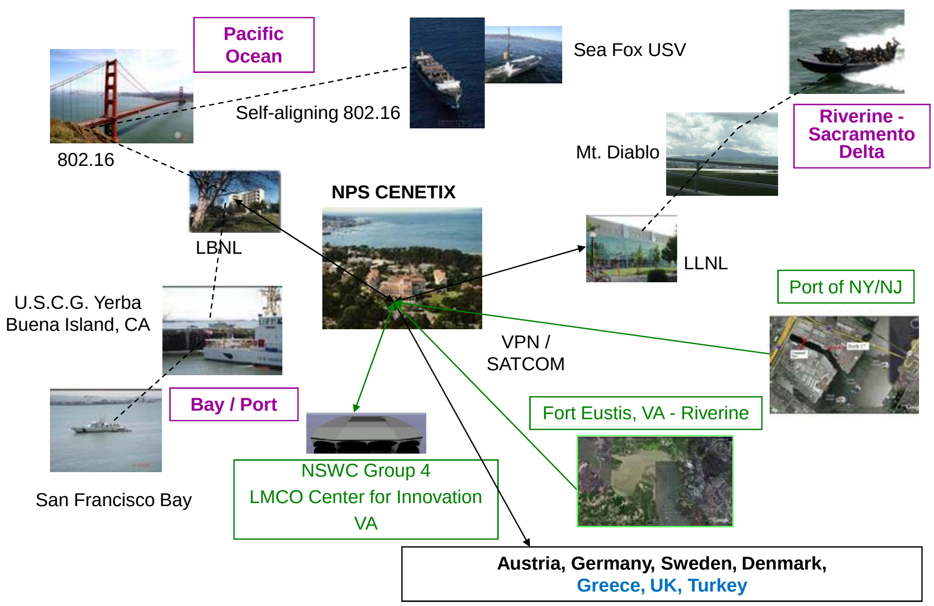

Figure 5. Plug-and-Play TNT MIO Testbed Segment: SF Bay, East Coast and Overseas

This series of experiments is being conducted to test the technical and operational challenges of searching large cargo vessels and interdicting small craft possessing nuclear radiation threat. One goal is to test the applicability of using a wireless network for data sharing during a MIO scenario to facilitate "reach back" to experts for radiation source analysis and biometric data analysis. This technology is being tested and refined to provide networking solutions for MIOs where subject matter experts at geographically distributed command centers collaborate with a boarding party in near real time to facilitate situational understanding and course of action selection. With the use of collaborative technologies and adaptive ad-hoc networking, TNT-MIO experiments have shown the ability to return a positive match within 4 minutes of collecting nuclear radiation and biometric data (Bordetsky, Dougan, Foo, and Kihlberg, 2006). While this is under somewhat controlled experimental conditions, results even within an order of magnitude of this time allow the boarding party to take action while they are still on board the suspect vessel and long before the suspect can evade. Figure 6 illustrates MIO Testbed in action supporting simultaneous interdiction of target vessels in open waters, inner bay, and riverine and with an immediate reachback to expert sites and multipoint video/data exchange between the boarding parties.

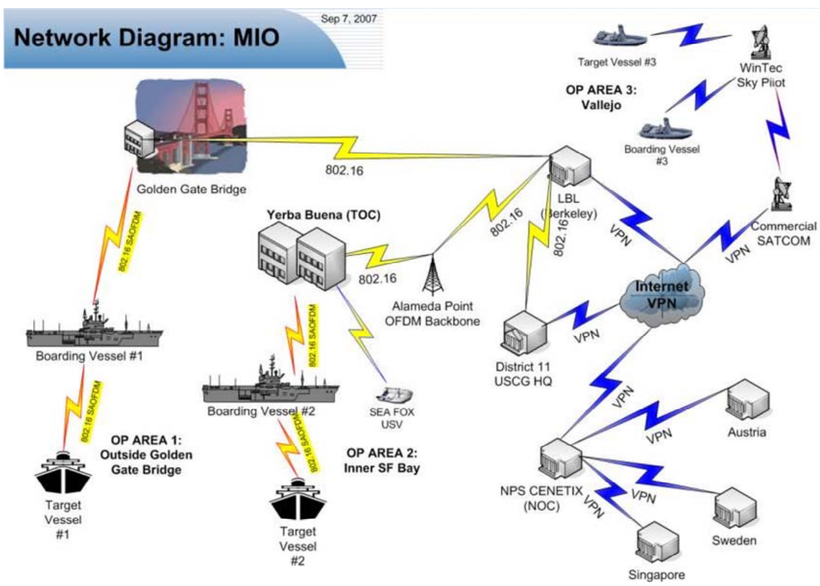

Figure 6. Simultaneous interdiction and data sharing between boarding parties conducted in three geographically distributed locations.

Each MIO experiment appears to be a significant next step forward in evaluating the use of networks, advanced sensors, and collaborative technology for rapid MIO response, including the ability to search for radiation sources, set up ship-to-ship and ship-to-shore communications while maintaining network connectivity with command and control (C2) organizations and collaborating with experts on the radiological and biometrics identification threat.

For example, the specific goal for the MIO 08-4 experiment was to explore new sensor, networking, and situational awareness solutions for interdicting, searching, tagging, and monitoring a large vessel as well as small craft, threatening the security of the coastal metropolitan areas on the scale of the radiological threat in the Port of NY and NJ and subsequent events in the riverine area of Hampton Roads, VA.

The situational awareness focus of the experiment was to explore the requirements for broad interagency collaboration and data sharing using the capabilities of PANYNJ JSAS, JAC feedback, and two-way data sharing with the Riverine Area of operation.

Figures 7, 8, and 9 illustrate the TNT MIO testbed in action during the MIO 08-4 search of the large cargo vessel in the Port of Newark and high-speed Riverine chase nearby Ft. Eustis.

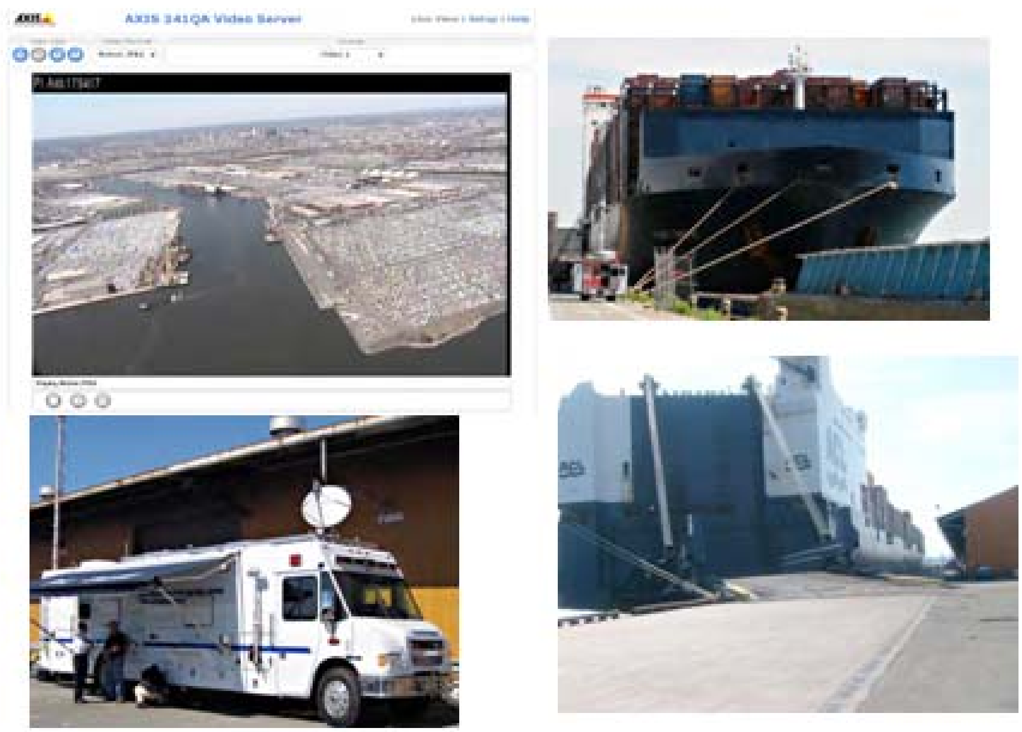

Figure 7. TNT MIO Testbed in action providing on-the-move network to multiple boarding parties searching a large cargo ship and reachback to PANYNJ EOC and DoE expert centers.

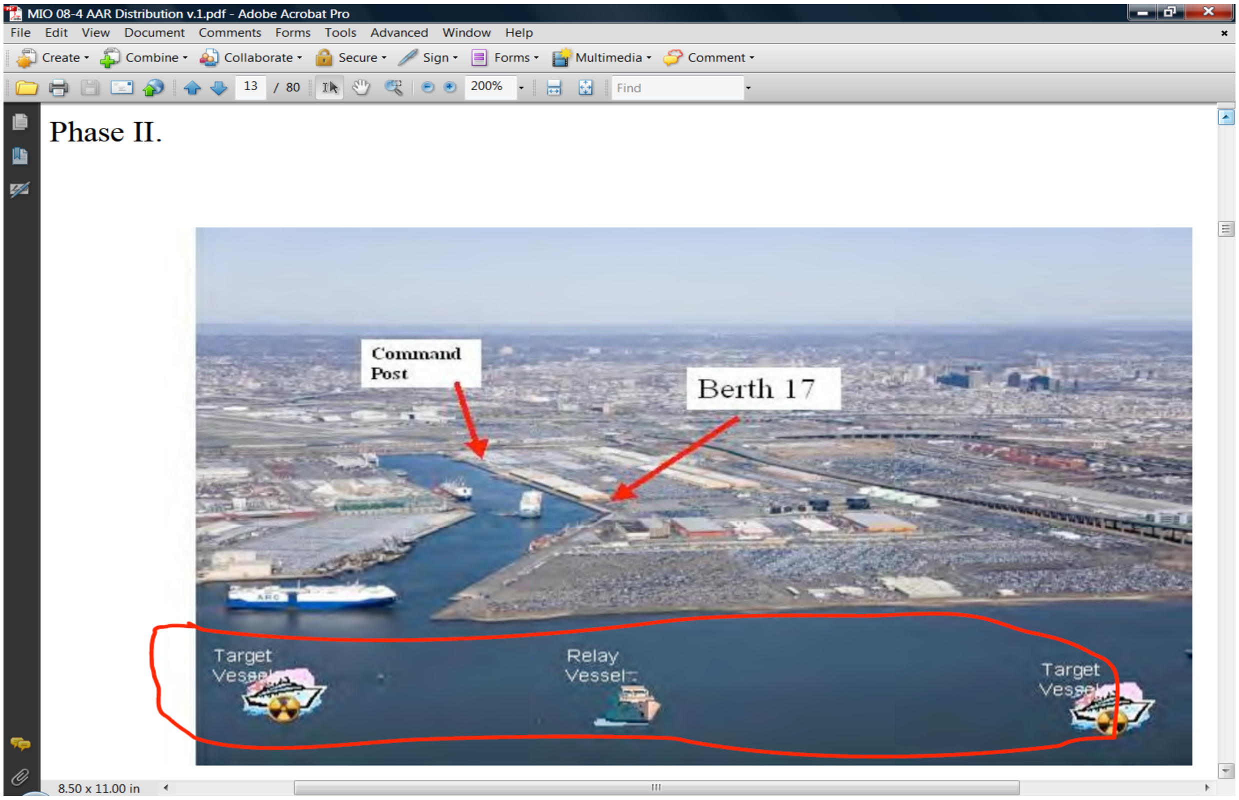

Figure 8. Simultaneous small craft search in Port of Newark, Sweden, and Denmark and data sharing operations.

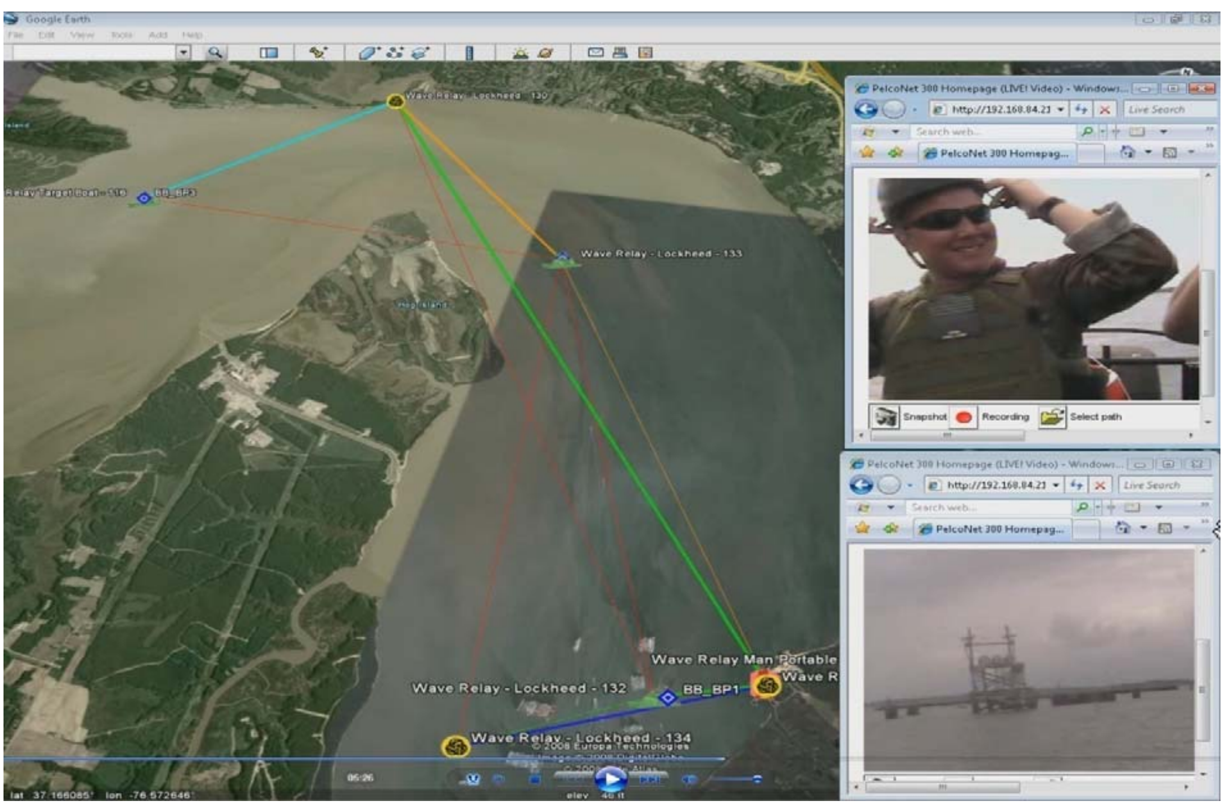

Figure 9. MIO testbed mesh segment in action supporting the video exchange during the high-speed riverine chase of the target vessel.

2. Testbed Service Architecture: An Interface System for Field Experimentation

From the Systems Theory standpoint the TNT testbed represents a unique research service of social and information networking. It provides for the adaptation and integration processes between people, networks, sensors, and unmanned systems. For a few days of intense experimentation the TNT testbed military, academic, and vendor users become a community of ***tactizens*** engaged in rapid system design processes, which produce new forms of synergy in the TNT cyberspace of man and tactical machinery. The new term of *tactizens* is our reflection on *Second Life* metaphor of *netizens* (Sectliffe, 2009).

The testbed enables several layers for integrating models, tools, and experimentation procedures:

-The TNT *tactizens* can integrate their sensors and mesh networking elements in the unclassified but closed IP space of the TNT testbed by getting fixed IPv4 and lately IPv6 addresses. Figure 10 illustrates the online portal enabling rapid integration of experimental assets in TNT testbed IP space,

- Users can connect their remote local area network, including command and operation centers, via the virtual private network (VPN) client on top satellite or commercial IP cloud services,

-Sensors and unmanned vehicles can be integrated with the TNT Situational Awareness Environment via the applications layer interoperability interface. The current option includes Cursor-on-Target (CoT) integration channel, initially developed at MITRE (Miller, 2004), comprised of the CoT message router and CoT XML adapters for each node needed to be integrated (Figure 11). In the very near future we will consider adding the Common Alert Protocol (CAP), which is becoming widely used by the DHS community,

- Human operators (both remote and local) can access the testbed collaborative environment via the collaborative portal or peer-to-peer collaborative clients, situational awareness agents, video conferencing room (Fig.12), and video client. This is human layer interface to the testbed.

- At the physical level the testbed reaches to even lower levels (like multiple mesh network enabled unmanned systems) which permit researchers to experiment with such things as airborne sensors and cooperative control (Fig. 13) without having to be concerned about network connectivity.

By accessing testbed at different levels, varying from application to physical, the TNT testbed users could have unique capability of exploring possible adaption patterns, i.e. management of their resources by experimenting with applications load or physically moving and re-aligning their assets. Figure 14 represents the TNT testbed adaptive management interface.

Figure 10. Plugging IP assets in the TNT Testbed: IP Space Portal (*Designed by Eugene Bourakov*)

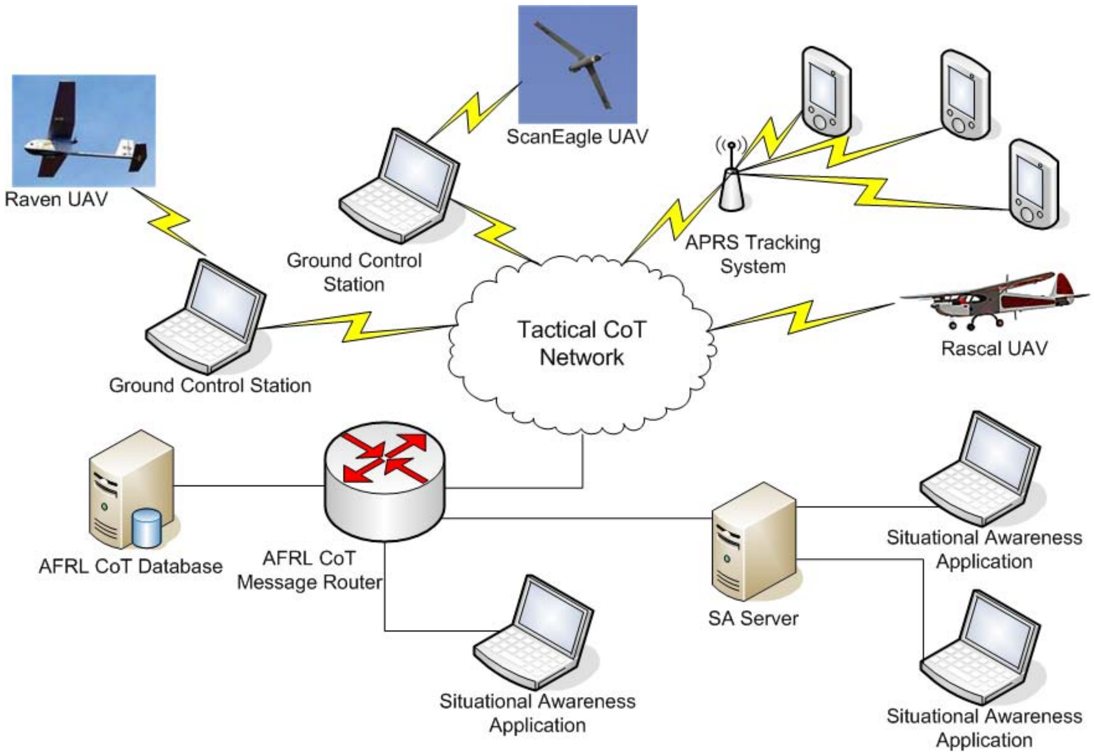

Figure 11. Applications Layer Testbed Interface via the CoT channel (*Diagram provided by Michael Clement*)

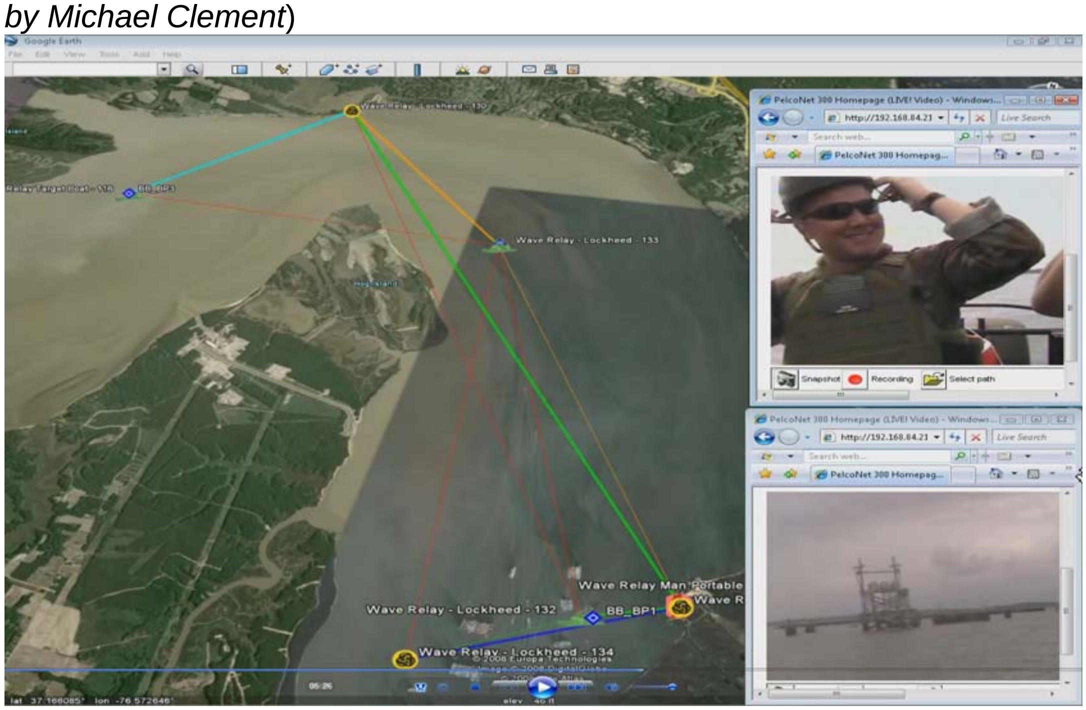

Figure 12. Operator interface: video clients and SA View in the Riverine Operations

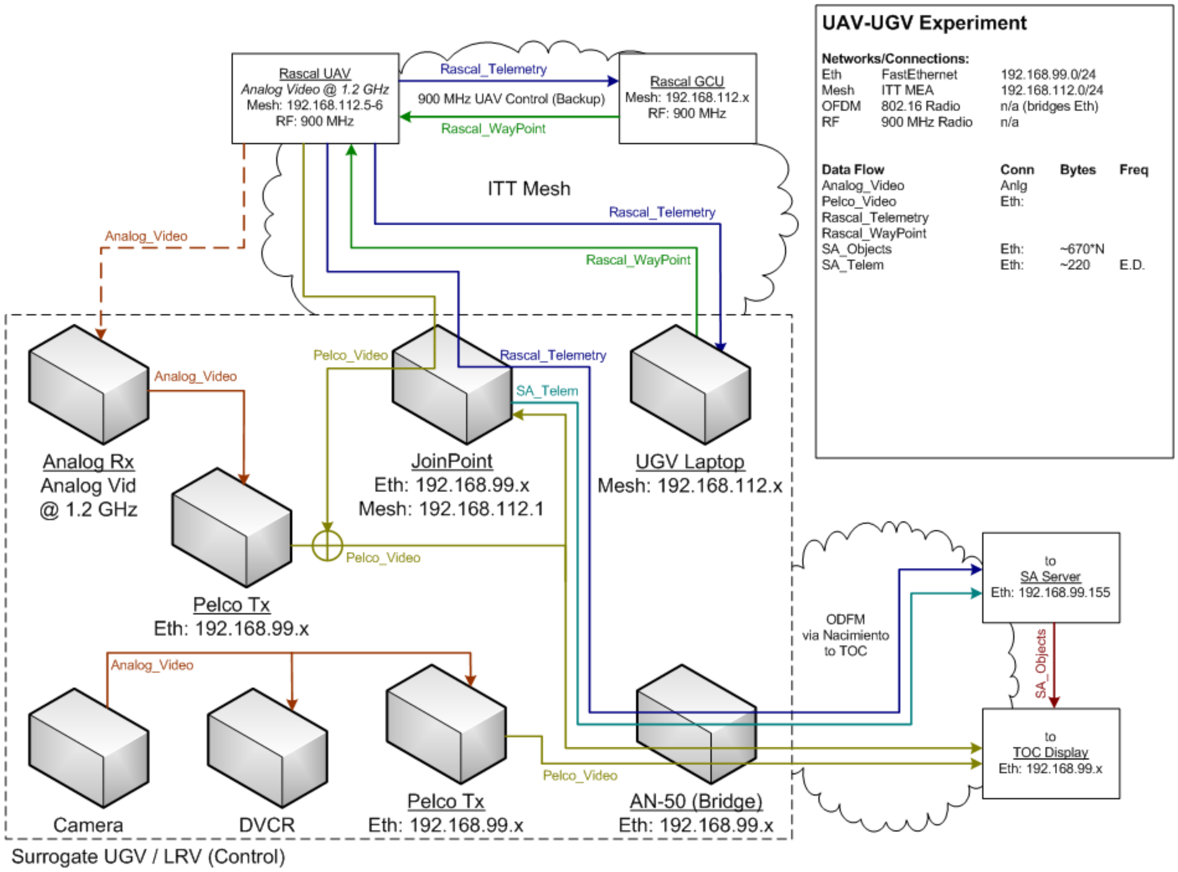

Figure 13. Mesh network interface enabling cooperative control of UAV and UGV (*Diagram provided by Michael Clement)*

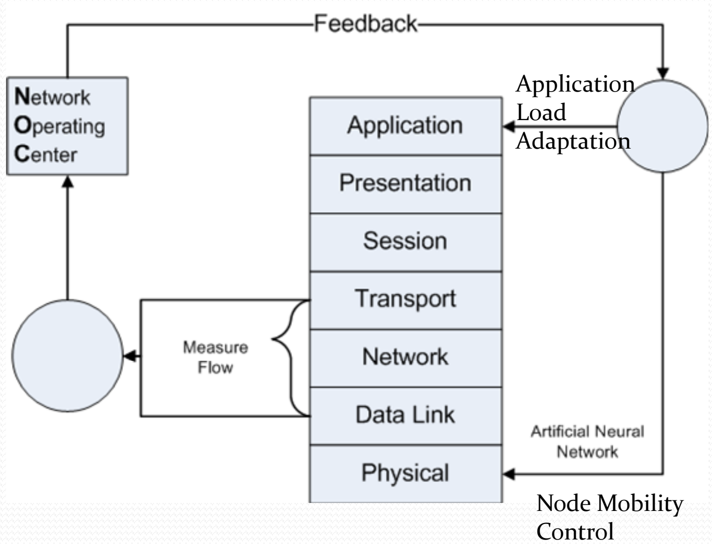

Figure 14. Layers of Adaptation in TNT Testbed

3. Field Model for Exploring Tactical Networking and Collaboration Frontier

From the scholarly stand point the TNT testbed represents a unique field model of emerging complex relationships between man and machine in the tactical networking and collaboration frontier. Exploring feasibility and major operational constraints associated with those relationships allows the TNT experimentation team to identify critical elements of tactical networking and collaboration frontier. Tables 1 and 2 illustrate several examples of these findings.

Table 1. Shaping Tactical Networking Frontier

	Self-forming agile adaptive networks	**Unmanned systems-sensor-decision maker cooperative networks:**	**Through-the-wall N-LOS Networking**
Self-Organizing Mesh Wireless Networks	TNT Reports from 2005-2008		
Network and SA controlled UAVs, USVs, UGVs: Unmanned vehicle is controlled by submitting the way points via tactical N-LOS mesh network		An ongoing study with Bourakov, Clement, Jones, Dobrokhodov, Kaminer (Clement, et.al., 2009) and (Jones, et. Al., 2009)	
Network-on-Target: Peer-to-peer links configured from the top of Common Operational Picture interface, self-aligning directional antennas	(Bordetsky & Bourakov,2006)		
Hyper-Nodes with 8th Layer: Tactical Self-Forming nodes as miniature network operations centers	(Bordetsky & Hayes-Roth, 2007)		
DMs as sensors to unmanned systems: Operators decision space MIB available to the unmanned system agents	First results accomplished in the thesis project of LCDR James Gateau**, (**Gateau &Bordetsky, 2008)		
Networking-by-touch: transmitting data via highly adaptive human network by using physical or electronic touch	First results accomplished in thesis of Rideout & Strickland (NPS), continuing research with Bourakov (NPS) Elman (MIT), and Lindeman (WPI): (Rideout and		

	Strickland, 2007), (TNT 08-2 QLR), (TNT 08-4 QLR)		
GPS denial navigation		An ongoing study since 2007 with Bourakov and MIT team (TNT 07-4 QLR, 2007), (TNT 08-2,QLR 2008)	
Ultra Wideband (UWB) Mesh networking: Integrating the UWB link into the peer-to-peer wireless mesh network			An ongoing study with Bourakov (NPS), Win and Weymereesh (MIT) (TNT 08-4 QLR 2008)
Projectile-based Networking		TNT MIO 07-4 After Action Report, 2007	
Small Distributed Unit Private Tactical Satellite Network	Study started in 2007, first results accomplished in thesis project of MAJ Conrad and LCDR Tzanos (Conrad and Tzanos, 2008)		
Small Distributed Unit Private Tactical Cellular Network		Study with Bourakov started in 2008 (TNT 08-4 QLR, 2008)	

Table 2: Shaping Collaboration Frontier:

	Collaborative networks for rapid interagency data sharing and expert response	**Synergy of social and information networking**
MIO Collaboration: Bringing the remote expert advice to an immediate support of the boarding officers	An ongoing research with Dougan & Dunlop (LLNL), Bourakov, Hutchins, Looney, Clement , Vega , Hudgens, Bergin-NPS; Friman (Swedish Defence Research Agency), Pickl (University of Bundeswehr)): (Bordetsky et al, 2006), (Hutchins, et.al., 2006), (Bordetsky & Friman, 2007), (Bordetsky & Hutchins, 2008),	With Hudgens, Vega, Koons, Bergin, Bekatoros: (Hudgens and Bordetsky, 2008), (TNT MIO 08-4 Report)
SA and Collaborative platforms interoperability: Propagating alerts between NPS SA tools, Port Authority NY-NJ (PANYNJ) Joint Situational Awareness System (JSAS)	First results accomplished with Bourakov and Clement (NPS), Reimers (BAE), Poulsen and Cooper (PANYNJ), Lindt (Kokums, Sweden), Hoy-Petersen and Nielsen (Systematik, Denmark): (TNT MIO 08-2 Report, 2008), (TNT MIO 08-4, Report, 2008)	
Collaboration with Coalitions partners		SNWC BFT-NPS SA-JSAS (with Hansson & Lindt (Sweden) - Danish MBS-NPS SA-JSAS (with Hoy-Petersen, Nielsen, and Riderring-Systematik, Denmark)

4. Conclusion: Enabling Business Process of Synergy Development

On top the TNT testbed interfaces there is unique business process, which allows participants to explore synergy of their solution. Quarterly experiments, supported by student and faculty experimentation services, allow the *tactizens (*vendors, academic, and other government partners) to rapidly adapt their solutions to the TNT environment and provide a unique collaborative environment in which the innovation of participants often results in additional unscheduled experimentation using combined technologies. The shortest adaptation cycle is 3-4 days of rapid team design during the TNT experiment. The next level cycle includes 8-10 weeks of research projects delivering feasibility or constraints analysis experiments. The longer adaptation term is in conjunction with dedicated student thesis project (about 6 months).

Industrial Participation		
Adaptive Flight	I-C Mobilisa	Remote Reality
AGI	iGov Technnologies	Restech
Amrel	ImSAR	Retica
AOptix	IST-Textron	Sarnoff
Applied Signal Technology	L-3 Com	Space Data Corp.
BAE Systems	LMCO	Step Labs
Blackbird Technologies	McLane Adv. Technologies	Strategic Initiatives
CDI	Metson Marine	Swe-Dish
CHI	Mission Technologies	Toyon Research
Commsfirst	Mitre	Trident Tech. Solutions
CrossMatch	Networx	TrellisWare
DRS	NGC	Triggerfinger
ESRI	Orion Networking	WinTech Arrowmaker
Extreme Endeavors	P&LE	XTAR
General Dynamics	Persistent Systems	
Harris RF Comms	Procerus	
Honeywell	QinetiQ	
Hoyos	Redline Communications	

Figure 15. TNT Testbed Industrial Users in 2008 Exepriments

To the business community supporting the experiments (Figure 15), the TNT testbed with it's research services and interfaces, which enable discovery and constraints analysis for frequently immature and disintegrated prototypes, provides a unique incubation path to the market of emerging tactical operations.

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