High Bandwidth Communications for VSWMCM Operations

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LONG-TERM GOALS

The goal of this research and experimentation is to utilize high bandwidth wireless communications to enable and improve collaborative autonomous operations in very shallow water (VSW) environments. Teams of autonomous vehicles can be deployed simultaneously to conduct wide-area surveillance and reconnaissance during Mine Countermeasures (MCM) or Intelligence, Surveillance, and Reconnaissance (ISR) operations. While these vehicles can quickly and efficiently collect vast amounts of data, they must be able to transfer the data to a command ship so it can be assimilated into actionable information for decision makers. High bandwidth data links are required to ensure timely distribution of the sheer volume of data being collected. This is critical for rapid operational planning, whether or not individual vehicles return from their missions. Unmanned aerial vehicles (UAVs) configured with high bandwidth communications links will allow survey vehicles to transfer their data while still underway, improving the efficiency of VSWMCM operations. Researchers at NPS are developing autopilot guidance algorithms that will allow UAVs to adopt and maintain an optimal loitering posture that ensures the best high bandwidth communications link between a command ship and multiple autonomous survey vehicles.

OBJECTIVES

A preliminary objective for FY 2007 was to implement a wireless communications architecture for networking autonomous underwater, surface, and aerial vehicles under the concept of operations described above. This allowed us to complete our primary objective: conducting field experiments to measure the received signal strength of the wireless links sensed by each network node. This experimental data represents the real-time sensory inputs to the guidance algorithms under development. It will be used to characterize the RF field around wireless nodes in the network, and support modeling, simulation, and testing of the algorithms before implementing them on a UAV. Our secondary objective for FY 2007 was to demonstrate this concept of operations on fleet-representative vehicles with the ScanEagle UAV and SeaFox USV at AUV Fest 2007.

APPROACH

Our initial research with commercially-available IEEE 802.11 wireless networking equipment determined that this architecture, originally designed for stationary nodes within a localized wireless infrastructure, was not well-suited to mobile vehicle platforms. Conversely, tests with self-forming, self-healing “Mesh” architectures for ad-hoc mobile networks at the Naval Postgraduate School’s

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quarterly Tactical Network Topology (TNT) field experiments produced promising results. Therefore, our first step for FY 2007 was to incorporate ITT Mesh Wireless Modem Cards onto our autonomous vehicles. Integration into the NPS-developed ARIES underwater vehicle required only the insertion of a PCMCIA card, while integration on the ScanEagle and SeaFox required the addition of a secondary embedded computer, a 1-Watt amplifier, and antenna modifications. This effort culminated in a system of networked, autonomous (underwater, surface, and aerial) vehicles that can perform transparent data relay within an overall mesh network. More importantly, the addition of secondary computers on the ScanEagle and SeaFox allow each vehicle to collect and (in the future) respond to the measured RF sensory data by sending commands to the primary autopilot computers.

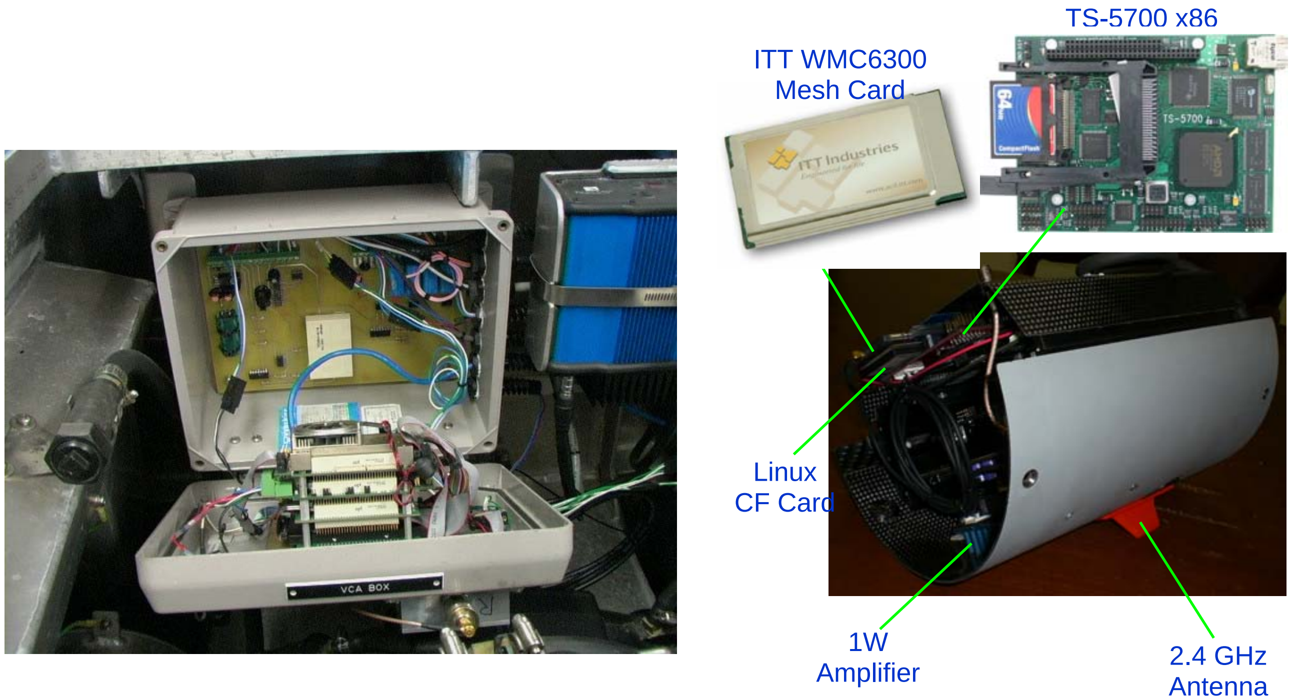

Figure 1: SeaFox secondary computer (left) and ScanEagle avionics bay modifications (right).

The next step in our approach was to conduct several field experiments to measure and log this sensory data. The Mesh card's application programming interface (API) can provide data about the strength of the signal received from each neighboring Mesh card, and the current network routing table for all Mesh cards in range. We wrote software to allow each vehicle computer to extract this information from its Mesh card. In addition, network test software from the Naval Research Laboratory was installed on each vehicle in order to generate representative data streams and quantitatively measure network performance. Under our proposed concept of operations, multiple underwater and/or surface vehicles conducting survey operations will transfer their data through an aerial relay orbiting overhead and capable of long-range communications with the command ship. The ScanEagle system is an ideal aerial platform for this concept. Its ground control station (GCS) communicates with the aircraft and receives analog video through a high-grain tracking antenna that has a communications range of over 100 km. Therefore, while experiments were performed to characterize both halves of this "bent pipe" communications link, most experiments focused on the UAV-USV component.

WORK COMPLETED

This year N sh wireless
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RESULTS

The develo lts.

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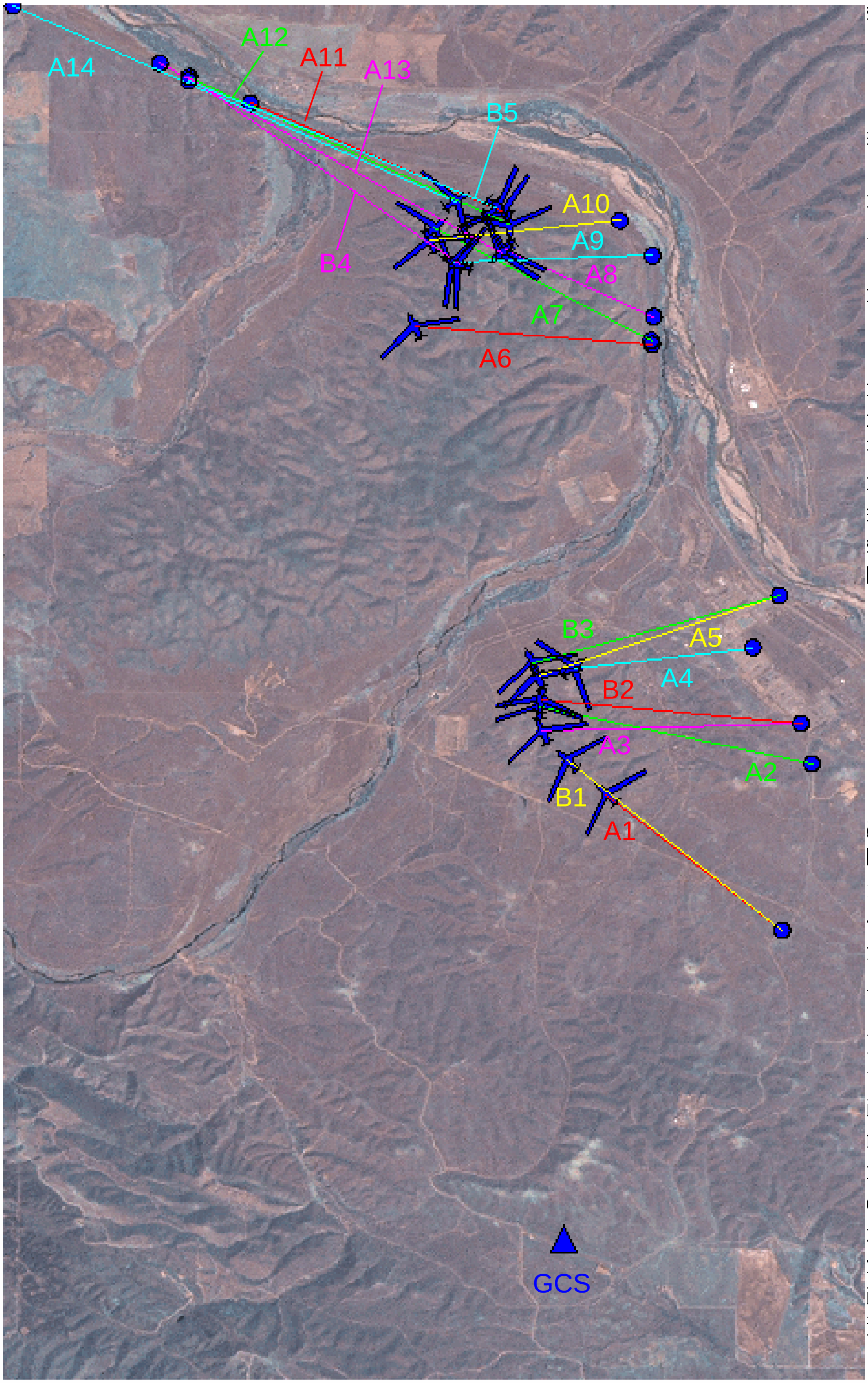

Figure 2. Testing

Table 1: Throughput vs. Total Separation Distance for 100 kB Qcheck Tests

Test Number	Total Link Distance (kilometers)	Throughput (kilobytes / second)
A1	8.9	81
A2	10.5	445
A3	10.0	319
A4	10.0	380
A5	10.8	482
A6	15.4	318
A7	17.0	174
A8	15.6	93
A9	15.8	139
A10	16.1	435
A11	17.4	94
A12	18.2	244
A13	18.3	359
A14	20.1	No Link

Table 2: Throughput vs. Total Separation Distance for 1000 kB Qcheck Tests

Test Number	Total Link Distance (kilometers)	Throughput (kilobytes / second)
B1	10.0	241
B2	10.4	407
B3	10.9	289
B4	17.5	188
B5	18.2	551

AUV Fest 2007, Tyndall Air Force Base, June 2007

This event successfully demonstrated our concept of operations in a maritime environment; however network performance was less than we had hoped based on the May experimental results. Operators at the ScanEagle GCS communicated with SeaFox via ScanEagle to initialize and launch the USV from their remote location. However, network connectivity from GCS to SeaFox via ScanEagle was intermittent and throughput was extremely low. One factor appears to have been network utilization, as this demonstration ran concurrent with several other network users in the same operating area. Of twelve active nodes, six were broadcasting state messages to every other node and at least one was streaming video. We surmise that this quickly saturated the network, making it unusable for high bandwidth data relay. This will require more study on network utilization and management techniques. Nevertheless, Figure 3 shows the maximum separation distance obtained for various “bent pipe” links achieved during this demonstration. These distances are listed in Table 3.

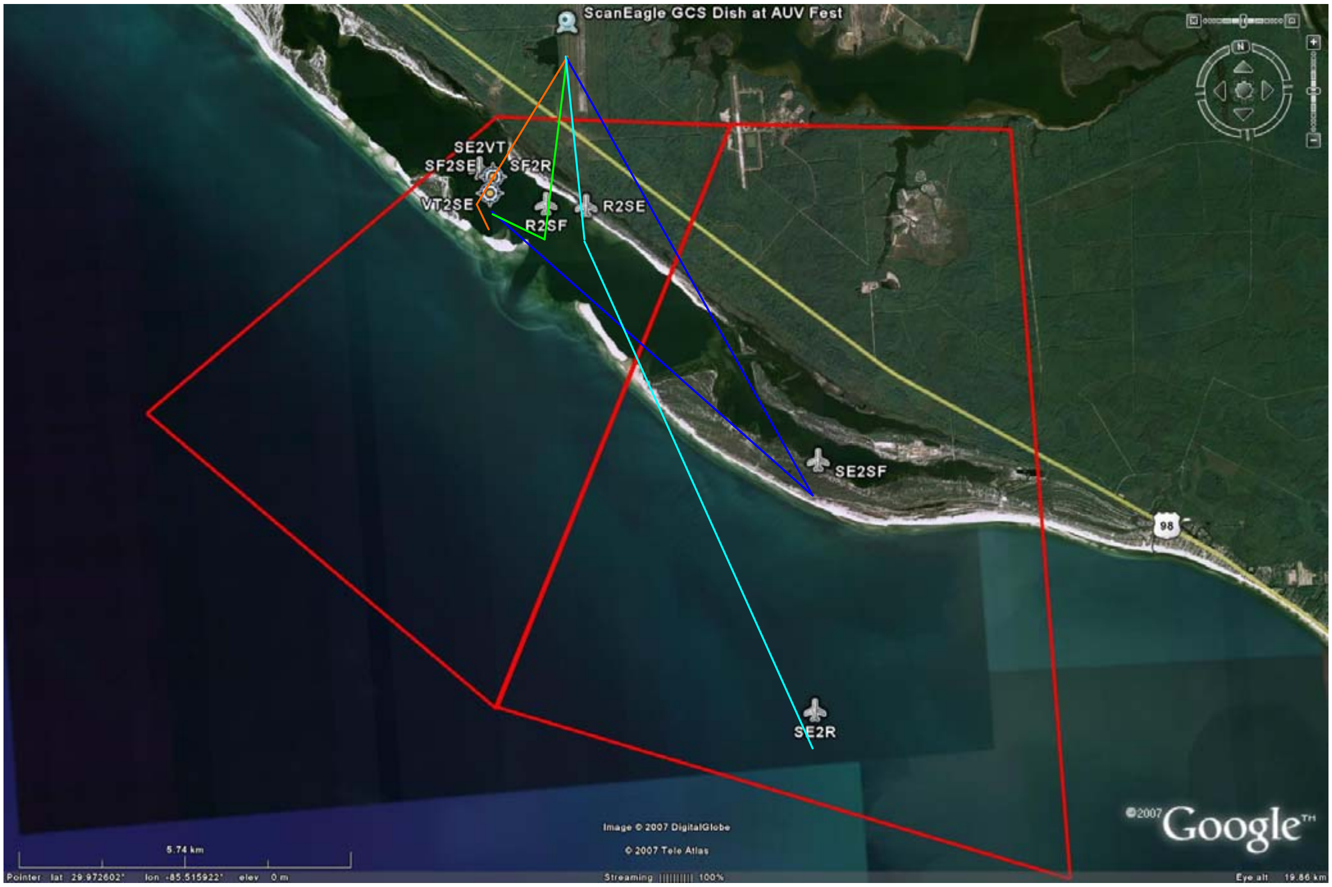

Figure 3: Maximum Link Separation for Autonomous Vehicles at AUV Fest 2007, Tyndall AFB

Table 3: Maximum Link Separation for Autonomous Vehicles at AUV Fest 2007, Tyndall AFB

Network Route	Total Link Distance (kilometers)
GCS to SeaFox via ScanEagle	16.2
GCS to SeaFox via NPS Rascal	4.2
GCS to VT USV via ScanEagle	3.4
GCS to ScanEagle via Rascal	12.7

ScanEagle Mesh Relay, Camp Roberts, August 2007

Another ScanEagle experiment was held at TNT 07-4 on August 18, 2007. The primary objective was to collect detailed signal strength measurements for a ground vehicle as sensed by the UAV. The ScanEagle flew a "lawnmower" flight pattern with one kilometer row spacing oriented both North-South and East-West above the ground vehicle (unamplified, 3 dBi antenna). The pattern was repeated for altitudes of 2000 ft and 3000 ft above mean sea level (MSL). Figure 4 and Figure 5 depict the ScanEagle signal strength recorded on the ground relative to ground vehicle position.

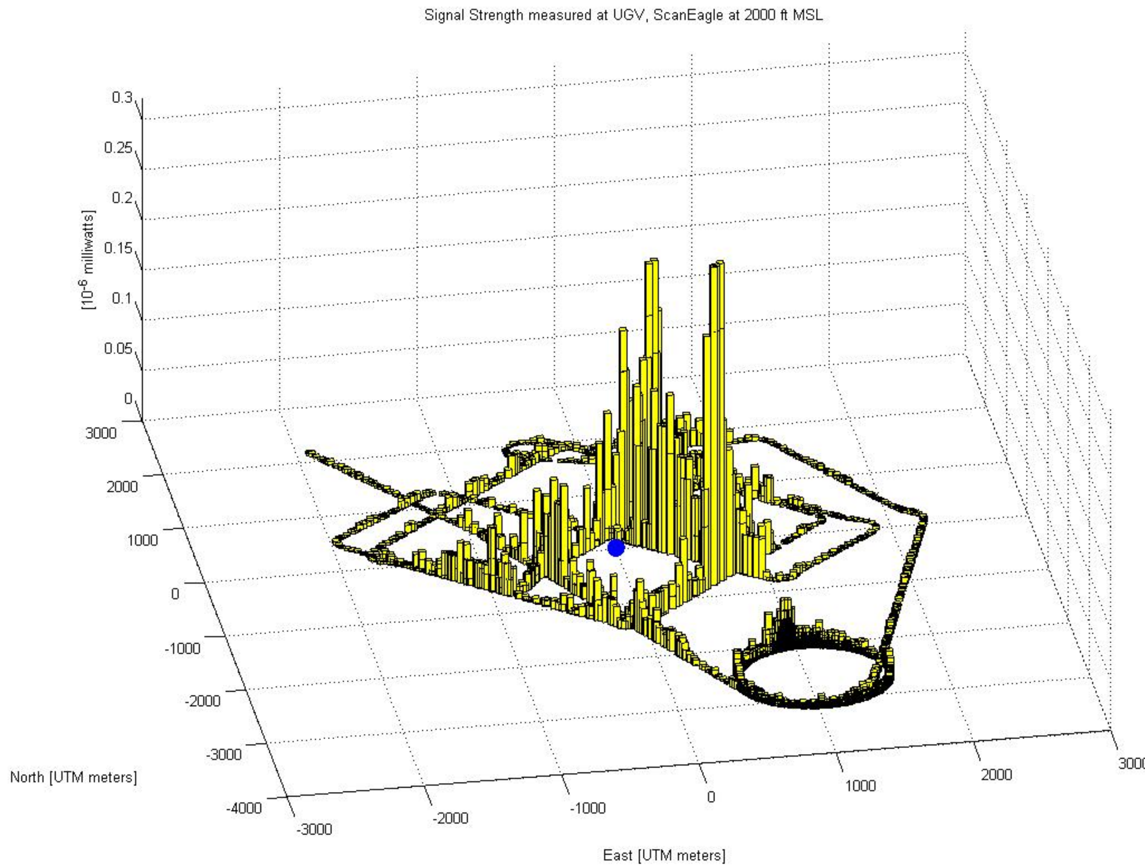

Figure 4: Mesh signal strength measured at UGV for ScanEagle at 2000 ft MSL

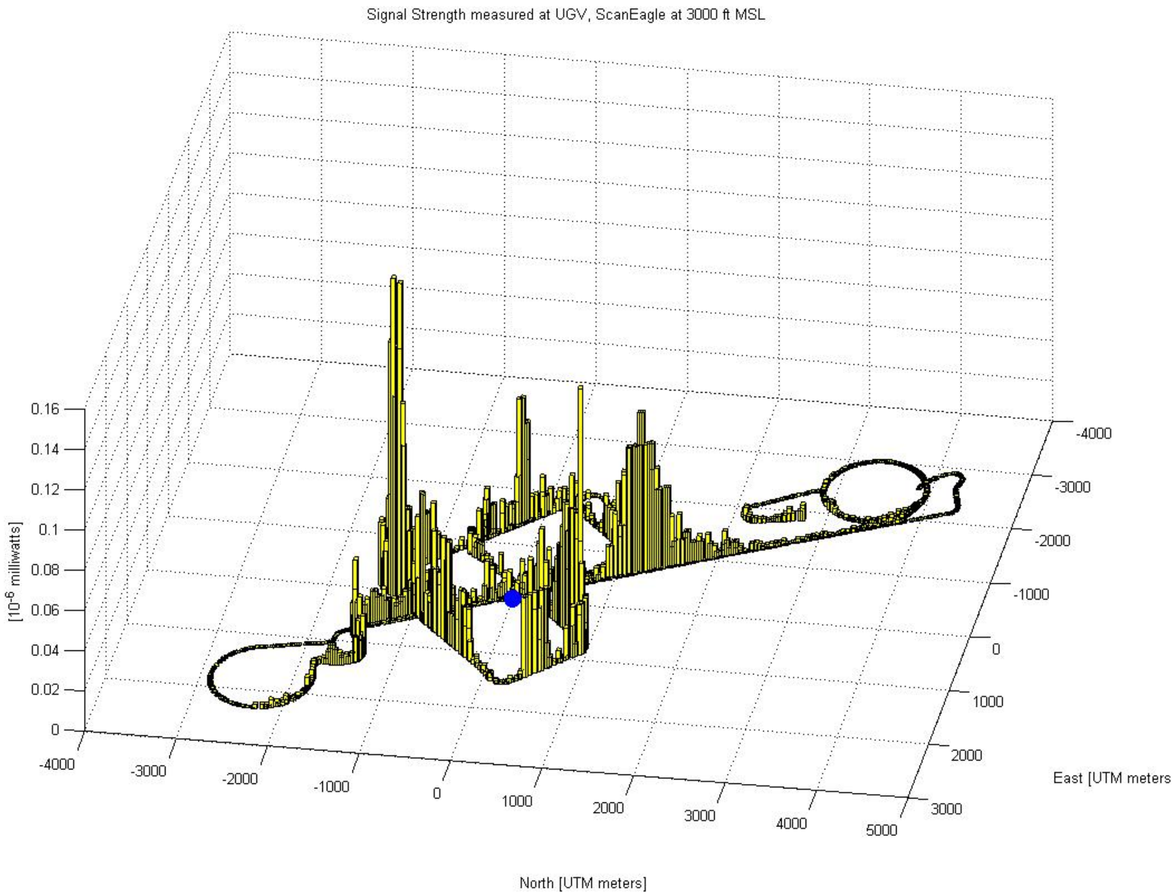

Figure 5: Mesh signal strength measured at UGV for ScanEagle at 3000 ft MSL

A secondary objective was to quantitatively measure network throughput by continuously generating and sending network traffic from the GCS to the ground vehicle. A data stream roughly equivalent to SeaFox USV digital video data rates was generated by the MGEN application running at the GCS. An MGEN application at the ground vehicle recorded the amount of data received (Figure 6). As expected, Figure 7 plots aircraft altitude and GCS-to-ScanEagle signal strength measured by the GCS and by the aircraft. Note that signal strength measured at the GCS (30 dBi antenna) is higher than the signal strength measured onboard the aircraft at the opposite end of the link. In addition signal strength is lower for aircraft at 3000 ft above MSL than for aircraft at 2000 ft above MSL. Subsequent analysis shows that this difference cannot be attributed to distance alone. Figure 8 and Figure 9 reveal a correlation with aircraft heading as it performs clockwise orbits around the commanded points of interest. More precisely, signal strength is closely correlated with aircraft attitude: received signal strength is greatest when the aircraft is heading east because positive roll now points its Mesh antenna directly at the GCS position to the south. While this relationship should be expected, it is important to continue characterizing this behavior since this orbiting behavior is a primary flight mode for most UAVs.

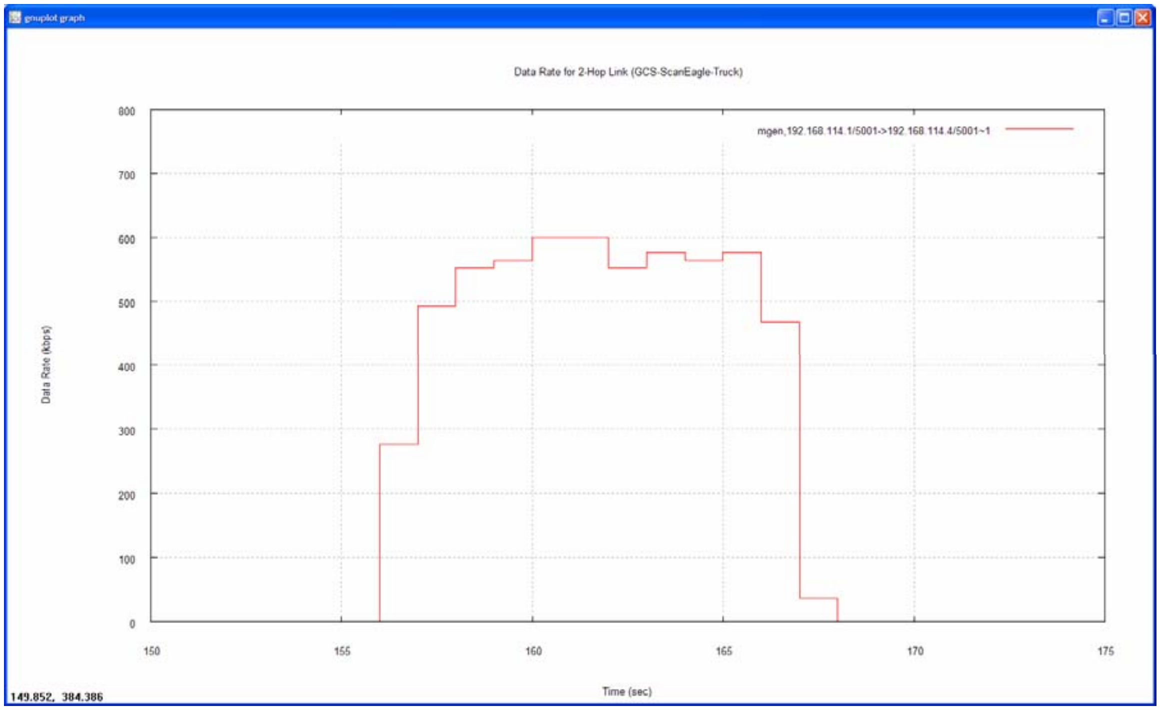

Figure 6: Received throughput of Mesh link from GCS to ScanEagle to ground vehicle

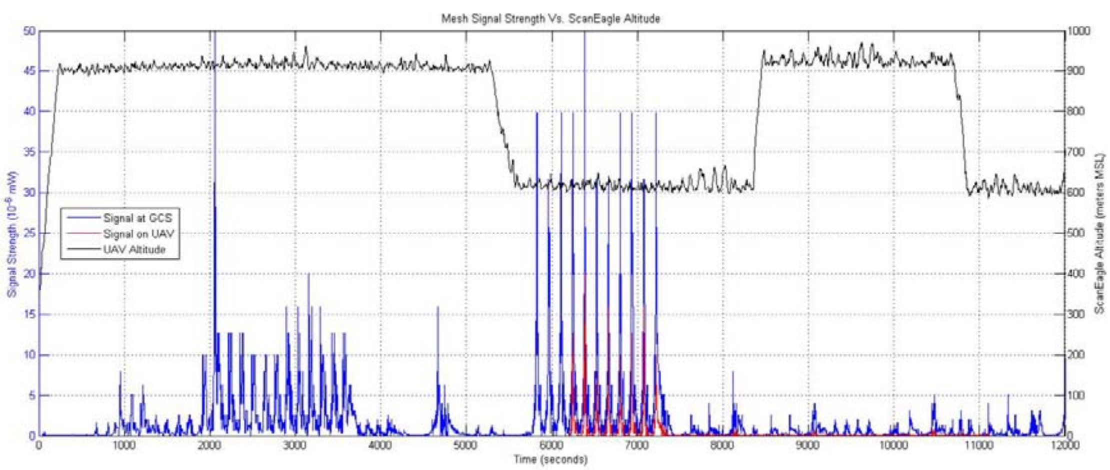

Figure 7: UAV altitude and GCS-to-UAV signal strength as measured by the GCS and ScanEagle Mesh cards

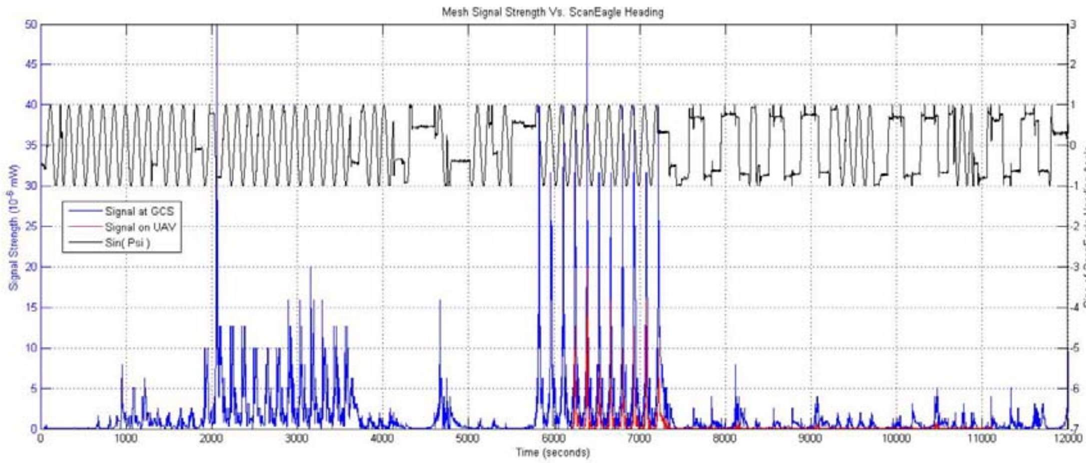

Figure 8: GCS-to-UAV signal strength as measured by the GCS and ScanEagle mesh cards plotted as a function of UAV heading to illustrate a strong correlation with aircraft attitude.

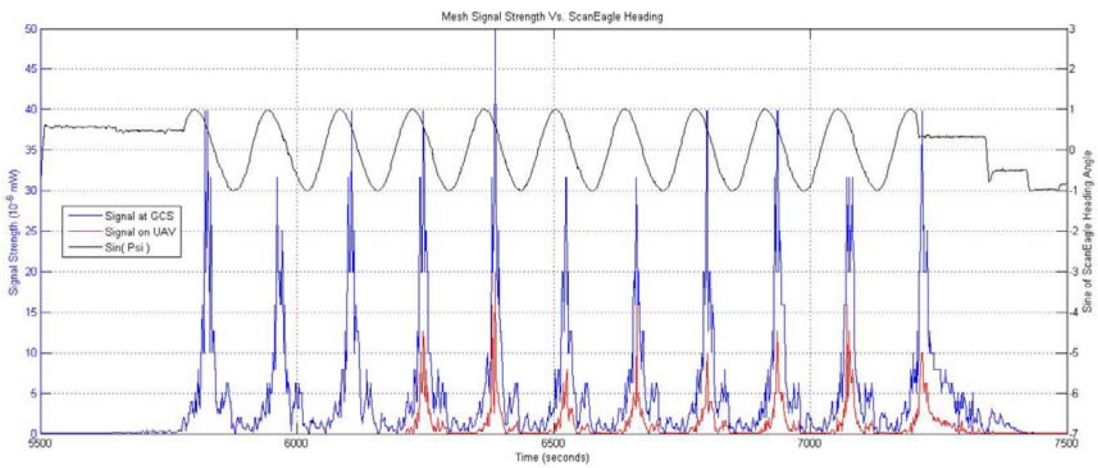

Figure 9: The data from Figure 8 plotted with a different zoom factor for clarity.

SeaFox Mesh Experiments, August and September 2007

Additional SeaFox experiments were performed to further investigate Mesh signal characteristics in a maritime environment under more pristine network conditions (i.e. without uncontrolled network utilization). During open-ocean testing on Monterey Bay in August, SeaFox drove on an approximately constant heading to increase separation from the command ship until the Mesh link failed. Figure 10 shows a close correlation between signal strength and separation distance. Similarly, at a TNT MIO experiment on San Francisco Bay in September SeaFox logged MGEN data from a stationary position while the command ship increased separation. Although the test was terminated prior to completion Figure 11 shows received Mesh data rates sufficient for digital video.

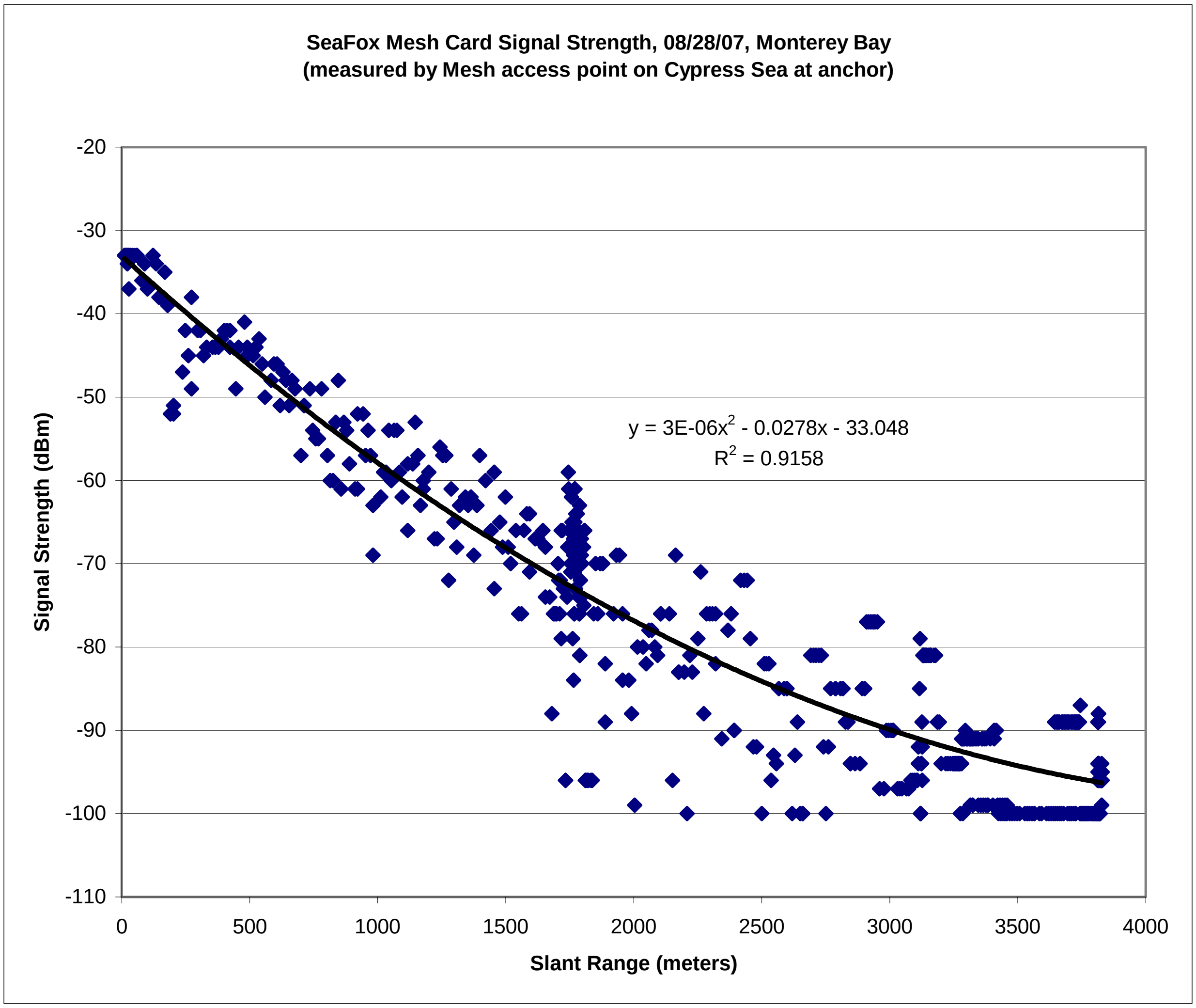

Figure 10: Command ship Mesh signal strength vs. separation distance as measured by SeaFox

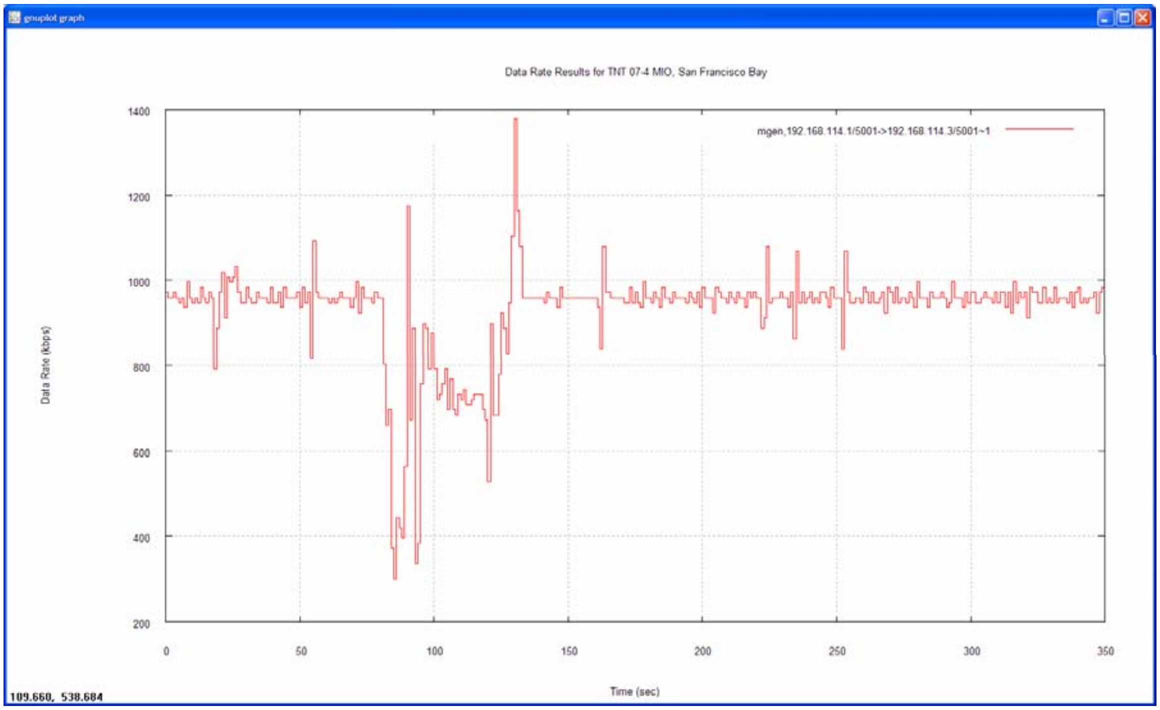

Figure 11: Received throughput of Mesh link from command ship to SeaFox

RELATED PROJECTS

A related project entitled "Coordinated Autonomy for Persistent Presence in Harbor and Riverine Environments" funded the development effort to upgrade the SeaFox USV for Mesh communications and networked autonomous operations.

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http://cs.itd.nrl.navy.mil/work/mgen/index.php
Ixia Qcheck Network Performance Measurement Software:
http://www.ixiacom.com/products/display?skey=qcheck

PUBLICATIONS

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