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Adaptive on-demand networking with self-aligning wireless nodes overview with interactive demo of ground (swf) and maritime (swf) operation - Alex Bordetsky and Eugene Bourakov

Adaptive On-Demand Networking with Self-Aligning Wireless Nodes

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Abstract

The emerging tactical networks represent complex network-centric systems, in which multiple sensors, unmanned vehicles, and geographically distributed units of highly mobile decision makers, transfer and analyze data while on the move. The network could easily scale up to hundreds of cooperating nodes, providing tactical extension to the system-of-systems environment of Global Information Grid [1]. The node mobility as well as ad hoc network topology reconfiguration becomes a powerful control option, which network operators or intelligent management agents could apply to provide for self-forming, self-healing behavior [2]. This in turn requires new techniques for adaptive remote management of mobile wireless nodes; their rapid remote or autonomous reconfiguration at both physical and application layers, subject to changing operational requirements.

We name this new adaptive tactical networking management paradigm as Network-on-Target (NoT). It is assumed that the NoT process starts at the level of Situational Awareness Interface used by the local or higher echelon commander, to point onto the Target, which in this case is the site to be reached by the self-configuring network. In response the mobile networking node, i.e. small boat, light reconnaissance vehicle, or operator are moved to the area to extend the tactical mesh. However, if site is too far, or the preceding links are about to break down, the UAV is deployed to stretch the network further to the remote most node , or to heal the overstretched intermediate link. This in turn would require rapid and frequent re-alignment, of the antenna assets including panel switching and tune-up decisions made right at the level of local commander situational awareness view. More so, the commander's remote advisers, located thousands miles away of surveillance and targeting area would be able to see the effects of the healing assets deployment in the Situational Awareness view and assist the commander in re-aligning and stretching the mobile network to the target area.

In this paper we describe an innovative solution, developed at the Naval Postgraduate School Center for Network Innovation and Experimentation (CENETIX), enabling the Network-on-Target process by multiplatform control (separation of control and data links) and remote re-alignment of the self-forming OFDM-based tactical networking assets.

Approach

Since the beginning of 2004 the group of Naval Postgraduate School researchers together with their sponsors started to put together Tactical Network Topology (TNT) testbed to address the challenges of emerging tactical networks integration and operation through the series of field experiments. The testbed (Fig. 1) represents multiplatform plug-and-play environment for emerging sensor - unmanned vehicle - decision maker networks, in which terrestrial long-haul wireless network is represented by the OFDM (Orthogonal Frequency Division Multiplexing) 802.16 backbone, combined with Unmanned Aerial

Vehicles (UAVs), air balloons, Light Reconnaisance Vehicles (LRV) on the ground, unattended sensors, and mobile operation centers.

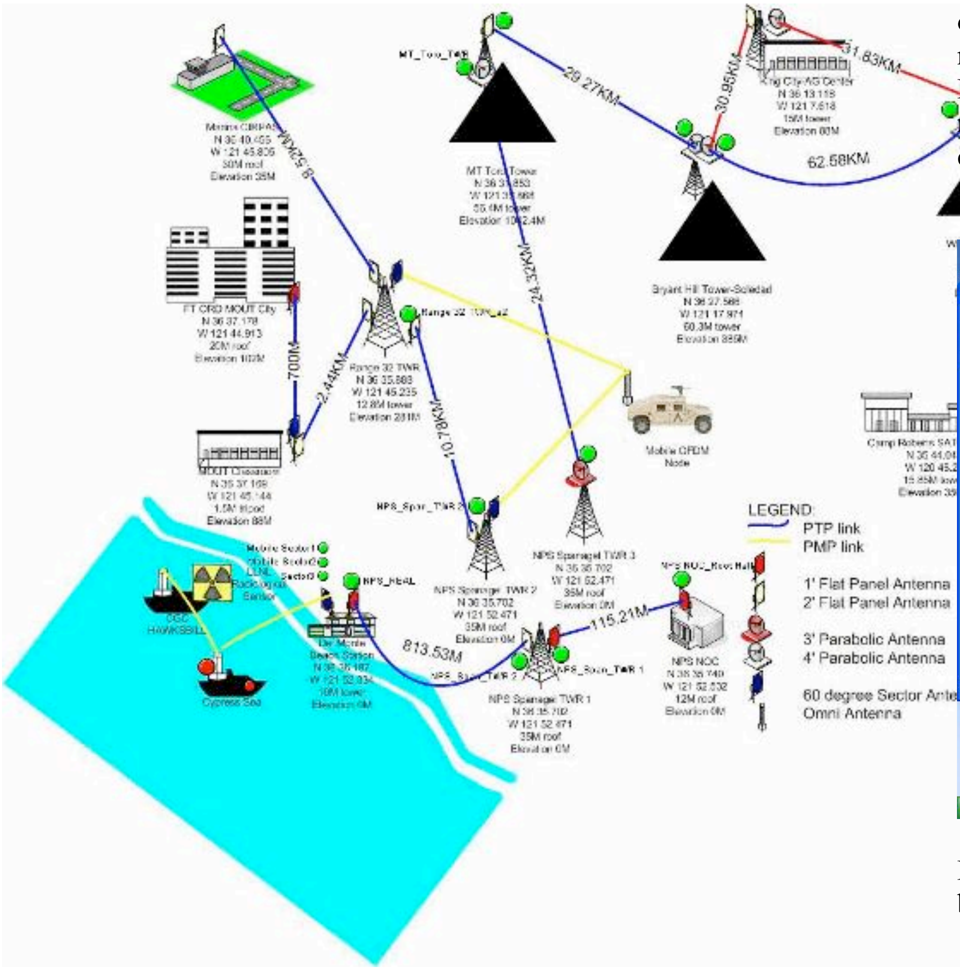
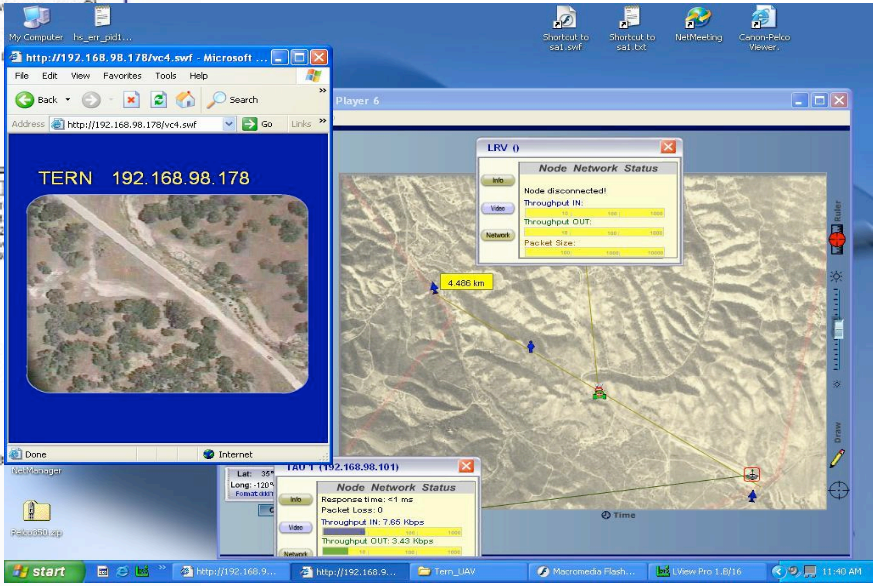


Figure 1. OFDM Backbone of NPS Tactical Network Topology testbed.

By conducting series of discovery and constraints testing experiments [3] with sensor, unmanned vehicle, and decision maker nodes of the tactical "network-on-the move", we've identified the fundamental role of applying multiplatform networking solution for reconfiguring the nodes or the whole networking segment of self-forming tactical network. For example, Figures 2 and 3 show how changing the distance to the next airborne node of mesh network from 4.4 to 7.6 km could effect the clarity of the video feed. This in turn sets up new operational requirements for node mobility and its rapid re-configuration.



TERN 192.168.98.178

Node Network Status

Node disconnected!

Throughput IN:

Throughput OUT:

Packet Size:

Node Network Status

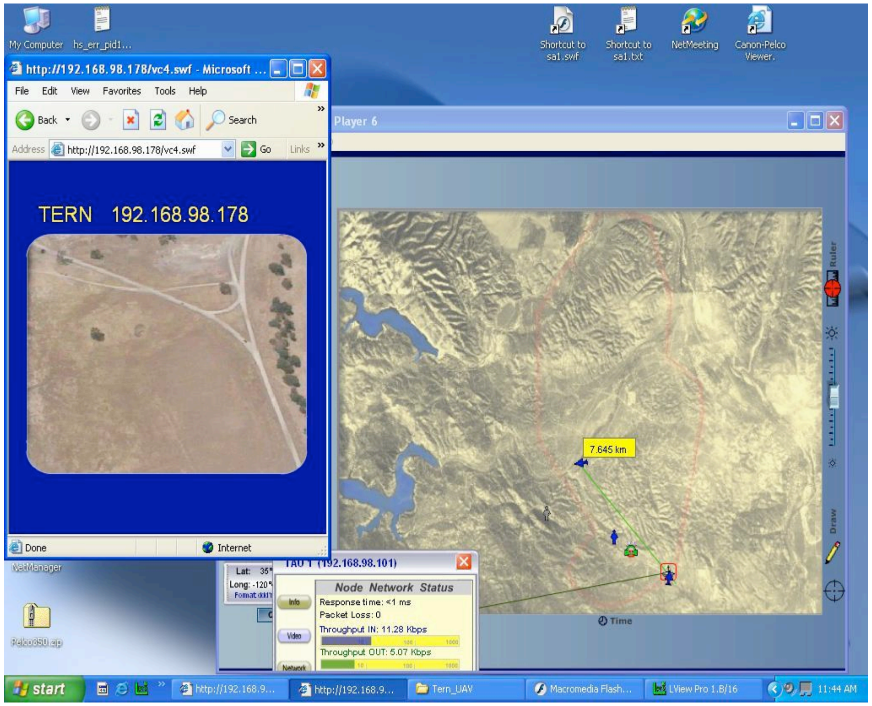
Response time: <1 ms

Packet Loss: 0

Throughput IN: 7.65 Kbps

Throughput OUT: 3.43 Kbps

Figure 2. Mesh wireless networking with UAV at the distance of 4.3 km between neighboring nodes with good video feed.



Node Network Status

Response time: <1 ms

Packet Loss: 0

Throughput IN: 11.28 Kbps

Throughput OUT: 5.07 Kbps

Figure 3: The UAV is 7.4 km apart of the neighboring node, network is still working, but video quality is no longer operationally viable.

Self-aligning OFDM Node controllable over the radio link

Current TNT experimentation network uses OFDM 802.16 technology to provide a long haul link enabling high bandwidth connectivity up to 54 Mbps. It utilizes technology of Redline Communications (http://redlinecommunications.com/), the TNT's industrial partner, manufacturing wide range of OFDM equipment. The basic Redline OFDM node consists of IP-enabled high frequency radio and outdoor transceiver. This set may work with Omni directional and/or variety of directional antennae.

The Redline OFDM radio is designed to provide a long haul 802.16 wireless link between stationary nodes, which limits its direct application to tactical nodes, required to be highly mobile, rapidly deployable, robust, and easily operable. More so, allocating the OFDM antennas to tactical vehicles and other mobile nodes, requires precise simultaneous alignment at both ends of the OFDM link.

This issue may be resolved by utilizing self-aligning OFDM (SAOFDM) unit with OFDM antenna controlled over the wireless link, which is separate from the main OFDM link. The control link would be used for obtaining SAOFDM unit GPS position and OFDM link signal strength (RSSI). Based on this information the antenna control commands will be sent to mechanical pan-tilt rotator enabling antenna alignment, which in turn improves the OFDM link quality.

The key new element is commercial pan-tilt rotator (Figure 4), examples of which could be found at http://www.dperception.com/. The pan-tilt rotators are modular computer-controlled over the serial port devices designed for fast, accurate positioning of heavy payloads. They provide high torque, while maintaining speed, precision, and a very small form-factor.

Initially we envision the SAOFDM control link commands to be sent over the 900 MHz link using FeeeWave Ethernet radio (http://www.freewave.com/FGRHT900.html) connected to the Single Board Computer (SBC) over the network switch. The SAOFDM architecture also requires two sensors: the GPS and IMU, both connected to the SBC for providing SAOFDM GPS position and antenna orientation.

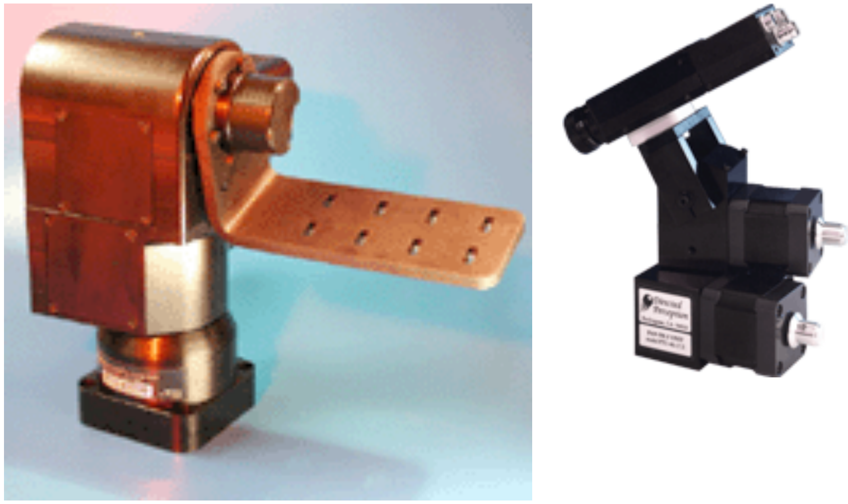


Figure 4. Pan-Tilt Units (PTU)

The SAOFDM control process is provided by Single Board Computer, which is running Windows XP operating system executing the following tasks:

- RSSI, SNR, and operating frequency gathering from the OFDM radio;
- Obtaining GPS and IMU data from the sensors;
- Executing self-aligning algorithm;
- Integrating with local area network;
- Providing PTU rotator control over serial port.

Unfortunately the implementation of 900 MHz link is limited in the environment effected by radio link jamming or radio interference or non line of sight problems. To resolve the problem we propose to use multi-path capability enabling selection of alternative wireless links. Given the fact that control command are sent in a form of simple text message, which could be transferred by practically any low-bandwidth link, the other communication channels, such as Iridium and GPRS, may be employed. The GPRS is beneficial for urban area applications, as it's widely available via commercial cellular telephone services. The Iridium or similar satellite-based communication represent the only alternative that works when neither of above described links is operational. It is important to emphasize that SAOFDM control link may be extended by utilizing relays (repeaters) or multi-hop mesh networking techniques. Also, it is essential for the 900 MHz radio link technology to use the relay mode as a standard option. In case multi-hop mesh network is available, it could also be used to carry on the control link data.

The complete package of all devices representing proposed solution for low bandwidth SAOFDM control link is shown on Figure 5. Figure 6 illustrates the overall multi-path compatible equipment set.

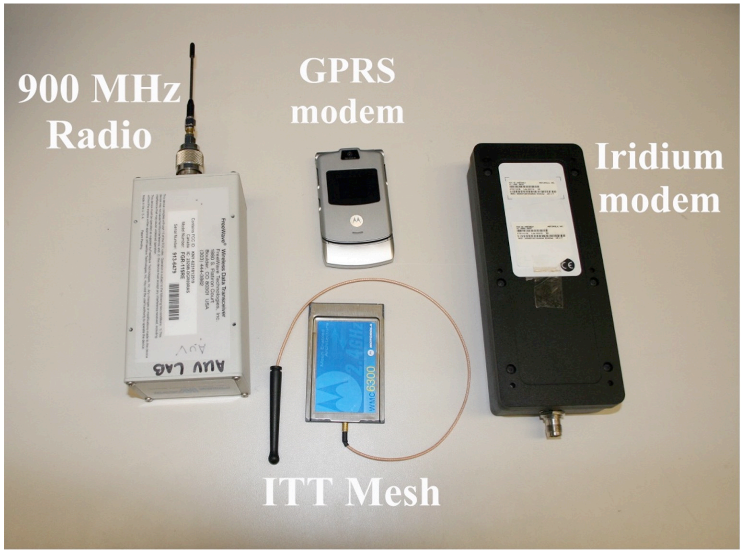
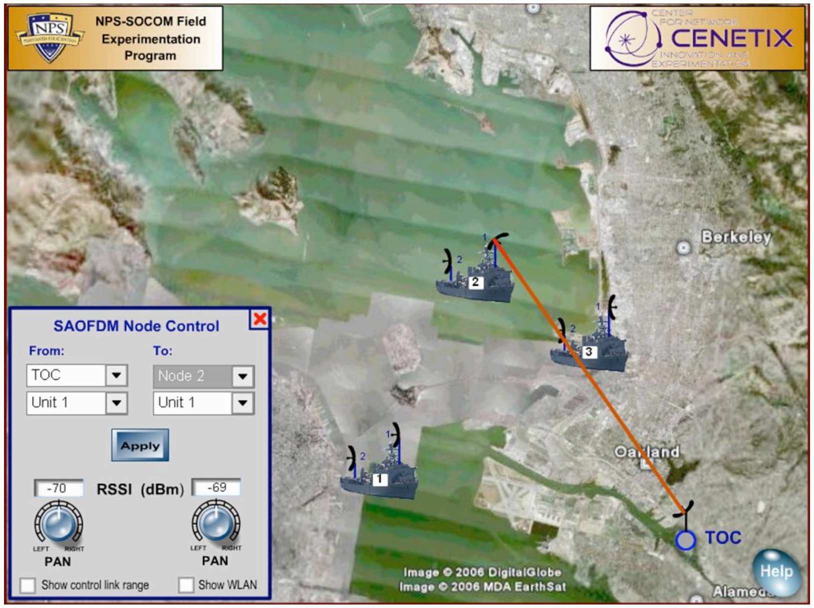


Figure 5. Control link communication devices

Figure 6. Overall equipment set.

Application Scenario

The proposed solution enables the NoT process in the following way. Suppose you need to extend adaptive tactical network Ship 2 moving out of the TOC to intercept the target. By remotely targeting the antenna directly of the Situational Awareness View (the control menu in Figure 7) the OFDM link is established. The red line highlights it is feasible.



From: TOC, Unit 1

To: Node 2, Unit 1

-70 RSSI (dBm) -69

☐ Show control link range ☐ Show WLAN

Figure 7.

However, as local commander moves ship out to the point of intercept (Figure 8) the OFDM based tactical data link breaks down. The SA View shows it is infeasible, three OFDM WLAN circles don't overlap. The control panel shows Restore Link option.

From: TOC, Unit 1

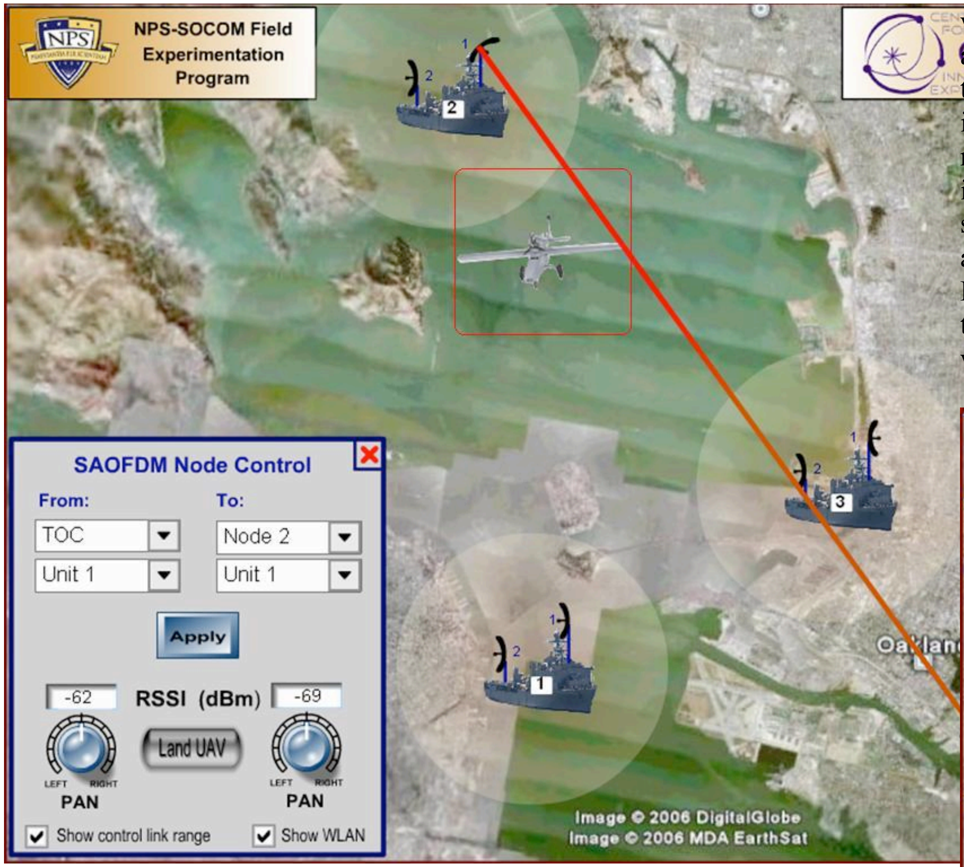
To: Node 2, Unit 1

-70 RSSI (dBm) -69

☑ Show control link range ☑ Show WLAN

Figure 8.

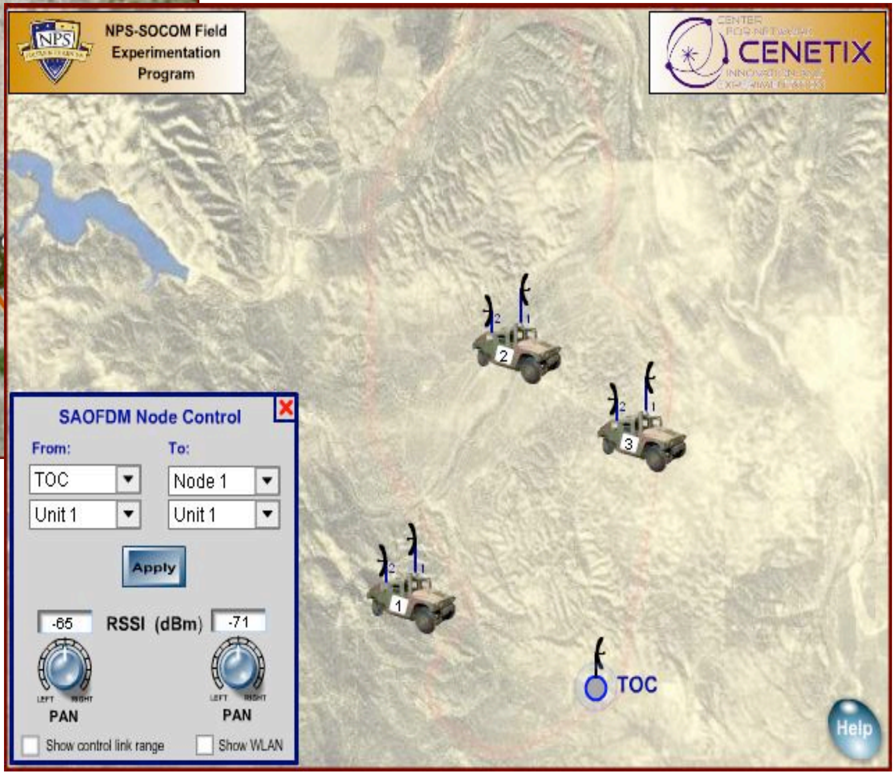
By initiating Restore Link option local or remote commanders are calling for UAV to fly out for extending the control link to Ship 2 target position. The next figure (Figure 9) shows that this solution is doable, and more so suggest the Way Point for UAV loitering.



From: TOC, Unit 1
To: Node 2, Unit 1
RSSI (dBm): -62, -69
☑ Show control link range
☑ Show WLAN

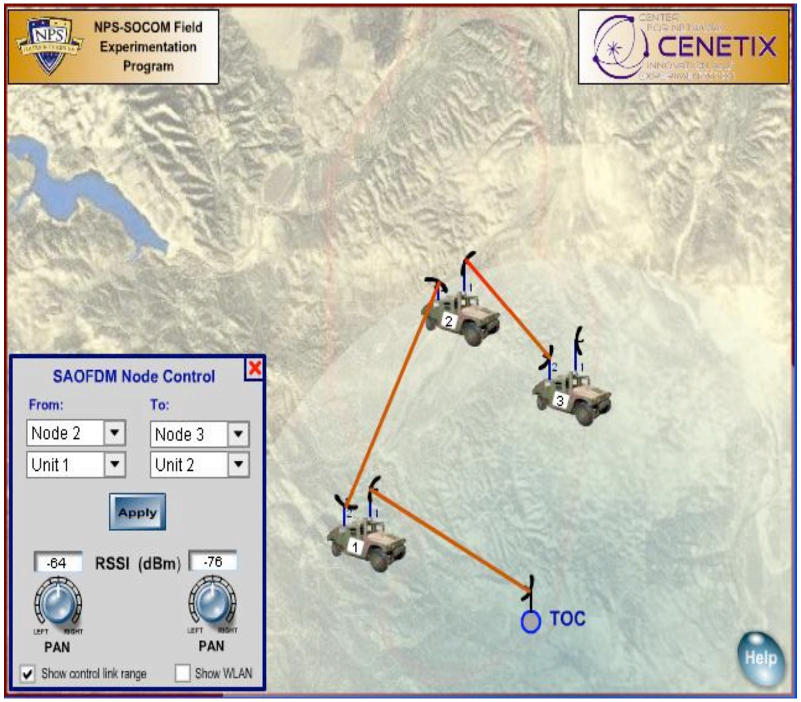
Figure 9.

Figures 10 - 12 illustrate another example of utilizing OFDM node controllable over the radio link for supporting collaborative actions of small mobile units on the ground. Suppose, the received surveillance task requires stretching high bandwidth OFDM link from the site of the Tactical Operations Center to mobile node 3 joining the network. However, the link couldn't be established immediately because of terrain obstacles obstructing the TOC-mobile node 3 line-of-sight. At the same time, allocating additional mobile nodes 1 and node 2 along the valley would resolve the connectivity problem, subject to rapid remote OFDM antenna re-alignment. In this case radio control link would be used to transfer the GPS position for each pair of nodes trying to link, enabling initial antenna self-alignment, link quality feedback, and, if needed, manual antenna alignment at each node via the SAOFDM control panel interface. Using the SAOFDM Node Control panel local commander or small unit network operator could assign particular sequence of alignment procedures to get node 3 connected to the TOC as shown on Figure 11. Correspondingly, extending the control by the UAV utilizing the 900MHz relay node, as shown on Figure 12, would allow to connect with mobile unit 3, under the non-line-of-sight conditions.



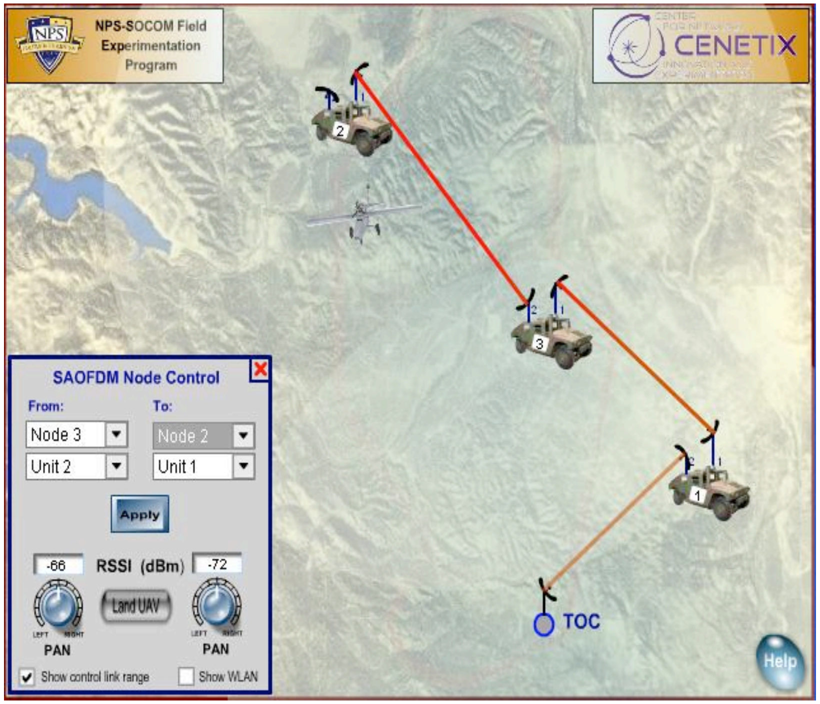
From: TOC, Unit 1
To: Node 1, Unit 1
RSSI (dBm): -65, -71
☐ Show control link range
☐ Show WLAN

Figure 10. Original positions of TOC and three mobile nodes



From: Node 2, Unit 1
To: Node 3, Unit 2
RSSI (dBm): -64, -76
☑ Show control link range
☐ Show WLAN

Figure 11. Self-aligning OFDM technique in action over 900 MHz control link



From: Node 3, Unit 2
To: Node 2, Unit 1
RSSI (dBm): -66, -72
☑ Show control link range
☐ Show WLAN

Figure 12. Self-aligning OFDM technique in action over 900 MHz control link extended by UAV relay node.

Maritime Interdiction Experiment

The proposed adaptive networking solution has been recently tested by supporting the Maritime Interdiction Operation (MIO) Experiment conducted in San Francisco Bay with help of US Coast Guard, Oakland Special Police Unit, and Alameda County Sheriff’s vessels.

The SAOFDM unit was installed on the board of the Alameda County Sheriff's Boat, playing the role of the Boarding vessel (Fig.13) . It served ship-to-shore communications with closest wireless node ashore at Yerba Buena Tactical Operations Center.

Figure 13. First SAOFDM node in action onboard of the Alameda County Sheriff's Boat (Boarding Vessel).

The Boarding Vessel is supposed to move rapidly for intercepting the vessel of interest (Target Vessel). As it get close enough to the Target Vessel (1.5-2 mi), it deploys the Boarding Party, which stretches the high-bandwidth point-to-point network to the Target Vessel . The two vessels continue to move as the search process of Target Vessel proceeds. The network should provide connectivity and level of bandwidth capable of carrying on several video streams and data sharing situational awareness applications While on the move at speeds 3-5 nm/hour and zigzag maneuvering of the Boarding Vessel trying to chase the Target, the SAOFDM node by using designed self-aligning algorithm applied via the control channel enabled to keep ship-to-shore directional link intact, providing transmission rates up to 5 Mbps. Figure 15 illustrates the basic components of SAOFDM payload, control unit and data communication elements in action.

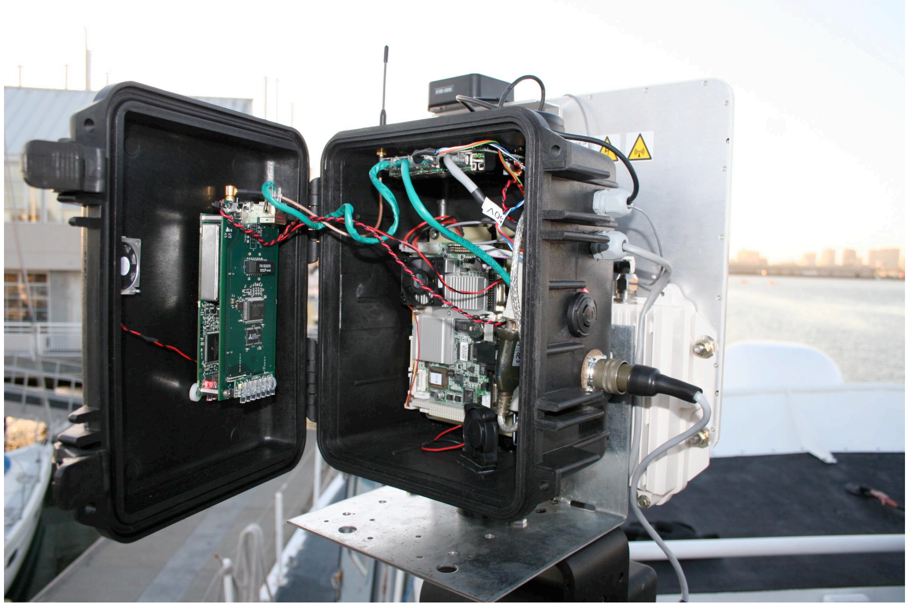


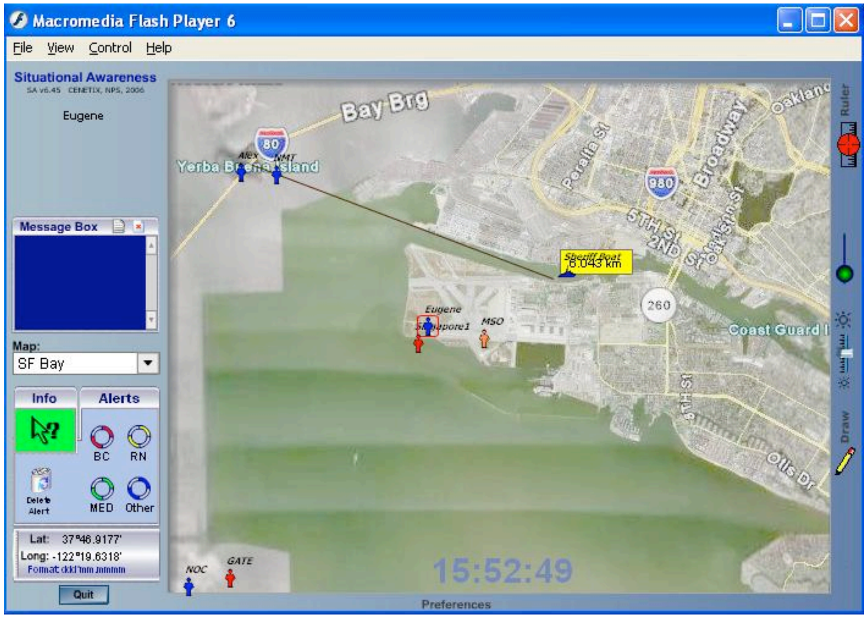
Figure 15. Basic components of SAOFDM node deployed to the Boarding Vessel.

Figures 16 and 17 illustrate the Tactical Operations Center view of ship-to-shore adaptive communication work across the Bay and in the Oakland Channel (obstructed by huge Port cranes and cargo ships).

Map: SF Bay

Lat: 37°48.4756'
Long: -122°22.0021'
Format: ddd°mm.mmmm

Figure 16. Adaptive SAOFDM 3-5 Mbps Ship-to-Shore link operational on-the-move in SF Bay at distances of 4.4 km.



Map: SF Bay

Lat: 37°46.9177'
Long: -122°19.6318'
Format: ddd°mm.mmmm

Figure 17. Adaptive Ship-to-Shore link with Boarding Vessel operational behind port structures in the Oakland Channel.

Conclusion

Application of self-aligning antennas makes self-forming on-demand networking with unmanned vehicles feasible and rapidly deployable. It enables one of the most sought of emerging tactical network qualities, i.e. the capability of linking at the tactical level via the high bandwidth directional links. The SAOFDM technique provides this capability by enabling self-forming and self-aligning of OFDM nodes via the separate radio control link. The proposed SAOFDM solution is one of the first steps in developing this new trend in agile adaptive tactical network. The described test of proposed solution in the Maritime Interdiction Operation experiment, conducted with two vessels on-the-move demonstrated capability of the SAOFDM solution to extend broadband ship-to-shore wireless link up to 4.5 mi off shore. More so, the link continued to support 3 Mbps demanding video streams while vessel on the move at 3-5 nm/hour.

Acknowledgments

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