High Bandwidth Wireless Networks for Unmanned Maritime Vehicle Communications

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Need Statement

• Unmanned Maritime Vehicles (UMVs) can collect environmental data quickly and economically
• Tactical applications (ISR, OMCM) can benefit from simultaneous deployment of multiple UMV systems
• Data must be collected, distributed, and assimilated into meaningful information quickly
• Volume of data can overwhelm existing comms systems
• Higher bandwidth communications can significantly improve collaborative UMV missions
Operational Concept

- Blue Force tasked with finding the best beach landing site
- Teams of UMVs deployed for wide area reconnaissance & VSWMCM
- Challenges and considerations:
  - Interoperability of different UMVs
  - Sonar, video, and bathymetry data is voluminous
  - Data must be passed back for rapid assimilation, assessment & planning
  - Not always feasible (or desirable) for vehicles to return from missions
Solution

- Enable UMVs with high bandwidth data links (currently 802.11b)
- Employ UAVs to extend comms to C2 ship in international waters

**BENEFITS**
- Common WLAN architecture
- Overcome comms range limitations
- Increased UMV time on station
- Data transfer: no more “snippets”
- C2: facilitates coordinated behavior

UMV (AUV, USV or Crawler)
NPS ARIES
(Acoustic Radio Interactive Exploratory Server)

**FEATURES:**
- 802.11B Wireless LAN antenna
- GPS, DGPS receivers, Kearfott INS
- 900MHz Freewave modem
- APL:UW Blazed Array Forward Look Sonar
- Benthos Telesonar Acoustic Modem
- RDI 600KHz ADCP
- Video Camera
- Digital Video Recorder
NPS Wireless Network Experiments

• Quarterly USSOCOM field experiments:
  – 2003-04: STAN
  – 2005: TNT

• Employ COTS networking equipment in operationally relevant scenarios
  – Enhance warfighting capability of SOF with wireless links to vehicles and sensors

• Demonstrate tactical utility of WLAN

• Test & evaluate network performance and robustness on the battlefield
Experiment Results

**IEEE 802.11b**
- Provided a reliable TCP/IP compliant data link
- Total link length of 3 nodes with ranges out to 28 km
- File transfer rate vs. range:
  - 2 Mbps under 1 km
  - 500 kbps from 3 km to 22 km
  - 200 kbps at 28 km

**IEEE 802.16 (OFDM)**
- Max range (LOS) of 13 km
- Used for wireless backbone from NPS to CR (>150 km)
- Data rates up to 6 Mbps
Optimal UAV Positioning

- UAV positioning is critical to maximize data throughput
- Signal strengths of surface nodes can be measured by spectrum analyzer
- Use sensory-based navigation to autonomously position the UAV for optimal throughput
- As surface vehicles enter/exit the network topology, UAV automatically repositions

$$V_i = \tau e^{-\frac{(x-x_i)^2}{\sigma_x^2}} -\frac{(y-y_i)^2}{\sigma_y^2}$$
Seaweb Underwater Comms Network

- Extend command and control comms range (node-node distances of 2500 m)
- Ad Hoc underwater tracking and navigation aid
- Mobile nodes can function as data trucks or communications gateways
UMV Testing & Data Acquisition

High Bandwidth WLAN
- UMV-recorded data is available instantly
  - Vehicle recovery not necessary
  - Wireless download to operators and analysts
- More tests and data per range time
  - Onsite mission review (i.e. navigation data or sonar imagery)
  - Permits vehicle re-tasking or reprogramming

Seaweb Underwater Comms Network
- Ad Hoc underwater tracking range
- Extend command & control comms range
Conclusion

• Benefits of COTS Wireless Networks for UMV T&E:
  – Low cost
  – Reliable
  – Readily available
  – Easy to administer
  – Industry standard protocols
  – Promote interoperability

• Issues requiring attention:
  – Easy to jam
  – Security considerations for sending classified data
Backup
General Methodology

- Model signal strengths with representative Gaussian distributions
- Estimate the intersection of the distributions as another Gaussian function
- Use Artificial Potential Fields together with a Sliding Mode Controller to enable autonomous UAV navigation
- Using the intersection of signal strengths from the surface network nodes ensures that there exists at most one global maximum

\[ \text{Intersection of Gauss Functions} \]

\[ V_{\text{total}} = V_f + \sum_{i=1}^{\infty} I_i V_s \quad \text{for } i = 1, \infty \]
Sensory-Based Navigation

• The measured signal strength can be used for UAV navigation
• The intersection of multiple surface nodes signal strength is where the maximum data transfer rate should be.
• Artificial Potential Fields is a technique which can be applied for an autopilot algorithm for UAV navigation
Artificial Potential Fields

• Draws from Potential Field Theory in Physics
• APF traditionally thought of for Obstacle Avoidance

• Basic idea
  – A vector field is constructed consisting of a preferred path and obstacles
  – Desired path has an attractive force (gradient is steep)
  – Obstacles have a repellant force (gradient is shallow)
  – At each navigation step the field gradient is calculated and the vehicle navigations toward the steepest gradient
Artificial Potential Fields

• Limitations
  – You need to be able to identify the obstacles in advance
  – Trap situations can occur due to local minima
  – Difficulties in passage between closely spaced obstacles
  – Oscillations in the presence of obstacles
  – Oscillations in narrow passages

• Good News
  – For this particular application none of these present difficult issues for UAV navigation
  – The Vector field is an intersection of signal strength vs an additive field so that calculation of the additional attractive object is straightforward.
UAV APF Algorithm
(Conceptual Overview)

- Support vessel at sea
- AUV operations are underway
- UAV launches from the ship
- Through prior knowledge and over-flights
  UAV characterizes signal strength of sea
  nodes
- UAV start/defaults to waypoint nav
- When AUV surfaces Freewave msg
  (900MHz) sent to UAV giving position
- UAV calculates the Total vector field and
  reverts to APF Navigation
- When in vicinity UAV uses onboard
  sensors for fine tuning positioning

⭐ AUVs, Crawlers
APF Algorithm
(Conceptual Overview - continued)

• As vehicles become available the intersecting calculations determine if there is an optimal position
• If no optimal position is available UAV continues with present loitering position until data transfer is complete
• AUV waiting to transfer data either waits for the UAV to reposition or continue on its mission
• Many other variants possible
  – UAV collects from one node and acts as a data bus

★ AUVs, Crawlers
APF UAV Navigation
(Mathematical Steps)

• Initially using a Gaussian equation to model the SNR ratios of the surface vehicles.
• Construct the intersecting volume – again modeled as Gaussian volume using the max/mins to determine $\sigma_x \sigma_y$
• Orient the volume to the vector field through Euler azimuth transformation
• Bearing calculated based on the highest gradient in the vector field