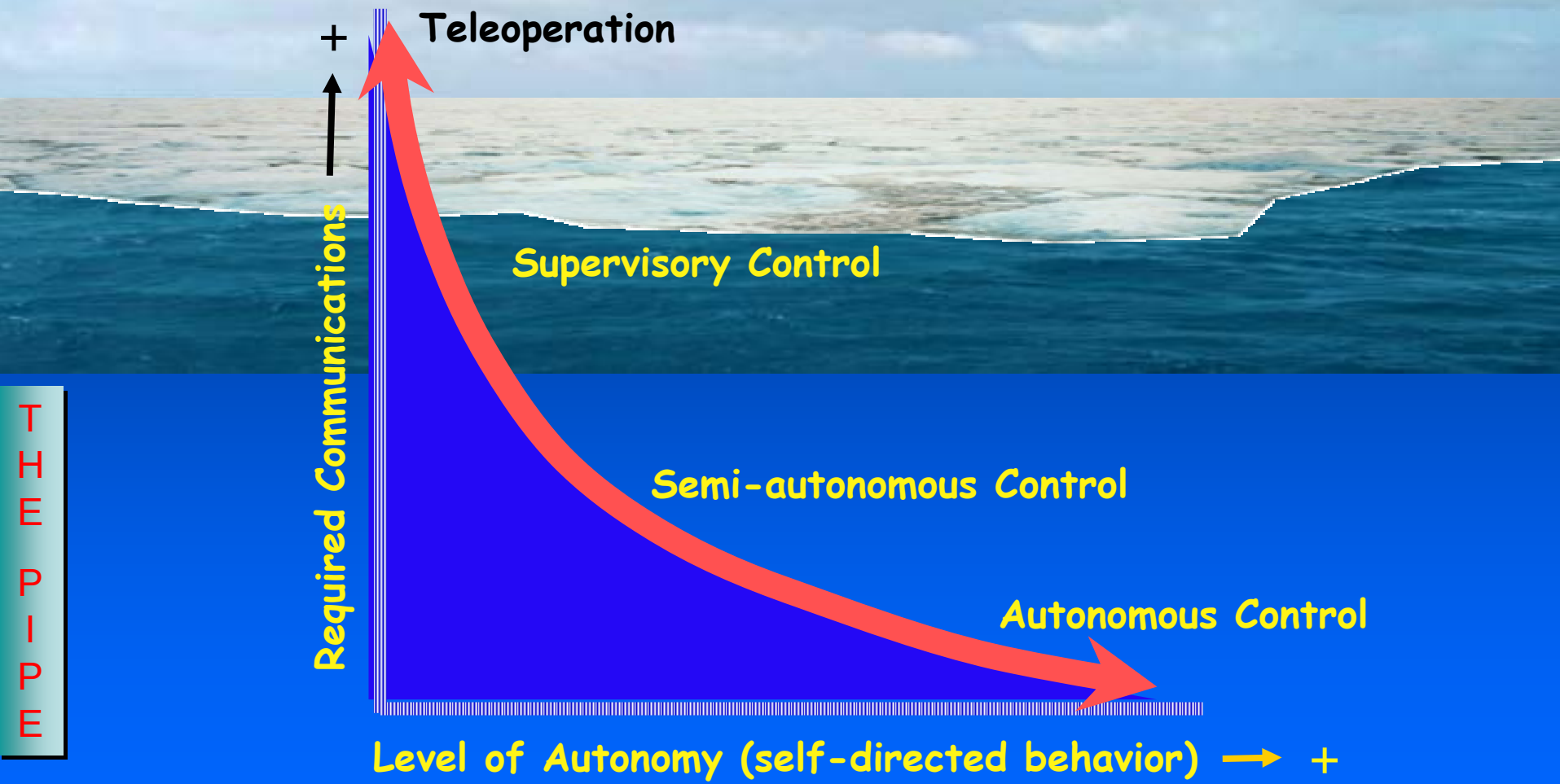
# Objective Is To Identify

- What are the Requirements
- What are Current Capabilities
- What Gaps exist – Prioritize
- Who is Doing What
  - In Other Communities
- What Should be done
  - What Problems to Focus on

# Components of Communication

- The Pipe - Physical Link – The Channel
  - Bandwidth Range Product
  - Interoperability
  - Latency
- The Network of Pipes
  - Data Reliability
  - Media Access
  - Ad Hoc Routing
  - Store & Forward
- The Information In the Pipes
  - Priority of Information
  - Quality (Acceptable Error Rates)
  - Timeliness
  - Display / User Interface / Analysis Tools

# Communication Requirements Are Driven By the Level of Autonomy Required



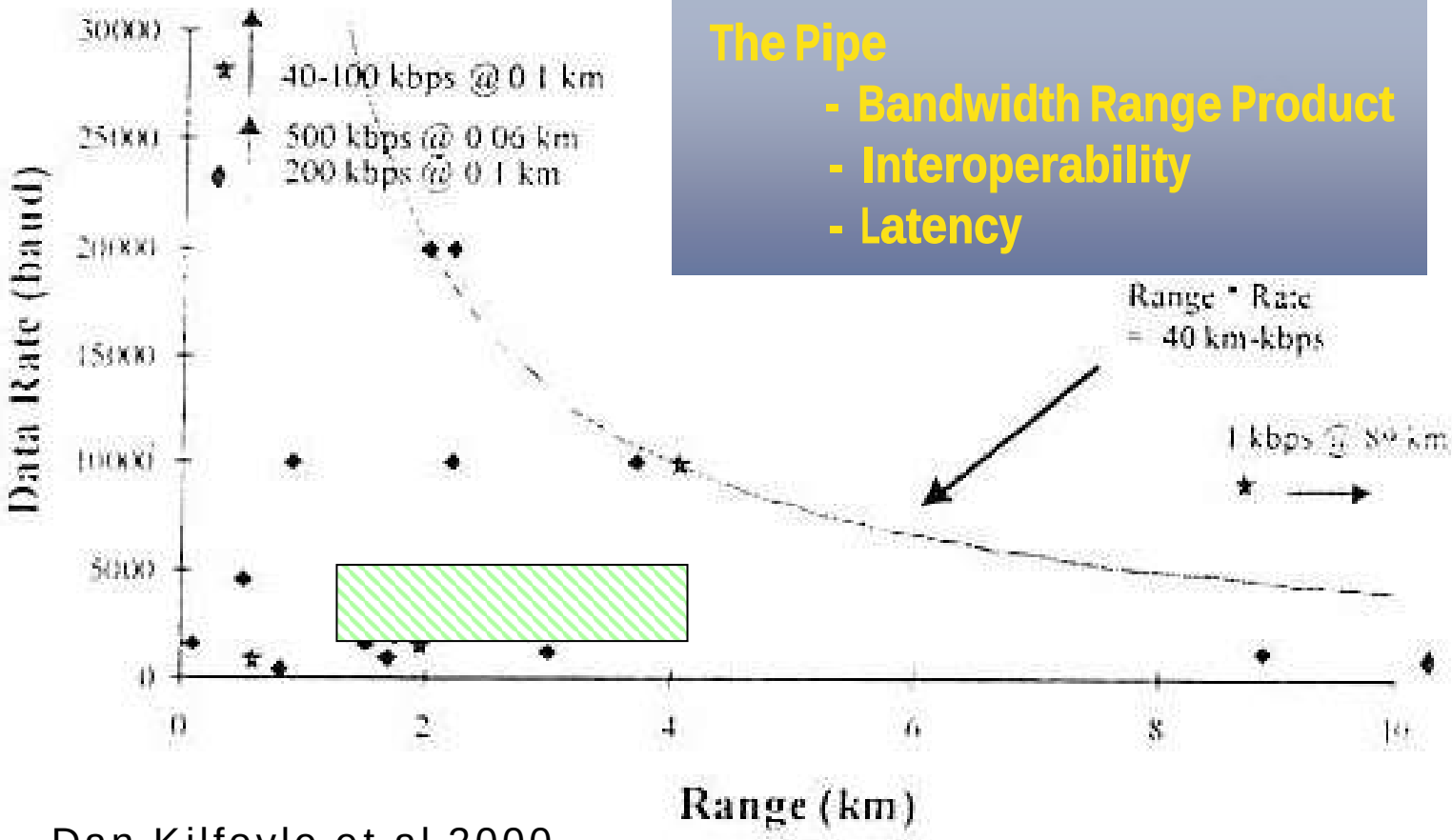

THE PIPE

# Performance of Acoustic Communications Links

THE PIPE

**The Pipe**

- Bandwidth Range Product
- Interoperability
- Latency

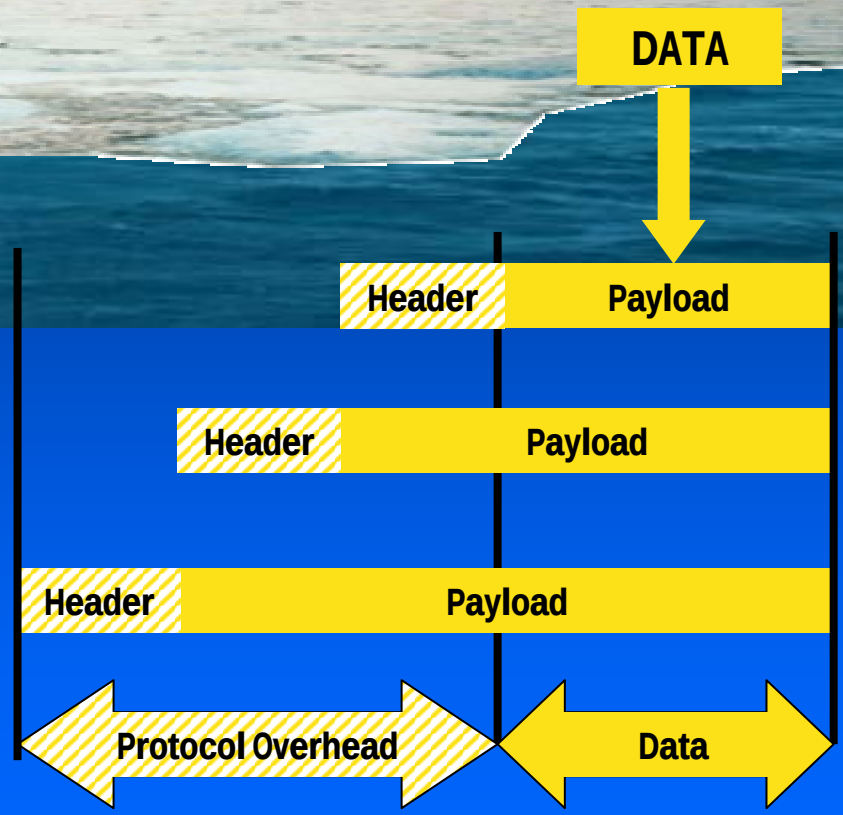



Dan Kilfoyle et al 2000

THE NETWORK OF PIPES

# Overhead in the Acoustic Channel

| Network Stack | Driving Analogy |
|---|---|
| Network Layer | Maps (or) Mapquest |
| Data Link Layer | Traffic Rules & vehicles |
| Physical Layer | Roads |



THE NETWORK OF PIPES

# Metrics of Interest

- Time to reconnect after a **link failure**
- Performance under **multipoint** communication patterns.
- Performance under **multi-hop** transmissions
- Time to **establish connectivity** (setup time of the routing protocol)
- **Measures**:
  - Throughput (node to node vs. total network throughput)
  - Latency and latency variation under stable conditions
  - Transient effects during recovery from a link/node failure

THE NETWORK OF PIPES

# A Comparison of Efforts

| Network Stack | AUSI Team | Seaweb | WHOI |
|---|---|---|---|
| Network Layer | COFSNet & AUSNet (Dynamic Routing) | Static Routing | Star Network Topology for packet forwarding (no routing) |
| Data Link Layer | Frames No MAC | No Frames MAC: CSMA/CA | No Frames MAC: TDMA |
| Physical Layer | Benthos Acoustic Modems | Benthos Acoustic Modems with enhanced features | WHOI Micro Modem |

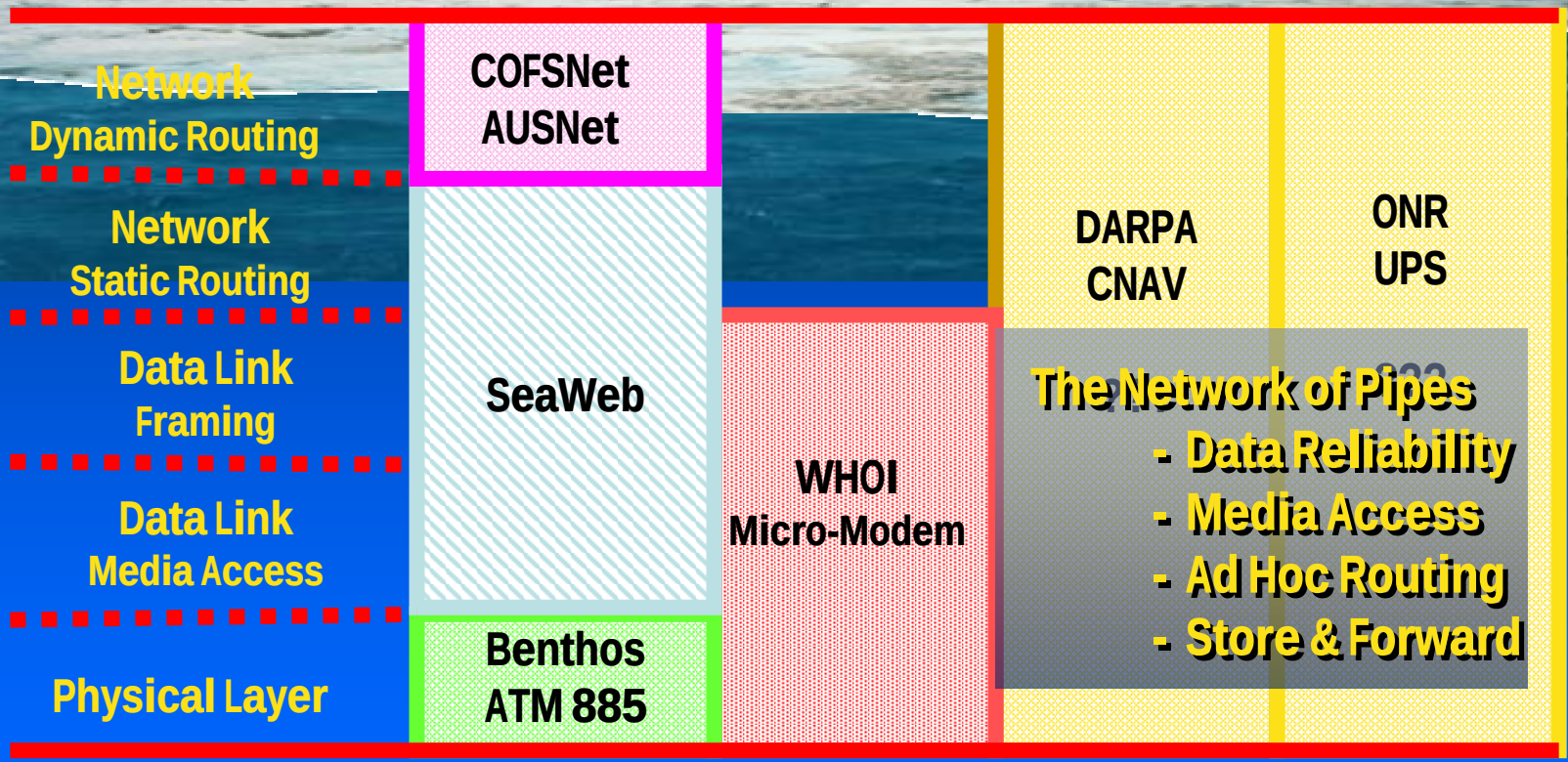
THE NETWORK OF PIPES

# Mobile Ad Hoc Network Protocols for the Underwater Environment

- AUSNet
  - Route Discovery
  - Route Maintenance
  - Dead Reckoning
  - Effective for More Nodes > 6 ????
- COFSNet
  - Flooding
  - TTL (Time To Live)
  - Effective for Few Nodes <6 ???

THE NETWORK OF PIPES

# Program Efforts Related to Underwater Acoustic Networking



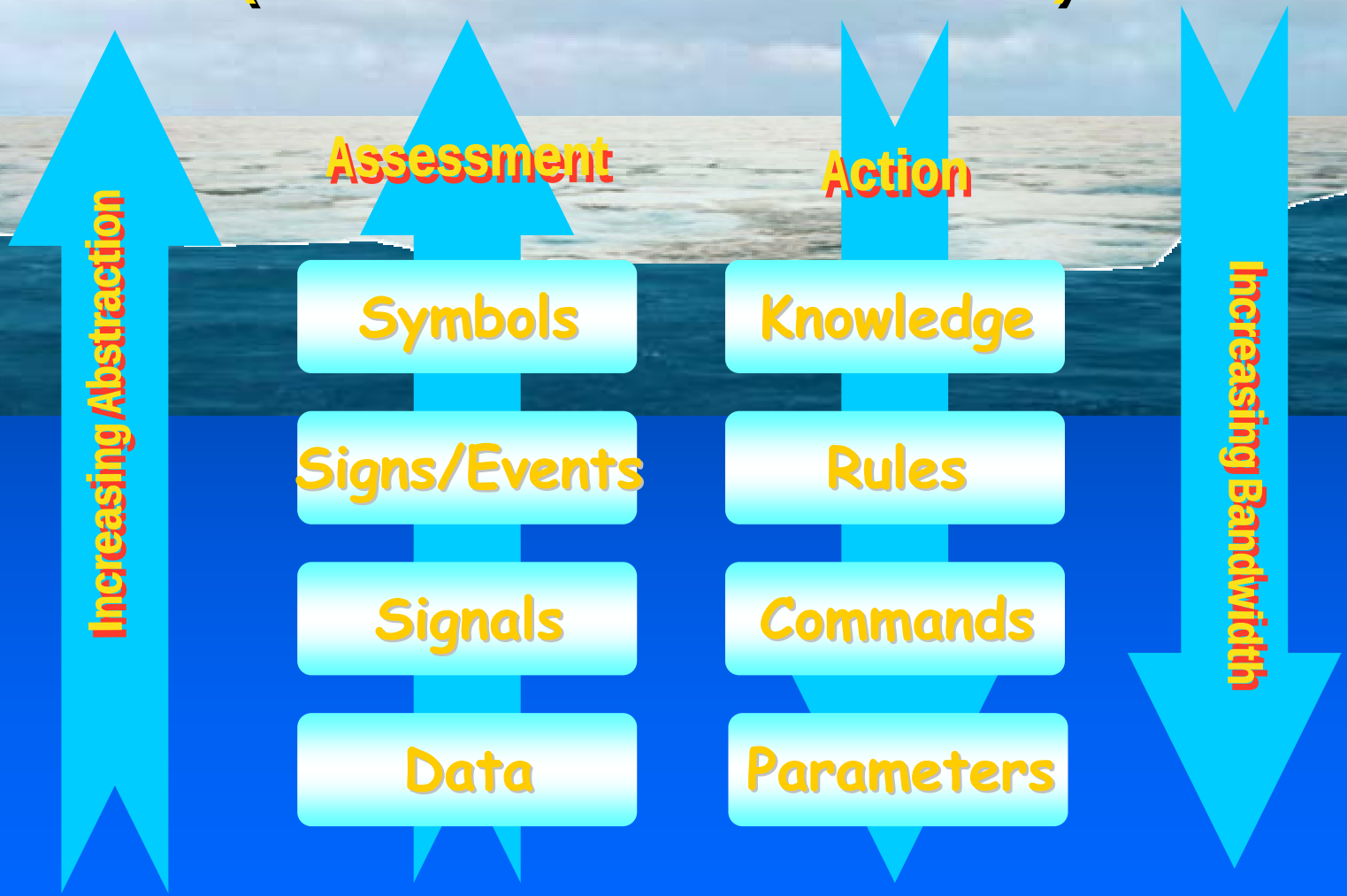
# An Autonomous System's Control Factors

INFORMATION IN PIPES

# Information Hierarchy

## (More Abstraction - Less Bandwidth)

INFORMATION IN PIPES



# Common Control Language (CCL)

## Implicit vs. Explicit Knowledge

INFORMATION IN PIPES

Mission

Mission Is Defined by a Set of Aggregate Behaviors

Aggregate Behaviors
e.g. Survey, Box, etc

Each Aggregate Behavior Decomposes into Basic Behaviors

Configure
Navigate
Communicate
Monitor
Maneuver
Exec
Convention

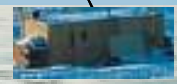
The Network of Pipes
- Priority
- Quality
- Timeliness
- Display

Each Behavior is Interpreted for a Specific Command Set

Vehicle Command Set

# Sample Scenario 1
# - Ice Camp -

Remote User

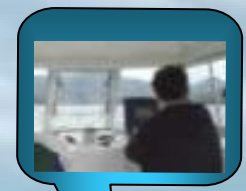


Ice Camp

AUV

Bottom Mounted Instruments

# Sample Scenario 2
# - Support Ship -



Remote User

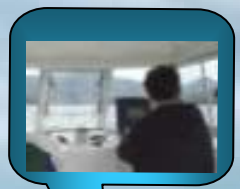
Support Ship

AUV

AUV

Bottom Mounted Instruments

# Sample Scenario 3
## - 24/7 AUVs -



Remote User

Long Endurance AUV

Solar Powered AUV (SAUV)

SAUV

SAUV

SAUV

SAUV

# Communication System Limitations

| | RF (e.g. Freewave) | Satellite (e.g. Iridium) | Acoustic (e.g. Many) |
|---|---|---|---|
| **Pipe** | Reasonable data rates<br>Cost minimal issue<br>Mechanical integration | Costly<br>Limited Access<br>Low Data Rates<br>Coverage in polar regions | Limited range<br>High latency<br>Limited data rates<br>Noisy, unreliable channels<br>Channel access not guaranteed |
| **Network** | Networked systems?<br>RF/Acoustic interface<br>Limited range<br>Antenna issues | Latency<br>Integration with other protocols | No standard protocol<br>Overhead impacts data rate<br>Interface with other protocols<br>Mobility complicates protocol |
| **Information** | Few information standards<br>Limited bandwidth<br>No accepted languages | Few information standards<br>Limited bandwidth<br>No accepted languages | Few information standards<br>Limited bandwidth<br>No accepted languages |

# Requirements - Subjective

| | Status | Commands | Emergencies | Data/Info |
|---|---|---|---|---|
| Access | scheduled | scheduled | unscheduled | scheduled |
| Bandwidth | medium | medium | low | high |
| Reliability | medium | high | very high | low |
| Quality | medium | high | very high | Low to very high |
| Latency | minimal | minimal | minimal | low |
| Cost | low | minimal | not important | minimal |

# Requirements - Quantitative

| | Status | Commands | Emergencies | Data/Info |
|---|---|---|---|---|
| Access | 1 per 4 hrs | | | |
| Bandwidth | 200 bits | | | |
| Reliability | 8 of 10 | | | |
| Quality | $1^{-5}$ | | | |
| Latency | minutes | | | |
| Cost | 50 P/blk | | | |

# Objective Is To Identify

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Autonomous Undersea Systems Institute
www.ausi.org
Masterclass in AUV Technology for Polar Science
NOC, Southampton, UK
March 28-30, 2006