Sensor Networks for Network-Centric Warfare

John Walrod
Director
Planning Systems Incorporated
Engineering Center
21294 Johnson Road Long Beach, MS 39560
Phone: (228) 863-0007 FAX: (228) 863-0281
e-mail: jwalrod@plansys.com
www.plansys.com

NETWORK CENTRIC WARFARE CONFERENCE
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Falls Church, VA

Platform-Centric vs Network-Centric

- Perhaps the greatest distinction between platform-centric warfare and network-centric warfare involves linkage between sensors, shooters, and decision-makers.

- Platform-centric warfare tightly links all three logically and physically, while network-centric may separate these assets and then link them in different ways.

- Traditionally, platforms own weapons which own sensors.

- In network-centric, sensors may not necessarily belong to the platforms or shooters.

Sensors Everywhere

- Traditional platforms: Ships, subs, planes, tanks, vehicles
- Environmental monitoring - Air, sea, and ground
- Machinery monitoring, vehicle tracking, smart surfaces
- Robots, microbots, micro UAVs, UUVs, pico-satellites
- Surveillance, security, detection, command views
- Chemical, biological, and nuclear weapon detection
- Human and animal bio monitoring

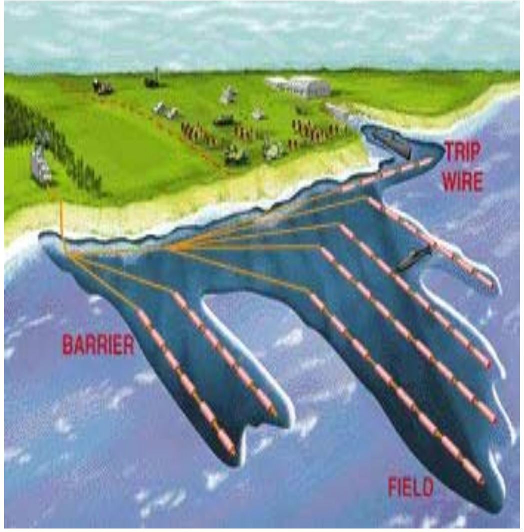
Why Sensor Networks?

Sensor Networks Decrease System Costs

- Use commercial network technologies (ATM, Ethernet, Fibre Channel) in traditional sensor systems to reduce Total Cost of Ownership and increase performance
- Create common network-centric sensor interfaces across programs

NSWC
Vehicle Noise & Vibration
Measurement System:
ATM-SONET network

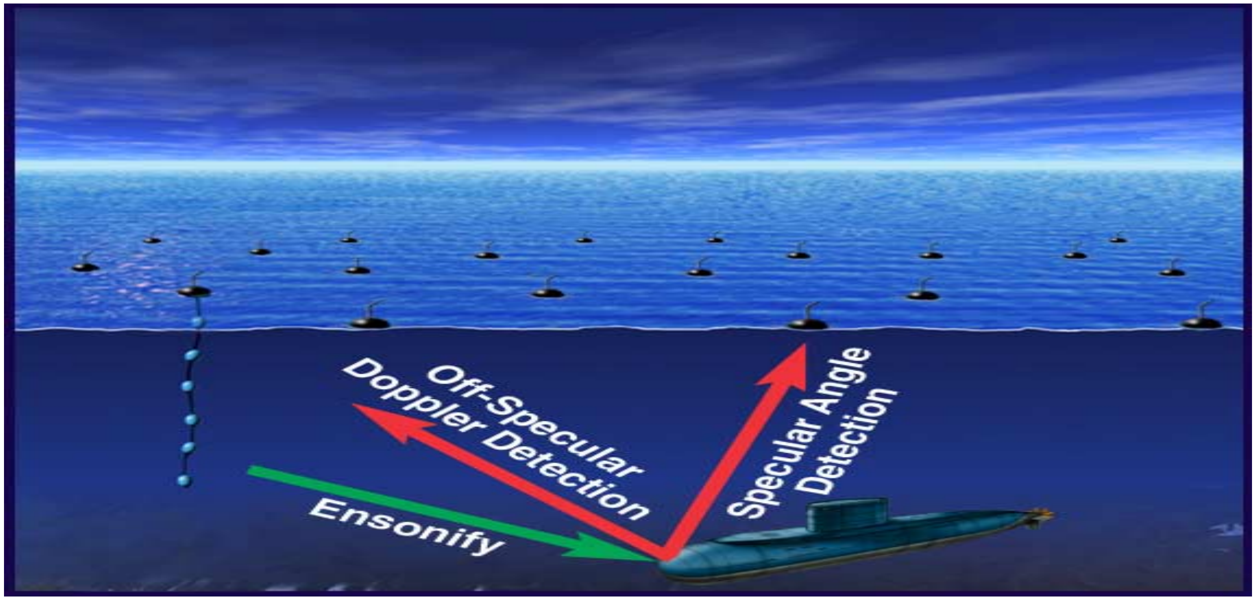
NUWC
Surface Ship
Towed Arrays:
ATM-SONET Network



SPAWAR
Seafloor
Surveillance Arrays
ATM-SONET Network

Sensor Networks Enable Detection of Low-Signature Targets

- Low signature targets are difficult to detect, classify, & engage.
  - Low radar cross sections. Low active sonar cross sections.
  - Low radiated noise. Low radiated IR/heat.
- Combine sensors and sources in numbers, types, and locations to sense and illuminate low signature targets.



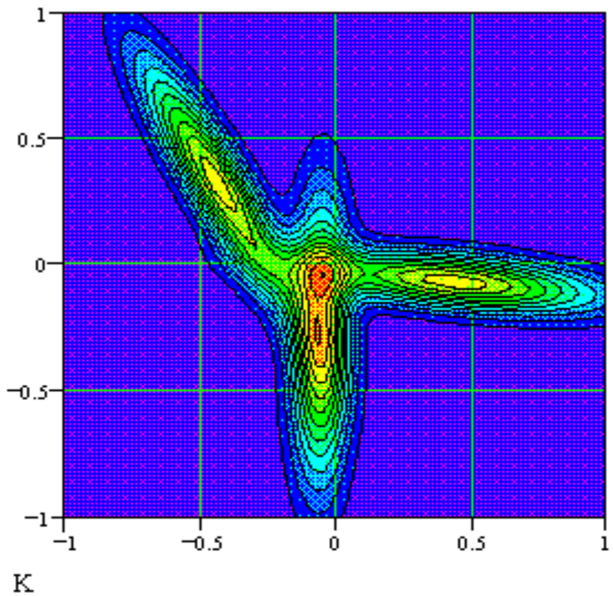
Source: J. Zittel, N84, "ASW Requirements for the Littoral", NCW99

Sensor Networks Reduce Error

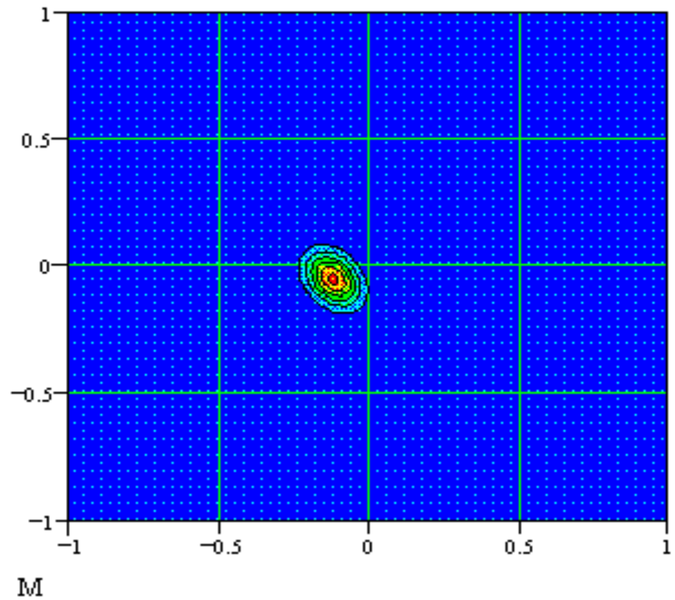
- Combine sensors from different positions or with different frequency ranges to improve meaurement accuracy.
- Requires precise synchronization and position of sensors.

Radar-Y Area of Uncertainty
Radar-B Area of Uncertainty
Networked Radars Area of Uncertainty

Sensor Network Fusion Improves Targeting



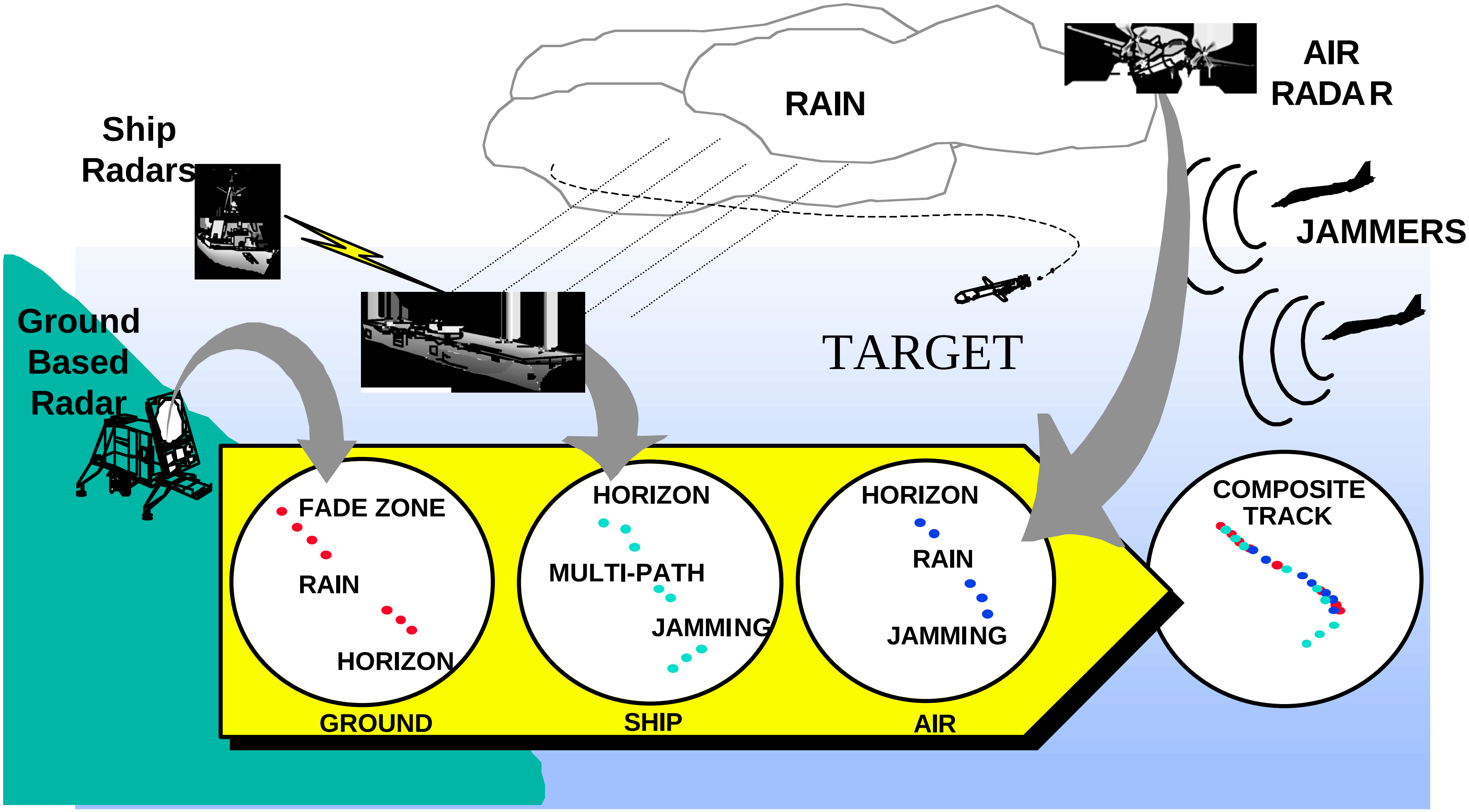
3 Sensor Position Estimates



Fused Position Estimate

Source: Dr. David Alberts (OASD-C3I) and John Garstka (JCS J-6), "Information Superiority & Network Centric Warfare", Information Superiority/Command and Control Seminar: Keynote Presentation, Dec. 14, 1999 , www.dodccrp.org

Sensor Network Fusion Improves Tracking



Source: Dr. David Alberts (OASD-C3I) and John Garstka (JCS J-6), "Information Superiority & Network Centric Warfare", Information Superiority/Command and Control Seminar: Keynote Presentation, Dec. 14, 1999 , www.dodccrp.org

Sensor Networks Improve Operational Picture

- Fleet Battle Experiment Delta in September 1998 combined Navy and Army sensors and shooters, real and simulated, to combat a simulated attack by North Korea.

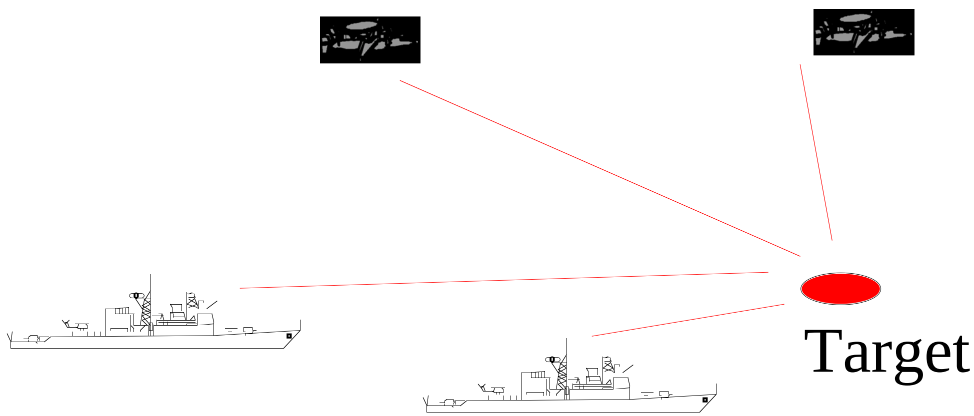
- Submarines, surface combatants, and aircraft were linked with a joint fire coordination network.

- "The common operational picture enabled by Navy sensors was exploited by Army helicopters to react on time lines not previously demonstrated."

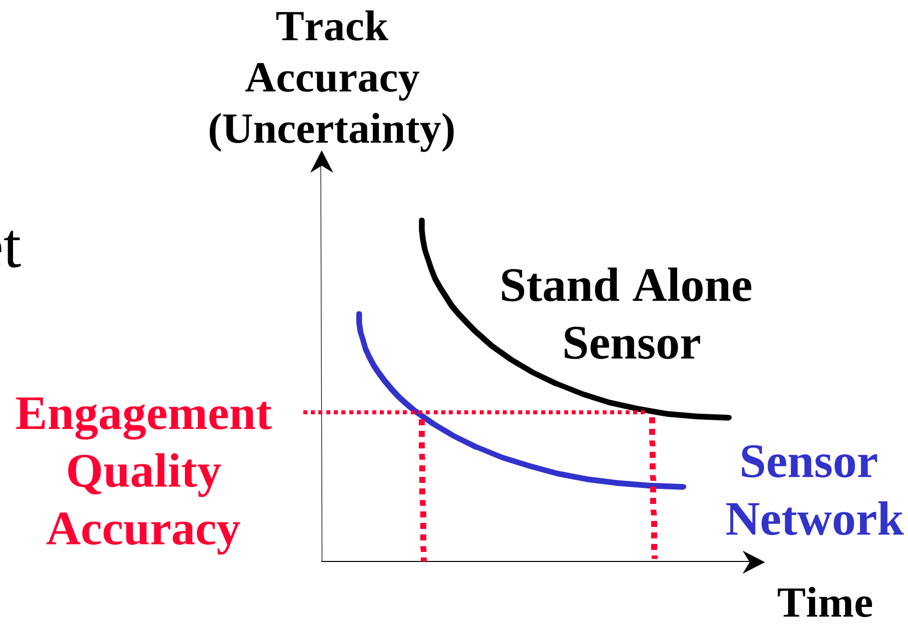
Source: Network-Centric Naval Forces, National Academy of Sciences, 2000

Summary: Improved Engagement

- Decreased time to engagement
- Improved track accuracy & continuity
- Improved target detection & identification
- Extended detection ranges



Networked Sensors on
E-2C Hawkeyes and Cruisers

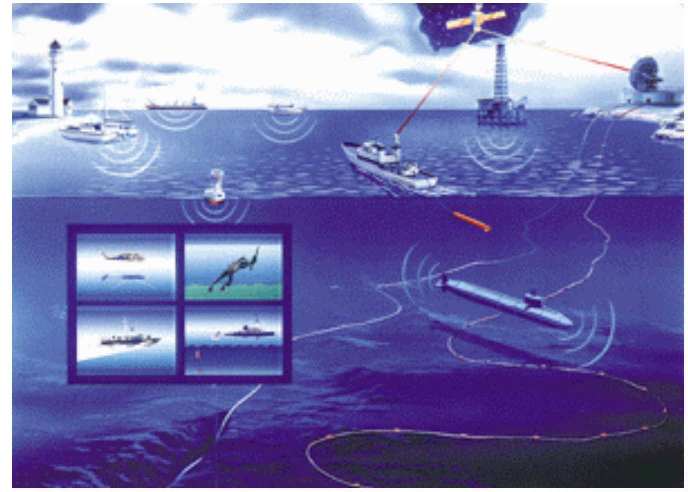


Source: Dr. David Alberts (OASD-C3I) and John Garstka (JCS J-6), "Information Superiority & Network Centric Warfare", Information Superiority/Command and Control Seminar: Keynote Presentation, Dec. 14, 1999, www.dodccrp.org

Example Sensor Network Systems

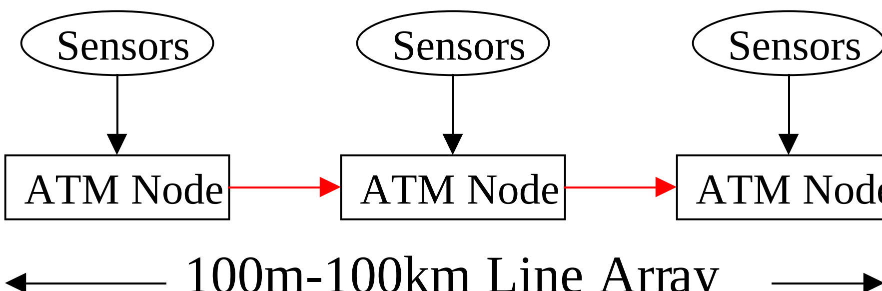
Navy Line Arrays using ATM-SONET

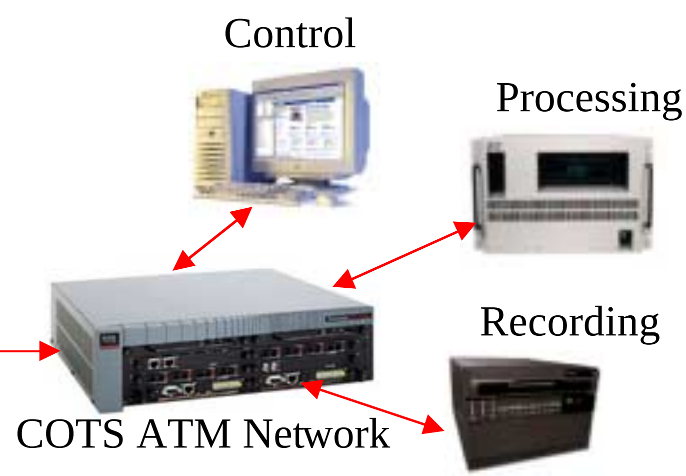
- SPAWAR FDS-c Surveillance Array & ADS Surveillance Array
- SPAWAR T-AGOS class towed arrays
- NUWC ASATS portable range
- NUWC AUTEC measurement range
- NUWC towed arrays, TARS, TB-29 upgrade, MLTA
- DERA Wideband Research Towed Array
- DREA DASM(D) Towed Array (proposed)
- NATO SACLANT Towed Array
- UK Sonar 2087 Towed Array (proposed)
- Korean Towed Arrays and Surveillance Arrays (proposed)
- Swedish Measurement Range (UDAMS)



Fixed Distributed System (FDS)

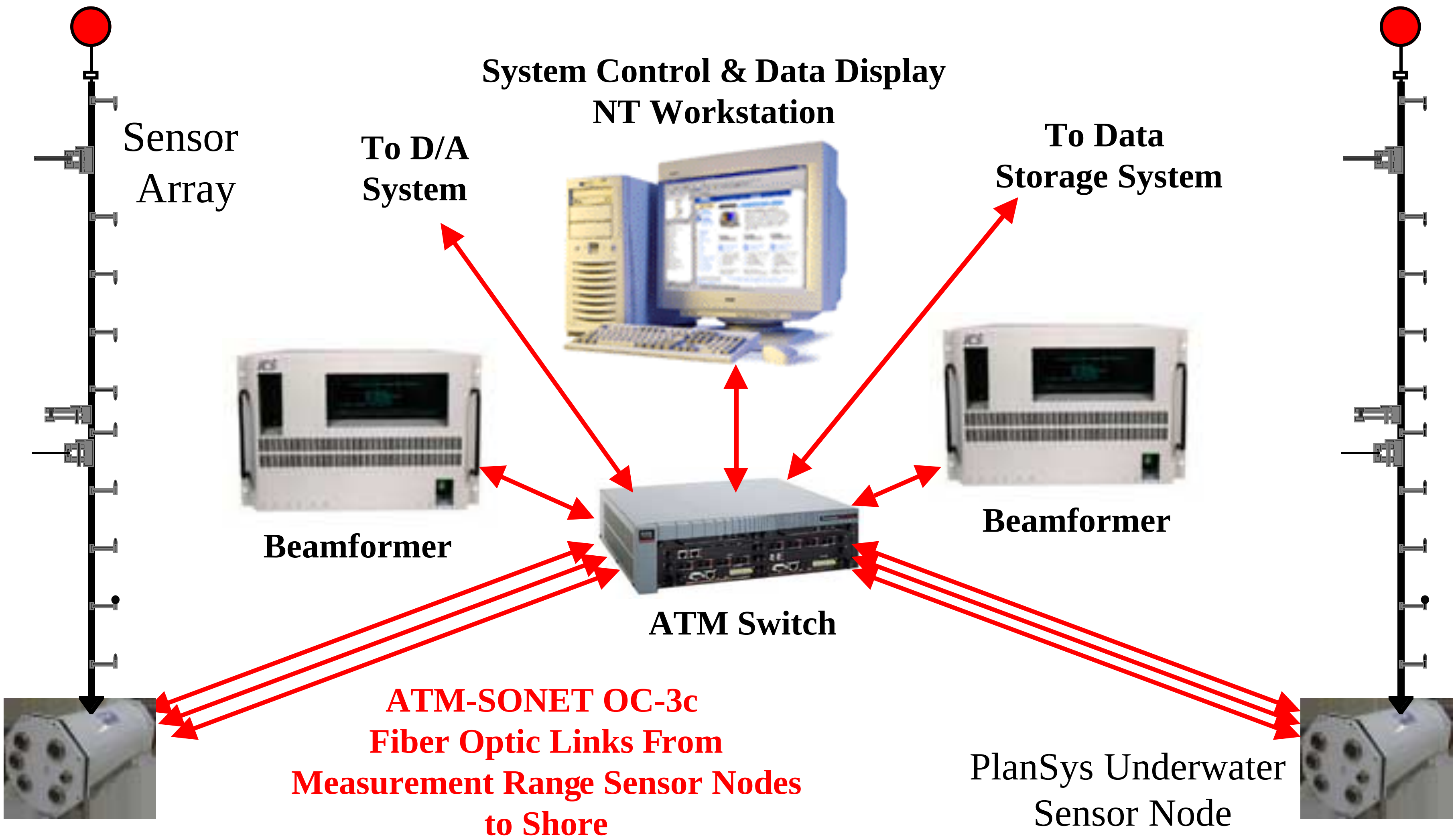
BASIC NETWORK ARCHITECTURE:
Daisy-Chained Sensor Nodes





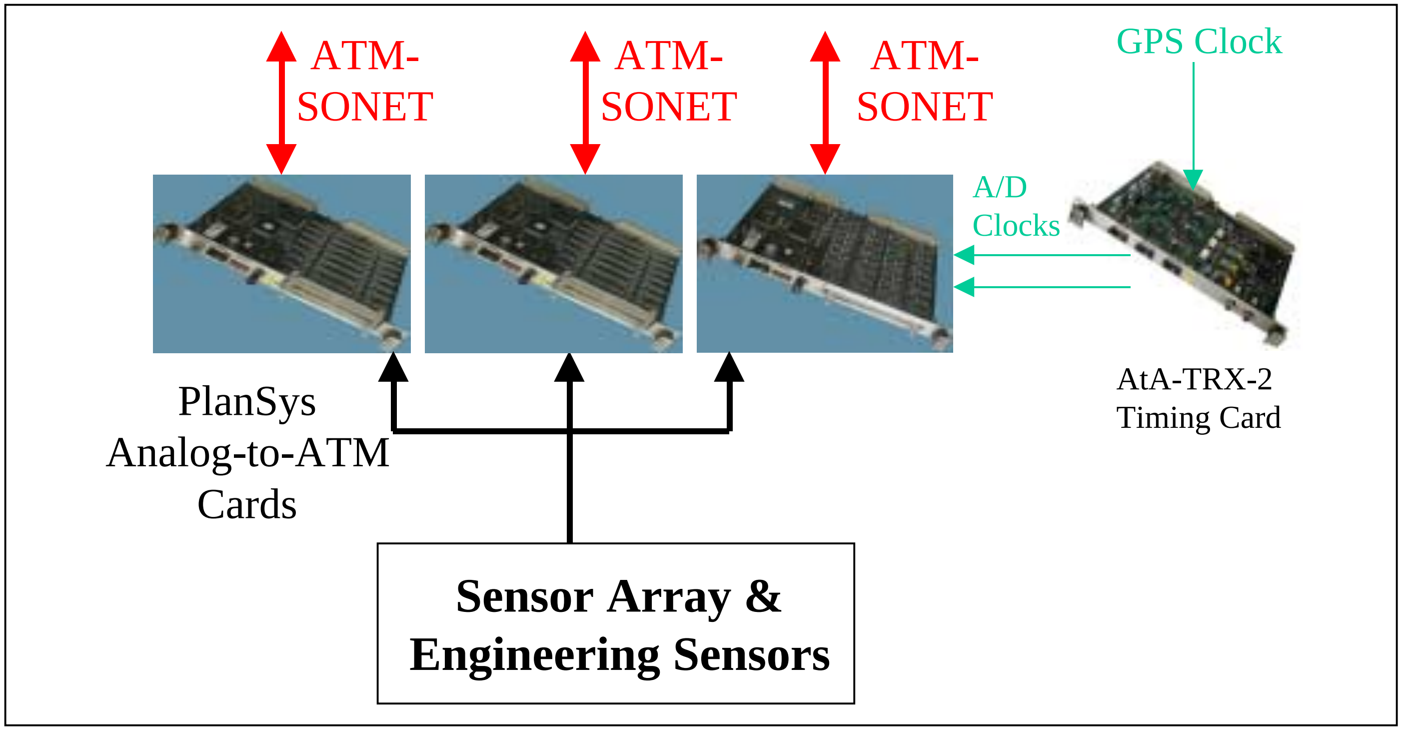
NSWC Measurement Range Network

- Underwater sensor network for radiated acoustic noise measurements



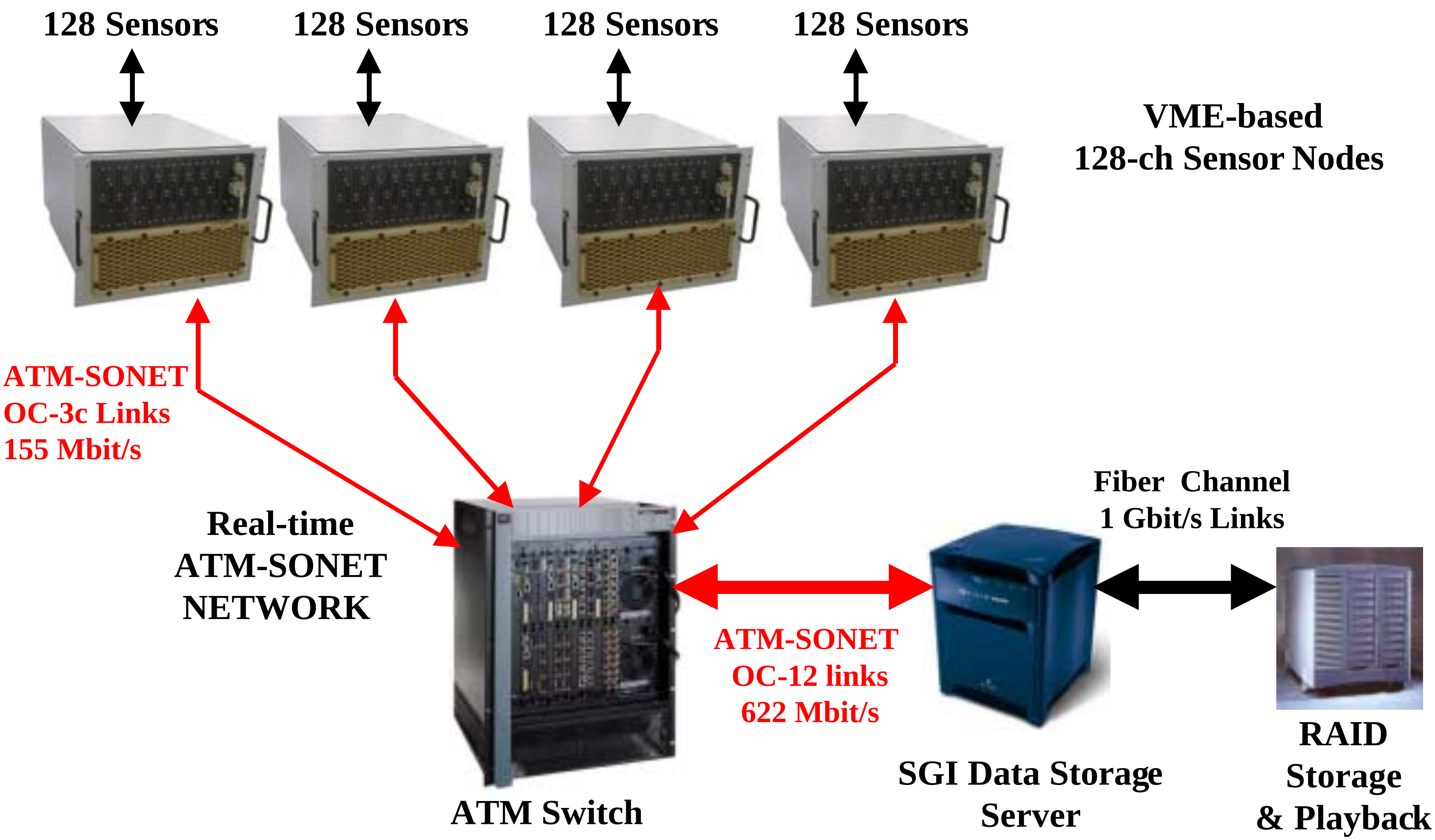
Measurement Range Sensor Node

- Mid-frequency noise measurement channels
- High-frequency ranging channels
- Low-frequency engineering sensor channels
- Sample rates synchronized to GPS clock
- All data and controls accessed via ATM-SONET OC-3c network

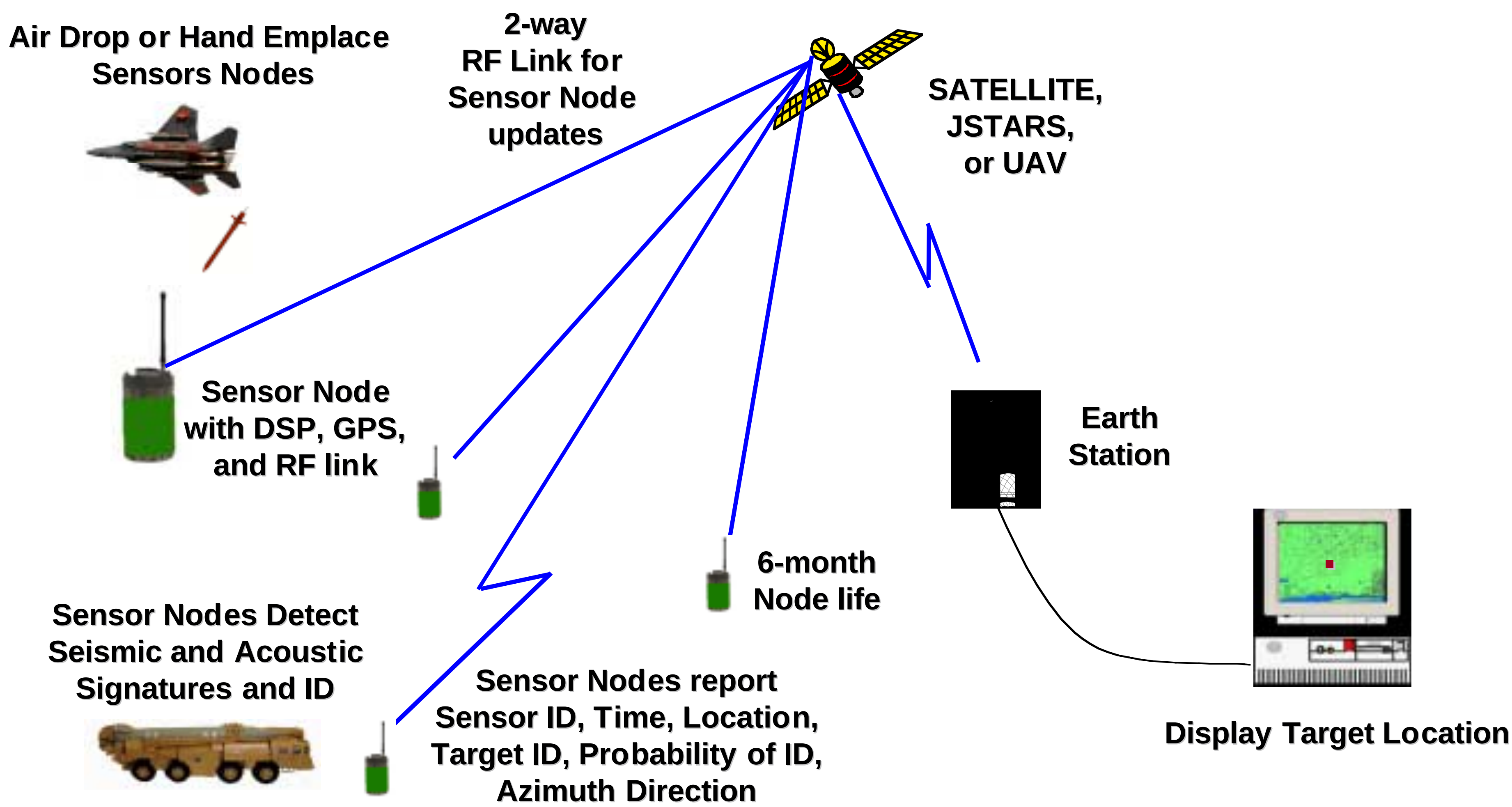


NSWC Submarine On-Board Data Acq. System

- 512-channel accelerometer and hydrophone network



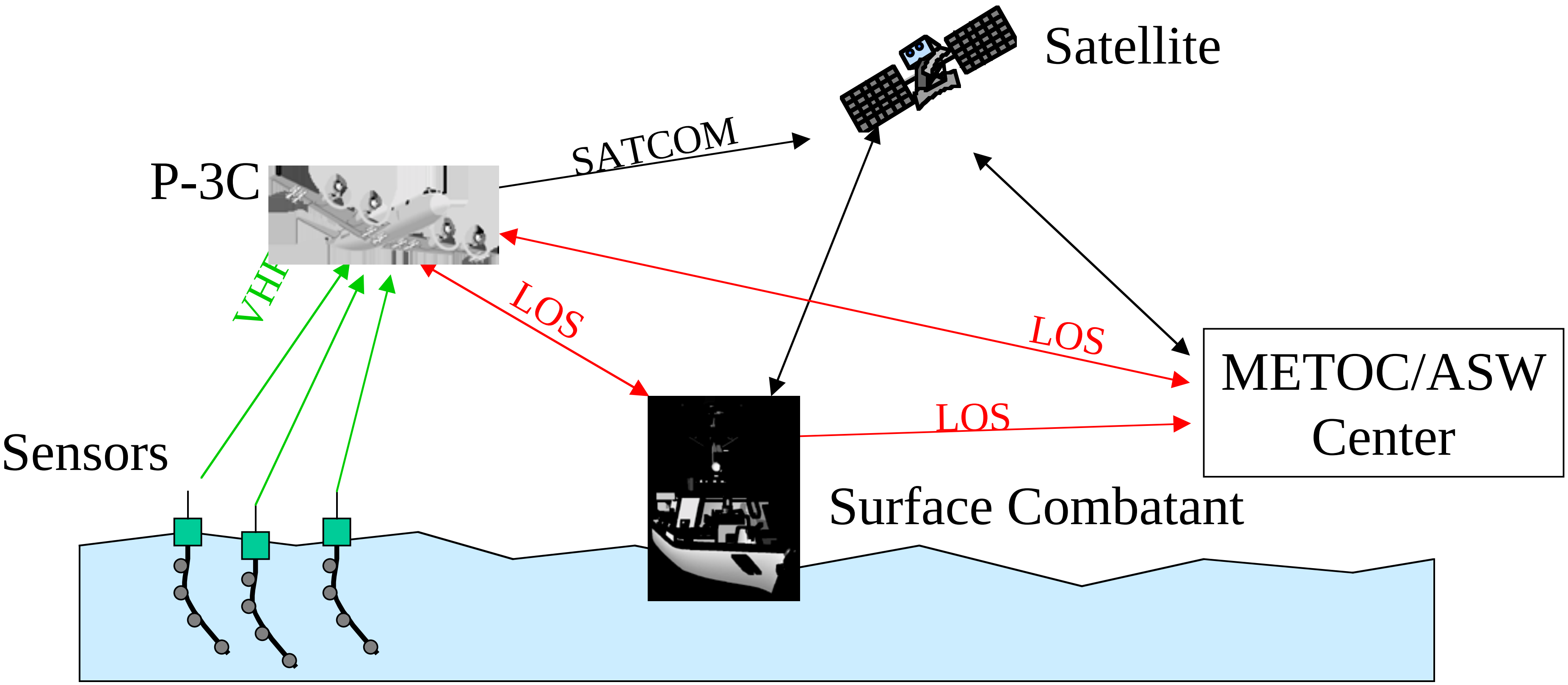
Advanced Remote Ground Unattended Sensor ARGUS



Source: MASINT Acq Center, HANSCOM AFB, ARGUS Industry brief, March 14, 2000

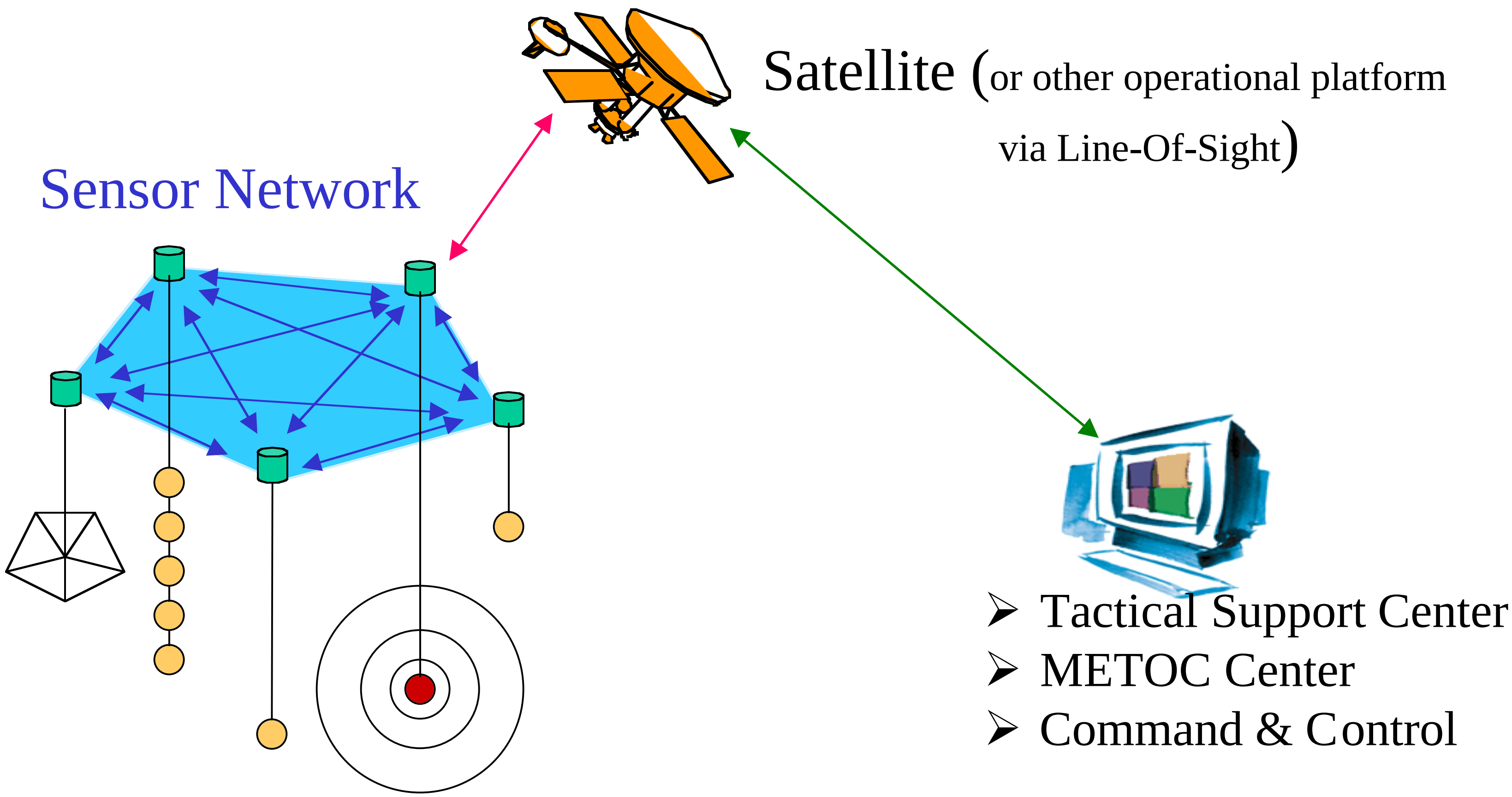
PlanSys MIPS Network

- METOC Interface Processor System
- Provides real-time meteorological, oceanographic, and acoustic data for ‘now-casting”.



Next-Generation MIPS Network

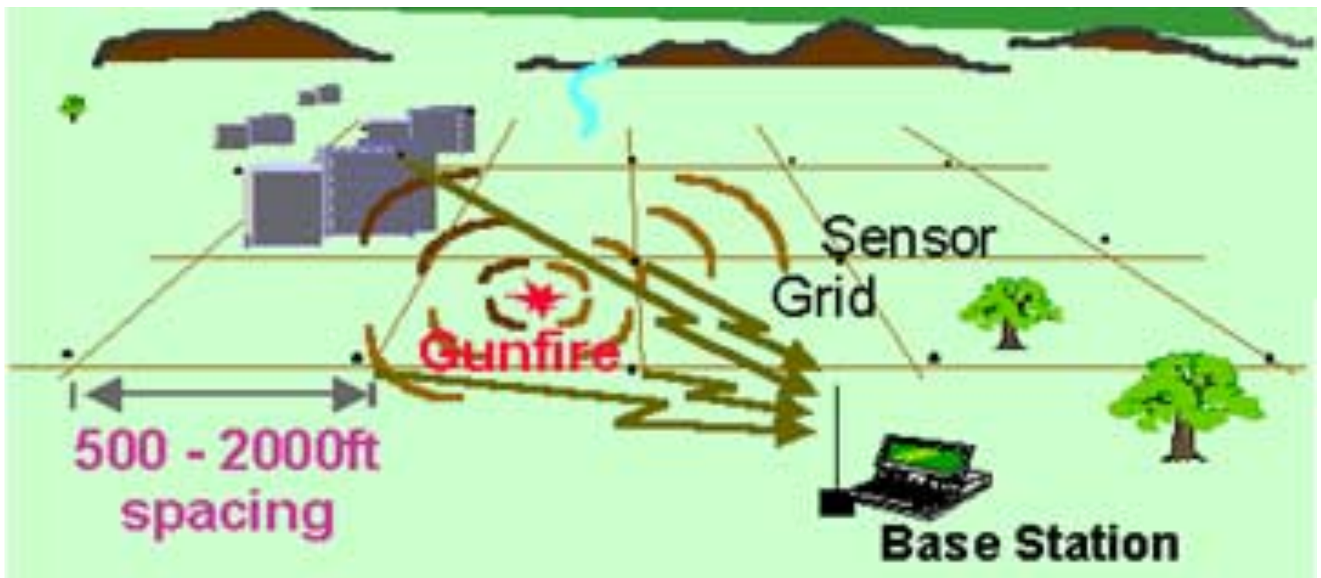
- Move processing to sensors nodes
- Use Distributed Collaborative Computing to perform tasks



PlanSys SECURES® Network

- Patented acoustic sensor network for gunshot detection
- Wireless sensor nodes contain ultra-low power processing for automatic detection, discrimination, and localization of gunshots.
- Nodes operate 12 months on battery pack

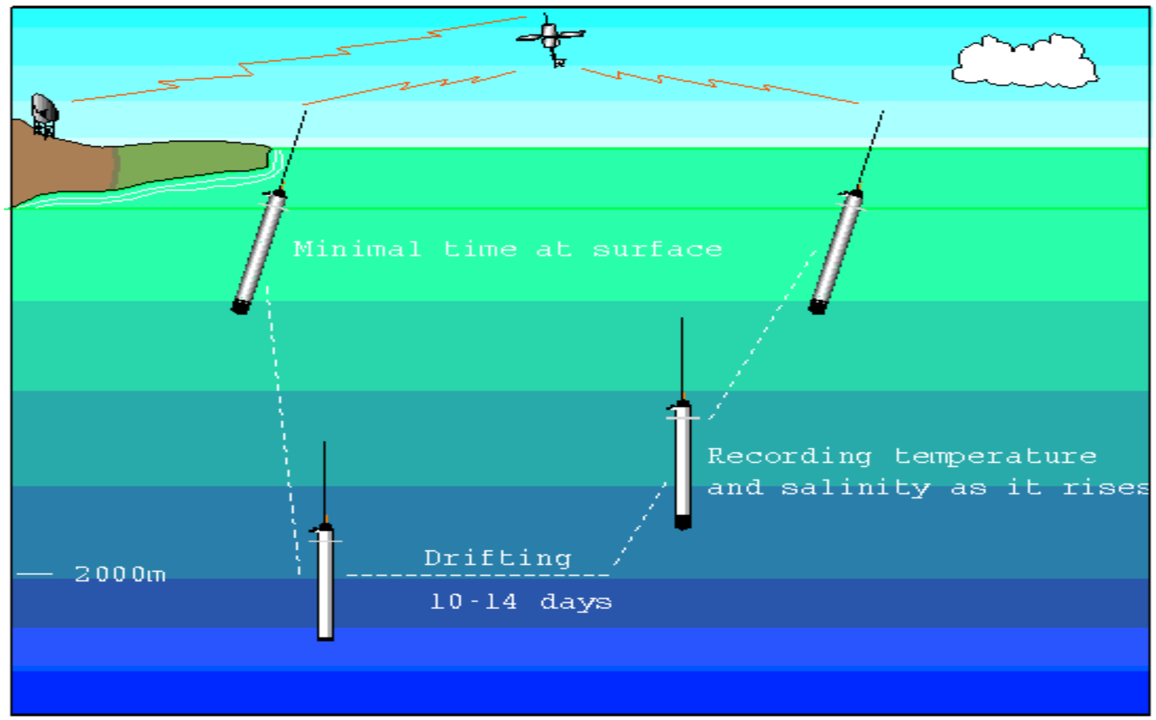
SECURES Acoustic Sensor Node



SECURES Wireless Sensor Network

ARGO: Global Ocean Sensor Network

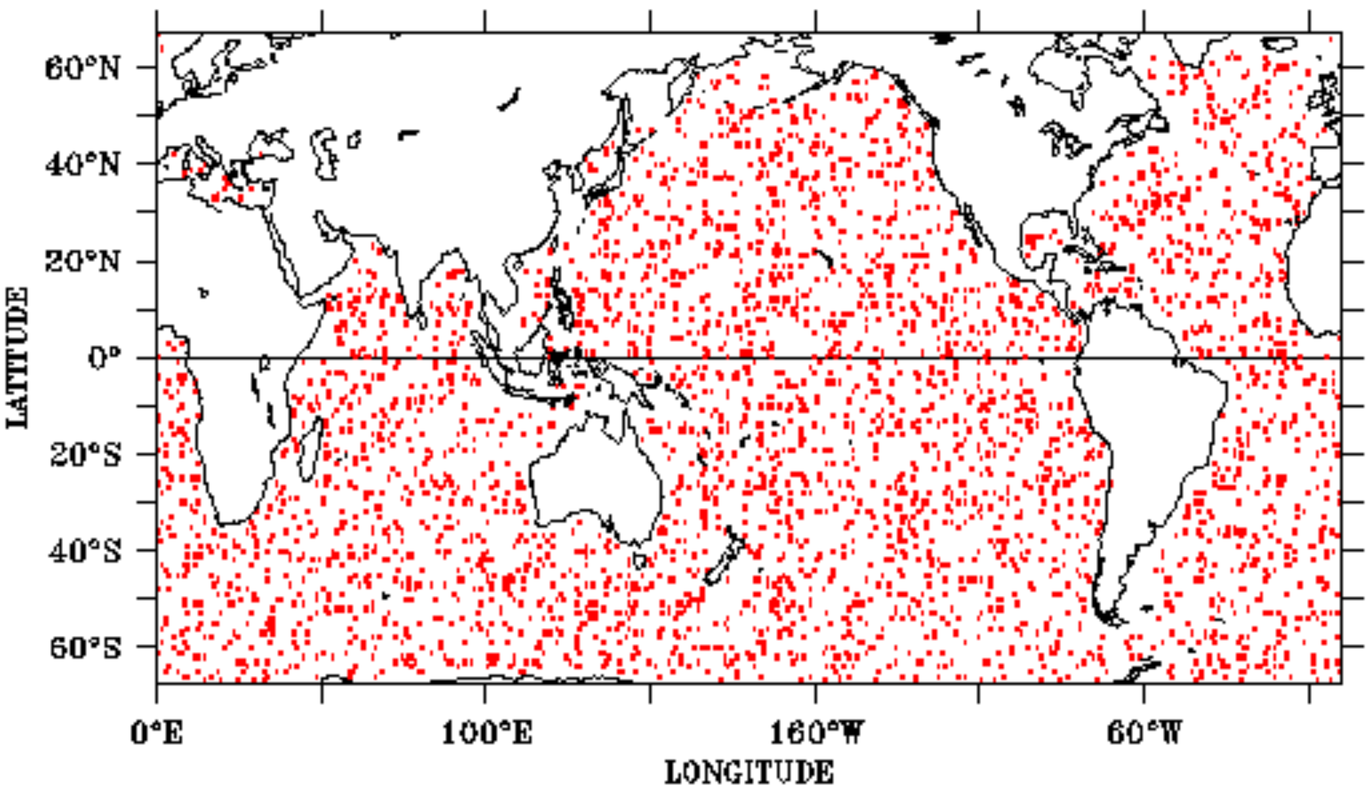
- 3,000 free-drifting profiling (0-2000 m) sensor nodes with temperature and salinity sensors
- Continuous monitoring of the ocean with near real-time public availability of data.
- Floats will cycle to 2000 m depth every 10 days, with a 4-5 year lifetime
- The Nodes will cost an estimated $12,000 apiece. Can be deployed from ship or plane.
- Deployment of the Nodes is expected to reach 700 per year by 2002



Source: http://www.argo.ucsd.edu

ARGO Sensor Network

- 100,000 Temperature/Salinity profiles and reference velocity measurements per year
- 3000 floating Sensor Nodes distributed over the global oceans at 3-degree spacing.
- Data to be used for climate prediction



Source: http://www.argo.ucsd.edu

Emerging Technologies

Leading Sensor Network Challenges

- Assure information. Reduce susceptibility to countermeasures.
- Improve sensor detection underground, under foliage, and in littoral.
- Provide accurate sensor node georegistration and synchronization.
- Fuse data and coordinate sensors within network.
- Reducing information overload. Simplify queries and user interfaces.
- Provide target recognition. Make sensors smart.
- Simplify network deployment, set-up, and management
- Reduce Sensor Node power:
  - Operational life vs processing vs time*bandwidth vs range
  - Dispose/replace node vs maintenance (recharge/replace battery) vs alternative power
- Reduce sensor node size and detectability:
  - Microsensors, MEMS, microbots, micro vehicles, UAVs

Sensor Network Queries

- Sensor networks must be usable without the need for signal analysts

- Sensor monitoring is best described in a declarative manner – users submit queries concerning a sensor network regardless of its physical structure or its organization. Query types include:

- Historical queries: Query historical data obtained from the sensor network. e.g. "Show the heavy vehicle traffic on road X for the past 10 days."

- Snapshot queries: Query the sensor network at a given point in time. e.g. "Provide IR image view of area Y."

- Future queries: Query the sensor network over a time interval. e.g., "For the next 12 hours, report any AUVs or divers that cross perimeter Z"

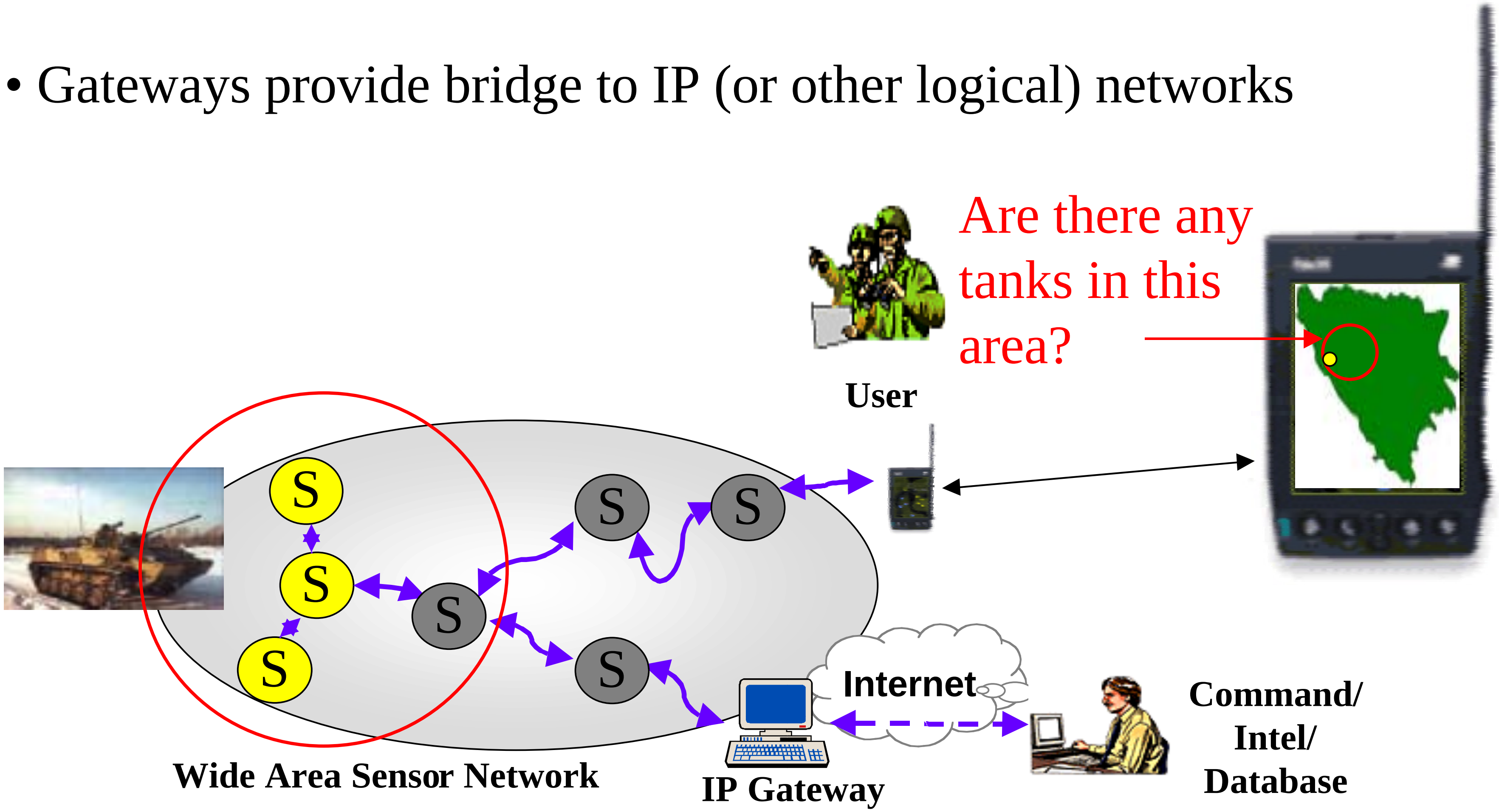
Spatial vs Logical Addressing

- The Internet and most data networks use logical addresses (e.g., IP Address 206.185.34.43) for routing and identification of network nodes.
- TCP/IP protocols do not support spatial addressing (e.g., latitude, longitude, altitude, or x,y,z)
- Logical addressing works OK in Local Area Sensor Networks (e.g., beamform sonar sensor channels #512-1024 of hull array)
- Spatial addressing provides benefits in Wide Area Sensor Networks (e.g., beamform acoustic sensors located within 1000 meter radius of bridge).

Spatial Addressing - Queries

- Spatial addressing permits natural spatial queries

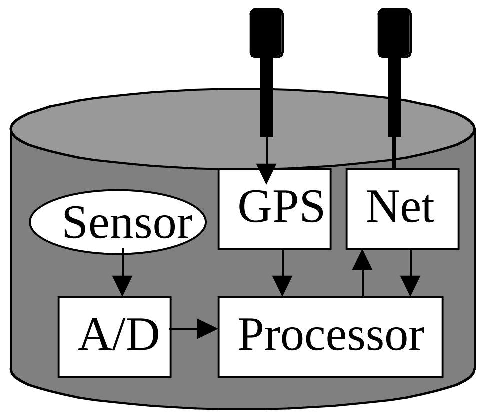
- Gateways provide bridge to IP (or other logical) networks



Spatial Addressing- Network Management

- Nodes which self-assign spatial addresses can simplify management and ad-hoc network organization.

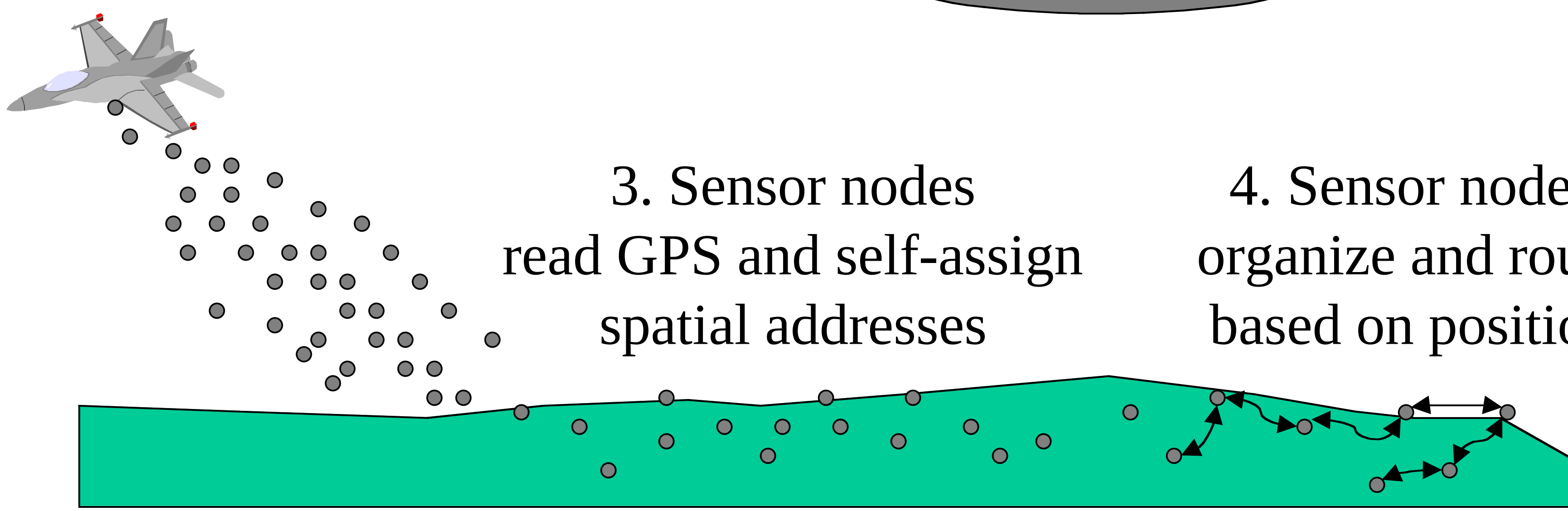
1. Wireless sensor node with GPS



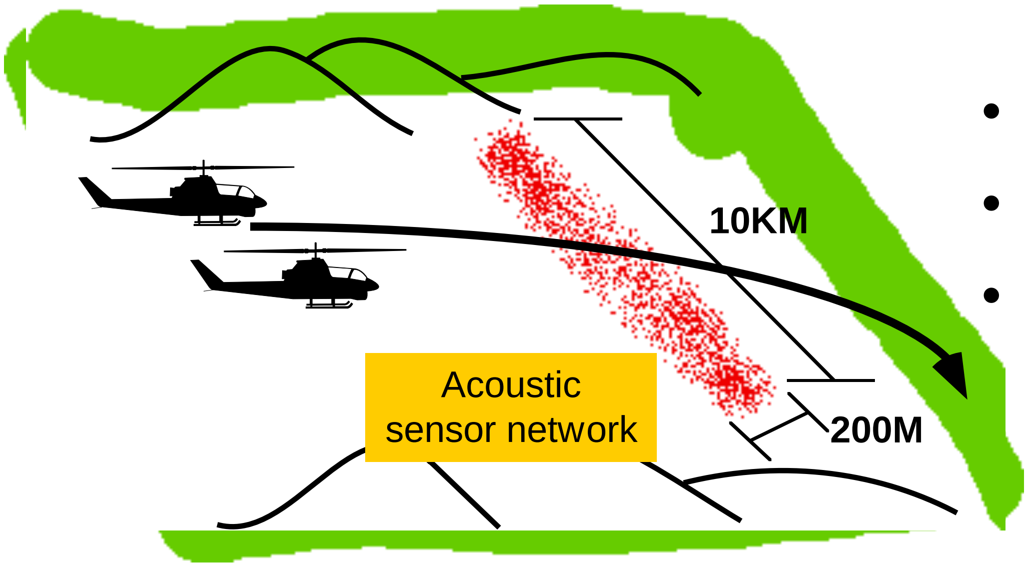
2. Air deployment of many sensor nodes

3. Sensor nodes read GPS and self-assign spatial addresses

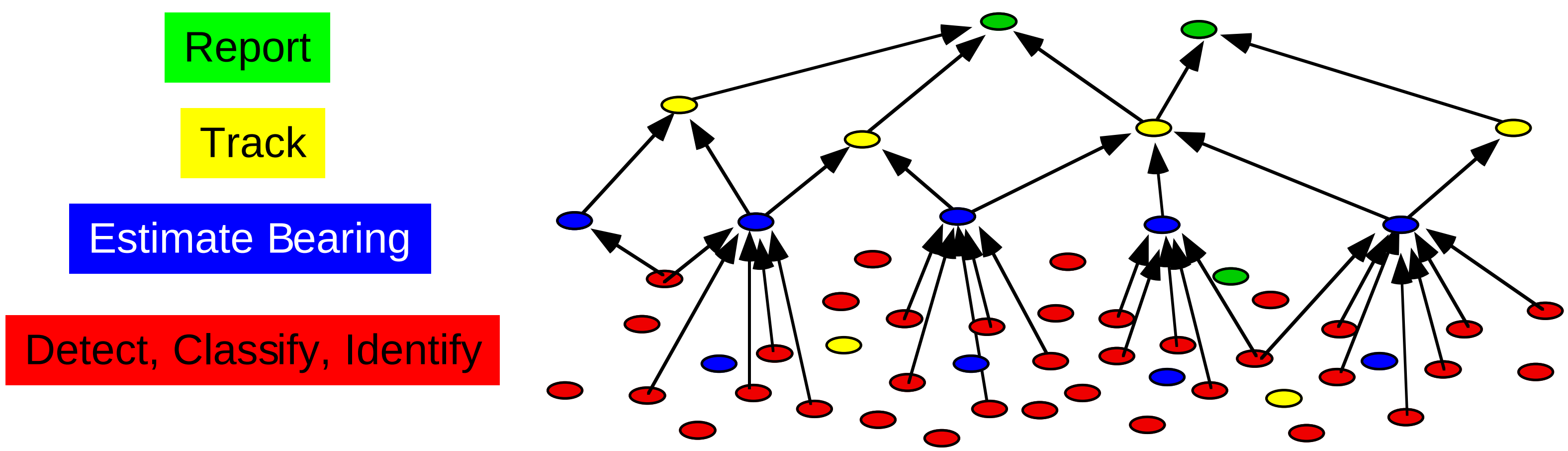
4. Sensor nodes organize and route based on position



Self-Organized Sensor Fusion



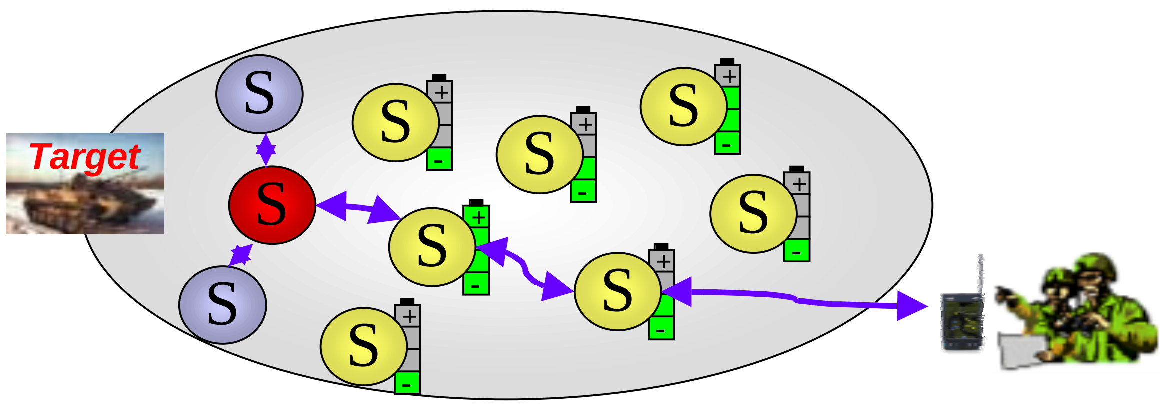
- Hierarchical sensor fusion
- Network self–organizes
- Increased power efficiency



Source: Daniel Van Hook, MIT, "Dynamic Declarative Networking", DARPA SensIT meeting, Oct 7-8, 1999

Power-Aware Routing

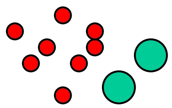
- Organize routing to optimize sensor network power (lifetime)
- Leverage spatial addressing
  - Minimize transmit power to match node-node link distances
  - Choose optimum geographic routes
- Exploit GPS time to synchronize Node TX and RX to minimize transmission windows.
- Route to nodes with high energy levels. Avoid low-energy Nodes.



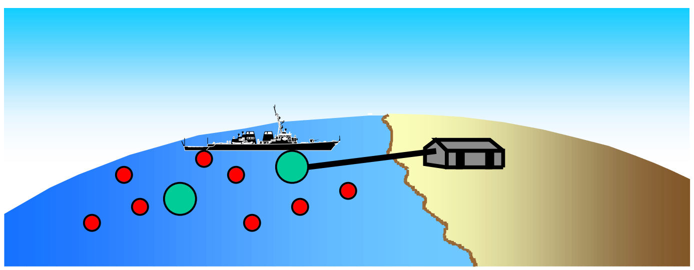
Source: Mani Srivastava, UCLA, "Dynamic Sensor Networks", DARPA SensIT meeting, Oct 1999

SPAWAR/ONR Seaweb Experiments

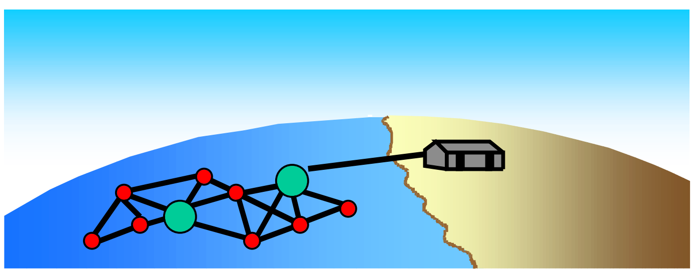
• Distributed underwater sensor network using acoustic modem links



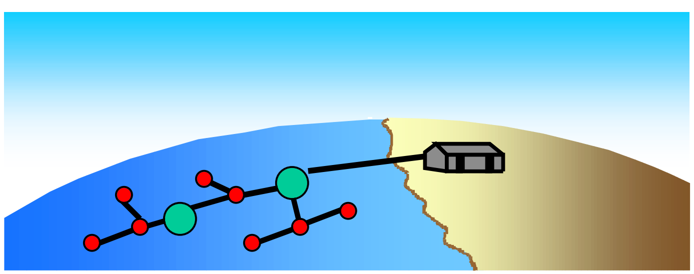
10 days: Prep Sensor Nodes
- Predict environment, connectivity
- Specify spacing for mission
- Pre-program master nodes



1 day: Install & Activate
- Obey spacing constraints
- Test master node links to gateway
- Awaken network neighbors
- Handshake with neighbors



3 hours: Initialize & Register
- Obtain reciprocal channel response
- Perform 2-way ranging
- Synchronize clocks
- Measure depth
- Set transmit power and shape
- Report link parameters to master node

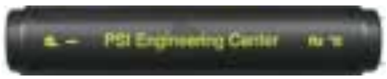


1 hour: Optimize
- Choose primary & alternate data routes
- Assign protocols

90 days: Operate
- Monitor energy levels and links
- Optimize life, security, & latency
- Assimilate new and mobile nodes

State-of-the-Art Sensor Network Hardware

← 10 cm →



PlanSys
ATM-SONET
Node

← 10 cm →

CrossBow
4-ch wireless
Sensor Node

← 8 cm →

Rockwell
4-ch wireless
Sensor Node

USAF Ground
Sensor Node

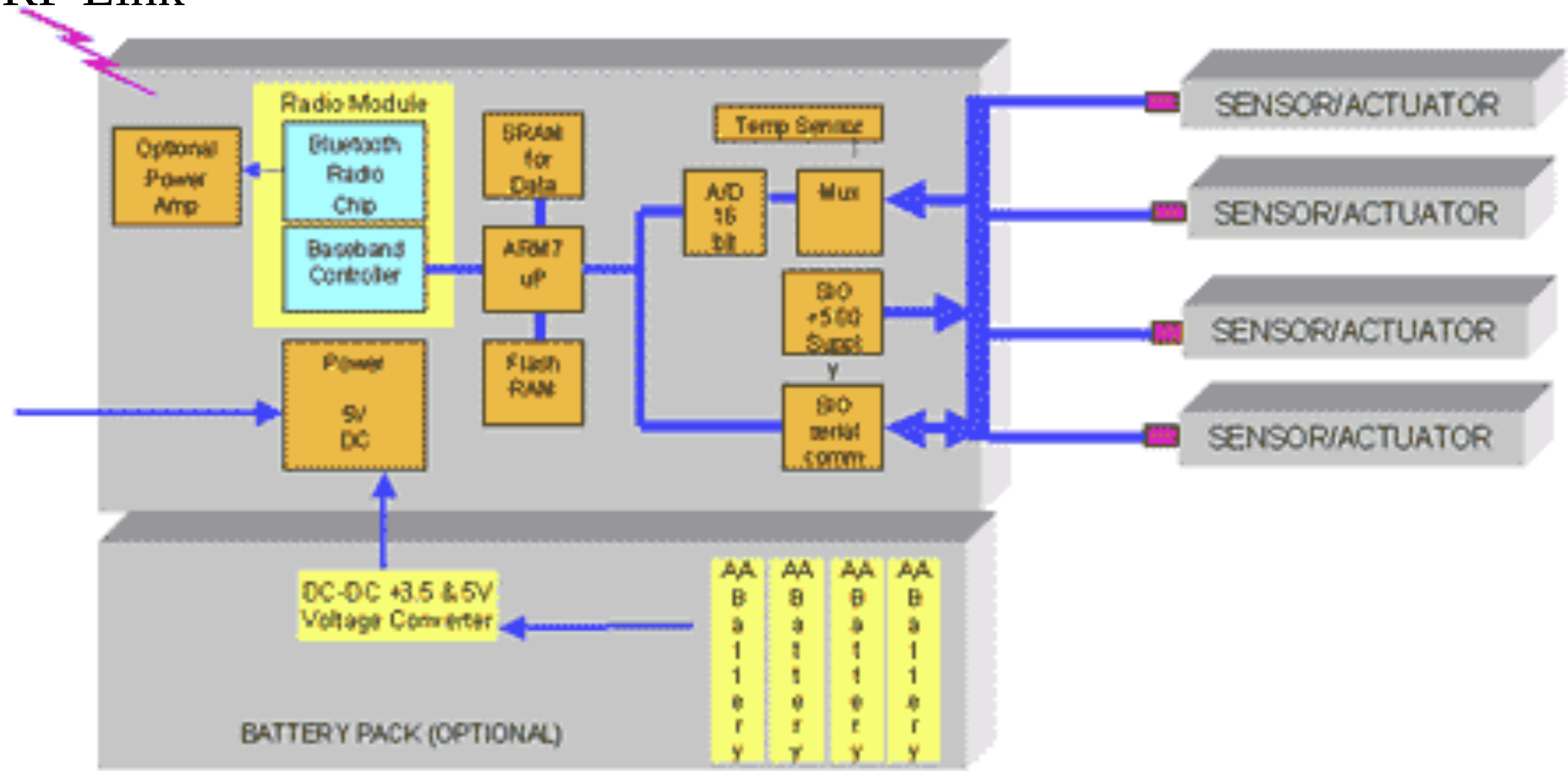
Nova Engineering
Wireless TCP/IP
Mobile Node

PlanSys
64-ch ATM
Sensor Node

Fluke
8-ch Ethernet
Sensor Node

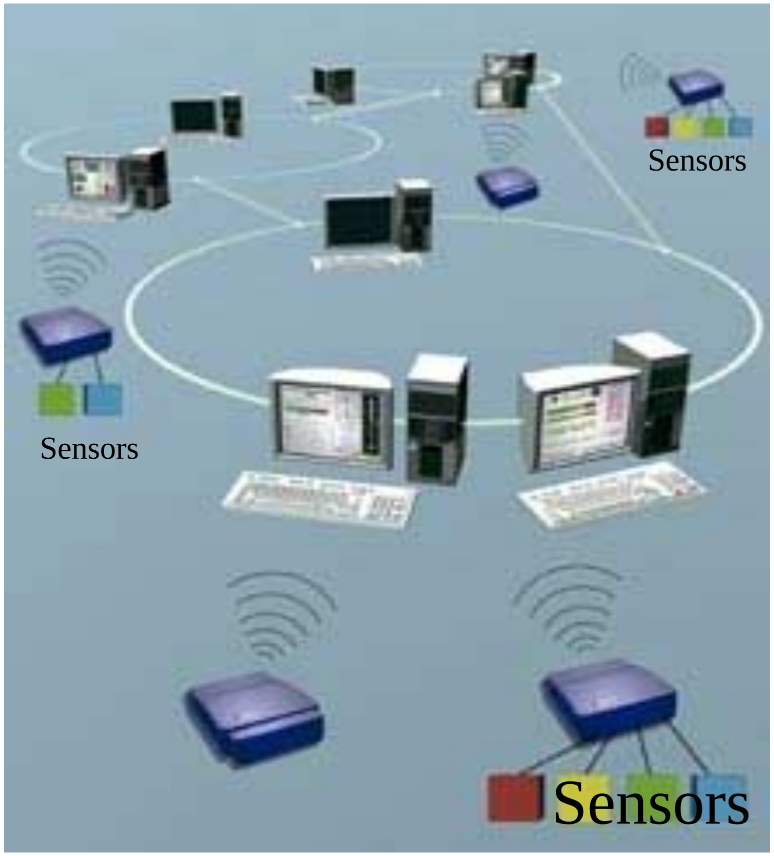
Example 4-ch Data Acq Node using Bluetooth Wireless Network

Bluetooth
RF Link



Bluetooth Wireless Links

- Emerging 1 Mbit/s wireless network standard. Www.bluetooth.com
- PlanSys predicts that Bluetooth will become a very popular network technology.



Wireless Ethernet

- 1 Mbit/s and 11 Mbit/s products available
- Future evolution towards 50 Mbit/s expected

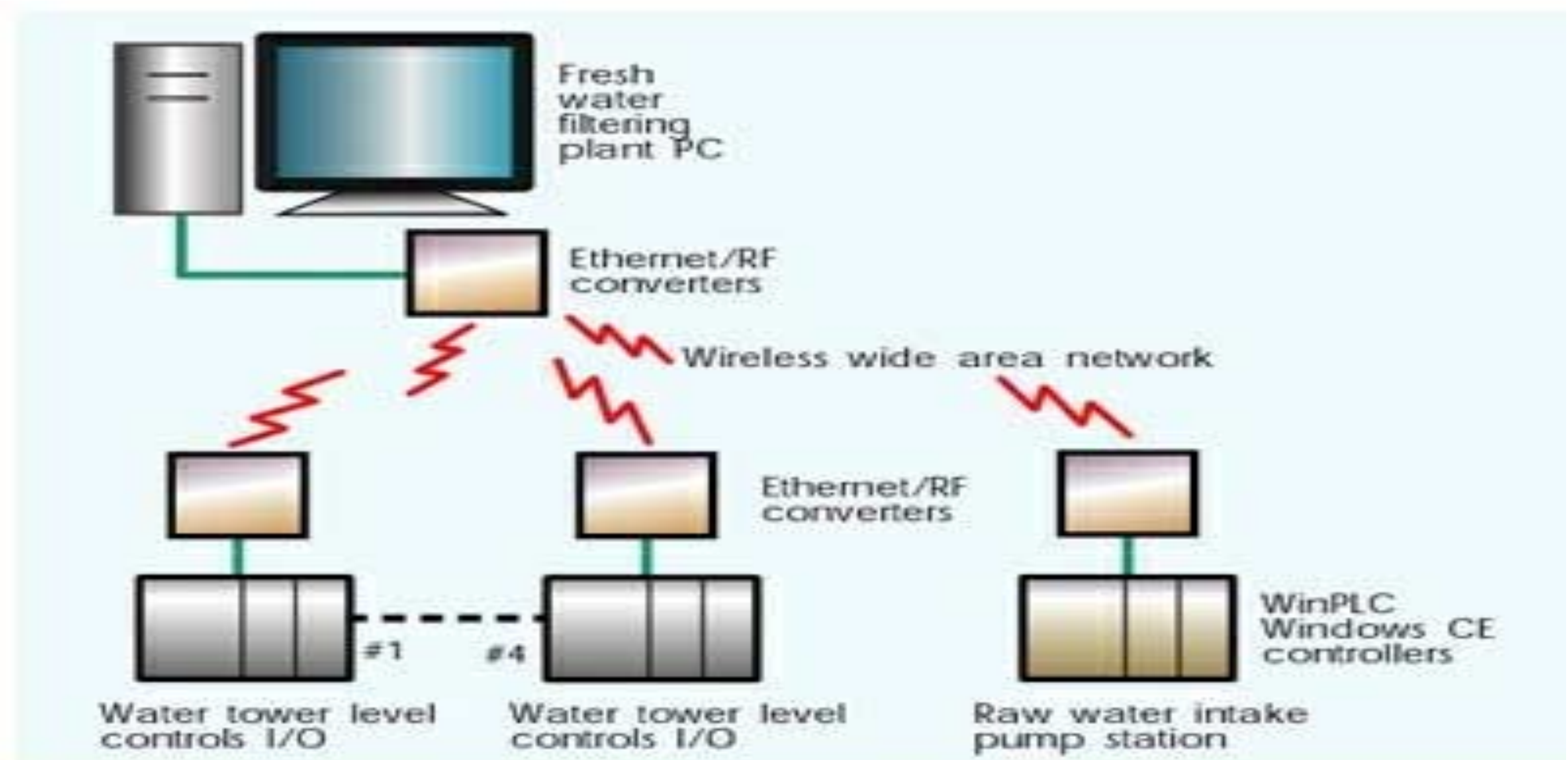
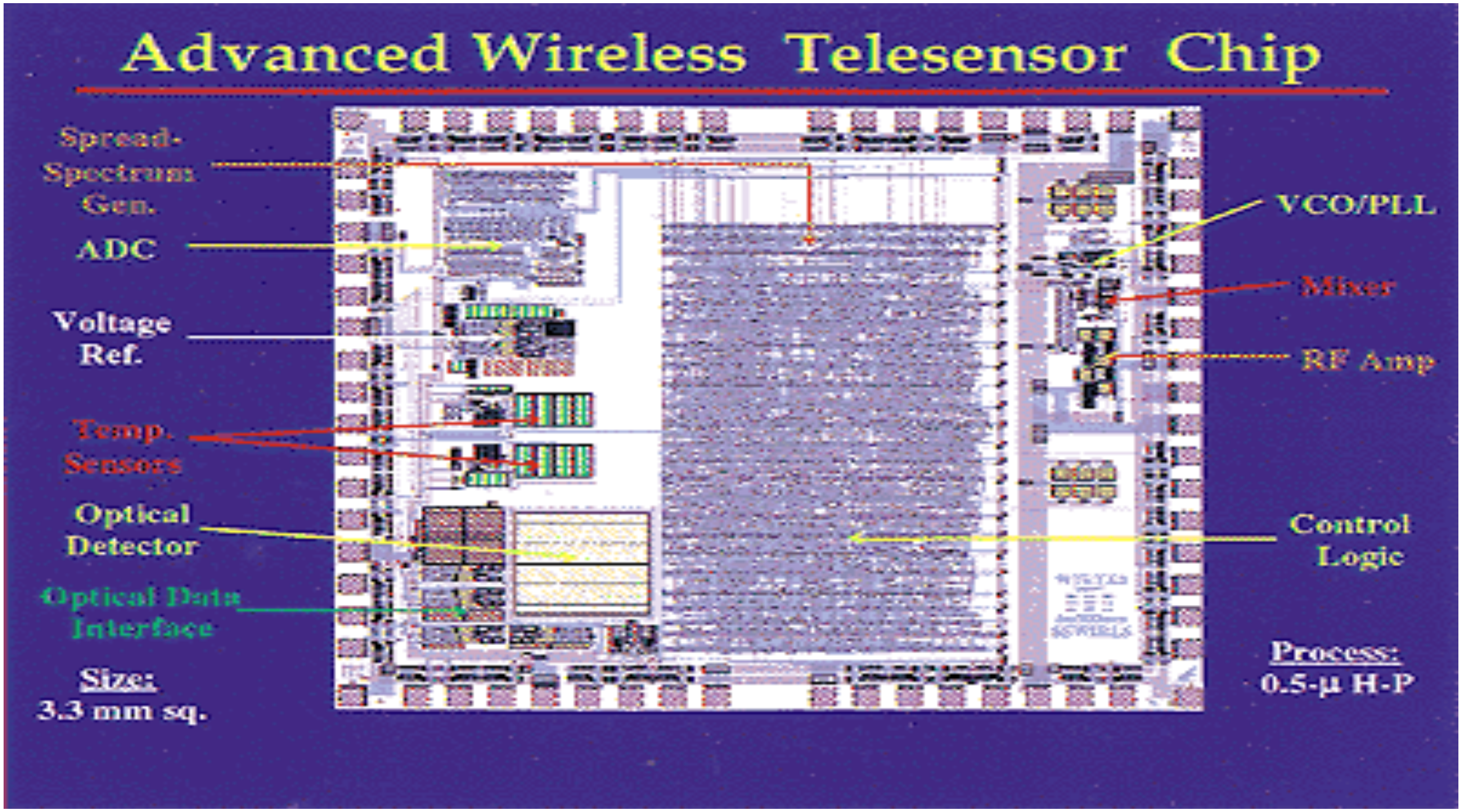


FIG. 2: Municipal water waste treatment for the City of Rock Hill, NC uses wireless Ethernet.

Source: Gary Marchuk, Open Technolgy Paves Way for Wireless Communications, I&CS, June 2000

Wireless Sensor Chips

- Developed by Oak Ridge National Labs
- Major sensor node functions on 3.3 mm sq. semiconductor
- Includes multiple sensors, A/D, and wireless RF link section



Source: Wayne Magnes, et.al., "Intelligent Wireless Sensors for Industrial Manufacturing", SENSORS, April 2000

Summary

- Billions of sensors will be deployed in numerous applications
- Sensor networks are providing decreased system costs in traditional sensor applications such as sonar arrays.
- Sensor networks are enabling new applications such as sniper detection and localization.
- Sensor networks will improve operational pictures and engagement through more accurate detection, identification, and tracking.
- Emerging software technologies such as spatial routing, sensor fusion, distributed collaborative computing, and declarative queries will enable smart sensor networks that improve performance and use.
- Emerging hardware technologies such as MEMS, wireless links, and Node miniaturization will enable large distributed sensor networks.