Professional Development Short Course On:

Self-Organizing Wireless Networks

Instructor:

Timothy D. Cole

ATI Course Schedule: http://www.ATIcourses.com/schedule.htm

ATI's Self-Organizing Wireless Networks: http://www.aticourses.com/self_organizing_wireless_networks.htm

Self-Organizing Wireless Networks

Design and Operation of Unattended Ground (Networked) Sensors

NEW!

July 20-21, 2009

Laurel, Maryland

$1040 **(8:30am - 4:00pm)**

"Register 3 or More & Receive $100⁰⁰ each Off The Course Tuition."

Summary

Summary: This two-day course addresses use of ad hoc network sensors to address "smart" reconnaissance, the employment of sensing motes with relay architecture, to enable objectives as: vehicular/personnel detection and tracking, persistent surveillance, perimeter control, event monitoring, and tagging/tracking/locating (TTL) functions. The course is designed for engineers, program managers, scientists, practitioners, as well as government and industry decision-makers involved in programs and technologies that address the surveillance. The course presents the concept of using small (<30 in3) micro-sensors ("motes") within a wireless ad hoc network to perform tasks previously assigned to larger, more power hungry sophisticated sensors. Through distributed processing of sensory signals within a networked field, motes can accomplish a myriad of tasks. The course introduces technologies that spawned and promoted mote-sized wireless sensors, discusses design of mote cores and associated sensors, middleware functionality and implementation requirements, and provides insights concerning C2 interfaces. Examples are provided that presents low power ad hoc networking, mote-based sensor design rules, middleware implementations, and issues associated with data exfiltration and deployment. Actual implementations of mote arrays in laboratory and field tests are reviewed along with underlying designs for specific applications.

http://dtsn.darpa.mil/ixo/programs.asp?id=87#. Examples of motes, mote sensors, exfiltration approaches, middleware issues, and C2 capability are presented along with trade-offs and actual evaluation results.

Instructor

Timothy D. Cole is the chief scientist at the Northrop Grumman/TASC, Tampa, FL. Mr. Cole has evaluated, operated, and designed motes and mote-based sensors and relays for various government and military organizations. He was the Technical Lead for TASC's effort on the NEST program and is the principal investigator (PI) on multiple NG IRaDs associated with emerging mote sensing and operational capabilities. He is the inventor, designer, and scientific team member for several remote sensing instruments and programs including: laser radars for NASA (Near-Earth Asteroid Rendezvous Laser radar, NLR), photorefractors (Hopkins/Wilmer Eye Institute), imagers (NASA's Long Range Reconnaissance Imager for the New Horizons mission) and currently designing sensors for NG/TASC based upon Laser Vibrometry Systems (LVS).

Course Outline

1. Mote Definitions. What is a mote? Fundamental building blocks that comprise a mote core. Subsystem designs and implementations. Review of ad hoc network reviewed.

2. Mote Design. Mote design goals and objectives. Descriptions and examples of mote subsystems. Mote sensor systems descriptions and examples. Passive sensors, RF (ultrawideband, UWB) sensors, active-optical sensors, olfactory-based sensors.

3. Mote RF Design. RF propagation at ground level. RF designs. RF reliability.

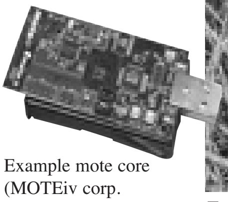
4. Mote Programming. Review of network management systems (NMS), employing low-power media Access Communications (LPMAC). Middleware functionality. Mote constraints. Distributed sensor, signal, and data processing.

5. Mote Field Architecture. Self-organizing capability. Mote field logistics. Mote field initialization. Localization techniques. Relay definition and requirements. Interfaces to backhaul data communications, interfaces: Cellular, SATCOM, LP-SEIWG-005A, UHF, other.

6. Mission Analysis. Mission definition and needs. Mission planning. Interaction between mote fields and sophisticated sensors. Mote/sensor selection. Distribution of motes. Deployment mechanisms. Relay statistics. Exfiltration capabilities.

7. Situational Awareness. Situational displays employed. Sensor injection design rules and examples. Display capabilities and examples, including: C2PC. COT. Falcon View. PULSEnet.

8. Design of systems. Area persistent surveillance. MOUT application.



Example mote core (MOTEiv corp. tmote).

Tactical mote (TASC-modified XSM mote, TXSM), in situ, complete with camouflaged "jacketing".

What You Will Learn

- Why can be accomplished using ad hoc mote networks?
- What are the limitations and strengths associated with mote fields?
- Which sensor technologies are suited for low-power mote applications?
- How do systems get integrated into "useable" systems and architectures?
- What exfiltration routes exist to get data out and commands in?
- How do I program motes? And how would I reprogram motes?
- What programming can I employ?
- How to command and control unattended sensors? What are the emerging architectures to accomplish such (e.g., PULSEnet)?

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INTRODUCTION: Objectives/goals

- **The course introduces technologies that spawned mote-sized wireless sensors**
  - Sensor modalities stemming from MEMs and/or miniaturization
  - Radio stack (chip) development
  - Distributed processing (middleware) functionality & implementation
- **Efforts in self-organizing wireless networks and are discussed including that associated with the `DARPA/NEST` program:** **http://dtsn.darpa.mil/ixo/programs.asp?id=87 (Network Embedded Sensor Technology)**
- **Background information that describes *ad hoc* networking,**
  - Mote core designs, mote-based sensor design rules
  - Issues associated with data exfiltration and deployment
  - Provides insights concerning mote-field C^2 interfaces
  - Data associated with mote arrays resulting from testing
  - Trade-off criteria and evaluation procedures
  - Hands-on experiences and issues that are being worked…

INTRODUCTION: Objectives/goals

- **Course does <u>not</u>:**
  - Teach how to code using C (NesC) nor wield TinyOS, TinydB, Deluge, Serial Forwarder, C2PC…
  - Indicate to layout & design a mote core
  - Demonstrate programming issues due to concurrent real-time programming
    - Hint: get a RTOS! Hint hint: get a debugger
  - Indicate how to specifically setup simulations (TOSSIM)
- **Prerequisites, assume familiarity with:**
  - Computer languages and OS environments
  - Principles behind RF communication theory and implementation
  - Protocol in MAC, routing, and capacity of multi-hop wireless network
- **Good news:**
  - TinyOS = open source, a LOT of help exists online (join TinyOS help)

    https://www.millennium.berkeley.edu/mailman/listinfo/tinyos-help
  - Same for TOSSIM, tutorial: http://www.tinyos.net/tinyos-1.x/doc/tutorial/lesson5.html
  - If C programmer, not too difficult to make transition to NesC
  - TinyOS et al, takes some spin up time, but tutorials abound!
  - Also, Java Virtual Machine (JVM) for motes coming to town

INTRODUCTION: Instructor Background

- **Timothy D. Cole, wbi@mac.com , 813.468.6233 (813.205.2661)**
  - **Education**
    - **JHU undergraduate (BES/EE) & graduate (MSEE, MS) degrees**
    - **Univ. of Alabama, physics**
  - **Work Experience**
    - **JHU/APL – SSD (4 years), Space Dept (17 years)**
    - **Teledyne – BMDSCOM (5 years)**
    - **Raytheon – MUOS (1.5 y)**
    - **Northrop Grumman IT (TASC) – National Intel (*last* 4 years)**
      - **DARPA NEST & EXANT Programs**
      - **DIA ANDSC/D Program**
      - **IRaD, Micro-Laser Radar (MLR), Sensor Exfil Relay Integration (SERI), PulseNET™**
  - **MOTE PROGRAMS:**
    - **NEST: 2000-2005** **DARPA Embedded Sensor Technology**
    - **EXANT: 2006-2007** **DARPA Mote Scalability & Code Repository**
    - **ANSC/D: 2005** **DIA Motefield/Sensor Integration and Test**
    - **MLR/SERI:2006-2007** **NGIT IRaD Motefield R&D**

INTRODUCTION: Concepts involved

1. **Mote core (fundamental):** ***radio-stack***, low-power ***microprocessor*** systems, power distribution, memory, uC/uP, data acquisition microsystems (ADC).
2. **Programming environment.** Real-time, event-driven, with OTA programming, deluge, distributed processing (middleware)
3. **Low-power.** Mote design, field design, overall architecture regulation & distribution,
4. **Localization**. Autonomous (iterative) solutions, GPS chipset, & interface(s).
5. **Sensor modalities.** Design goals and objectives. descriptions and examples of mote passive and active (e.g., ultra wideband, UWB) sensors
6. **RF propagation.** Multi-path, fading, scattering, attenuation at ground level. RF reliability.
7. **Network management systems (NMS).** Self-organizing capability and multi-hop capabilities. Low-power media Access Communications (LPMAC). Middleware functionality. Mote constraints.
8. **Mote Field Architecture.**. Mote field logistics. Mote field initialization. Relay definition and requirements. Backhaul data communications: Cellular, SATCOM, LP-SEIWG-005A.
9. **Mission Analysis**. Mission definition and needs. Mission planning. Interaction between mote fields and sophisticated sensors. Distribution of motes.
10. **Deployment mechanisms.** Relay statistics. Exfiltration capabilities.
11. **Situational Awareness.** Situational displays employed. Sensor injection design rules and examples - capabilities and examples, including: C2PC, COT, Falcon View, PULSEnet.

INTRODUCTION: Mote subsystems

QuickTime™ and a
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are needed to see this picture.

INTRODUCTION: Motivation

- **Evolution of Computing**

One to Many

Billions
of Computers

One to One

Millions
of Computers

Many to One

Thousands
of Computers

INTRODUCTION: Motivation

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

In the ultimate volumes

INTRODUCTION: Motivation

- ***Ad hoc*** **networking of sensors – power in numbers**
  - ***Ad hoc***, meaning what?
  - **Smart** reconnaissance?
  - **Mission** types served?

- **Concept of using small (<30 in^3) micro-sensors (referred to as "motes") within a** wireless *ad hoc* network
  - Why not use sophisticated sensors? ($/km^2, agility, SPOF, versatility)
  - Through distributed processing of sensory signals within a networked field, motes can accomplish a myriad of tasks.
  - Mote "fields" can be applied using numerous configurations that allow for novel security and/or military applications.

INTRODUCTION: WSN Overview

- **A wireless sensor network (WSN) is a wireless network consisting of spatially distributed autonomous devices using sensors to cooperatively monitor physical or environmental conditions (temperature, sound, vibration, pressure, motion, chem) at different locations**
  - Originally motivated by military applications, as battlefield surveillance.
  - Now used in many civilian application areas
  - Wireless Sensor Networks WSN, Self-Organizing Wireless Sensors (SOWN), interchangeable -- connotation stems for origins and field of study.
- **In addition to one or more sensors, each node in a sensor network is typically equipped with a radio transceiver or other wireless communications device, a small microcontroller, and an energy source, usually a battery.**
  - The envisaged size of a single sensor node vary from shoebox-sized to devices the size of grain of dust -- functioning 'motes' of genuine microscopic dimensions yet to be created.
  - The expected cost of sensor nodes is similarly variable, ranging from hundreds of dollars to a few cents, depending on size of sensor network & complexity required of individual nodes.
  - Size and cost constraints on sensor nodes result in corresponding constraints on resources such as energy, memory, computational speed and bandwidth.
- **A sensor network constitutes a wireless *ad hoc* network, meaning that it each sensor supports a multi-hop routing algorithm (several nodes may forward data packets to the base station).**

INTRODUCTION: WSN Overview

- **Unique characteristics of a WSN require:**
  - **Small-scale sensor nodes**
  - **Limited power (ample capacity and supply, harvest and/or storage)**
  - **Harsh environmental conditions**
  - **Node failures tolerance**
  - ***Ad hoc* placement and localization of nodes**
  - **Dynamic network topology**
  - **Communication link failures**
  - **Heterogeneity of nodes**
  - **Large scale deployment**
  - **Unattended operation (command, control, data extraction)**
  - **Integration into an unified system capability**

INTRODUCTION: WSN Overview

- **Motes (nodes) can be imagined as small computers, extremely basic in terms of their interfaces and their components.**
  - Consist of a processing unit with limited computational power and limited memory
  - Sensors (including specific conditioning circuitry)
  - Communication device (usually radio transceivers or alternatively optical), and a power source usually in the form of a battery.
  - Other possible inclusions are energy harvesting modules, secondary ASICs, and possibly secondary communication devices (e.g. RS-232 or USB).
- **More field architecture requires**
  - Large numbers of motes
  - Adherence to RF-range, network reliability, terrain (topography), and sensor performance
  - Typically, exfiltration occurs via base stations are one or more distinguished components of the WSN with much more computational, energy and communication resources -- gateway between sensor nodes and GIG (end users)

INTRODUCTION: Final thoughts….

- **Recent excitement comes from cost per unit and ability to use large numbers of ad hoc nodes to autonomously instrument any objective;**
    - **industrial**
    - **commercial**
    - **environmental**
    - **military**
    - **governmental**

- **These characteristics combine to address a plethora of data AND communication intensive missions via a cost-effective and adaptable approach**

INTRODUCTION: Final final thoughts…

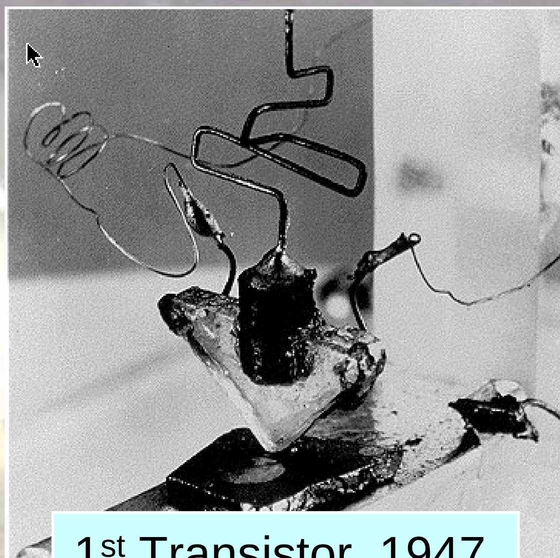
AGENDA

- INTRODUCTION
- **BACKGROUND**
- MOTE DESIGN
- CASE STUDIES
- DESIGN CONSIDERATIONS

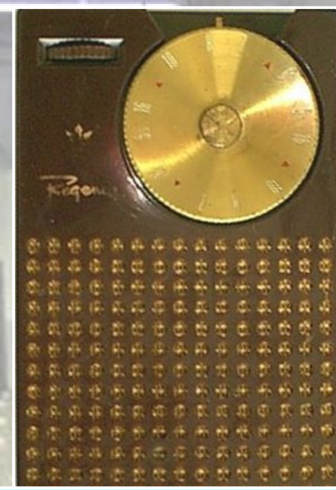
BACKGROUND: Agenda

- Historical/Evolution/Revolution
- Seminal Program (DARPA's NEST)
- Mote Defined
- Integration with the World
- Subsystem considerations
- Interface considerations
- Overview of Applications

BACKGROUND: The IC Revolution

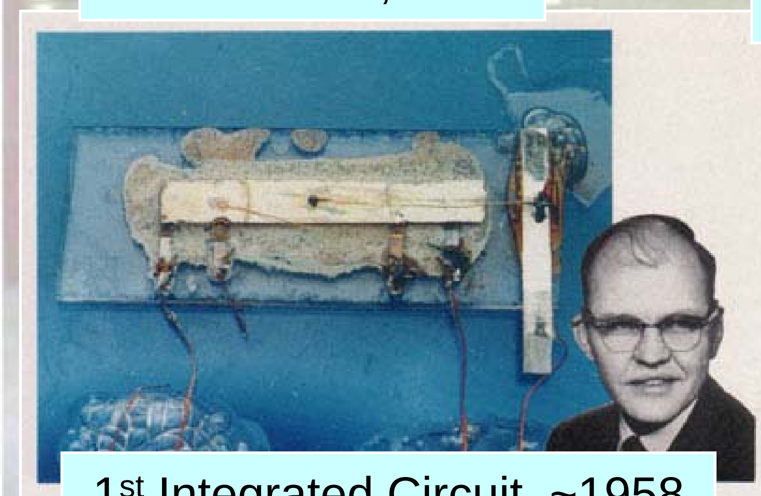


1st Transistor, 1947



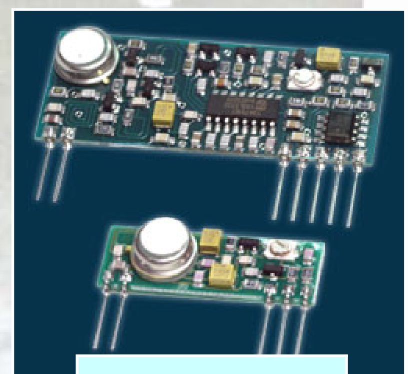
TI REGENCY TR-1, 1955, $450 (today)

Sony TR-610, 1958



1st Integrated Circuit, ~1958

Integrated Circuit, 1963



Today ~$5

BACKGROUND: Computer Revolution

Original IBM PC (1981)	*MICAZ Mote (2005)*
4.77 MHz	4 MHz
16-256 KB RAM	128 KB RAM
160 KB Floppies	512 KB Flash
~ $6K (today)	~ $35
~ 64 W	~14 mW
25 lb, 19.5 x 5.5 x 16 inch	0.5 oz, 2.25 x 1.25 x 0.25 inch

BACKGROUND:

Wireless (cellular) technology evolves

BACKGROUND:
μP & wireless combine, following Moore's law

Gordon E. Moore, Intel CEO, 2x transitor count/IC every 2 years

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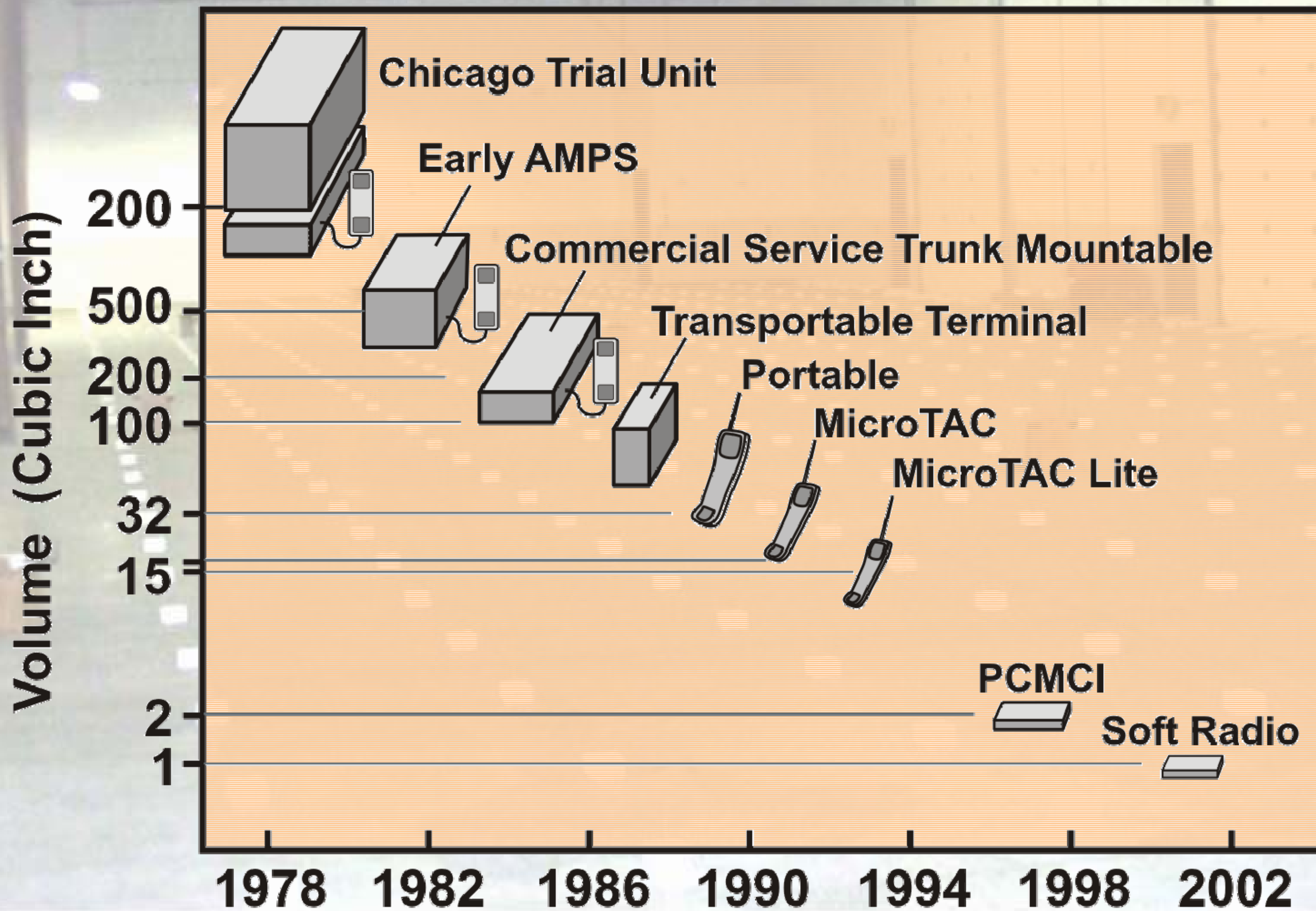
BACKGROUND: Wireless Revolution

BACKGROUND: The wireless evolution

Size reduction of cellular telephones



BACKGROUND: Integration with worldwide data communication architectures

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BACKGROUND: Autonomy + Sensors + RF + worldwide distribution = new missions

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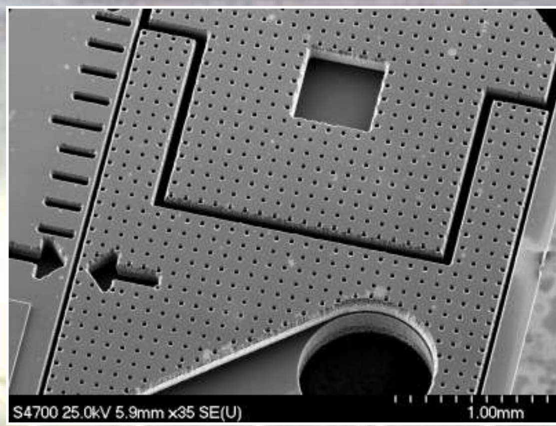
BACKGROUND: Micro-Electro-Mechanical-Systems (MEMS)



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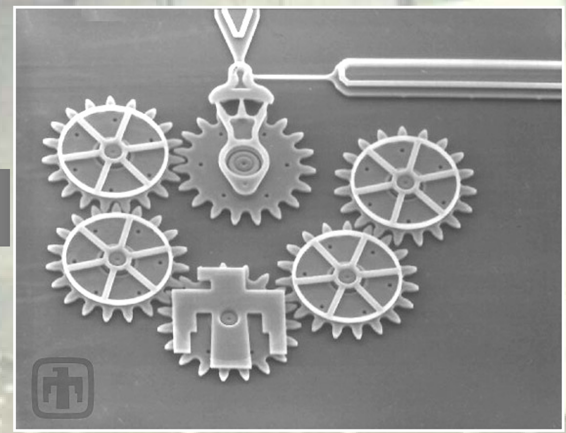
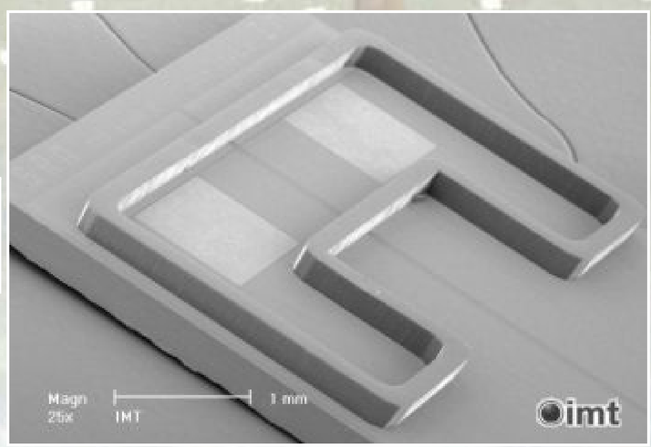


Sensor uses electrochemical and photonic properties to perform bioanalysis



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BACKGROUND: Use of small RF-connected nodes to perform complex tasks

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BACKGROUND: Groundswell of WSN & associated technologies

- **Reasons for wireless networks**
  - Low Power/Small Physical Size
  - Reduced setup costs (no wires needed)
  - Ability to monitor remote test sites
  - Ability to monitor large areas with minimal hardware
  - Capability to monitor data in real time
  - Great versatility (programmable/upgradeable)

- **Combination of emerging technologies into unified system approaches requiring distributed measurement capabilities**
  - Existing backbone data communication systems (e.g., SATCOM, GSM, CDMA, IP)
  - *Borrowed* RF technology off cellular technologies & infrastructures
  - *Borrowed* processing technology off device technologies & infrastructures
  - *Borrowed* embracement of distributed processing (recall The Mersenne prime search formed 1996, -- a new world-record Mersenne prime discovered every year; also SETI@home originated in a conversation w/ David Gedye & Craig Kasnov in 1994. In May 1999, after several months of testing, the project launched. 15 December 2005, turned off server of SETI@home Classic, ending the **largest computation in history**.)
  - Arrival of low-power, low-cost sensor modalities (e.g., MEMS)

BACKGROUND: Evolution of Technologies used in WSN

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BACKGROUND: DARPA Networked Embedded Systems Technology (NEST)

- **In 2000, DARPA sought novel approaches to the design and implementation of software for networked embedded systems.**
  - ◆ Embedded information processing primary source for superiority in weapon systems.
  - ◆ Wave of inexpensive MEMS-based sensors and actuators and continued progress in photonics and communication technology accelerated this trend.
  - ◆ Weapon systems increasingly “information rich,” where embedded monitoring, control & diagnostic functions penetrate deeper with smaller granularity in physical component structures.
- **Separation of physical and information processing architectures not sustainable.**
  - ◆ Strong mutual interdependence requires fusion at fine levels of granularity, i.e. the distribution of information processing among physical components.
  - ◆ Coordinated operation of distributed embedded systems makes embedding, distribution, & coordination = fundamental technical challenge for embedded software.

BACKGROUND: DARPA NEST

- **BAA #01-06**

  Networked Embedded Software Technology (NEST)
  CBD Reference
  Networked Embedded Software Technology (NEST)
  SOL BAA 01-06 DUE: 01/05/2001
  POC: DR. JANOS SZTIPANOVITS, DARPA/ITO
  E-Mail: baa01-06@darpa.mil
  FAX: (703) 522-7161

- **What is NEST trying to do?**
  - Develop technology for building dependable, real-time, distributed, embedded applications comprising 100-100,000 simple computing nodes:
    1. Provide **formally verified** algorithms and code for real-time coordination in networked embedded systems
    2. Develop theory and technology for **synthesis methods** that are embeddable in real-time systems.
    3. Develop methods and tools for the automated composition and customization of coordination services with **guaranteed** properties.

BACKGROUND: NEST “Players”

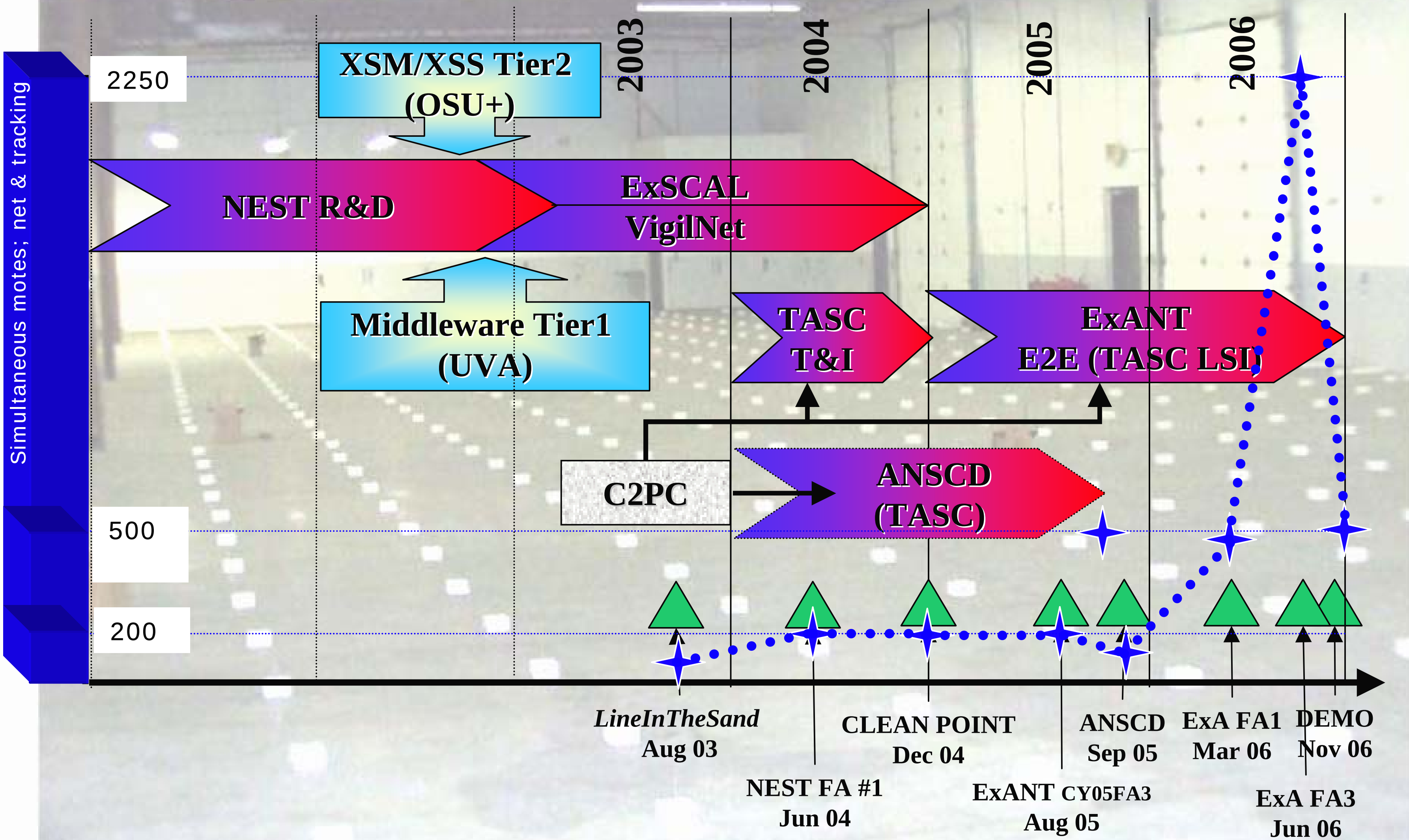
- **AFRL**
- **UCB**
- **UVA**
- **OSU**
- **Vanderbilt**
- **…**

- **Northrop Grumman**
- **Raytheon**
- **Crossbow**
- **…**

- **Intel**
- **MITRE**
- **Kestrel**
- **CACI**
- **…**

- **Countless “fathers” of SOWN/WSN, motes, etc, countless “Firsts” & “successes”**
- **Insure middleware and/or hardware employed *does* what it claims!**
- **At Issue:**
  - BIG on R&D
  - typical 6.1, 6.2
  - applications flow due to “opportunities”

BACKGROUND: *System-level* technology
NEST assessments --> DARPA ExANT Program



Successful Assessments Evolved from Successful R&D Contributions

BACKGROUND: Let's get technical… So what constitutes a mote, motefield, and/or a WSN???

What is a mote?

- **What are the mote subsystems?**
  - ◆ How to motes interact?
  - ◆ How are mote cores similar?
  - ◆ How do mote cores differ?
  - ◆ Which sensors?
- **How do you design and create mote software (middleware)**
- **What is the power behind netted sensors (motefield)?**
- **How do wireless sensor networks connect to the real world? And how do they interface to the existing data communication networks?**
  - ◆ What are the interfaces?
  - ◆ Why pick one exfiltration scheme over another?
  - ◆ How do you deploy the field?
  - ◆ …

BACKGROUND: What is a mote?

… "MOTE" …

- **"Tiny piece of anything"**
- **Low-power (RF) transceiver**
- **Microcontroller system**
  - Clocks
  - Memory
  - I/O
  - ADC

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TIFF (LZW) decompressor
are needed to see this picture.

Earth, as seen by Voyager 1 at a distance of 4 billion miles (Image from JPL/NASA).

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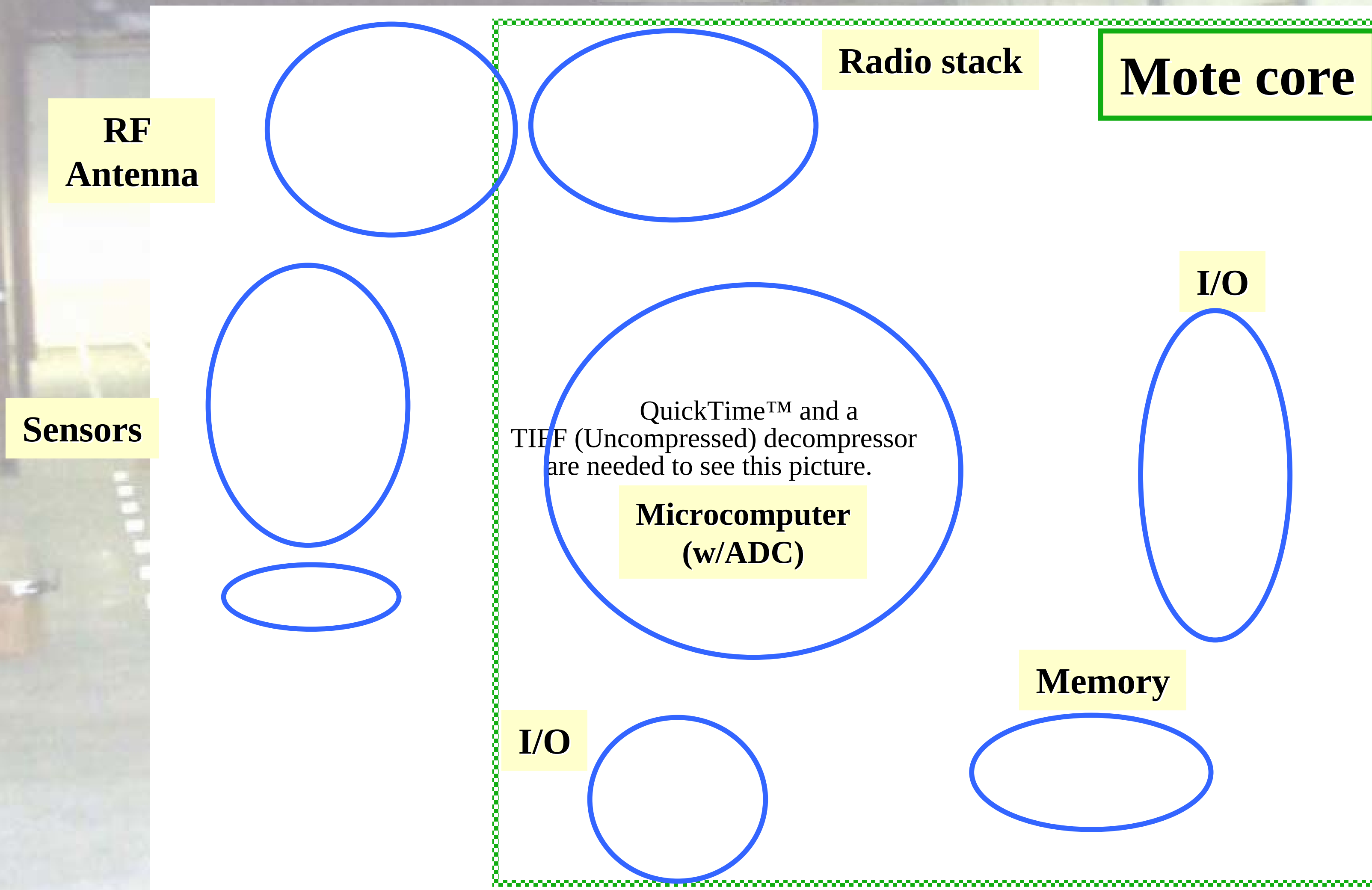
- **Operating system**
- **Programming language**
- **Simulation environment**
- **Debugger**

BACKGROUND: Concepts involved (Tmote Sky diagram), The Mote Core



BACKGROUND: Concepts involved (Tmote Sky), Mote Core Implementation (note USB)

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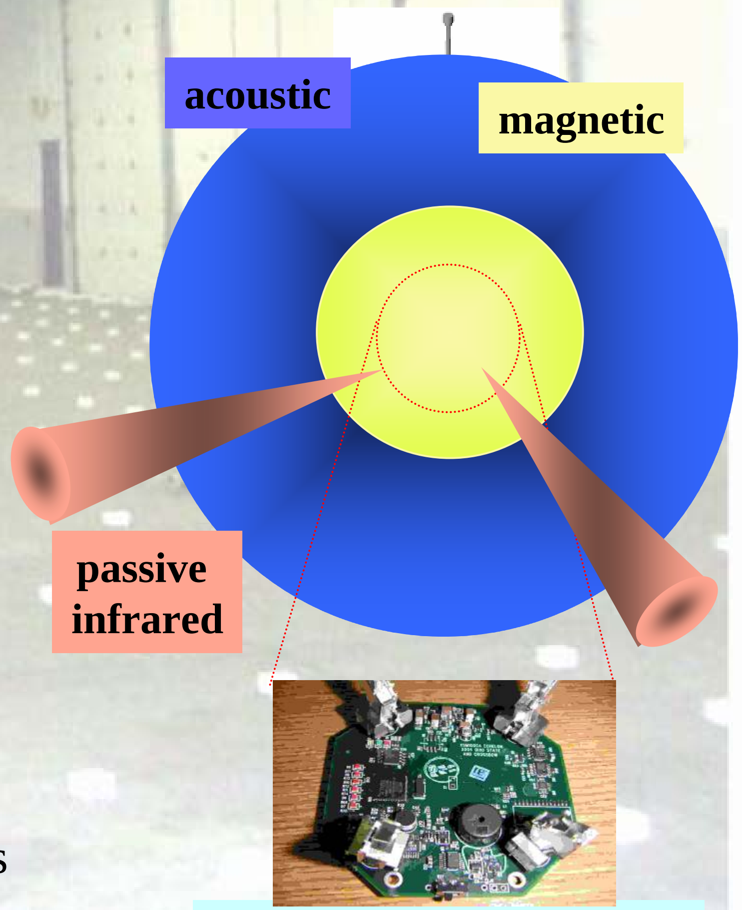
BACKGROUND: Simple Sensor Nodes

Mote ≡ Transducer (sensors) + Motecore (μC, Radio stack, RAM, power/dist)

- **Resource-constrained sensing & reporting**
- **Application-specific (<u>embedded</u> software)**
- **Data-centric routing; node = independent data collector**
- **Provide high-resolution information from *array* of nodes.**
- **Unattended, self-sufficient power sourced (e.g., batteries)**
  - Energy/transmit-bit v. processed instruction energy
  - Operational duration
  - Energy battle: RF Tx v. sensor op v. μP-cycles



The Crossbow XSM Mote

BACKGROUND: WSN Vendors and Products

MOTES/NODES:

- BTnode rev2
- BTnode rev3
- Ember
- eyesIFXv1
- eyesIFXv2.1
- FireFly
- Fleck
- Imote
- Imote2
- Mica
- Mica2
- Mica2Dot
- MicaZ
- Particles
- Rene
- ScatterWeb
- Sensinode
- SHIMMER
- SquidBee
- Sun SPOT
- Telos
- TinyNode 584
- Tmote Mini
- Tmote Sky
- T-Nodes
- WeBee
- WeC
- WiseNet

PROCESSORS:

* ARM7
* Atmel AVR
* Intel Xscale
* Intel 8051
* PIC
* TI MSP430

RADIO STACKS:

* Chipcon CC1000
* Chipcon CC1020
* Chipcon CC2420
* Xemics XE1205
* 802.15.4 Chipsets and SoC

BACKGROUND: So what would a WSN do for you?

BACKGROUND: Differentiation of WSN from other technologies such as RFID

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- **Small computers with wireless capability**
- **Alternative to RFID**

BACKGROUND: so why WSN-based sensing vs. “traditional” sensors?

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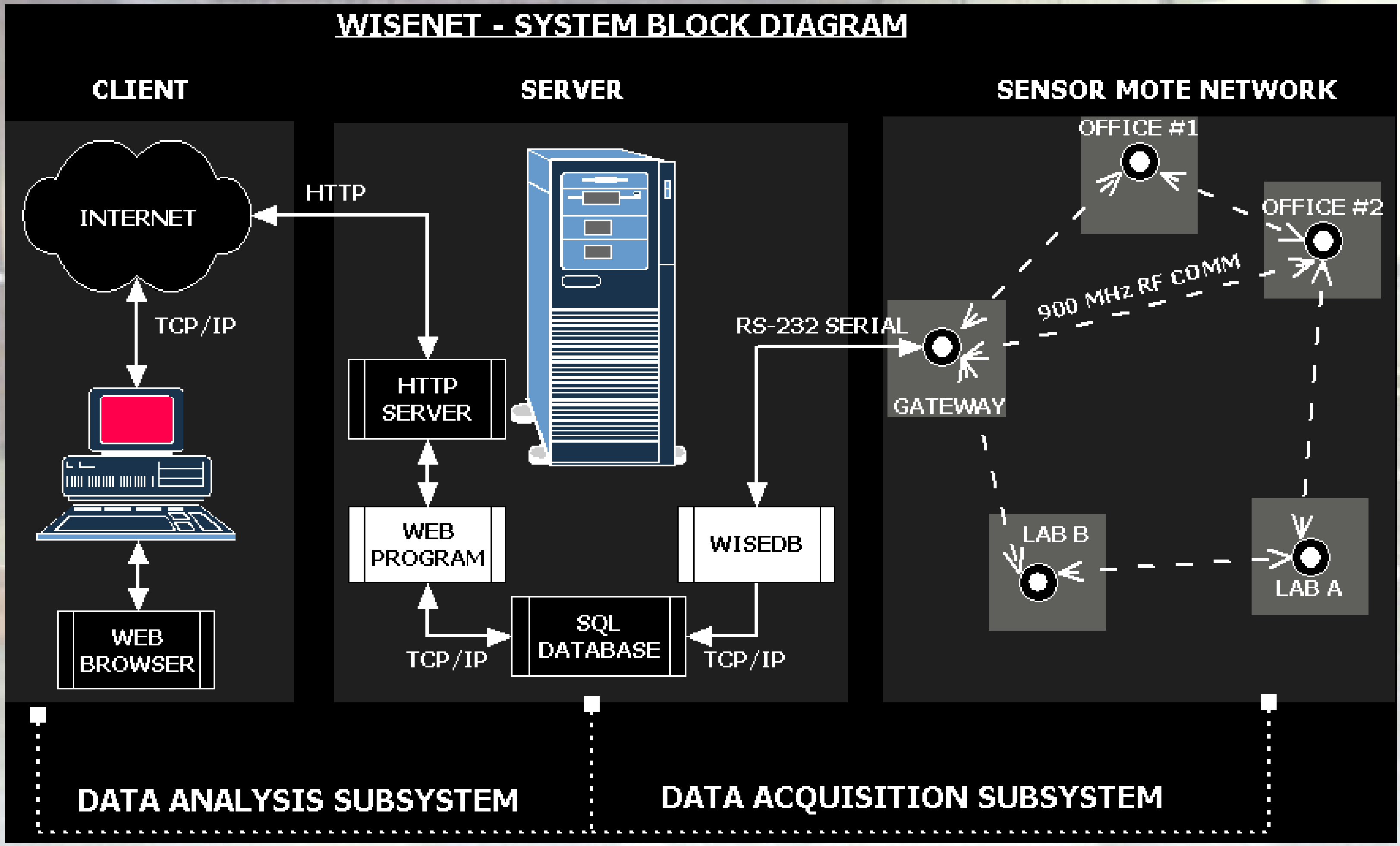
BACKGROUND: Integration of motes (motefield) into the end-user's path

<u>REQUIRES/DESIRES</u>

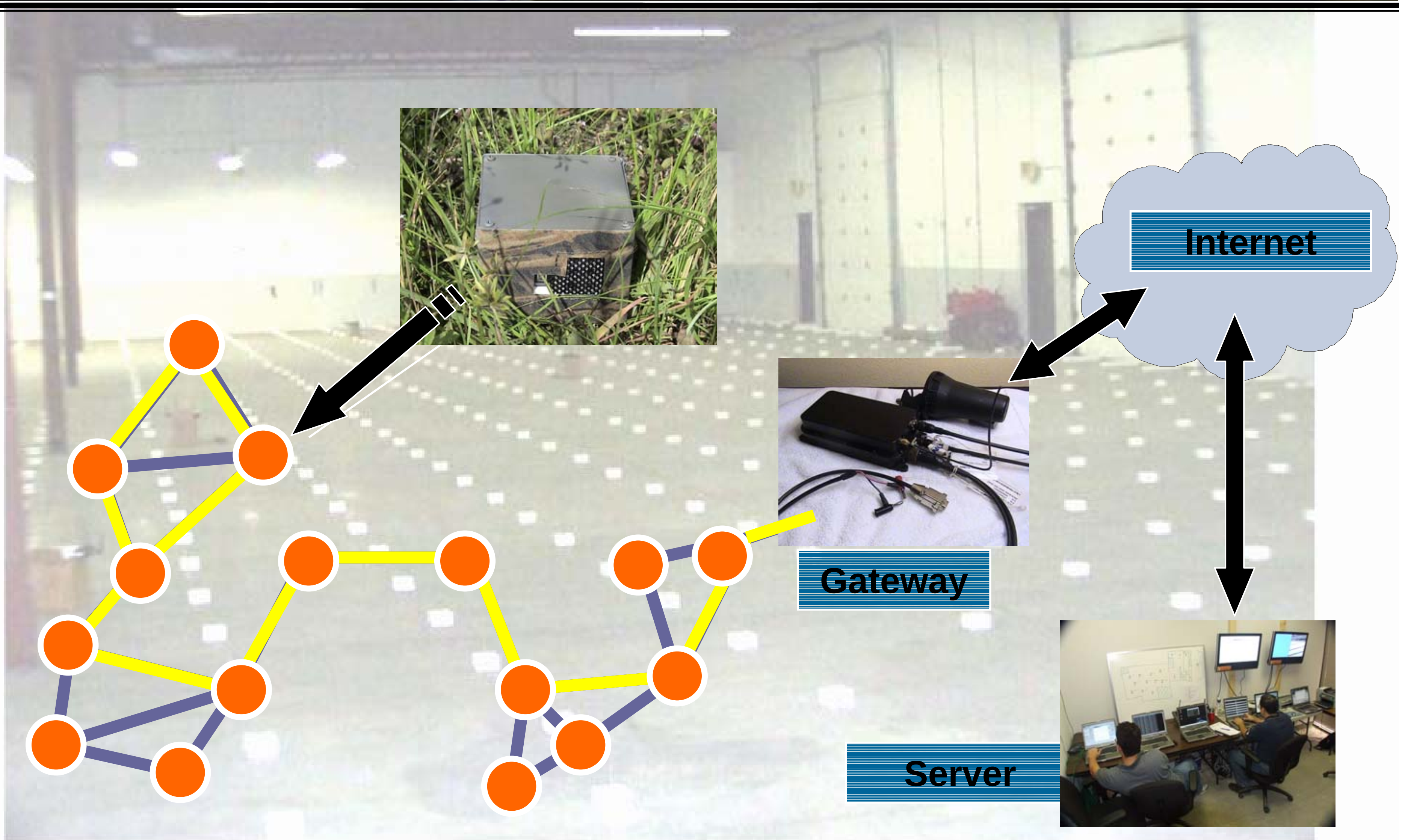
- **<u>Exfiltration</u> path (RELAY function)**
  - mote-based processing minimal
  - field-wide processing
  - extended RF range, at *ground* level
- **<u>Worldwide</u> (GIG) access**
- **<u>Standardized</u> situational awareness display(s) & GUI**
  - C2PC
  - COT
  - FalconView …
  - GoogleEarth (KML)
- **Sensor-web enablement (SWE)**
  - Open Geospatial Consortium (OGC) Standards
  - Northrop Grumman --> **PULSENet™**

    … MITRE, iGOV, SAIC, Raytheon, Sun Microsystem …
- **<u>Diagnostic</u> testing apparatus (throughout life-cycle)**

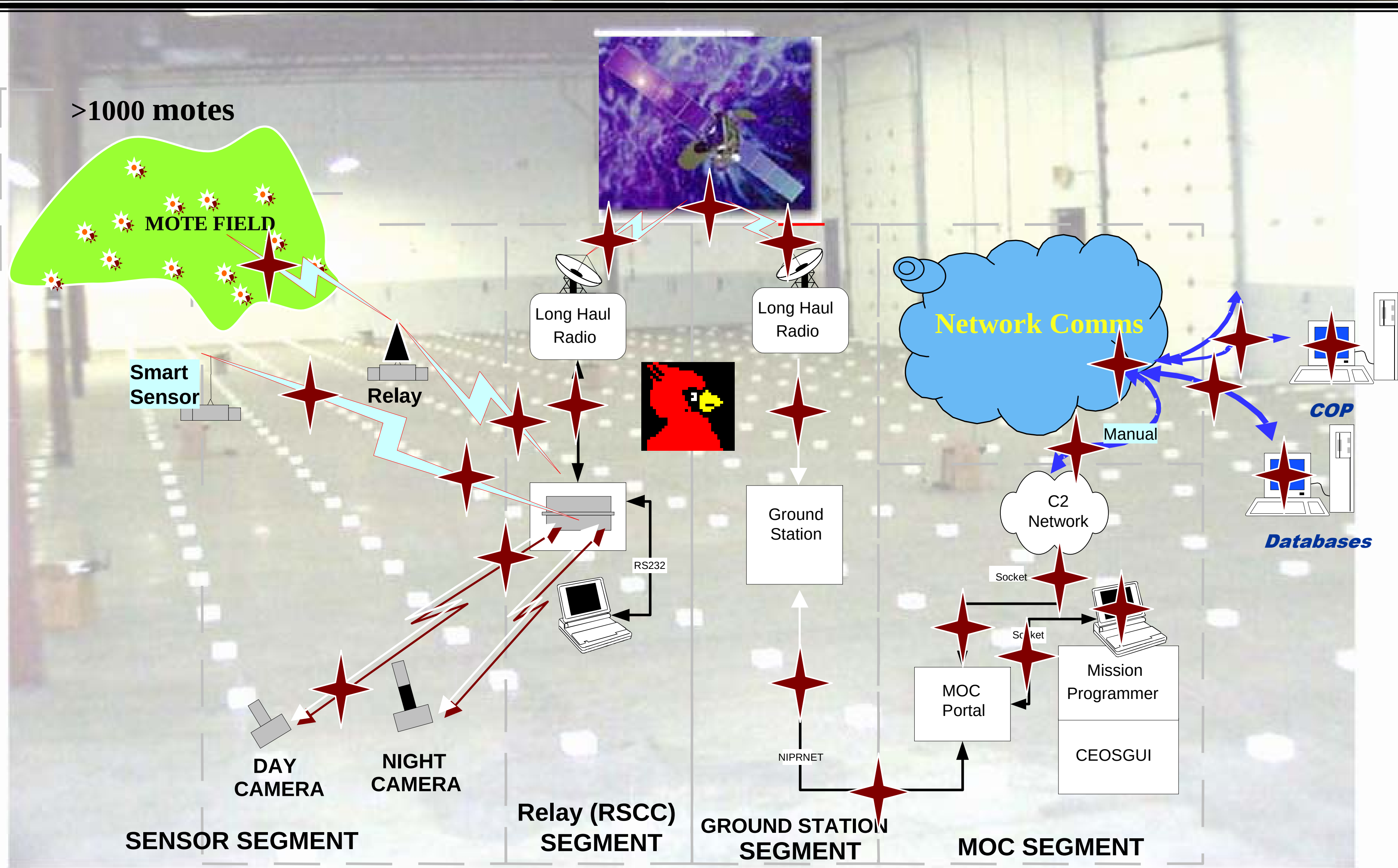
BACKGROUND: Local/IP network



BACKGROUND: Basic architecture of motefields (netted sensors)

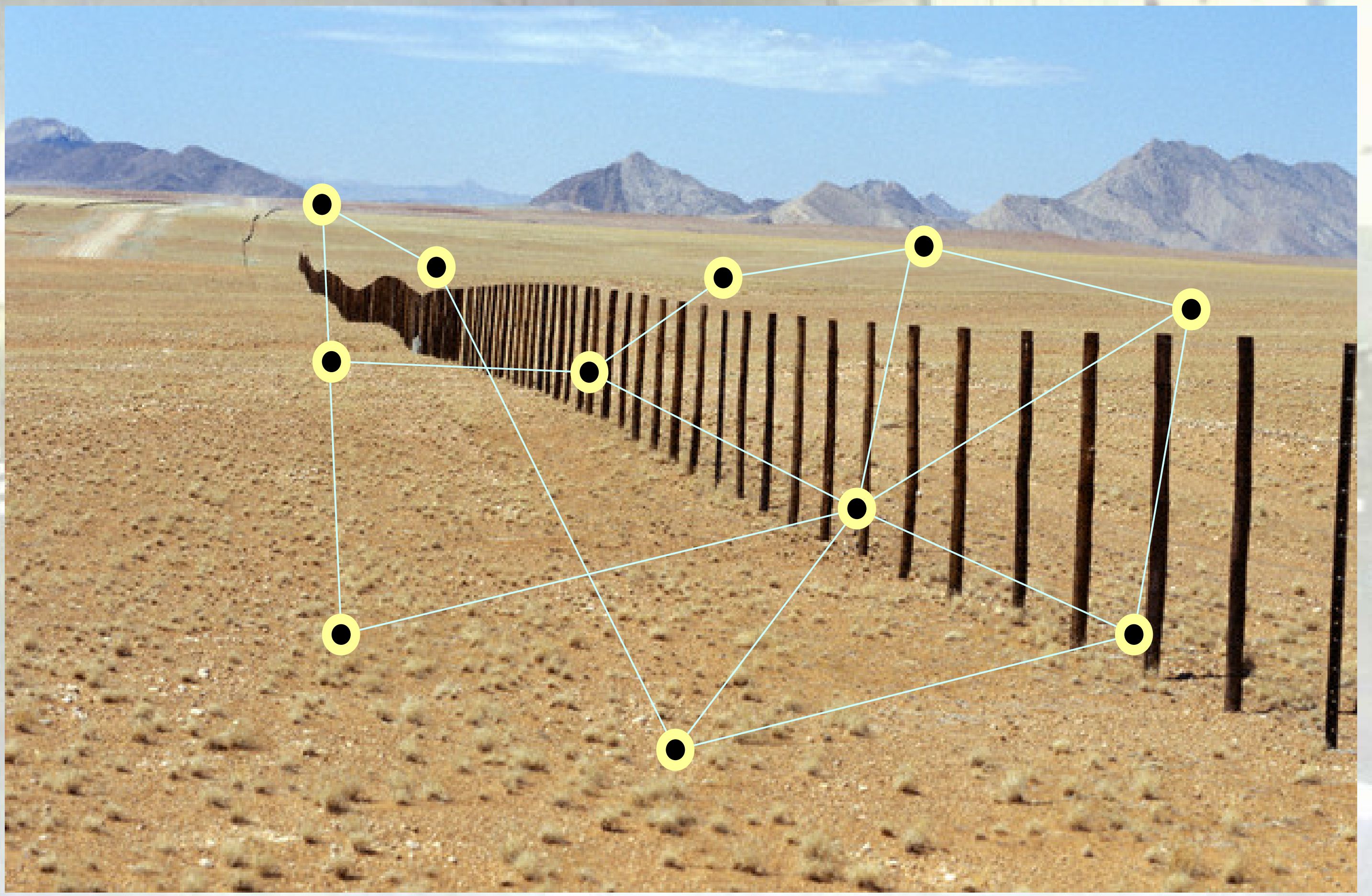


BACKGROUND: Worldwide integrated motefield

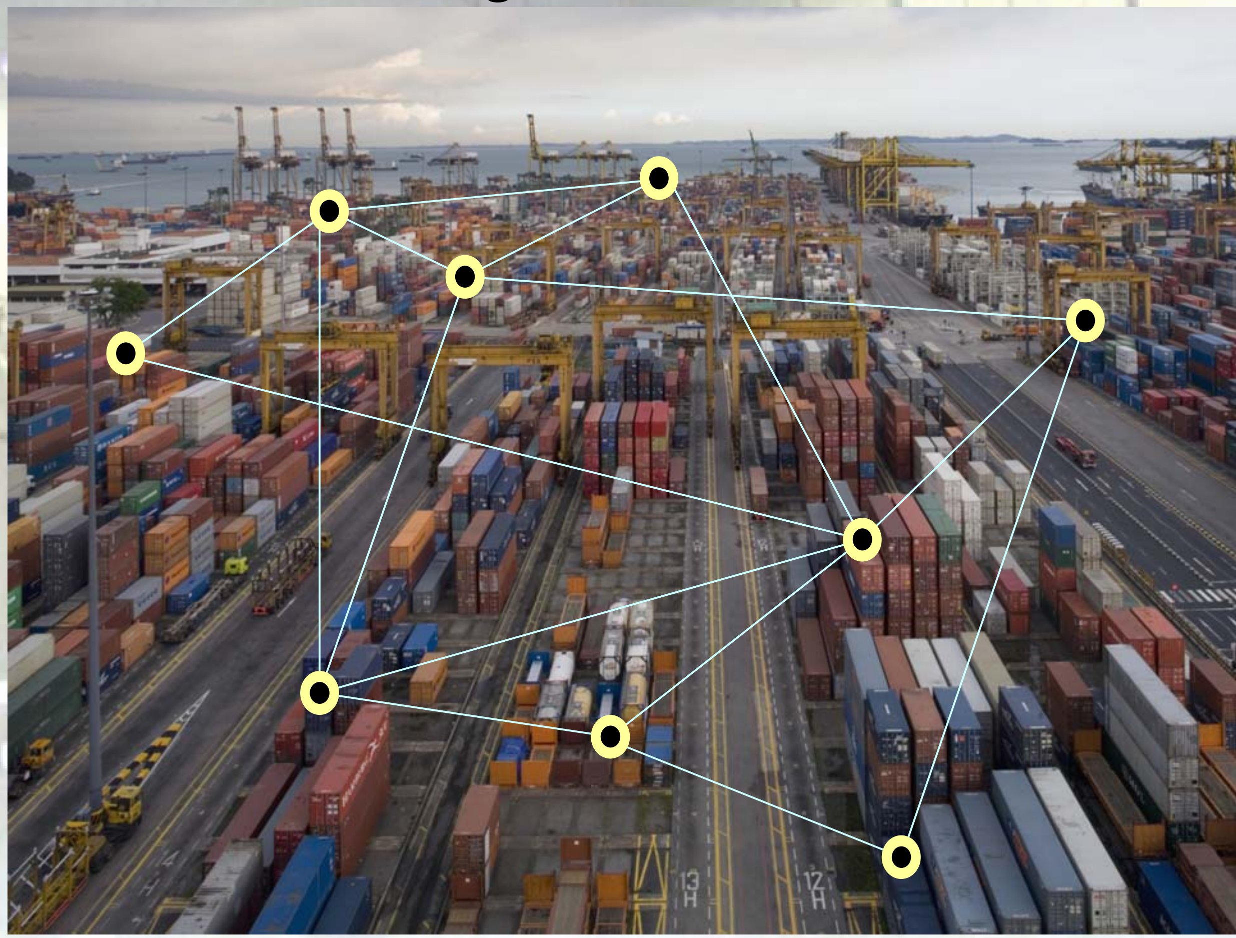


BACKGROUND: Preview of applications

- **Border patrol, linear surveillance, little/no infrastructure**



- **Container tracking; numerous surveillance areas, multiple situations in close quarters, status tracking**



BACKGROUND: Evolving mission and dynamics

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

BACKGROUND: What are others doing?

- **Health care and emergency response**
- **Public safety and first responders**
- **Monitoring critical infrastructure**
- **Rail industry**
- **Logistics**
- **Asset management**
- **Smart toys**

Essentially, cross-industry applications where physical data is necessary or optimizes the application.

35

BACKGROUND: Status --Technology Maturity

Five (5) Key Characteristics –

1. **Processor – already mature and at production volume**
2. **Network – already self-configuring and self-healing mesh**
3. **Power – conservation strategies available and successful**
4. **Software / Integration – availability of open source and/or offers standards-based**
5. **Packaging – can be engineered to necessary environmental conditions**

36

36

BACKGROUND: Next step -- push towards standards

Previous Approaches

- Non-standards based
- Costly embedded programming
- No base platform services
- Code reusability limited
- Application tied to HW
- Minimum18mo+ dev cycle

Emerging Approach

- OGC (Open Geospatial Consortium)
- Standards based
- Java programming
  - Scalable platform services provided
  - Better code reusability
  - Application more independent of HW
  - 1-2 mo dev equiv

--> Which leads to –

- Reduced implementation costs
- Faster time to market
- Scalability thru standards

37

BACKGROUND: Recap of WSN -- objective/goals

OBJECTIVES

- **Design, develop, integrate & demonstrate middleware deployed on a mini-sensor network of thousands of sensors capable of:**
  - ✓ self organizing
  - ✓ grouping
  - ✓ localizing
  - ✓ geo-referencing
  - ✓ power managing
  - ✓ reprogramming
  - ✓ detecting
  - ✓ categorizing
  - ✓ reporting presence of physical entities

- **Final product**
  - ✓ Creation of middleware applications & services library that conform to Common Architecture Framework.
  - ✓ Sensor services and applications library with re-use utility as part of a transition strategy.

GOALS

- **Develop technology, using sensing/processing nodes, that address:**
  - ✓ reliability
  - ✓ robustness
  - ✓ real-time
  - ✓ distributed sensing and processing
  - ✓ enable embedded applications
  - ✓ scalable

✓ **Demonstrate technology capabilities for operationally-relevant applications**

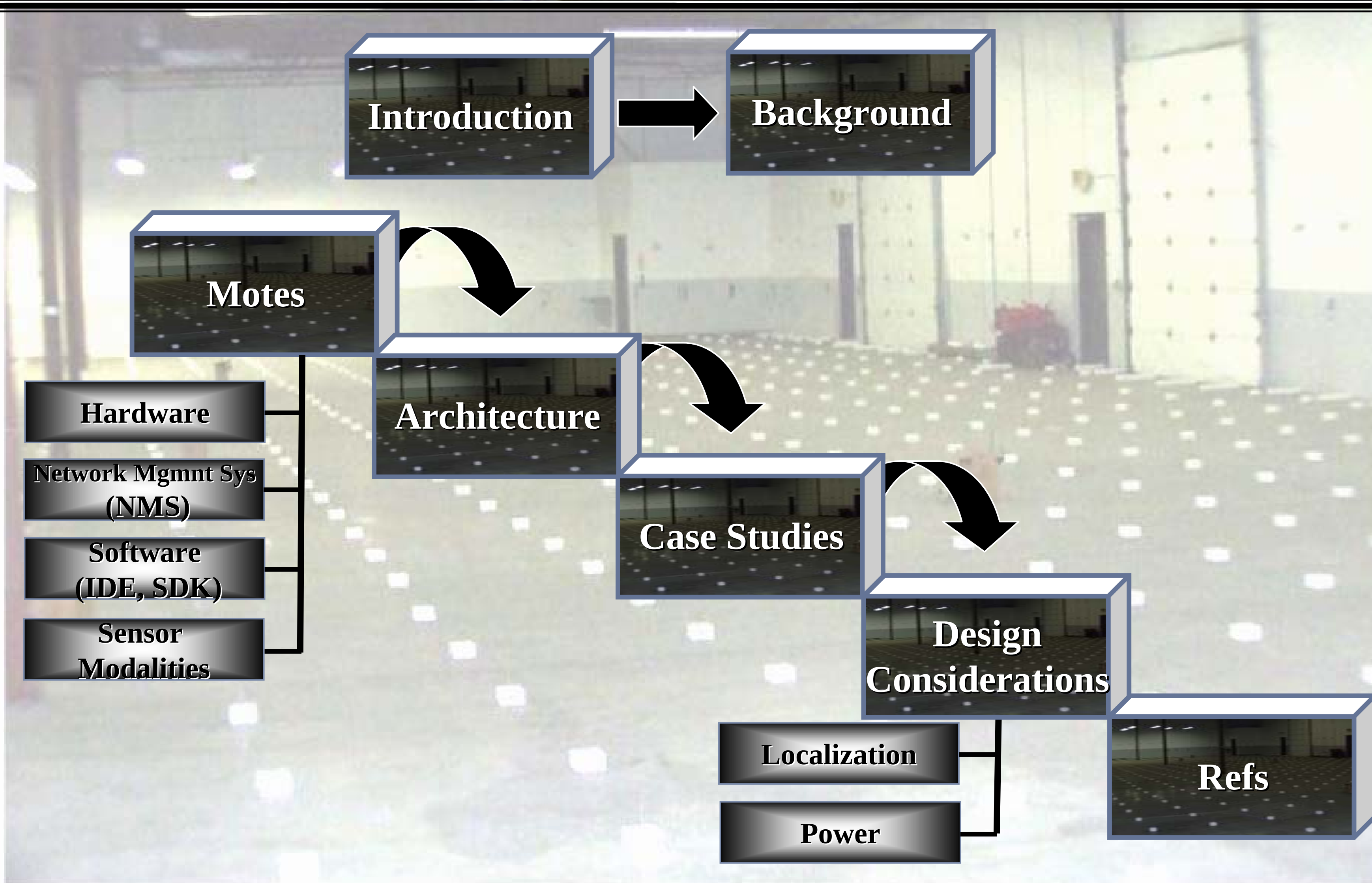
✓ **Integrate application outputs with accepted end user dissemination architectures**

✓ **Develop foundation software services for exploitation of large networks based upon wireless sensing/processing nodes.**

✓ **Demonstrate required capabilities in realistic environments for technology transition.**

BACKGROUND: Now to implement….

BACKGROUND: Rest of the course, break down



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