Embedded Systems

Ch 16
Sensor Network

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Contents

1. Introduction to Sensor Network

- **Overview of Sensor Network**
  - Advances in hardware and wireless network technologies have created low-cost, low-power, multifunctional miniature sensor devices.
  - These devices make up hundreds or thousands of ad hoc tiny sensor nodes spread across a geographical area.
  - These sensor nodes collaborate among themselves to establish a sensing network.
  - A sensor network that can provide access to information anytime, anywhere by collecting, processing, analyzing and disseminating data.
  - Thus, the network actively participates in creating a smart environment.

Introduction to Sensor Network (II)

- **Sensor Network Applications**
  - Sensor networks promise to revolutionize sensing in a wide range of application domains.
  - This is because of their reliability, accuracy, flexibility, cost-effectiveness and ease of deployment.
  - Smart sensors can offer vigilant surveillance and can detect and collect data concerning any sign of machine failure, earthquakes, floods and, even, a terrorist attack.
  - Sensor networks enable:
    - 1) information gathering,
    - 2) information processing, and
    - 3) reliable monitoring of a variety of environments for both civil and military applications.

Introduction to Sensor Network (III)

- **Features of Sensor Network**
  - The architecture of the sensor node's hardware consists of five components:
    - sensing hardware, processor, memory, power supply and transceiver.
  - They can self-organize and can adapt to support several applications.
    - These devices are easily deployed because no infrastructure and human control are needed.
    - They sense, compute and actuate into the physical environments.
  - Each sensor node has wireless communication capability and sufficient intelligence for signal processing and for disseminating the data.
  - The limited energy, computational power, and communication resources of a sensor node requires the use of a huge number of sensor nodes in a wider region.

Introduction to Sensor Network (IV)

- **Communication**
  - Communication in sensor networks is not typically end to end.
  - Energy is typically more limited in sensor networks than in other wireless networks because of the nature of the sensing devices and the difficulty in recharging their batteries.
  - Lastly, studies have shown that current commercial Bluetooth devices are unsuitable for sensor network applications because of their energy requirements, and expected higher costs than sensor nodes.

2. Sensor Network Applications

- **Examples of possible applications**
  - Detecting environmental hazards, monitoring remote terrain, or even customer behavior surveillance are among many sensor network applications.
  - Sensors are deployed to analyze remote locations (the motion of a tornado, fire detection in a forest);
  - Sensors are attached to taxi cabs in a large metropolitan area to study the traffic conditions and plan routes effectively;
  - Wireless parking lot sensor networks that determine which spots are occupied and which spots are free;
  - Wireless surveillance sensor networks for providing security in a shopping mall, parking garage or at some other facility;
  - Military sensor networks to detect, locate or track enemy movements, and
  - Sensor networks can increase alertness to potential terrorist threats.

3. A Hierarchical Sensor Network

- **The tactical military network architecture**
  - consists of a group of units (i.e., clusters) managed by *commanders* (i.e., parent nodes).

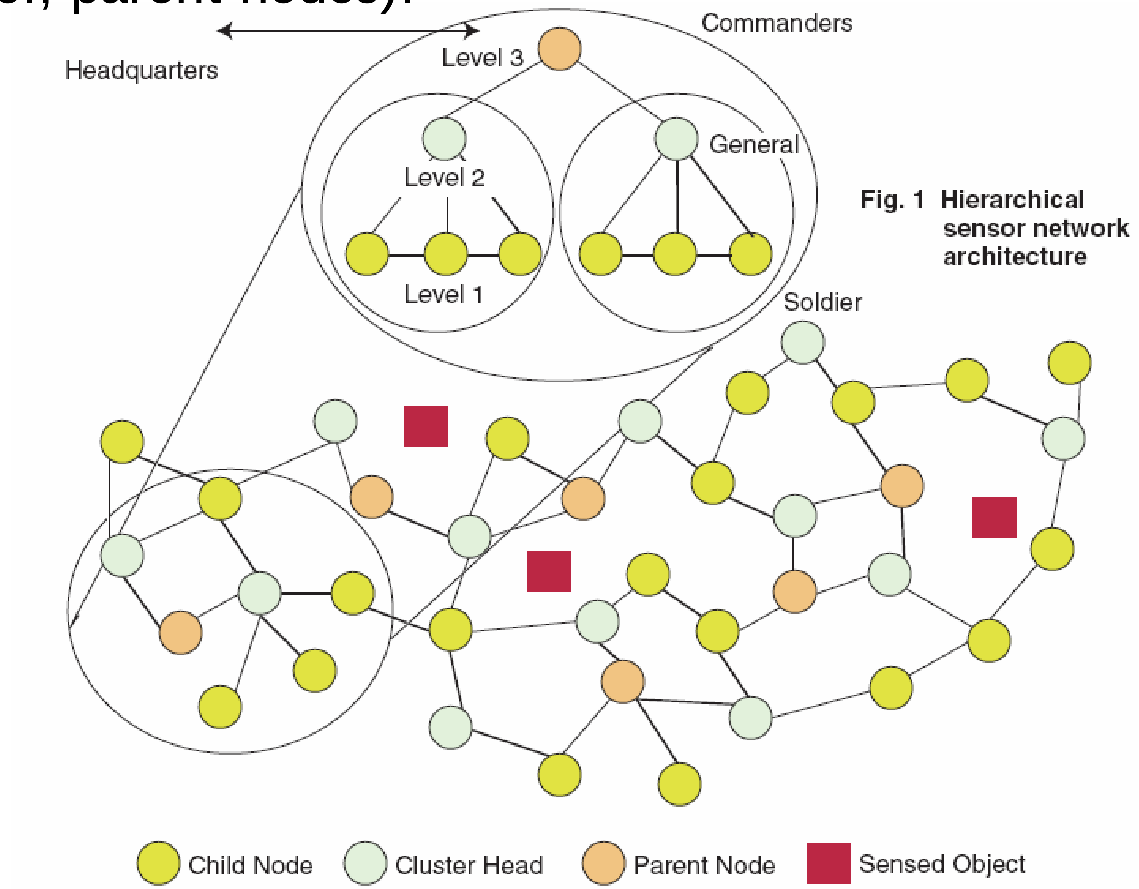


Fig. 1 **Hierarchical sensor network architecture**

A Hierarchical Sensor Network (II)

- **Commander**
  - These commanders receive orders from *headquarters* (i.e., the sink node) and, in return, send back their report.
  - The commanders send the order received from headquarters to their *generals* (i.e., cluster heads).
- **General**
  - Every general is responsible for a group of *soldiers* (i.e., children) in a unit.
  - After hearing the messages from their soldiers, generals send their observations to their commanders.
- **Soldiers**
  - Soldiers communicate locally (i.e., within a unit) with their counterparts or their general.
  - Soldiers in a unit cannot communicate with generals from other units whereas generals can only communicate among themselves.

A Hierarchical Sensor Network (III)

- **Sensing & action**
  - In a battlefield, soldiers in a unit contact their general to notify the general about a specific observation in their unit.
  - The general, then, can issue an order to his soldiers to take an action regarding their observation, or can contact his commander for an opinion.
  - In case of decisive actions, such as an *attack* command, only headquarters can order a decisive action based on the information from the commanders.

4. Sensor Network Challenges

- Challenges in hardware design, communication protocols and applications design face sensor network technology to make it a reality.
- Extending the lifetime of the sensor network and building an intelligent data collecting

- Other challenges
  - Sensor networks' topology changes very frequently;
  - Sensors use a broadcast communication paradigm whereas most networks are based on point-to-point communications;
  - Sensors are very limited in power, computational capacities and memory;
  - Sensors are very prone to failures;
  - Sensors may not have global identification (ID) because of the large amount of overhead;
  - Sensors are densely deployed in large numbers. The problem can be viewed in terms of collision and congestion:
  - Ad hoc deployment requires that the system identifies and copes with the resulting distribution and connectivity of nodes, and
  - Dynamic environmental conditions require the system to adapt over time to changing connectivity and system stimuli.

5. Sensor Network Requirements

- *Large number of sensors:*
  - To make use of the cheap small-sized sensors, sensor networks may contain thousands of nodes.
  - Scalability and managing these huge numbers of sensors is a major issue.
  - Clustering is one solution to this problem.
    - In clustering, neighbor sensors join to build one cluster (group) and elect a cluster head to manage this group.
- *Low energy use:*
  - In many applications, the sensor nodes will be deployed in a remote area in which case servicing a node may not be possible.
  - Thus, the lifetime of a node may be determined by the battery life, thereby requiring minimal energy expenditure. (Recharging a large number of sensor batteries would be expensive and time consuming.)
- *Efficient use of the small memory:*
  - When building sensor networks, issues such as routing-tables, data replication, security and such should be considered to fit the small size of memory in the sensor nodes.

Sensor Network Requirements (II)

- *Data aggregation:*
  - The huge number of sensing nodes may congest the network with information.
  - To solve this problem, some sensors such as the cluster heads can aggregate the data, do some computation (e.g., average, summation, highest, etc.), and then broadcast the summarized new information.
- *Network self-organization:*
  - Given the large number of nodes and their potential placement in hostile locations, it is essential that the network be able to self-organize itself.
  - Moreover, nodes may fail (either from lack of energy or from physical destruction), and new nodes may need to join the network.
  - Therefore, the network must be able to periodically reconfigure itself so that it can continue to function.
  - Individual nodes may become disconnected from the rest of the network, but a high degree of connectivity overall must be maintained.

Sensor Network Requirements (III)

- *Collaborative signal processing:*
  - Yet another factor that distinguishes these networks from *Mobile Ad-hoc Networks* (MANETs) is that the end goal is the detection/estimation of some event(s) of interest, and not just communication.
  - To improve the detection performance, it is often quite useful to fuse data from multiple sensors.
  - This data fusion requires the transmission of data and control messages.
  - This need may put constraints on the network architecture.

- *Querying ability:*
  - Two types of addressing in sensor network;
    - **data-centric**
      - a query will be sent to specific region in the network.
    - **address-centric**
      - the query will be sent to an individual node.

6. Ad Hoc Sensor Networks

- An ad hoc sensor network is a collection of sensor nodes forming a temporary network without the aid of any central administration or support services.
  - There is no stationary infrastructure such as base stations.
  - In general, the sensor nodes use wireless radio frequency (RF) transceivers as their network interface and communicate with each other using multi-hop wireless links.
  - Each sensor node in the network also acts as a router, forwarding data packets for its neighbor nodes.

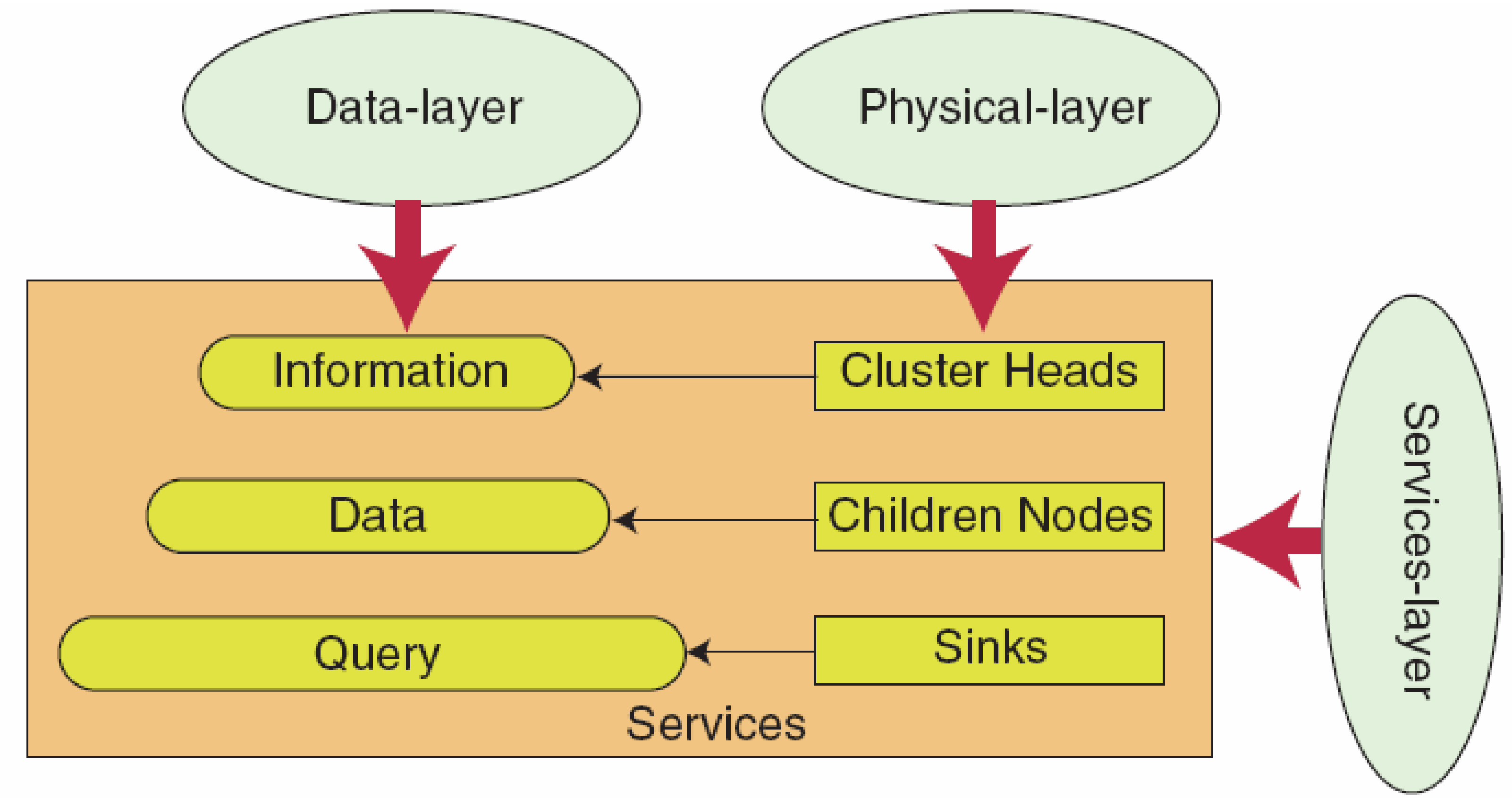
- Ad hoc networks must deal with frequent changes in topology.
  - Sensor nodes are prone to failure and also
  - new sensor nodes may join the network to compensate the failed nodes or to maximize the area of interest.
  - A central challenge in the design of the ad hoc sensor network:
    - The development of self-organizing sensor network and dynamic routing protocols that can efficiently find routes between two communicating nodes.

Ad Hoc Sensor Networks (II)

- **Cluster head**
  - For the tiny sensors to coordinate among themselves to achieve a large sensing task in a less power consumption, they should work in a cluster.
  - Each cluster assigns a *cluster head* to manage its sensors.
  - The advantages of cluster heads are:
    - Clustering allows sensors to efficiently coordinate their local interactions in order to achieve global goals;
    - Scalability;
    - Improved robustness;
    - More efficient resource utilization;
    - Lower energy consumption; and
    - Robust link or node failures and network partitions.

Ad Hoc Sensor Networks (III)

- **Sensor Network Architecture**



Ad Hoc Sensor Networks (IV)

- **Sensor Network Architecture (II)**
  - Physical layer
    - Physical nodes: sinks, children nodes, cluster heads, parents
  - Data layer
    - Query, data, information
  - Service layer
    - One big wireless ad hoc network
  - Action
    - Sink node
      - Broadcasts query
      - Detect environment: change in heat, location, speed, etc
      - Broadcasts data to neighboring sensor nodes
    - Children nodes
      - Retransfers data
    - Cluster head
      - Process and aggregate data to get information
      - Broadcasts the information to the sink nodes

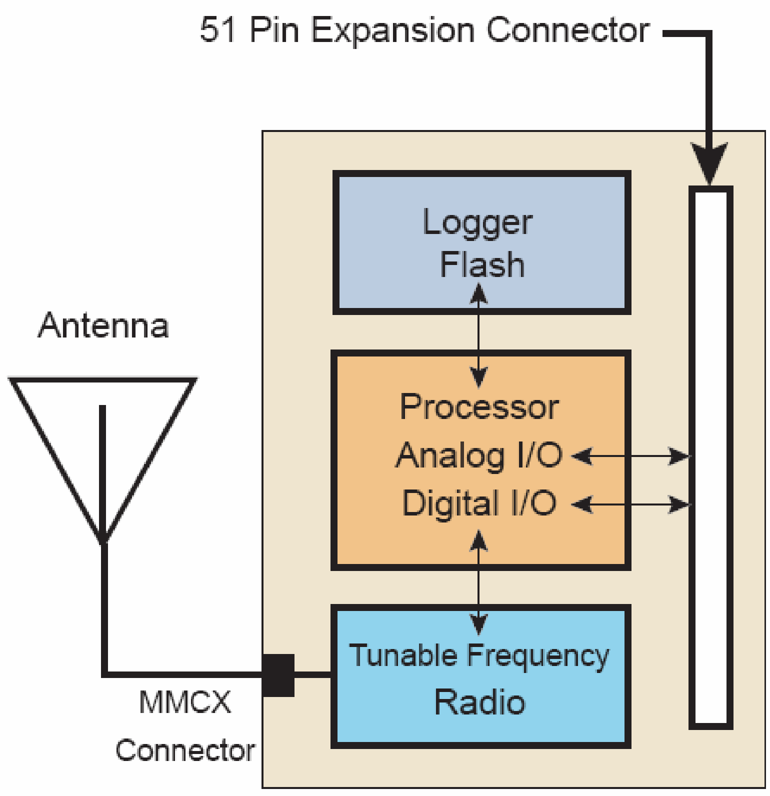
7. MOTE

MICA2

- Wireless Measurement System
  - 3rd Generation, Tiny, Wireless Platform for Smart Sensors
  - Designed Specifically for Deeply Embedded Sensor Networks
  - > 1 Year Battery Life on AA Batteries (Using Sleep Modes)
  - Wireless Communications with Every Node as Router Capability
  - 315, 433 or 868/916 MHz Multi-Channel Radio Transceiver
  - Expansion Connector for Light, Temperature, RH, Barometric Pressure, Acceleration/Seismic, Acoustic, Magnetic, and other Crossbow Sensor Boards

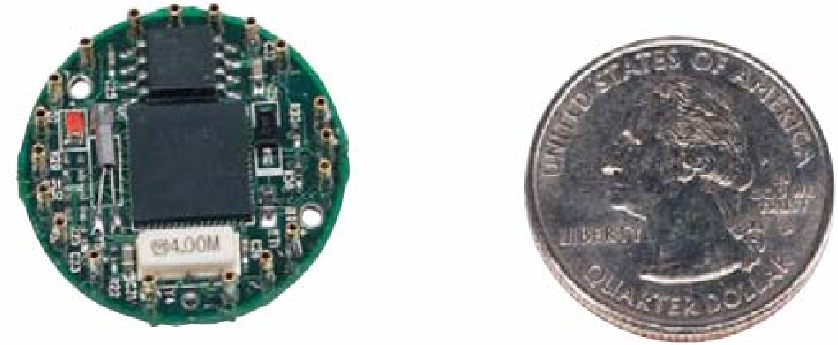
MOTE (II)

- **Features of MICA2**
  - 868/916MHz, 433 or 315MHz multi-channel transceiver with extended range
  - TinyOS (TOS) Distributed Software Operating System v1.0 with improved networking stack and improved debugging features
  - Support for wireless remote reprogramming
  - Wide range of sensor boards and data acquisition add-on boards
  - Compatible with MICA2DOT (MPR500) quarter-sized Mote.



MPR400CB Block Diagram

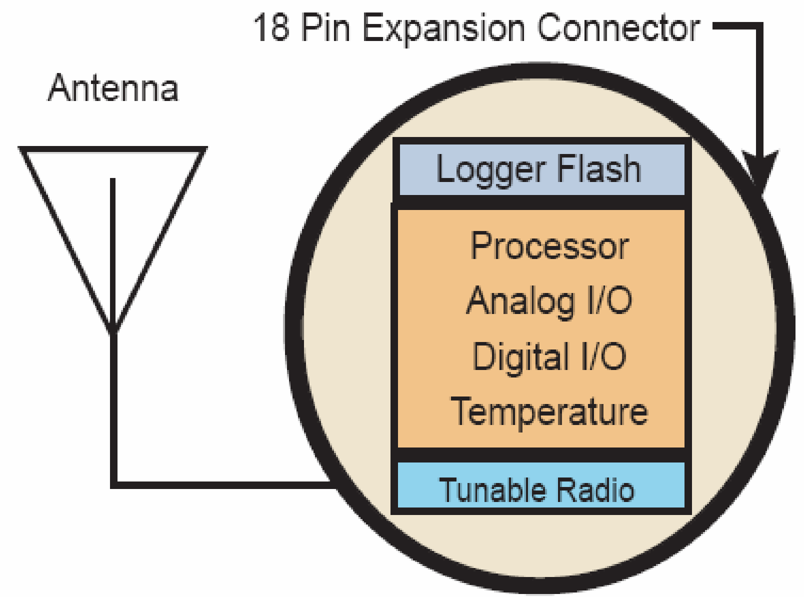
MOTE (III)



MICA2DOT

- Wireless Micro-sensor Mote
- 3rd Generation, Quarter-Sized (25mm), Wireless Platform for Smart Sensors
  - Designed Specifically for Deeply Embedded Wireless Sensor Networks
  - Battery-Powered, Low-Mass
  - Fits Anywhere, Wireless Reprogrammable
  - Wireless Communications with Every Node as Router Capability
  - 868/916 MHz, 433 MHz or 315 MHz Multi-channel Radio Transceiver (MICA2 Compatible)

MOTE (IV)



MPR500CA Block Diagram

- **Features of MICA2DOT**
  - 868/916MHz, 433MHz or 315MHz multi-channel transceiver with extended range
  - TinyOS (TOS) Distributed Software Operating System v1.0 with improved networking stack and improved debugging features
  - Support for wireless remote reprogramming
  - Compatible with MICA2 (MPR400) Mote
  - On Board Temperature Sensor, Battery Monitor, and LED.

8. ATmega128

8-bit Microcontroller with
128K Bytes In-System Programmable Flash

- **Features**
  - High-performance, Low-power AVR® 8-bit Microcontroller
  - Advanced RISC Architecture
    - 133 Powerful Instructions – Most Single Clock Cycle Execution
    - 32 x 8 General Purpose Working Registers + Peripheral Control Registers
    - Fully Static Operation up to 16 MIPS Throughput at 16 MHz
    - On-chip 2-cycle Multiplier
  - Nonvolatile Program and Data Memories
    - 128K Bytes of In-System Reprogrammable Flash
    - Optional Boot Code Section with Independent Lock Bits
      In-System Programming by On-chip Boot Program
    - 4K Bytes EEPROM
    - 4K Bytes Internal SRAM
    - Up to 64K Bytes Optional External Memory Space
    - Programming Lock for Software Security
    - SPI Interface for In-System Programming.

ATmega128 (II)

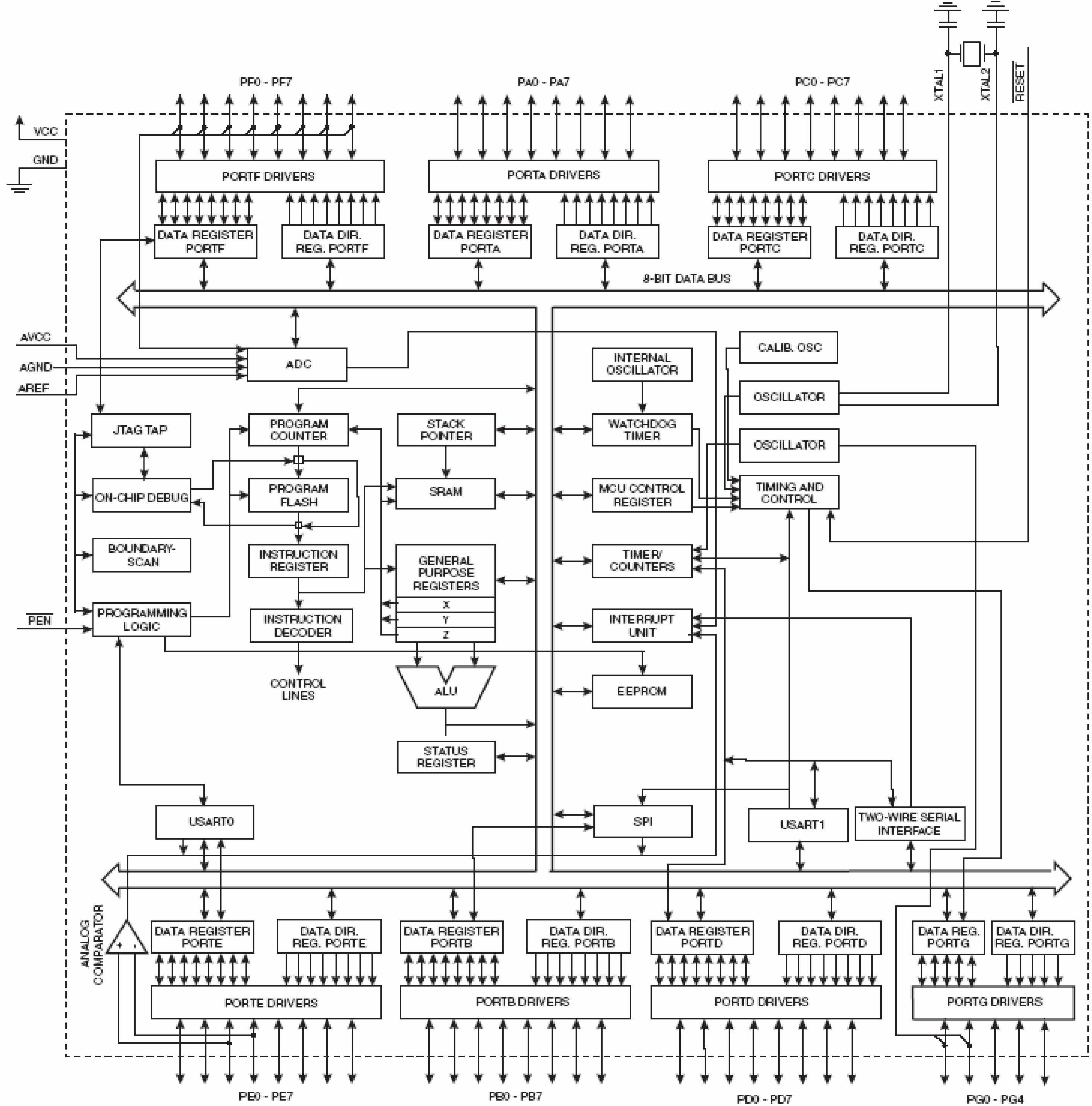
- **Features (II)**
  - JTAG (IEEE std. 1149.1 Compliant) Interface
    - Boundary-scan Capabilities According to the JTAG Standard
    - Extensive On-chip Debug Support
    - Programming of Flash, EEPROM, Fuses and Lock Bits through the JTAG Interface
  - Peripheral Features
    - Two 8-bit Timer/Counters with Separate Prescalers and Compare Modes
    - Two Expanded 16-bit Timer/Counters with Separate Prescaler, Compare Mode and Capture Mode
    - Real Time Counter with Separate Oscillator
    - Two 8-bit PWM Channels
    - 6 PWM Channels with Programmable Resolution from 2 to 16 Bits
    - Output Compare Modulator
    - 8-channel, 10-bit ADC
    - Byte-oriented Two-wire Serial Interface
    - Dual Programmable Serial USARTs
    - Master/Slave SPI Serial Interface
    - Programmable Watchdog Timer with On-chip Oscillator
    - On-chip Analog Comparator.

ATmega128 (III)

- **Features (III)**
  - Special Microcontroller Features
    – Power-on Reset and Programmable Brown-out Detection
    – Internal Calibrated RC Oscillator
    – External and Internal Interrupt Sources
    – Six Sleep Modes: Idle, ADC Noise Reduction, Power-save, Power-down, Standby,
    and Extended Standby
    – Software Selectable Clock Frequency
    – ATmega103 Compatibility Mode Selected by a Fuse
    – Global Pull-up Disable
  - I/O and Packages
    – 53 Programmable I/O Lines
    – 64-lead TQFP and 64-pad MLF
  - Operating Voltages
    – 2.7 - 5.5V for ATmega128L
    – 4.5 - 5.5V for ATmega128
  - Speed Grades
    – 0 - 8 MHz for ATmega128L
    – 0 - 16 MHz for ATmega128.

ATmega 128 (IV)

- Block Diagram



9. TinyOS

- **TinyOS**
  - An *open-source operating system* designed for *wireless embedded sensor networks*.
  - A *component-based architecture*
    - Enables rapid innovation and implementation while minimizing code size as required by the severe memory constraints inherent in sensor networks.
  - TinyOS's *component library*
    - Network protocols, distributed services, sensor drivers, and data acquisition tools
  - Event-driven execution model
    - Enables fine-grained power management yet allows the scheduling flexibility made necessary by the unpredictable nature of wireless communication and physical world interfaces.

TinyOS (II)

- **TinyOS (cont'd)**
  - Ported to over a dozen platforms and numerous sensor boards.
    - A wide community uses it in simulation to develop and test various algorithms and protocols.
    - Over 10,000 downloads.
    - Over 500 research groups and companies are using TinyOS on the Berkeley/Crossbow Motes.
    - Numerous groups are actively contributing code to the sourceforge site and working together to establish standard, interoperable network services built from a base of direct experience and honed through competitive analysis in an open environment.
  - Web site: http://www.tinyos.net

References

- Sensor network
  - M. Tubaishat and S. Madria, “Sensor Networks: An overview”, IEEE Potentials, April 2003.
- MOTE
  - http://www.corssbow.com
- ATmega128
  - http://www.atmel.com
- TinyOS
  - http://www.tinyos.net