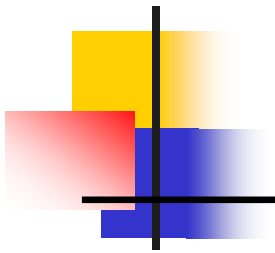
Introduction to Wireless Sensor and Control Networks

Tom Bender

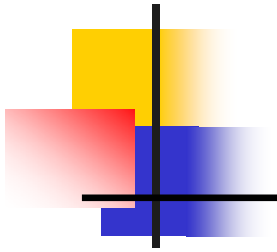
Tendril Networks

tbender@tendrilinc.com



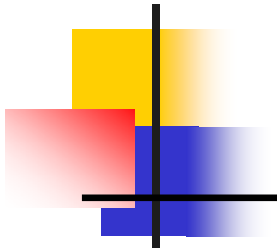
Agenda

- Brief History
- What is a Wireless Sensor & Control Network?
- Wireless / IEEE 802.15.4
- ZigBee
- TinyOS
- Sun SPOT
- Demonstration/Examples



Introduction

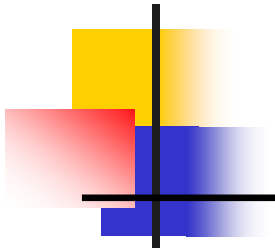
Tom Bender



Introduction

Systems Architect

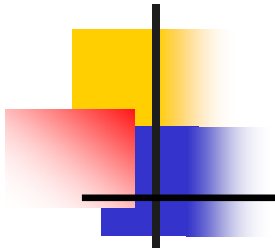
Product Manager



Introduction

Industrial Machine Vision

Ann Arbor, Michigan

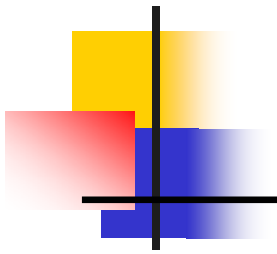


Introduction

Quantitative Expert

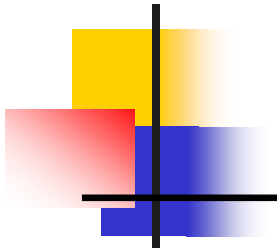
Trading Systems

Los Angeles, California



Introduction

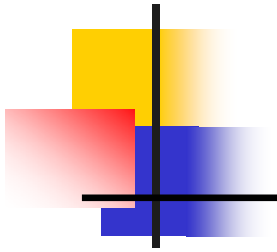
Constraint-based
Expert Systems &
Sales Force Automation
Golden, Colorado



Introduction

Consultant

Boulder, CO

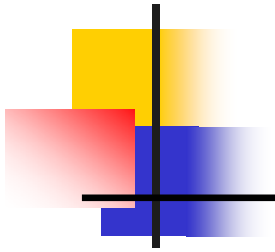


Introduction

Local Commerce

Jabber IM

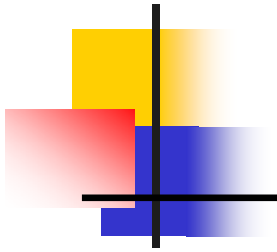
Denver, CO



Introduction

Satellite Scheduling & Geospatial Information Systems

Longmont, CO

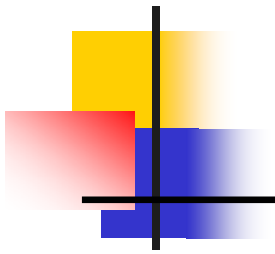


Introduction

Wireless Sensor Networks

802.15.4

Boulder, CO



Brief History

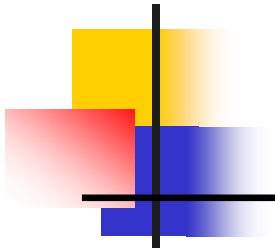
- A *Few* of the Pioneers …

WEST COAST

- David Culler & Friends
  - University of California Berkeley
  - Tiny OS
  - Co-Founder, Arch Rock
- Kris Pister
  - University of California Berkeley
  - Tiny OS
  - Co-Founder, Dust Networks

EAST COAST

- Robert Poor
  - Massachusetts Institute of Technology
  - Co-Founder of Ember with Bob Metcalfe
  - Board of Directors, Tendril Networks
- Adrian Tuck
  - Royal Military Academy Sandhurst
  - Interim CEO, Ember
  - CEO, Tendril Networks

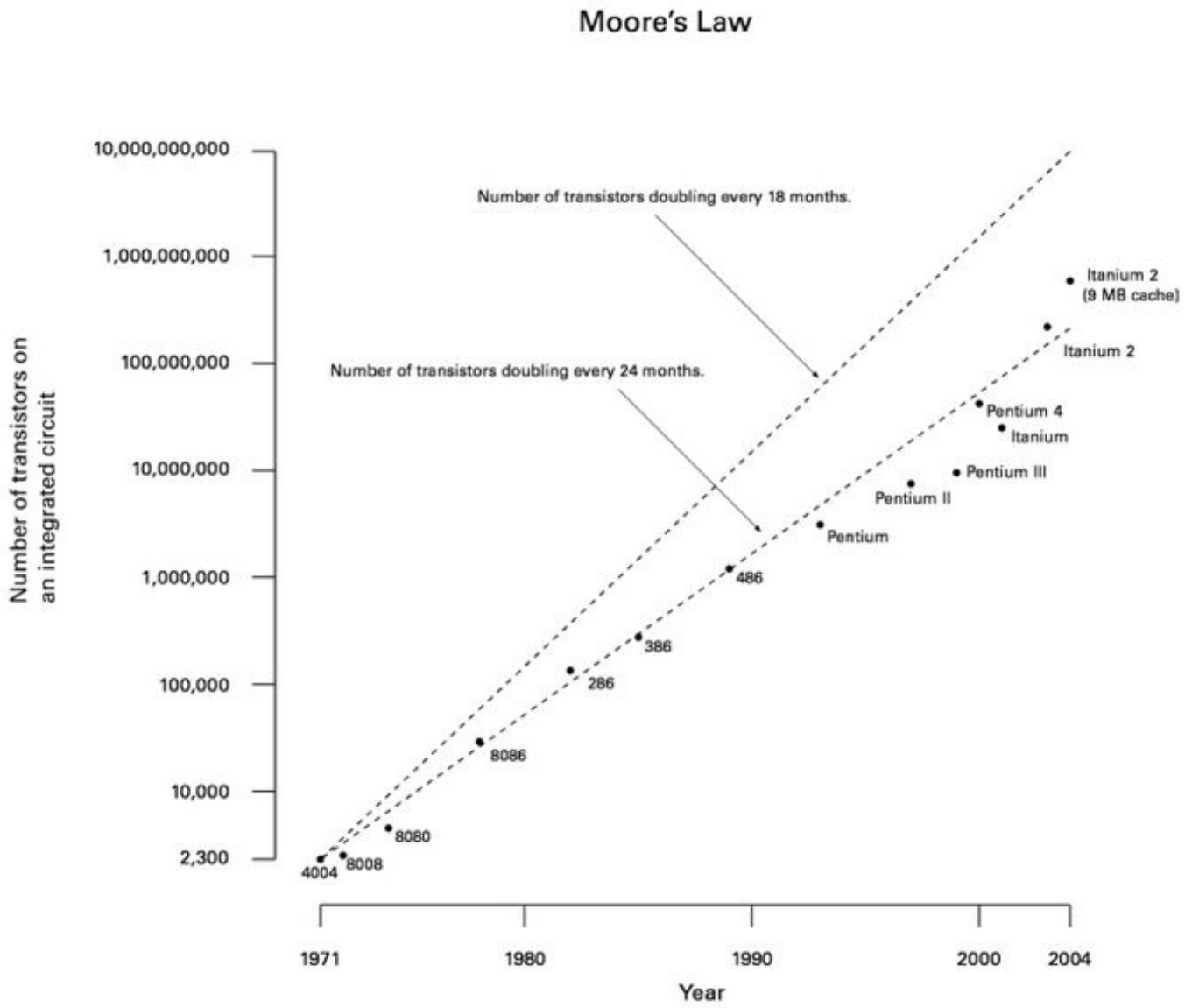


Brief History

- "Relatively" New Trend in Wireless
  - Most Wireless industry focus on increasing high data throughput
  - A set of applications requiring simple wireless connectivity, relaxed throughput, very low power, short distance and inexpensive
    - Industrial
    - Agricultural
    - Vehicular
    - Residential
    - Medical

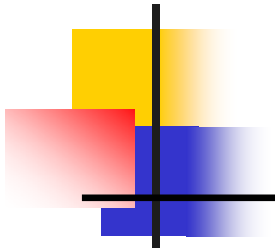
Brief History

Moore's Law



Brief History

- IEEE 802 - http://www.ieee802.org/
  - 802.1 Higher Layer LAN Protocols Working Group
  - 802.3 Ethernet Working Group
  - 802.11 Wireless LAN Working Group
  - 802.15 Wireless Personal Area Network (WPAN) Working Group
  - 802.16 Broadband Wireless Access Working Group
  - 802.17 Resilient Packet Ring Working Group
  - 802.18 Radio Regulatory TAG
  - 802.19 Coexistence TAG
  - 802.20 Mobile Broadband Wireless Access (MBWA) Working Group
  - 802.21 Media Independent Handoff Working Group
  - 802.22 Wireless Regional Area Networks

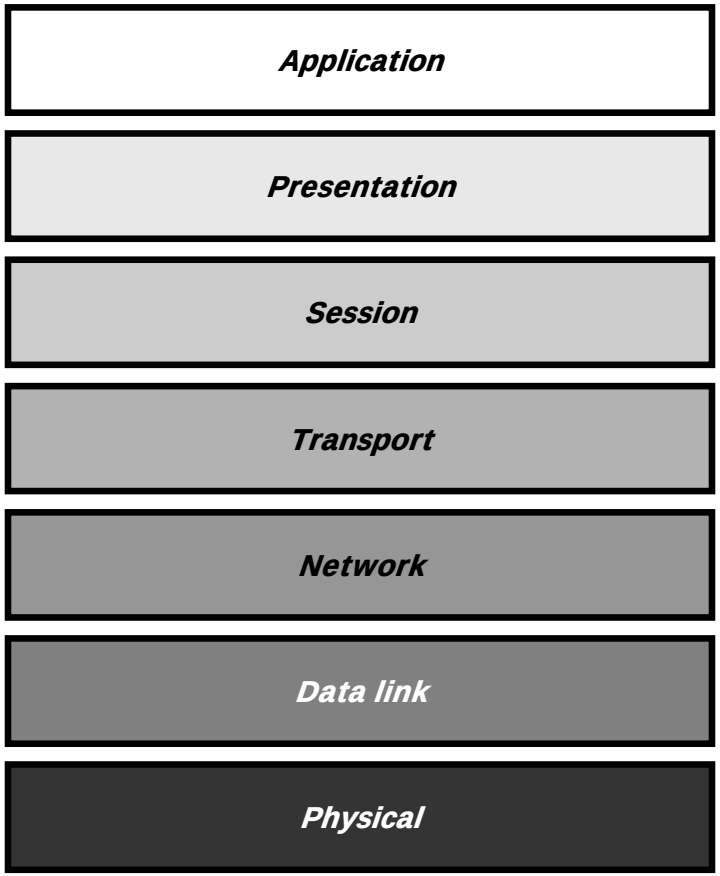


Brief History

- IEEE 802.15 Wireless Personal Area Networking
  - Four Subgroups
    - .1 - Bluetooth
    - .2 - Co-existence of WPAN (802.15) and WLAN (802.11)
    - .3 - High Data Rate, Low Cost
      - ✓(a) Consumer Media & Imaging
      - ✓(b) Revising earlier design issues
    - .4 - Low Data Rate, Low Power

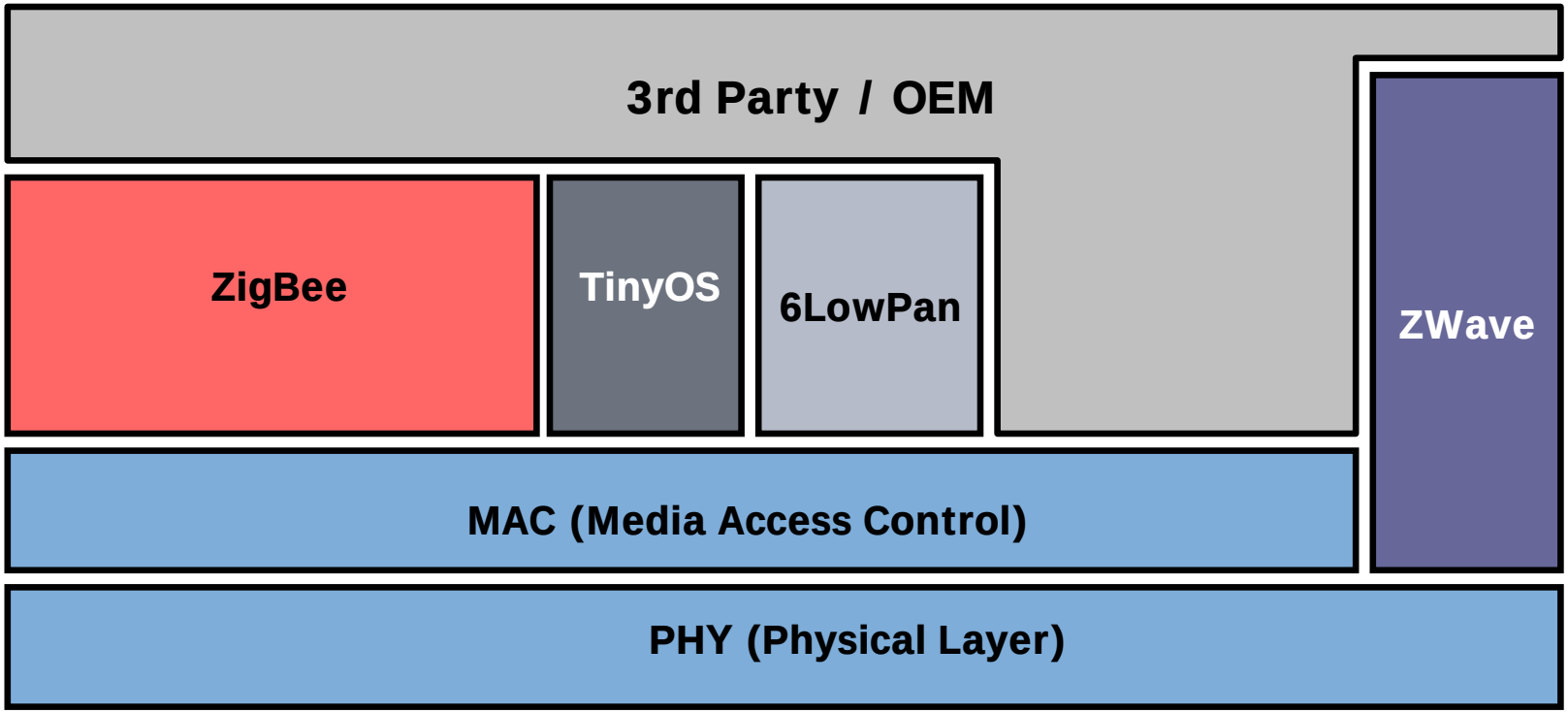
Brief History

- OSI (7 Layer Protocol)



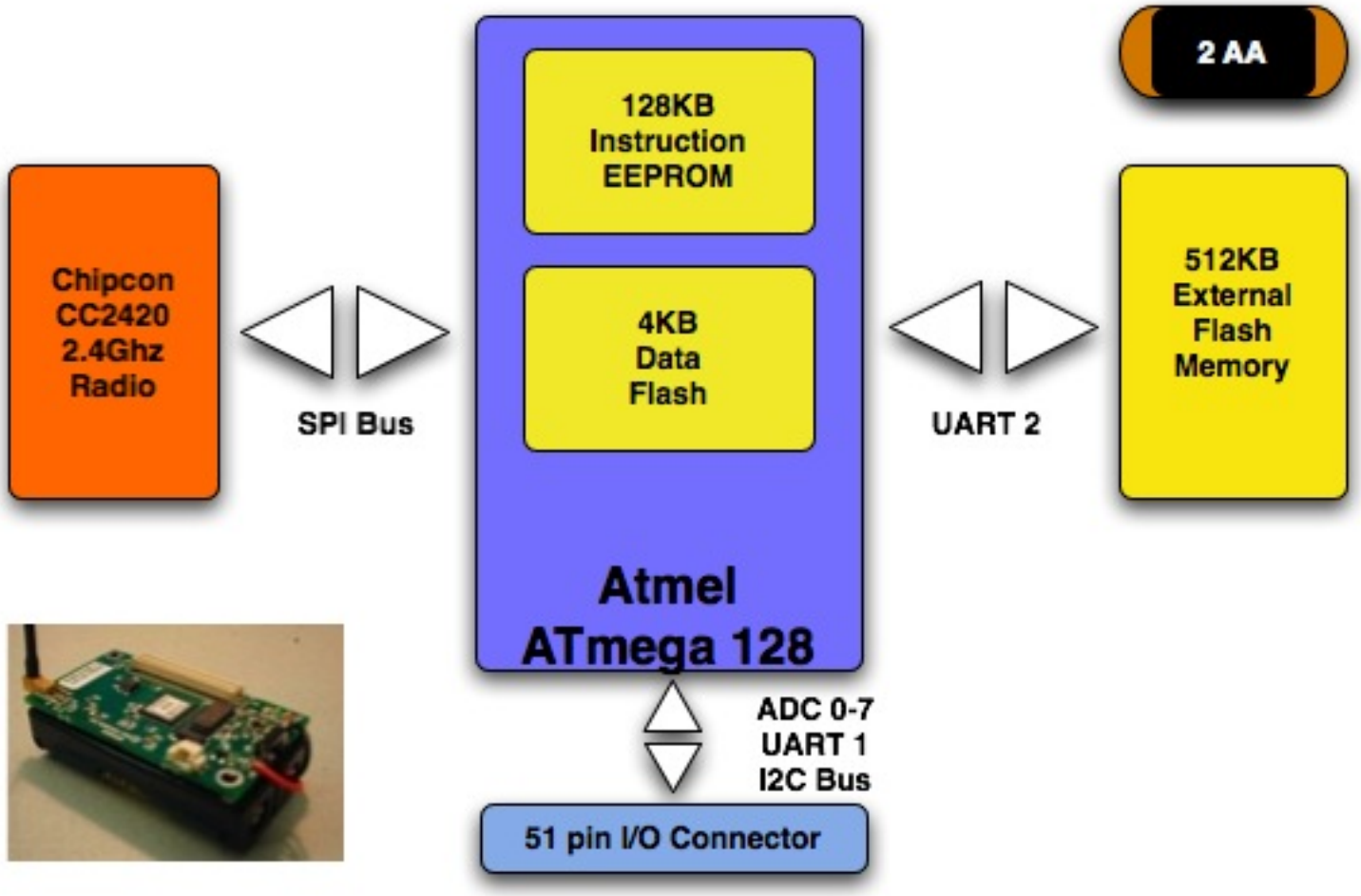
Brief History

- Network Layers



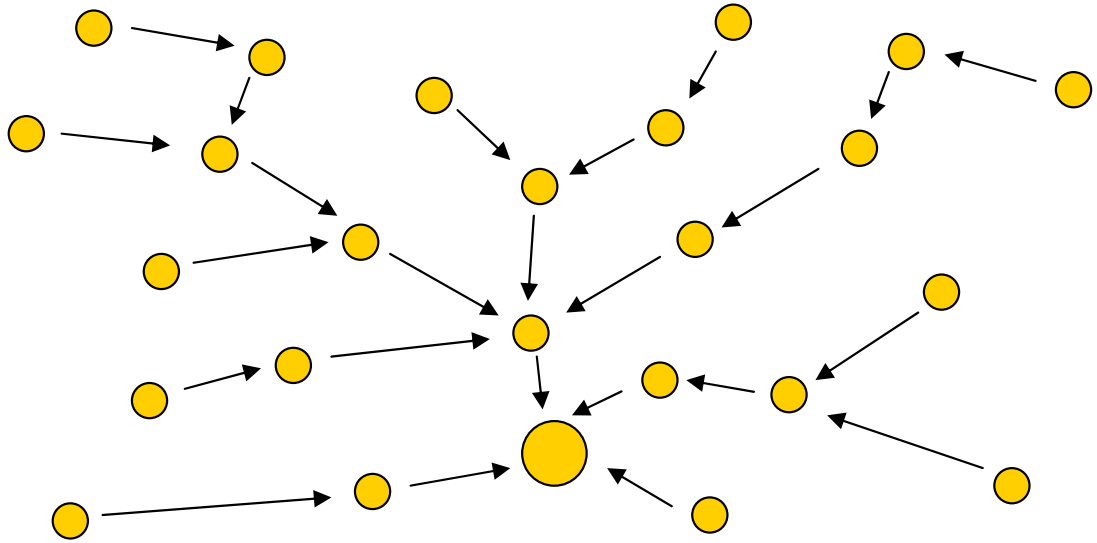
What Is a Wireless Sensor & Control Network?

- Wireless Sensor/Actuator



What Is a Wireless Sensor & Control Network?

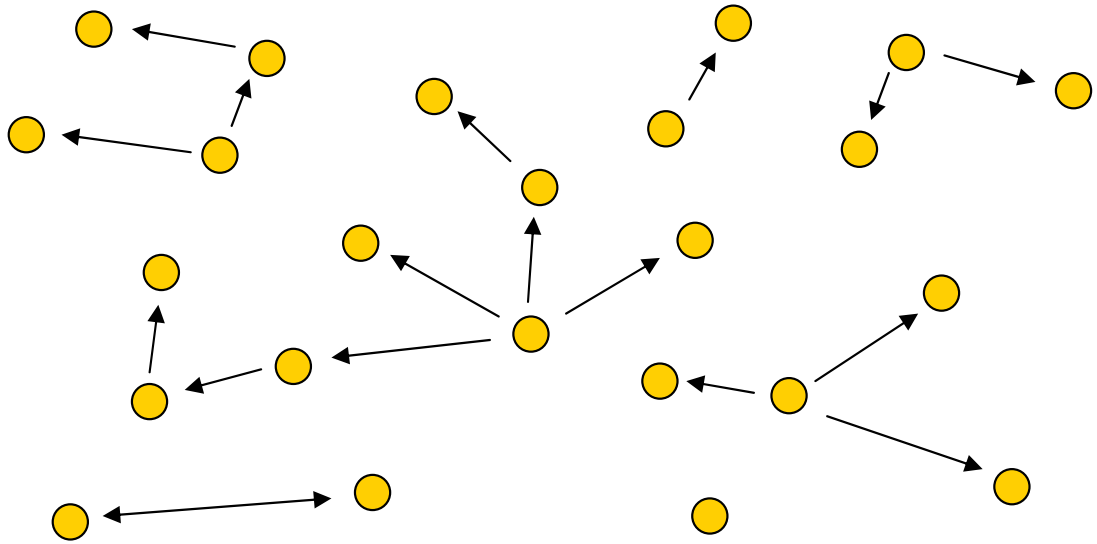
- Sensor



- Most data flows in to central “gateway” device
- Occasional data flows from gateway device to outlying devices
- Data almost never flows between adjacent devices

What Is a Wireless Sensor & Control Network?

- Control



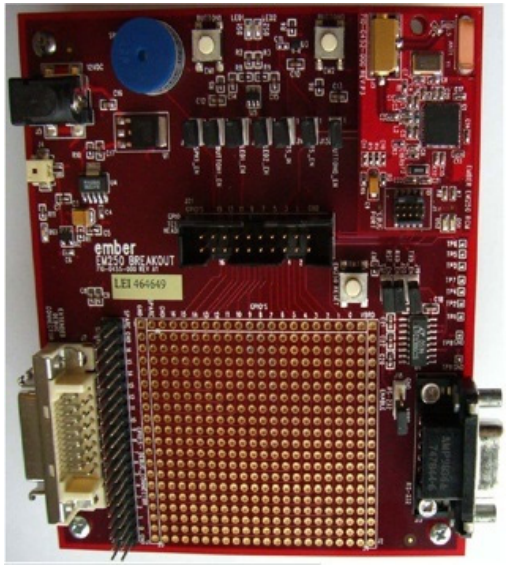
  - May be no central “gateway” node
  - Data often flows from a local control node to a nearby actuator node
  - Data almost never flows long distances across the network

What Is a Wireless Sensor & Control Network?

- Sensor Types
  - Environmental temperature/humidity/pressure
  - Industrial temperature/humidity/pressure
  - Vibration/seismic
  - Accelerometer (X:Y:Z)
  - Passive IR for motion detection
  - Magnetic
  - Acoustic
  - Soil moisture and temperature

What Is a Wireless Sensor & Control Network?

- Development Environment
  - Development IDE
    - IAR
    - avr-gcc
  - Flash Application/IDE
    - IAR
    - Ember Insight Desktop
  - Runtime Debug - Wireless Sniffer
    - Ember Insight Desktop/Eclipse
    - Daintree



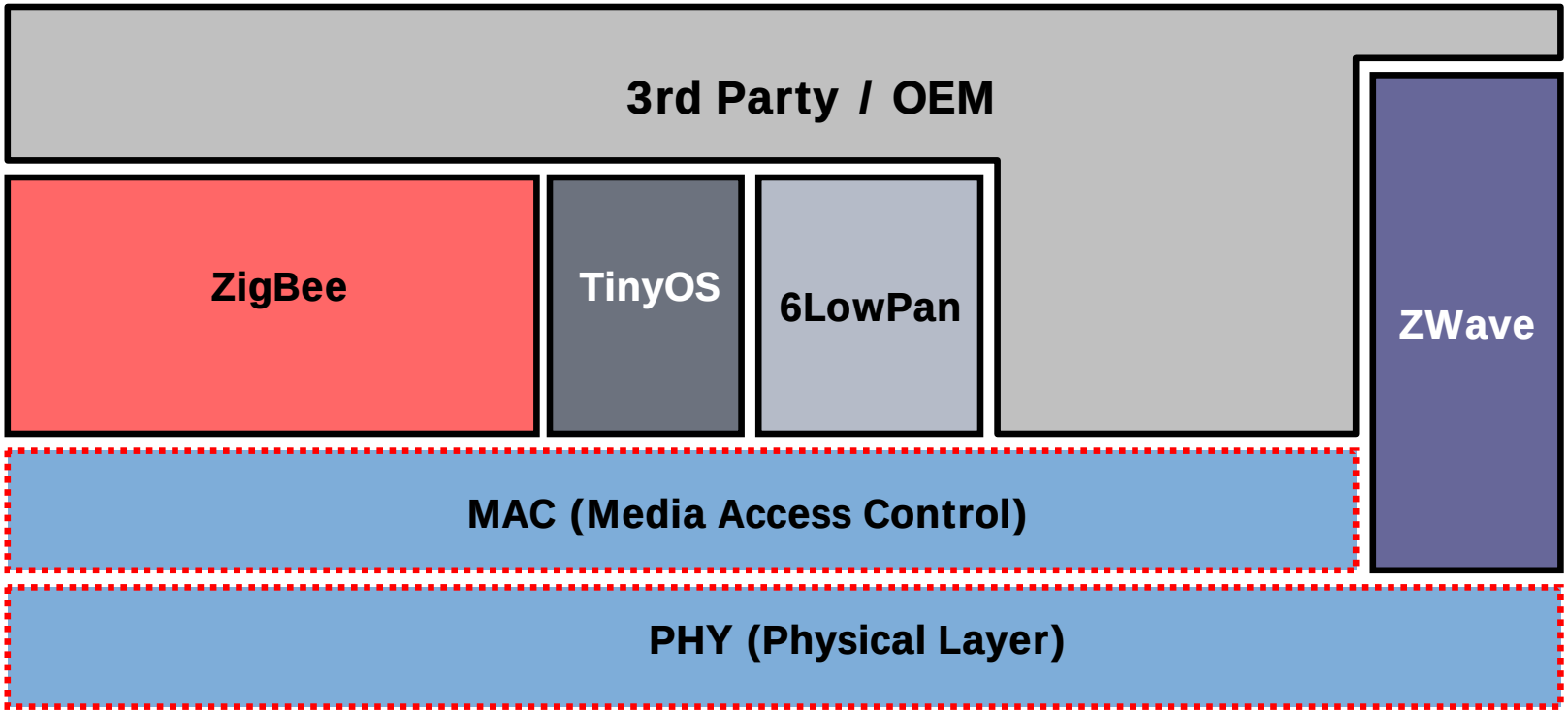
IP

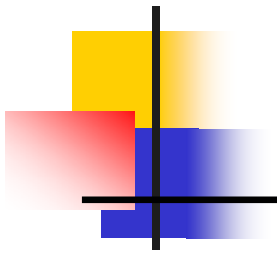
Serial

USB

IEEE 802.15.4

- Network Layers (IEEE 802.15.4)



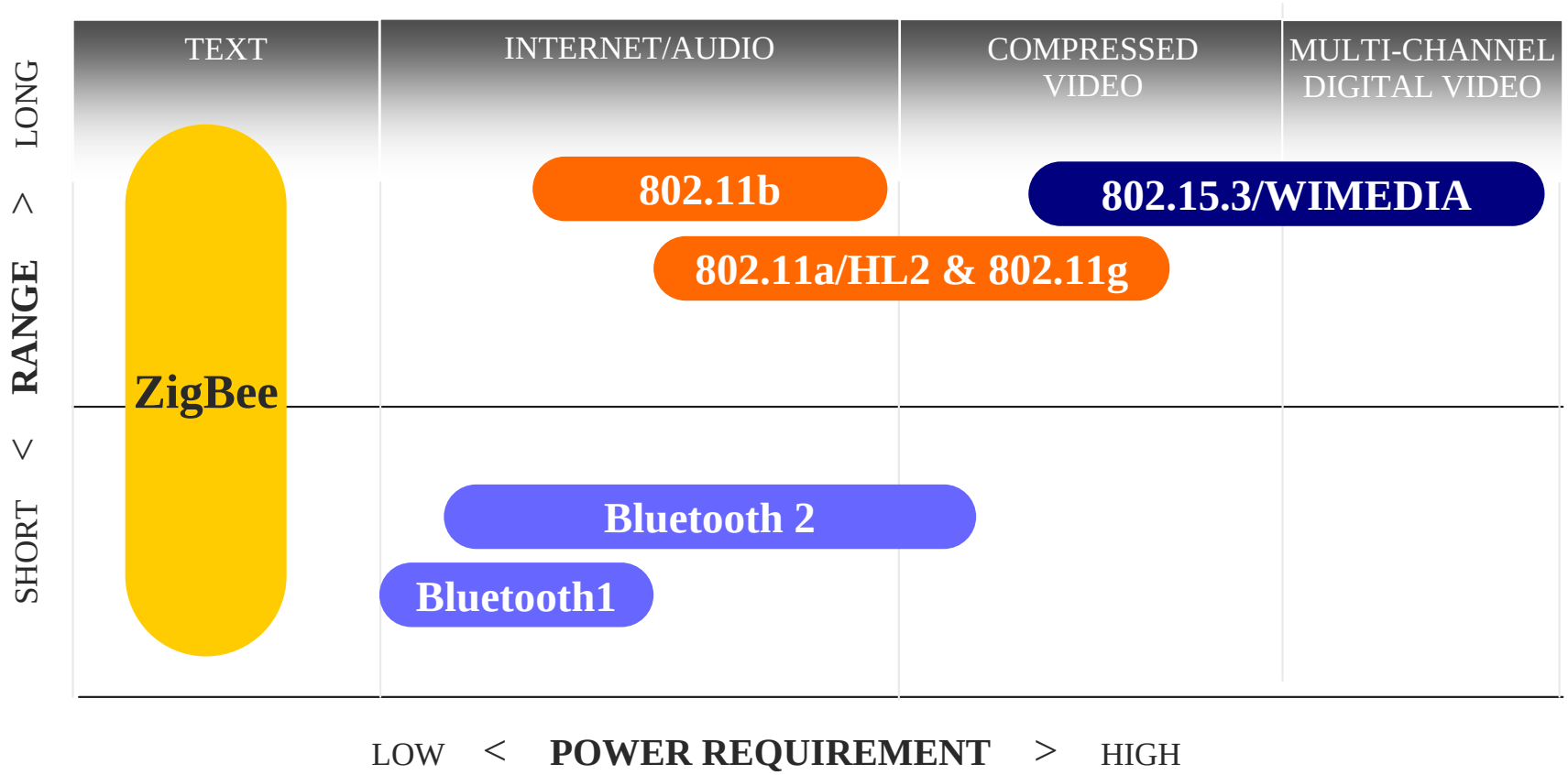


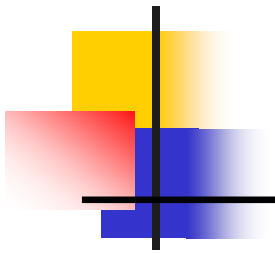
IEEE 802.15.4

Project	Data Rate	Range	Configuration	Other Features
802.15.1 (Bluetooth)	1 Mbps	10M (class 3) 100M (class 1)	8 active device Piconet/ Scatternet	Authentication, Encryption, Voice
802.15.3 High Rate	22, 33, 44, 55 Mbps	10M	256 active device Piconet/ Scatternet	FCC part 15.249 QoS, Fast Join Multi-Media
802.15.4 Low Rate	up to 250Kbps	10M nominal 1M-100M based on settings	Master/Slave (256 Devices or more) Peer to Peer	Battery Life: multi-month to infinite
802.15.2 Coexistence	Develop a Coexistence Model and Mechanisms Document as a Recommended Practice			

IEEE 802.15.4

- IEEE 802 Wireless Technologies



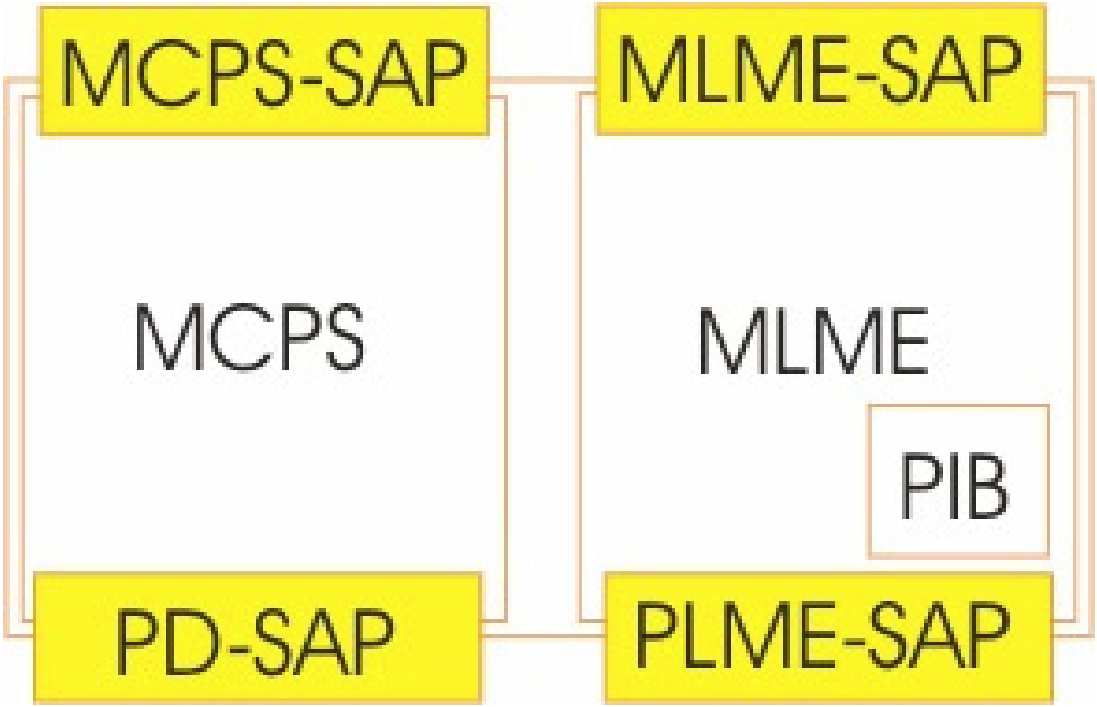


IEEE 802.15.4

- Data rates up to 250 kbps, 40 kbps, and 20 kbps
- Two addressing modes; 16-bit short and 64-bit IEEE addressing.
- Support for critical latency devices, such as joysticks.
- CSMA-CA channel access
- Automatic network establishment by the coordinator.
- Full handshake protocol for transfer reliability.
- Power management to ensure low power consumption.
- 16 channels in the 2.4GHz ISM band, 10 channels in the 915MHz I and one channel in the 868MHz band.

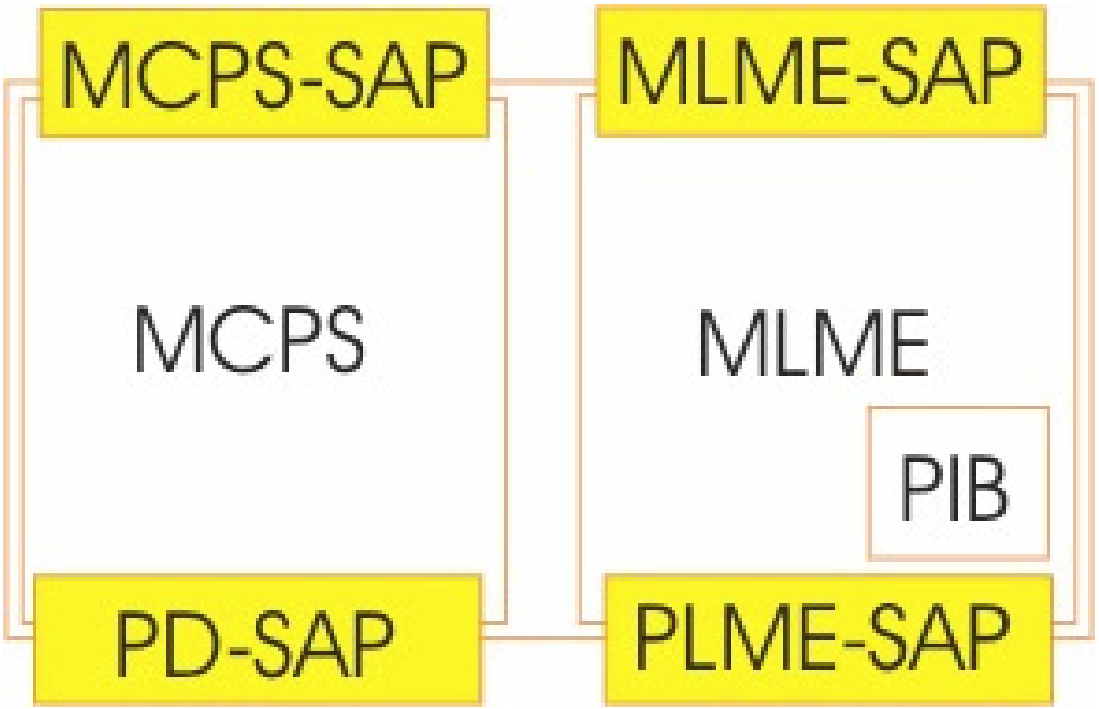
IEEE 802.15.4

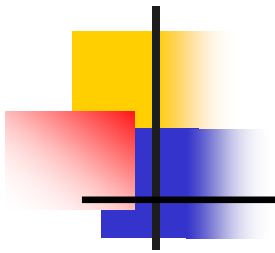
- 802.15.4 MAC Structure
  - MAC Common Part Sublayer
  - MAC Layer Management Entity



IEEE 802.15.4

- 802.15.4 Common Part Sublayer
  - Data transmission between two nodes





IEEE 802.15.4

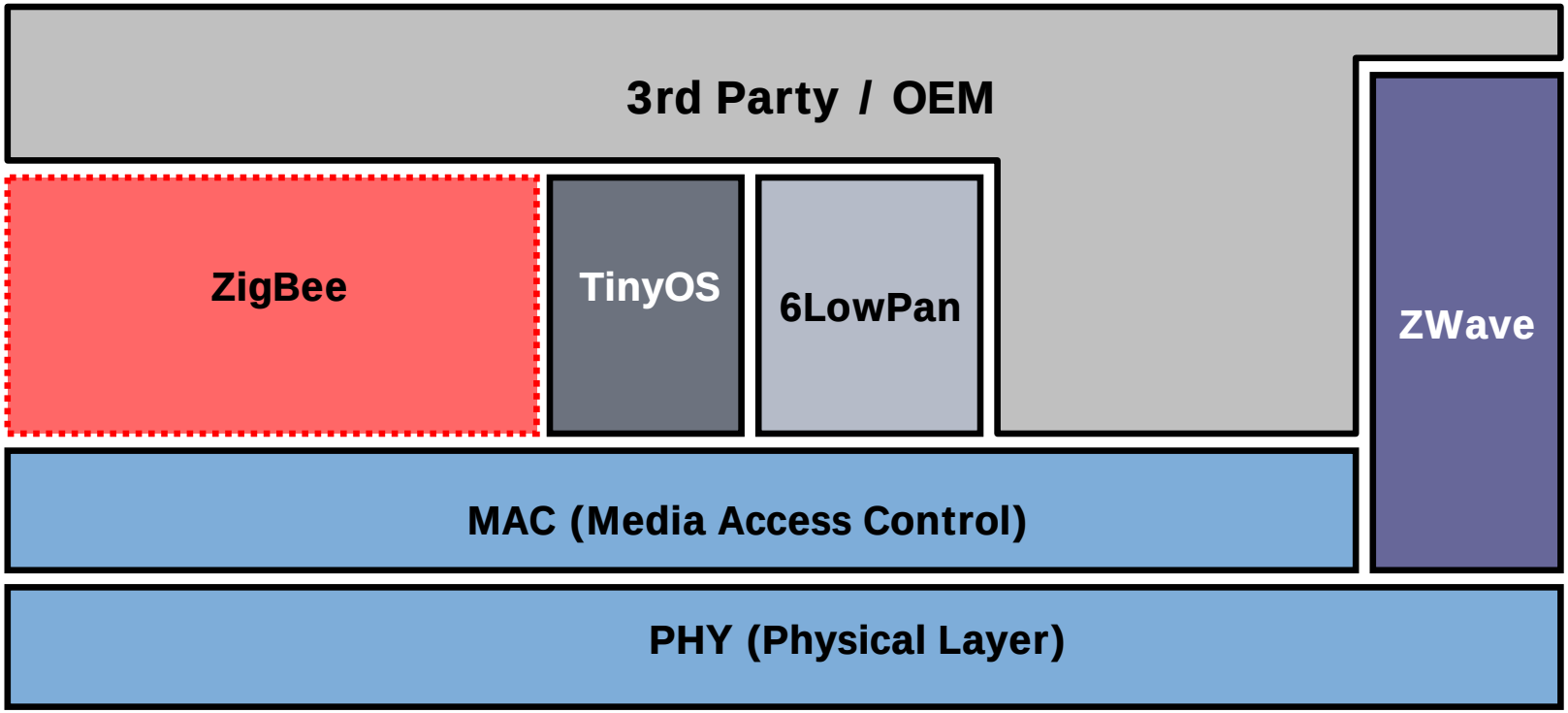
- 802.15.4 MAC Layer Management Entity
  - Maintain Communications
  - Allows access to a database of MAC specific attributes, called PAN Information Base (PIB).
  - The communication between the MAC and the neighbor layers (PHY and the upper layer) is made through Service Access Points (SAP).

IEEE 802.15.4

- 802.15.4 MAC Sequence
  - Device issues a request to the PAN coordinator to “Join” the network
  - The request goes down *via* the MAC to the PHY Layer, where it is modulated and sent over the air
  - Coordinator PHY receives the signal, demodulates it and sends it up to the MAC, where it is identified as a “Join” request from a remote device.
  - Indication is sent up to the application layer of the coordinator, which decides whether the device is allowed to join.
  - The coordinator then issues a responses that goes back to the remote device where is translated into a Confirmation.

ZigBee

- Network Layers (ZigBee)



ZigBee

- ZigBee Alliance
  - Association of companies working together to enable reliable, cost-effective, low-power, wirelessly networked, monitoring and control products based on an open global standard.

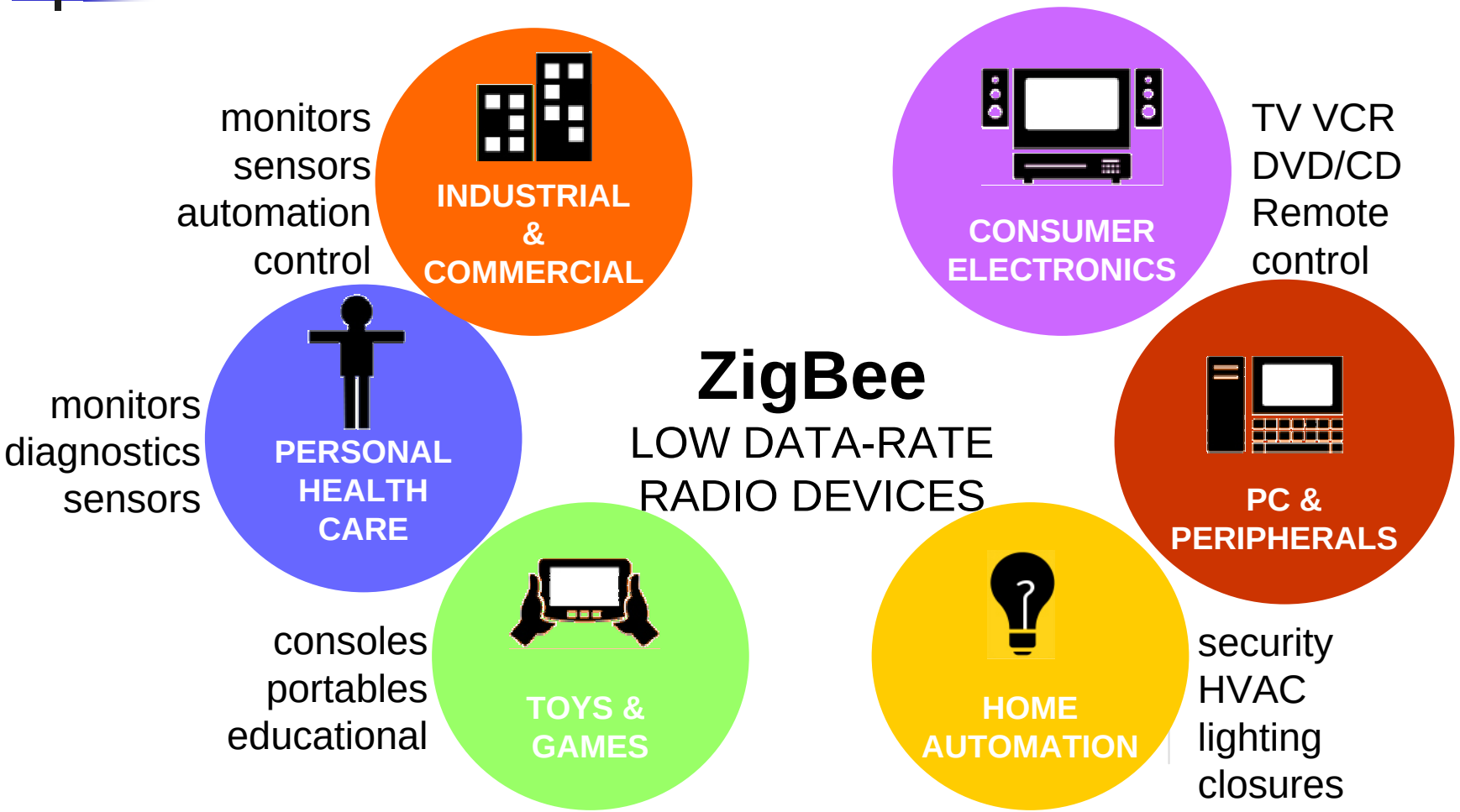
ZigBee™ Alliance
Wireless Control That Simply Works

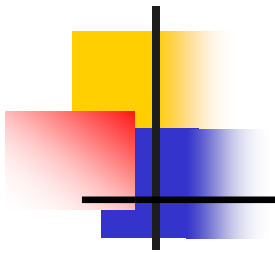
ZigBee

- ZigBee Alliance Objective
  - Flexibility, Mobility, and Ease of Use
  - Embedded in a Wide Range of Devices
  - Standards-based Wireless Platform
    - Monitoring
    - Control

ZigBee™ Alliance
Wireless Control That Simply Works

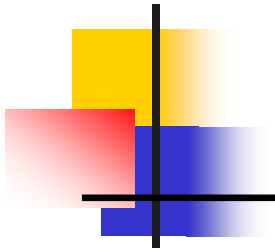
ZigBee





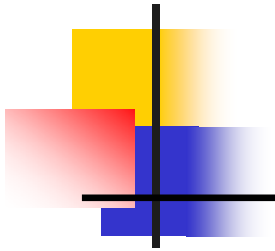
ZigBee

- Network Characteristics
  - *ad hoc*, self-forming networks
  - Mesh, cluster tree, and star topologies
  - Reliable broadcast messaging (CSMA/CD)
  - Non-guaranteed message delivery
  - Symmetric key security with AES-128
  - Authentication and encryption at MAC, network, and application levels



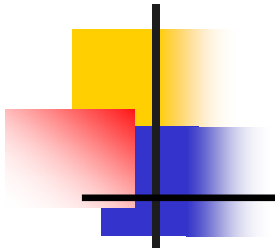
ZigBee

- ZigBee Membership
  - Promoters
  - Participants
  - Adopters



ZigBee

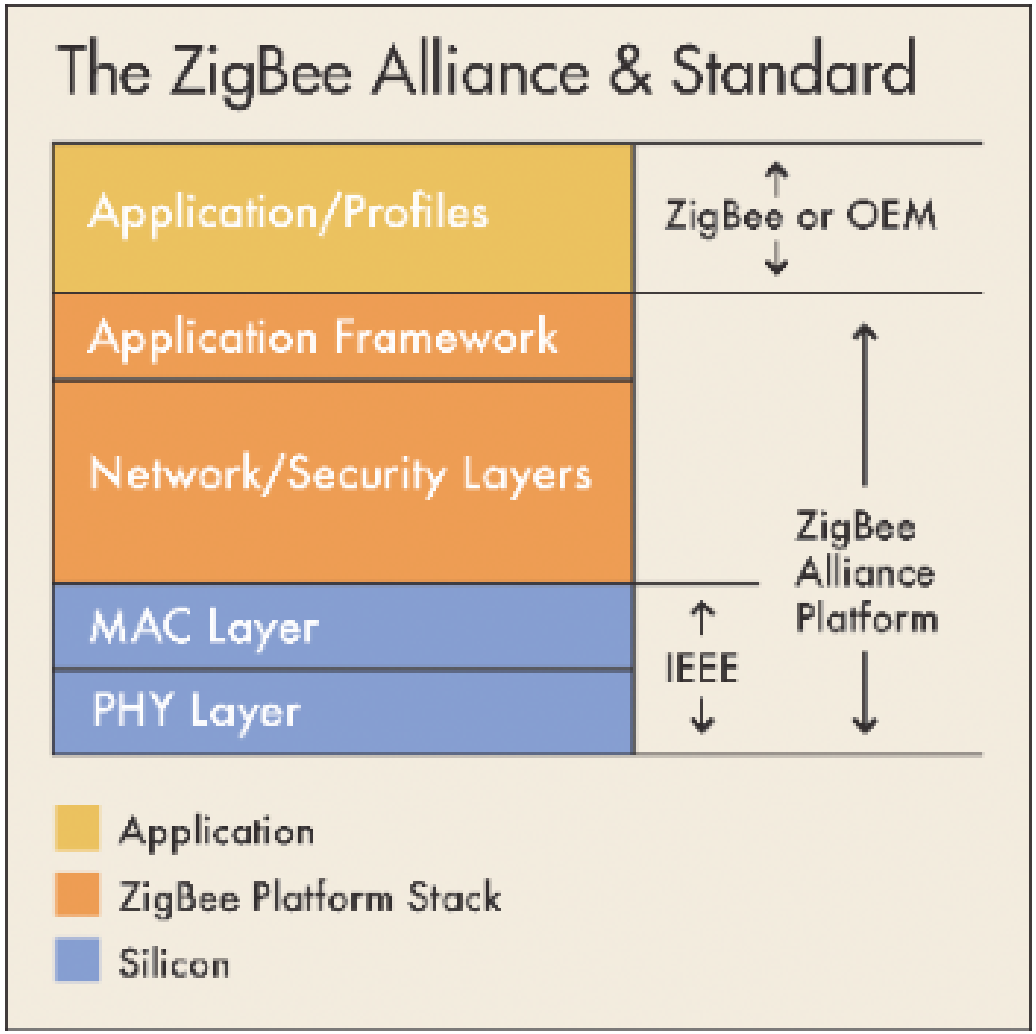
- ZigBee Specification
  - ZigBee v1.0 Specification
    - Download
      - ✓ http://www.zigbee.org/en/spec_download/download_request.asp
  - ZigBee Next Generation
    - ZigBee 2006
      - ✓ Release v13 - October 2006
    - ZigBee Pro
      - ✓ Release v14 - October 2006



ZigBee

- Working Groups
  - Application Framework Working Group
  - Architecture Subcommittee
  - Commissioning Tools Task Group
  - Gateway Working Group
  - IPV6 Stack Profile Task Group
  - Industrial Study Group
  - Network Layer Working Group
  - Security Working Group

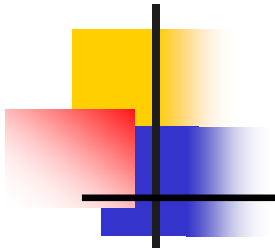
ZigBee



Colorado Software Summit

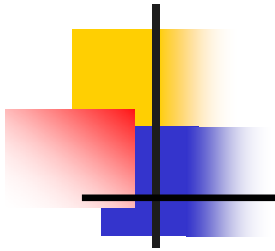
http://DeviceSoftwareOptimization.com

Zachary Smith, Ember



ZigBee

- Mesh Networking
  - Multi-hop
  - Self-configuring
  - Self-healing
  - Dynamic routing
  - Just like the Internet..

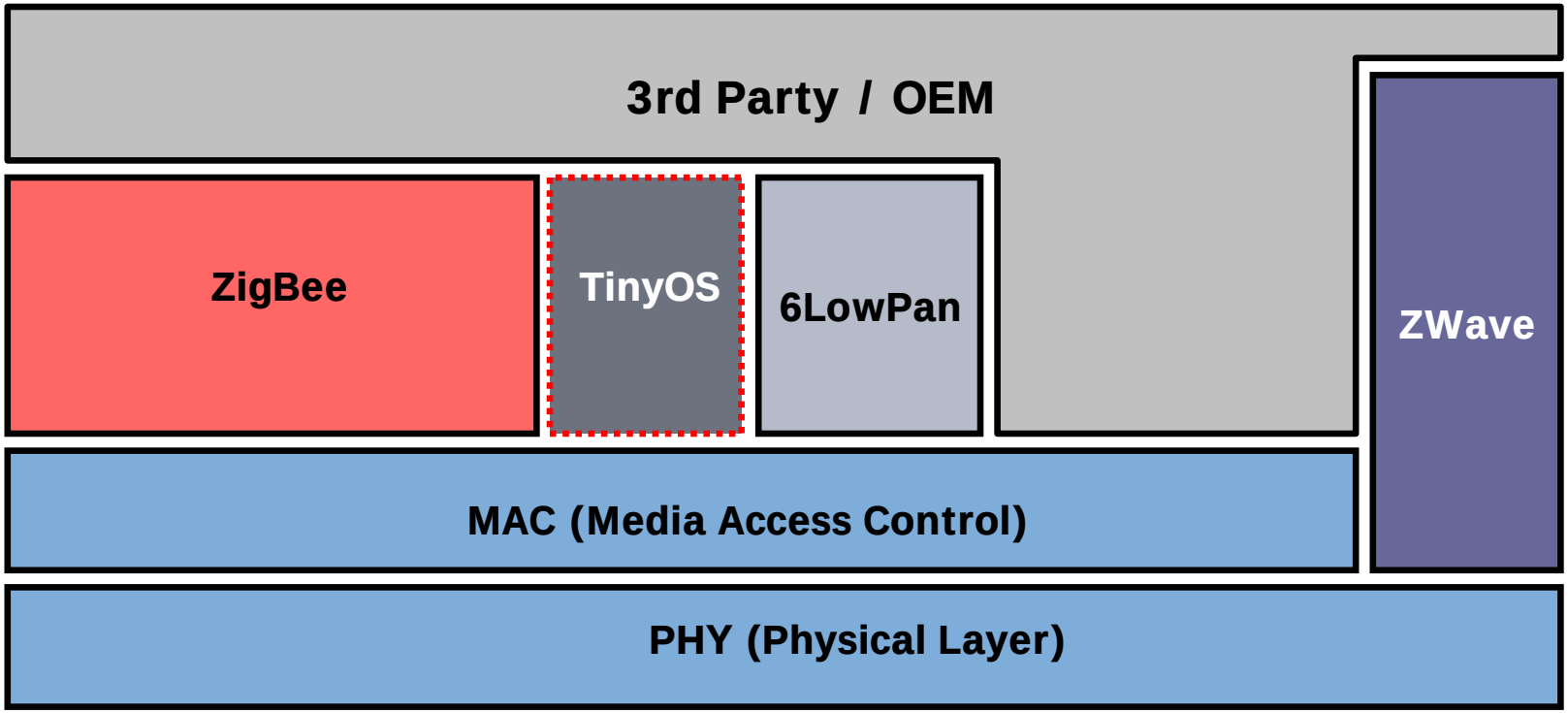


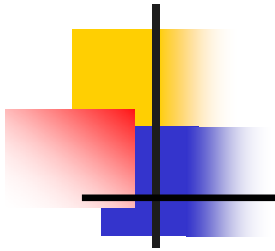
ZigBee

- ZigBee Mesh Protocol Reliability
  - Challenges
    - RF attenuation
    - Electromagnetic Interference
    - Multi-path signals.
  - Device Placement
    - Improve mesh characteristics

TinyOS

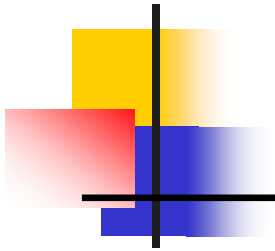
- Network Layers





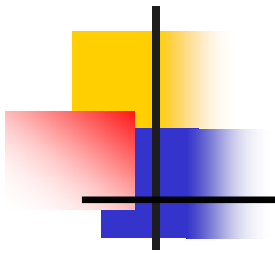
TinyOS

- Very small operating system for sensor networks
- Component-oriented architecture
- Concurrency based on **tasks** and **events**
- Split-phase operations
- Single shared stack
- No kernel/user space differentiation



TinyOS

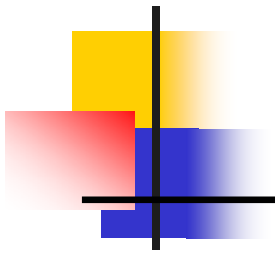
- TinyOS 2.0
  - Programming Language (NESC)
  - Platforms / Hardware Abstraction
  - Scheduler
  - Boot / Initialization
  - Virtualization
  - Timers
  - Communication
  - Sensors
  - Arbitration
  - Power Management



TinyOS

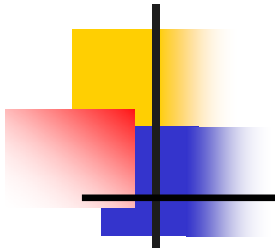
- nesC Programming Language
  - Architecture
    - Event-driven execution
    - Flexible concurrency model
    - Component-oriented application design
  - Benefits
    - Data-race detection
    - Aggressive function in-lining
    - Everything is static

The *nesC* Language: A Holistic Approach to Networked Embedded Systems



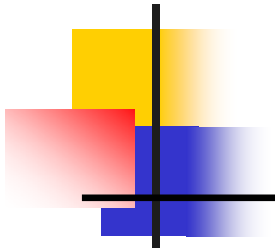
TinyOS

- Platforms
  - Radio
  - Microcontroller
- Hardware Abstraction Architecture
  - Hardware Independent Layer (HIL)
  - Hardware Abstraction Layer (HAL)
  - Hardware Presentation Layer (HPL)
  - TEP 2: Hardware Abstraction Architecture
    - http://www.tinyos.net/scoop/special/working_group_tinyos_2-0



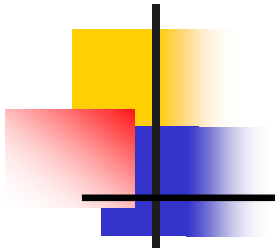
TinyOS

- Scheduler
  - "Improved" Non-preemptive FIFO policy
  - Pluggable Scheduler
  - TEP 106: Schedulers and Tasks



TinyOS

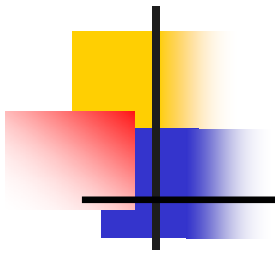
- Boot/Initialization
  - "Improved" Boot Sequence
    - No Power-up during Boot Sequence
      - ✓ Init
      - ✓ StdControl
  - TEP 107: TinyOS 2.x Boot Sequence
- Virtualization
  - Generic / instantiable component



TinyOS

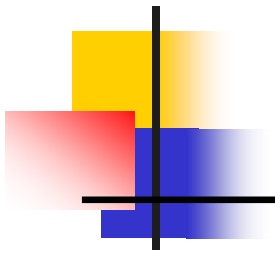
- Timers
  - Key Abstraction
  - Variable Granularity
    - Millisecond
    - 32kHz
  - Implemented using Virtualization
  - TEP 102: Timers
- Sample instantiation

```
components App, new TimerMilliC();
App.Timer -> TimerMilliC;
```



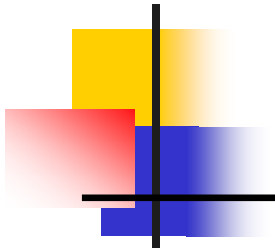
TinyOS

- Communication
  - Message Buffer
    - message_t
  - Size
    - Single Packet
  - Opaque
  - Message Types
    - Active Message (AM Interface)
    - Broadcasting & Collection (Send Interface)
  - TEP 111: message_t
  - TEP 116: Packet Protocols



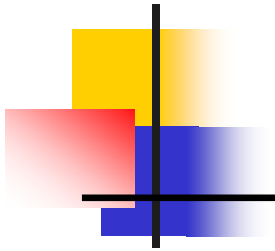
TinyOS

- Sensors
  - HIL Data Acquisition Interfaces
    - Read()
    - ReadStream()
    - Get()
  - High-Frequency / Very Accurate Sampling
    - Requires HAL
  - TEP 101: Analog-to-Digital Converters
  - TEP 109: Sensorboards
  - TEP 114: Source & Sink Independent Drivers



TinyOS

- Arbitration
  - Resource Interface
    - Request and Acquire Shared Resources and Arbiters
  - TEP 108: Resource Arbitration
- Power Management
  - Micro-controller
    - TEP 112: Microcontroller Power Management
  - Device(s)
    - TEP 115: Power Management of Non-Virtualized Devices

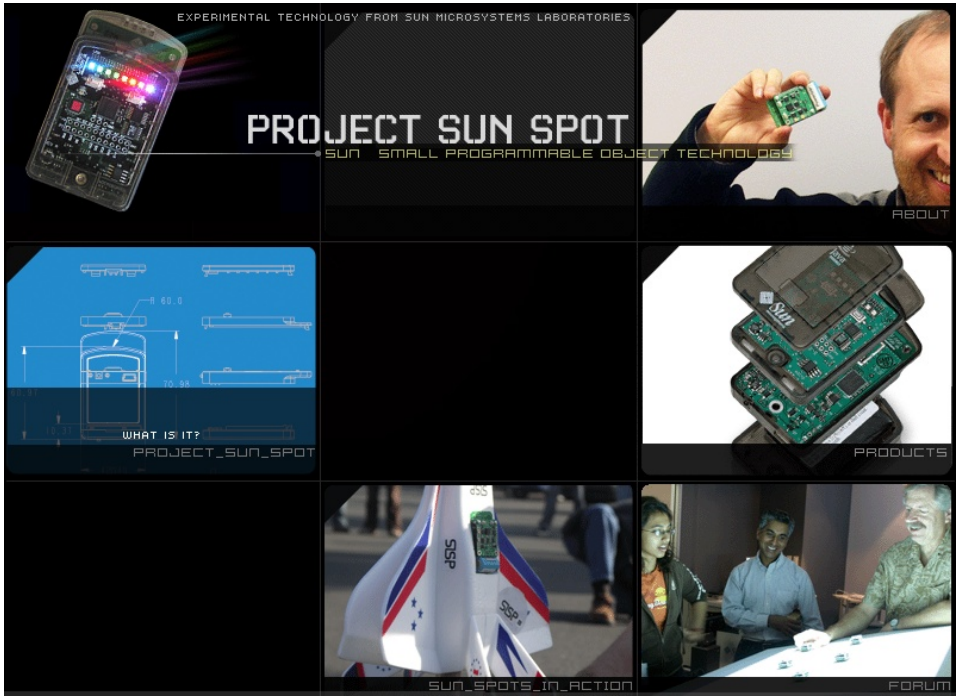


TinyOS

- Network Protocols
  - Dissemination
    - Reliably Delivers Small Data Items
    - TEP 118: Dissemination
  - Collection
    - Routing Tree Rooted at a Sink Node
    - TEP 119: Collection

Sun SPOT

- Small Programmable Object Technology



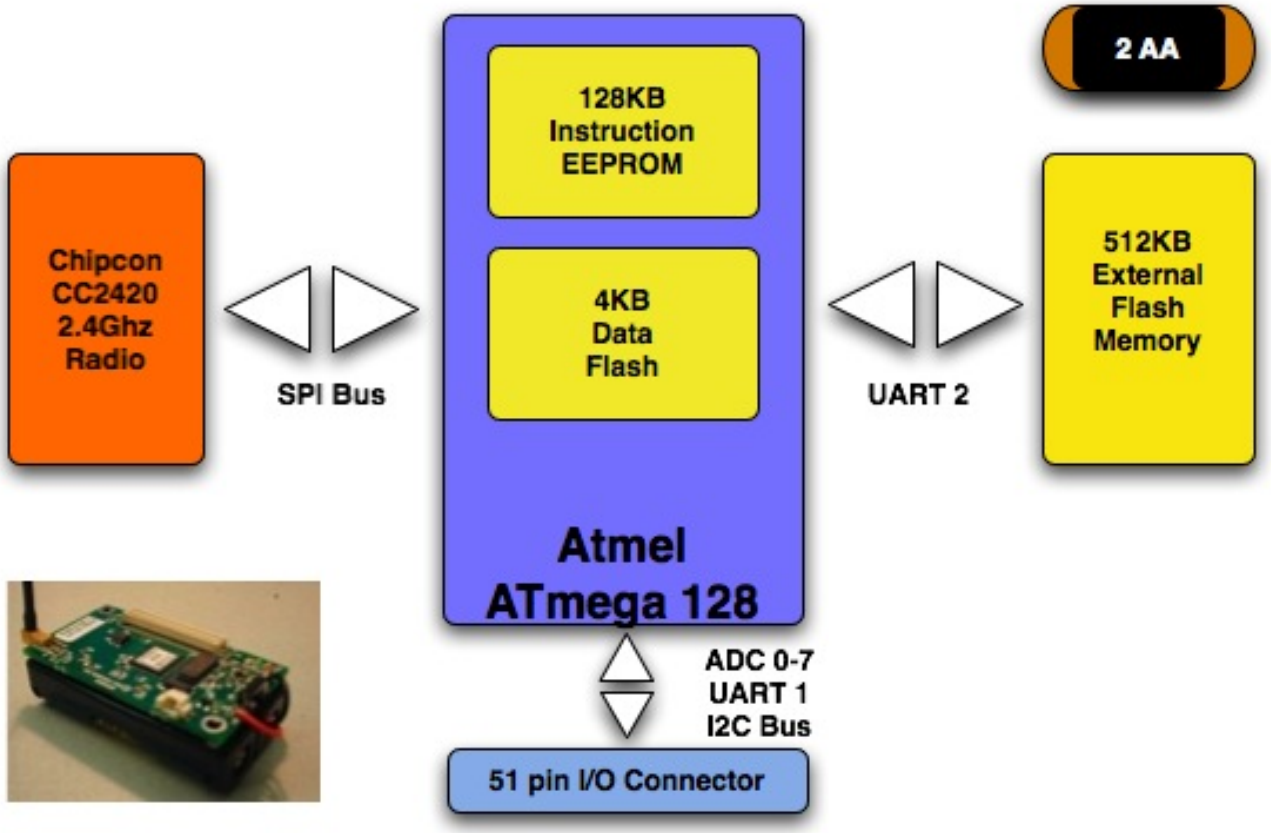
Simplified Development of Wireless Transducers Using Java™ Technology

Sun SPOT

- Hardware
  - 180 Mhz 32-bit ARM920T core
    - 512k RAM/4M ROM
  - ChipCon 2420 radio
    - 2.4 GHz IEEE 802.15.4
  - USB Interface
  - 3.7V rechargeable 750 mAh prismatic lithium ion battery
  - 40 uA deep sleep mode, 40 mA to 100+ mA
  - 64mm x 38mm
  - Double sided connector for stackable boards

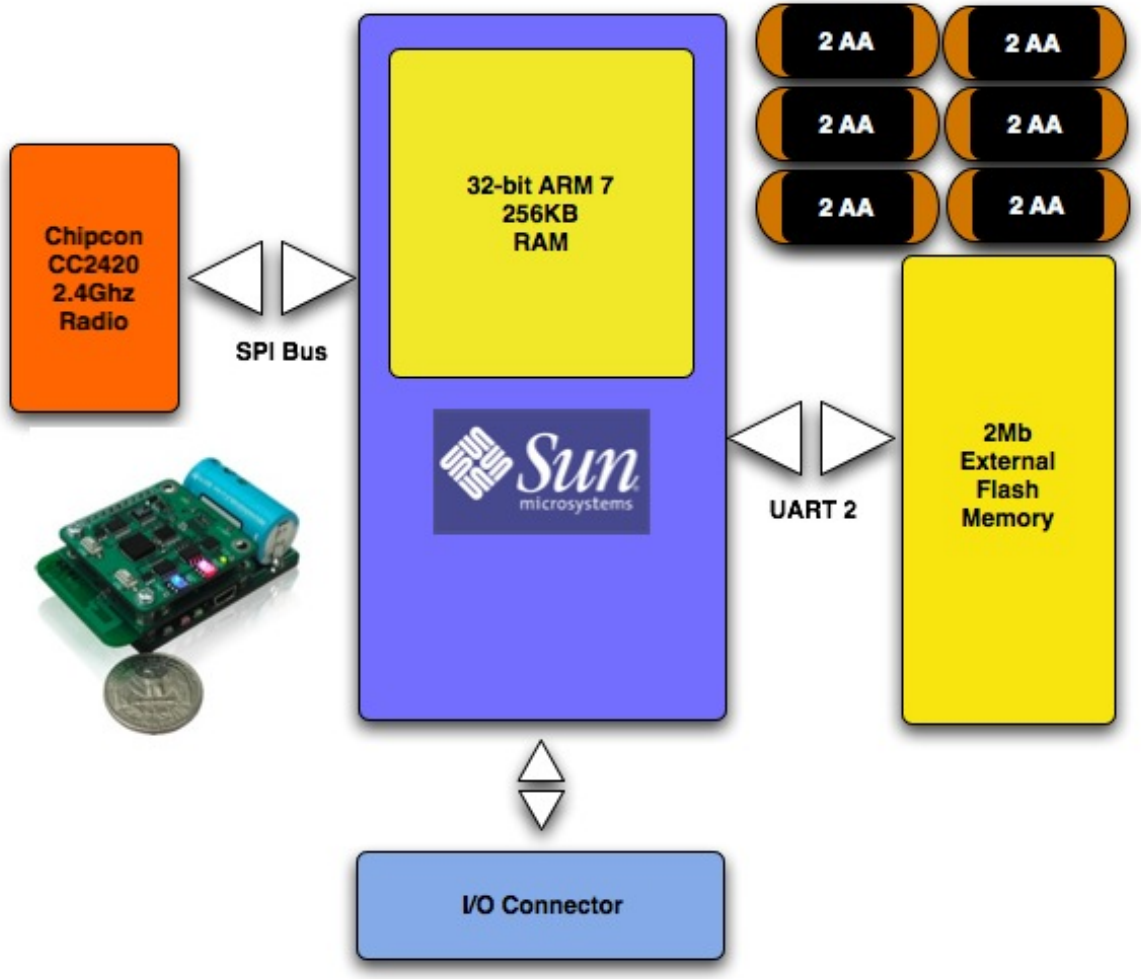
Sun SPOT

- Atmega 128/Chipcon 2420



Sun SPOT

- 32-Bit ARM7 Core Device

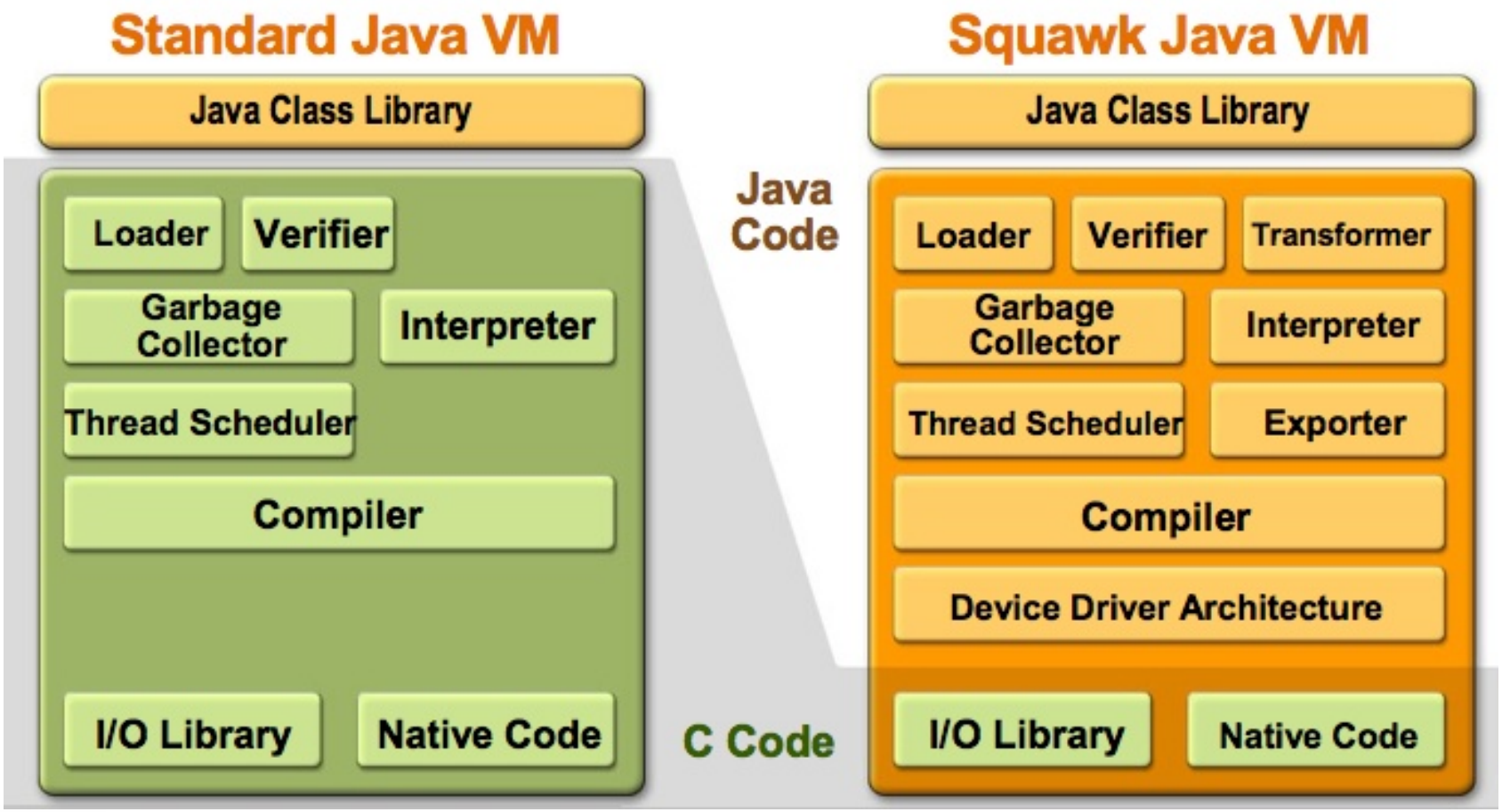


Sun SPOT

- The Squawk Java VM
  - Java VM mainly written in the Java programming language
  - Interpreter written in C
  - Garbage collector translated from the Java to the C programming language
  - Java ME CLDC 1.1
  - Runs on the bare ARM without an underlying OS
  - Interrupts and device drivers written in the Java programming language
  - Supports isolate application model

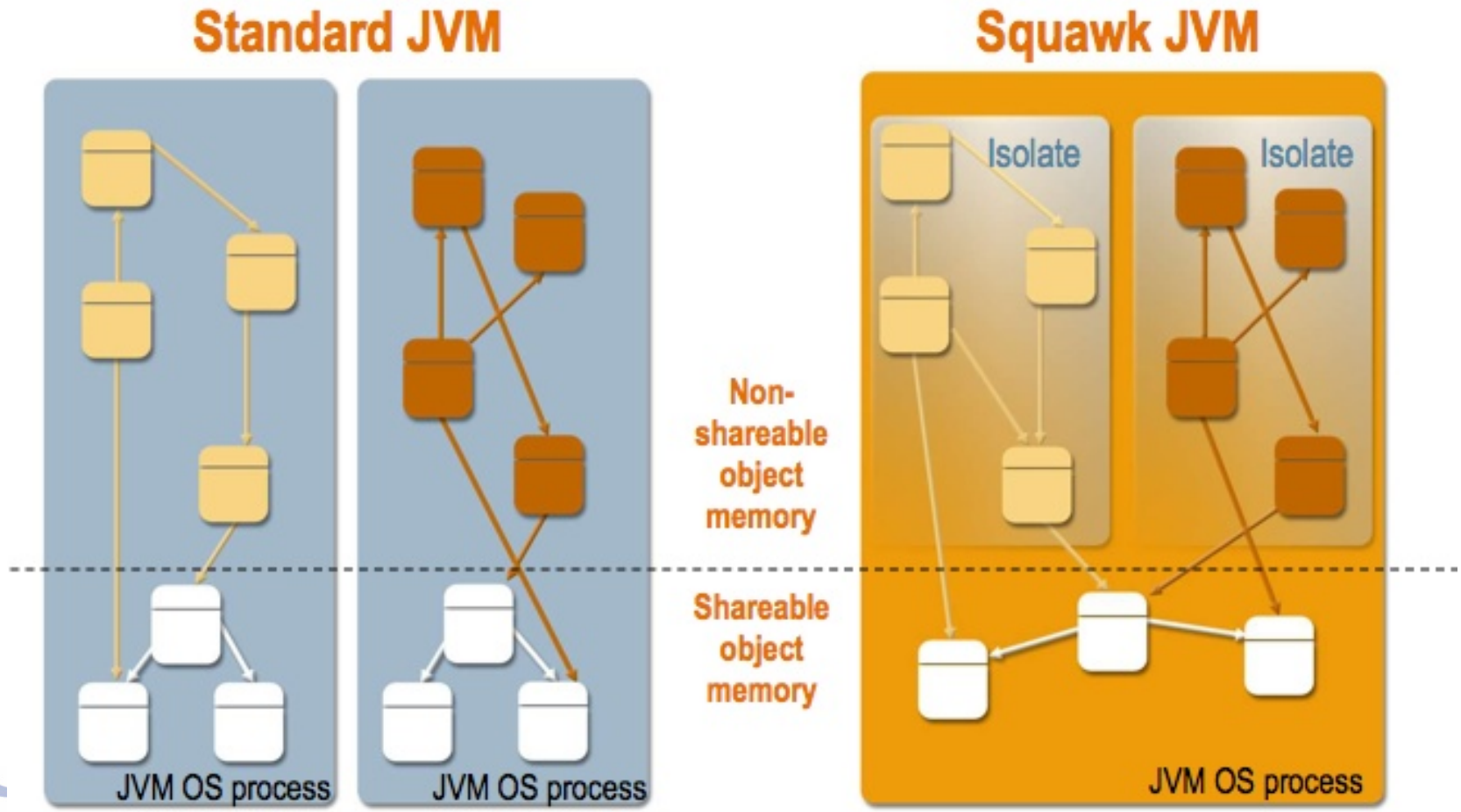
Sun SPOT

- Standard Java VM *vs.* Squawk Java VM



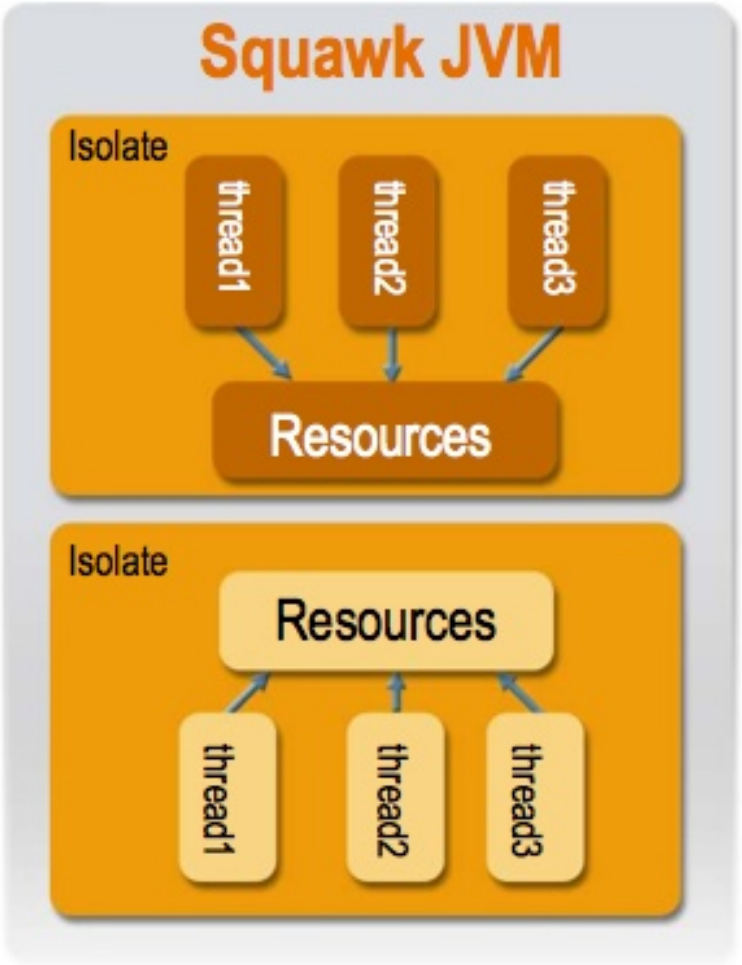
Sun SPOT

- Standard Java VM *vs.* Squawk Java VM



Sun SPOT

- Squawk Isolate



Sun Microsystems - 2005 Java One

Sun SPOT

- Squawk Isolate
  - Each application is represented by an Isolate object
  - Similar to JSR 121 Isolate API
    - Each isolate has resources that are shared amongst the threads of that isolate
    - Immutable state (*e.g.*, methods, string constants, parts of classes) is shared
    - Non-shared class state includes static fields, class initialization state, and class monitors
  - Allows for control of applications
    - Can start(), pause(), resume(), and exit()

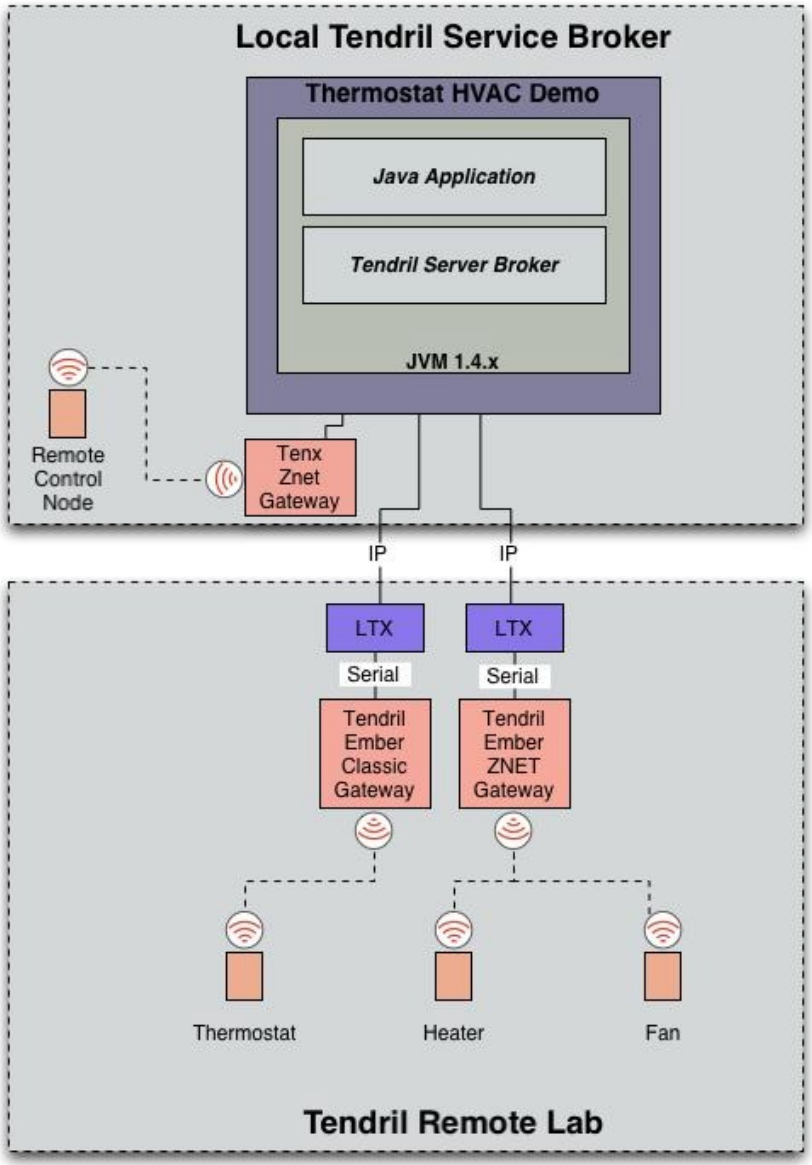
Sun SPOT

- For More Information
  - Squawk

    http://research.sun.com/projects/squawk
  - Sun SPOT
    - http://www.sunspotworld.com
  - Papers, Presentations
    - “Java™ on the Bar Metal of Wireless Sesnsor Devices - The Squawk Java Virtual Machine”, VEE, June 2006
    - “The Squawk Virtual Machine: Java™ on Bare Metal”, Extended Abstract, OOPSLA, Oct 2005
    - 2006 Java One™ “Squawk: a Java™ VM for Wireless Sensor and Actuator Devices”, Cifuentes, D. White, E. Arseneau

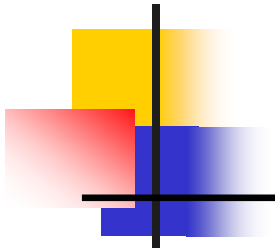
WSCN Demonstration

- Remote Control



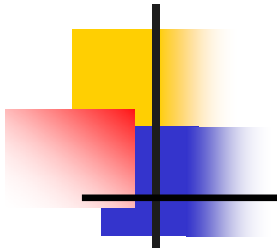
Keystone, Colorado

Boulder, Colorado



Resources

- B & B Electronics - http://bb-elec.com
  - Great online electronics store. Sensicast devices are currently available.
- WiSuite - http://www.wisuite.com
  - Wireless Control Company
  - 30 Kern Road, Suite 202 Toronto, Ontario Canada M3B 1T1
  - Contact Information: 866-862-2240
- Rabbit Semiconductor - http://www.rabbitsemiconductor.com
  - ZigBee/802.15.4 Application Kit
  - Inexpensive $299.00
- Ember Jump Start for EM 250 - http://www.digikey.com
  - Search for Ember
    - RF Evaluation & Development Kits Boards
    - RF Transmitter, Transceiver & Receiver ICs & Modules
      - ✓EM 2420 and EM 250 Parts
  - Expensive $2500.00 Development Kit



Book

- Low Rate Wireless Personal Area Networks
  - Enabling Wireless Sensors with IEEE 802.15.4
    - Jose A. Gutierrez
    - Edgar H. Callaway, Jr.
    - Raymond L. Barrett, Jr.

Introduction to Wireless Sensor and Control Networks

Please complete the questionnaires in the back of your CSS notebook.

Thank you

Tom Bender

Tendril Networks

tbender@tendrilinc.com