Design and Development of IoT Applications

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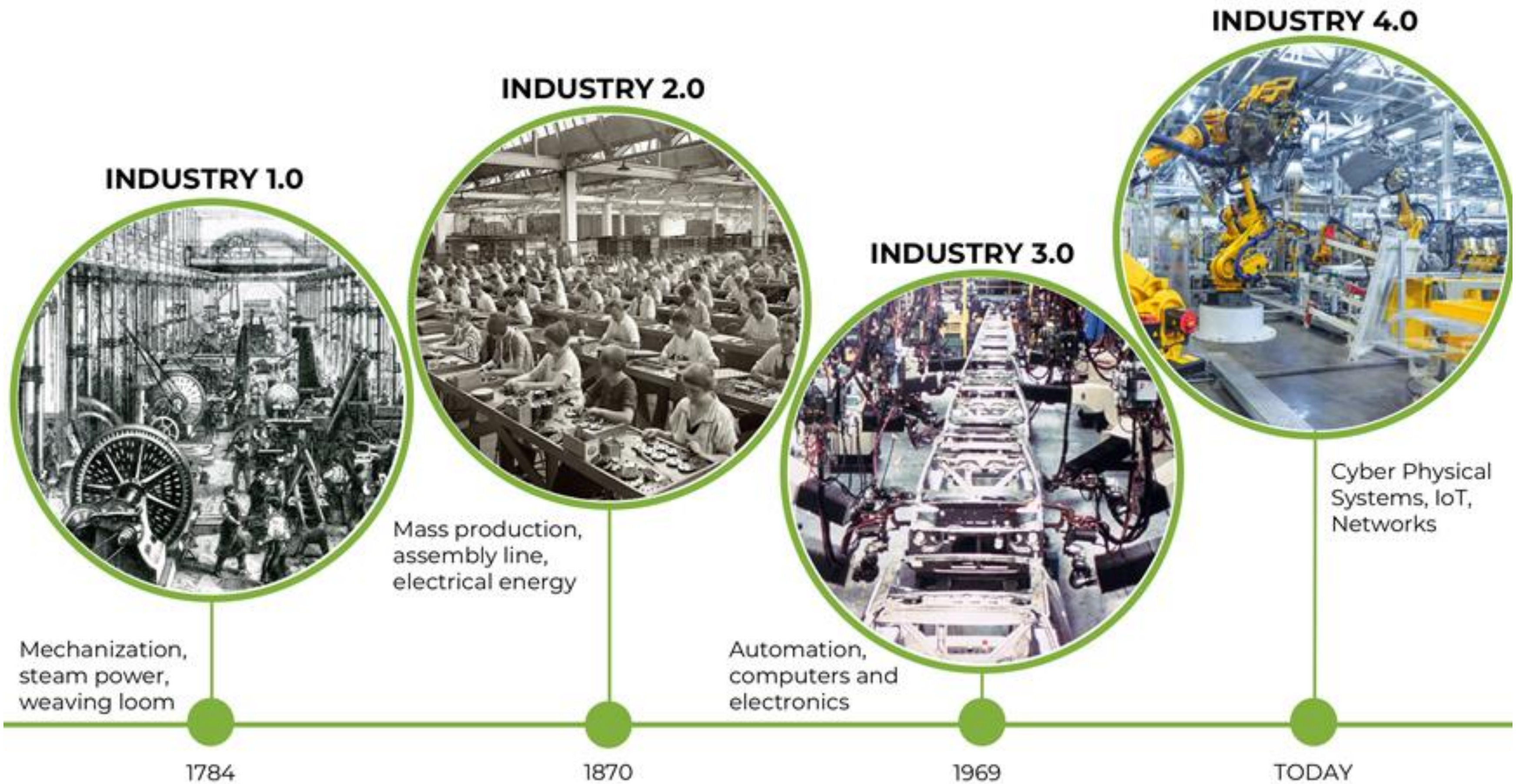
Wireless Sensor Networks and IoT

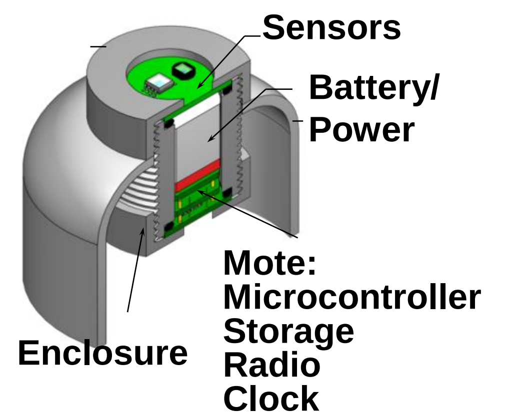


Wireless Sensor Networks

- A Wireless Sensor Network (WSN) consists of base stations and a number of wireless sensors (nodes).
- Characteristics of Wireless Sensor Networks
  - Requirements: small size, large number, tether-less, and low cost. Constrained by
  - Energy, computation, and communication
  - Small size implies small battery
  - Low cost & energy implies low power CPU, radio with minimum bandwidth and range
  - Ad-hoc deployment implies no maintenance or battery replacement
  - To increase network lifetime, no raw data is transmitted

Wireless Sensor Networks

- Large number of self-organizing static or mobile nodes that are possibly randomly deployed
- Near(est)-neighbor communication
- Wireless connections
  - Links are fragile, possibly asymmetric
  - Connectivity depends on power levels and fading
  - Interference is high for omnidirectional antennas
- Sensor Networks and Sensor-Actuator Networks are a prominent example.
- Integrated 3 core technologies:
  - Radio communication
  - Sensing
  - Distributed computation

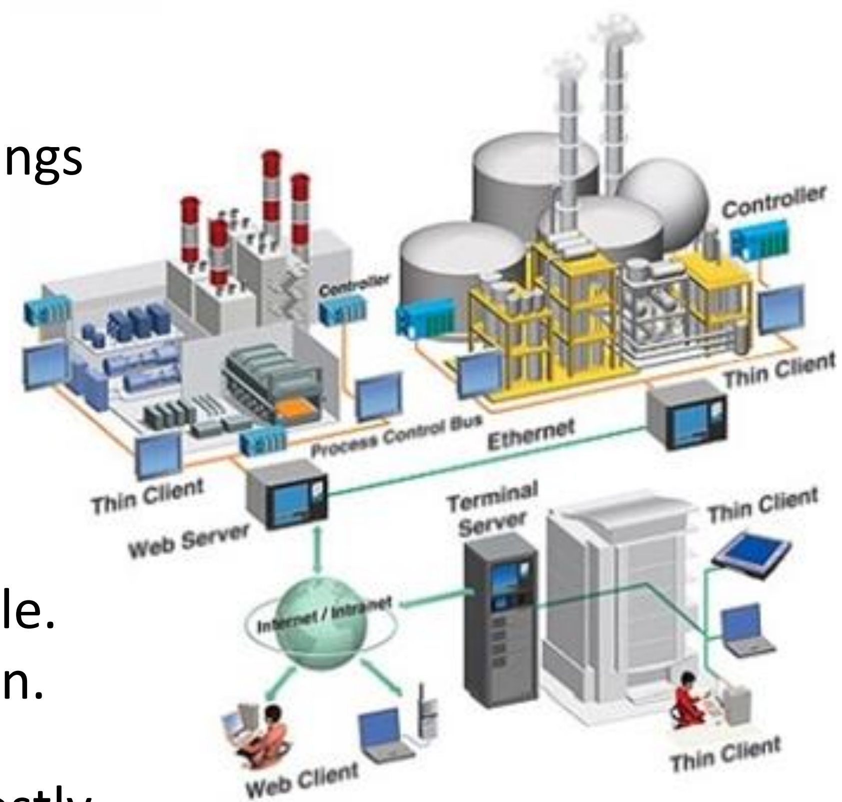


WSNs: Overview

- Distinguishing Features
  - WSNs are ad hoc networks (wireless nodes that self-organize into an infrastructureless network).
- BUT, in contrast to other ad hoc networks:
  - Sensing and data processing are essential
  - WSNs have many more nodes and are more densely deployed
  - Hardware must be cheap; nodes are more prone to failures
  - WSNs operate under very strict energy constraints
  - WSN nodes are typically static
  - The communication scheme is many-to-one (data collected at a base station) rather than peer-to-peer

WSNs: Overview

- Lifetime
  - Nodes are battery-powered
  - Nobody is going to change the batteries. So, each operation brings the node closer to death.



- ***"Lifetime is crucial!"***
- To save energy:
  - Sleep as much as possible.
  - Acquire data only if indispensable.
  - Use data fusion and compression.
  - Transmit and receive only if necessary. Receiving is just as costly as sending.

WSNs: Overview

- Scalability and Reliability, WSNs should
  - self-configure and be robust to topology changes (e.g., death of a node)
  - maintain connectivity: can the Base Station reach all nodes?
  - ensure coverage: are we able to observe all phenomena of interest?
- Maintenance
  - Reprogramming is the only practical kind of maintenance.
  - It is highly desirable to reprogram wirelessly.

WSNs: Overview

❑Data Collection

- ❖Centralized data collection puts extra burden on nodes close to the base station. Clever routing can alleviate that problem
- ❖Clustering: data from groups of nodes are fused before being transmitted, so that fewer transmissions are needed
- ❖Often getting measurements from a particular area is more important than getting data from each node
- ❖Security and authenticity should be guaranteed. However, the CPUs on the sensing nodes cannot handle fancy encryption schemes.

WSNs: Overview

- Power Supply
  - AA batteries power the vast majority of existing platforms. They dominate the node size.
  - Alkaline batteries offer a high energy density at a cheap price. The discharge curve is far from flat, though.
  - Lithium coin cells are more compact and boast a flat discharge curve.
  - Rechargeable batteries: Who does the recharging?
  - Solar cells are an option for some applications.
  - Fuel cells may be an alternative in the future.
  - Energy scavenging techniques are a hot research topic (mechanical, thermodynamical, electromagnetic).

WSNs: Overview

- Radio
  - Commercially-available chips
  - Available bands: 433 and 916MHz, 2.4GHz ISM bands
  - Typical transmit power: 0dBm.
- Power control
  - Sensitivity: as low as -110dBm
  - Narrowband (FSK) or Spread Spectrum communication. DS-SS (e.g., ZigBee) or FH-SS (e.g., Bluetooth)
  - Relatively low rates (<100 kbps) save power.

WSNs: Overview

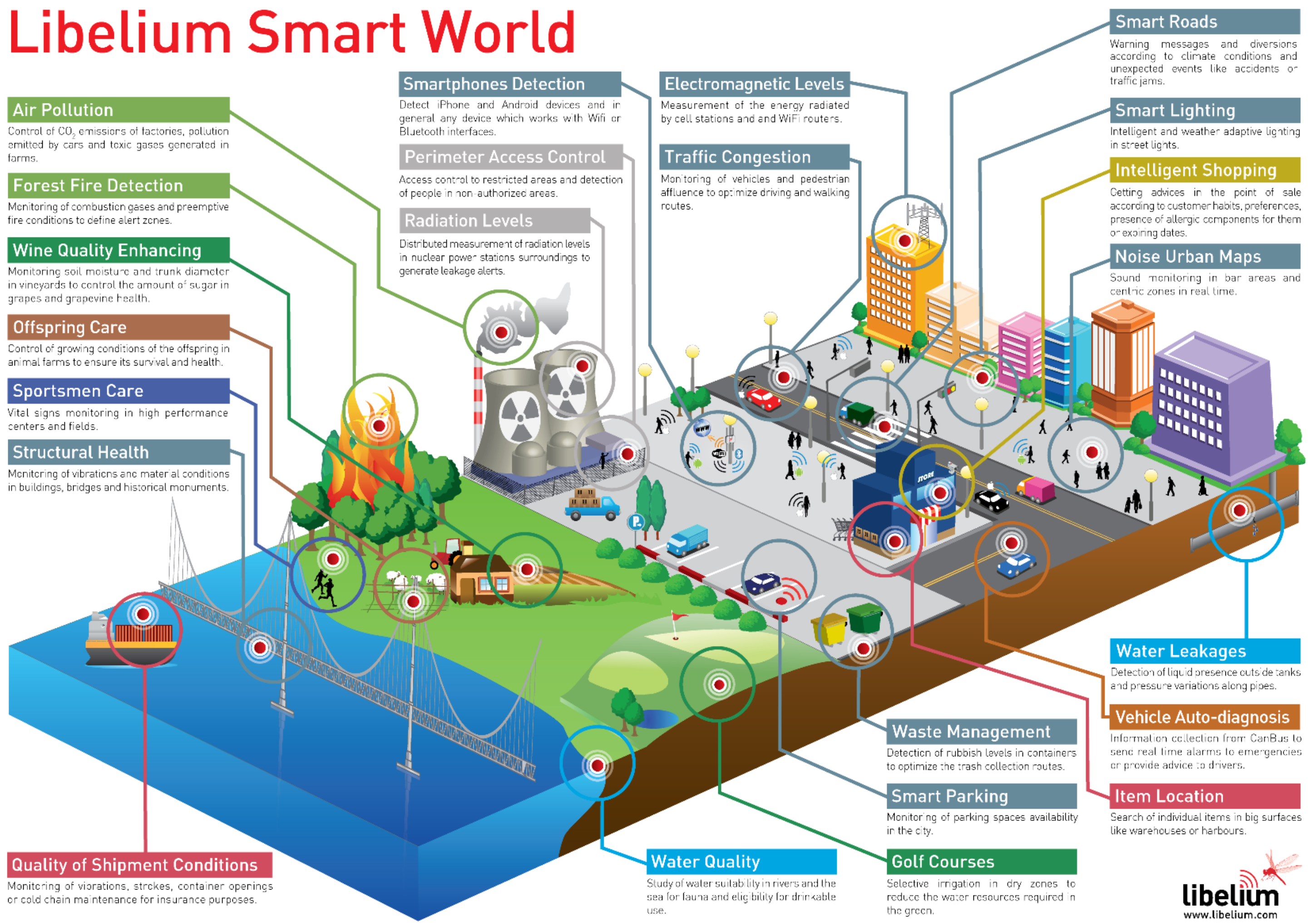
- CPU
  - The Microcontroller Unit (MCU) is the primary choice for in-node processing.
  - Power consumption is the key metric in MCU selection.
  - The MCU should be able to sleep whenever possible, like the radio.
  - Memory requirements depend on the application
  - ATmega128L and MSP430 are popular choices

WSNs: Overview

- Sensors
  - The power efficiency of the sensors is also crucial, as well as their duty cycle.
  - MEMS techniques allow miniaturization.

- Applications of Wireless Sensor Networks
  - Military and national security application
  - Environment monitoring
  - Medical application
  - Nearly anything you can imagine

Applications: Internet of Things



Applications of WSNs

- Monitoring Spaces
  - Env. Monitoring, Conservation biology, ...
  - Precision agriculture,
  - built environment comfort & efficiency ...
  - alarms, security, surveillance, EPA, OSHA, treaty verification ...
- Monitoring Things
  - automated meter reading
  - condition-based maintenance
  - disaster management
  - Civil infrastructure
- Interactions of Space and Things
  - manufacturing, asset tracking, fleet & franchise
  - context aware computing, non-verbal communication
  - Assistance - home/elder care
- Action and control
  - Optimizing processes
  - Automation

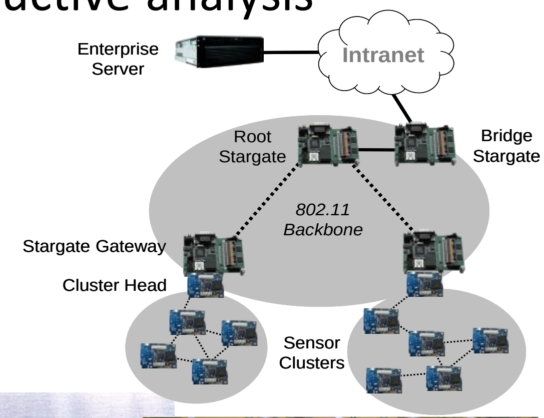
Environmental Monitoring Characteristics

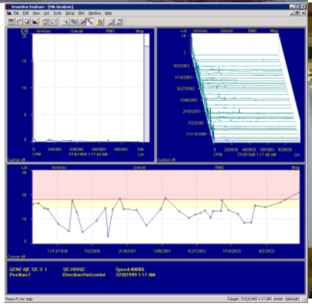
- Large number of nodes spread over physical space of interest
- Low sample rate (of multiple sensor modes)
- Further reduced by node signal processing and compression
- Reliable dissemination of configuration, command, or query
- Low-rate scalar data collection
- Many options for reliability, Predictable reporting delays
- Low duty cycle for long lifetime

- Energy availability is application specific
- Extension to event detection and triggering demands more responsive protocols
- Extension to control requires predictable outward routing

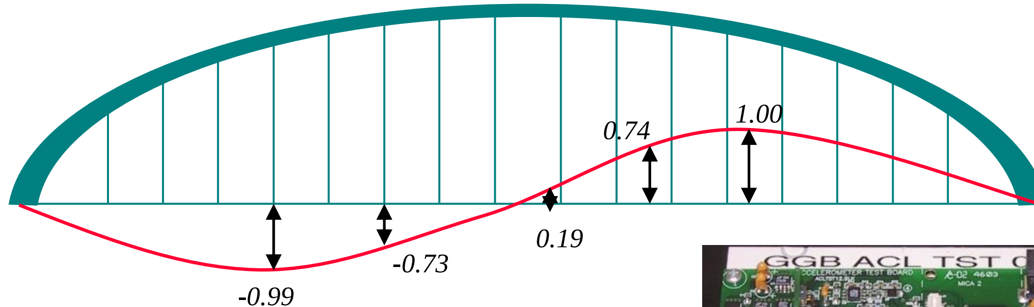
Intel Fab & BP Machine Monitoring

- Goal: Pre-empt equipment failures through non-destructive analysis
- Media Gap: Majority of data is collected by hand
  - Thousands of sense points
- Intel Fab and an Oil Tanker engine room
- Wireless vibration data collection
  - High-speed sampling, reliable bulk transfer
  - Sensor-to-Analysis App flow
  - Overcome interference
  - Support disconnected operation
- Loch Rannoch Network
  - 150 accelerometers
  - 26 motes
  - 4 stargates
  - 1 PC
- Efficient installation and management
  - 36hr install period on tanker
  - No crew intervention

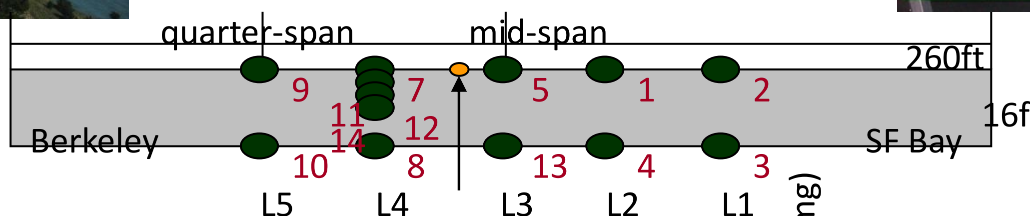


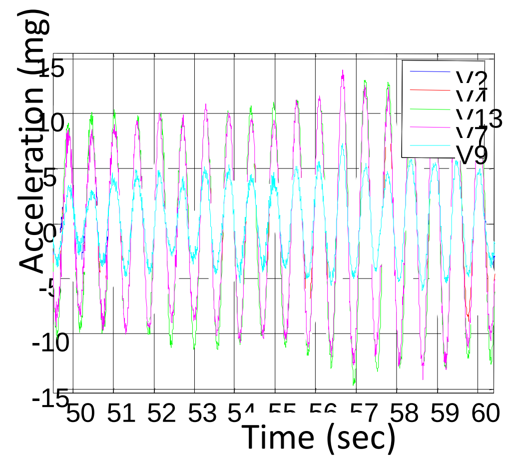


Golden Gate Bridge Structural Monitoring



Frequency: 1.41 Hz
Damping Ratio: 2%





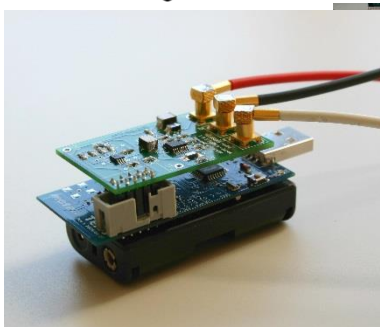
Machine Monitoring Characteristics

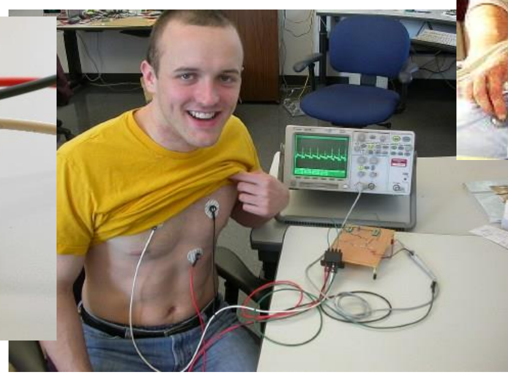
- Nodes clustered on specific equipment
- High sample rate (over short bursts)
  - Substantial local signal processing
- Control and management is like Env. Monitoring
- Data collection in single-point streams
  - Reliable end-to-end transport
- Shallow networks in practice

- Well understood
  - but not yet well supported
- Energy availability is site specific
- Natural extensions for local access (inspector)
- Structural monitoring is much harder than CBM
  - Time coordinated samples, cross-node data analysis
- Environmental factors critical to sensing accuracy

Medical Monitoring

VERITAS





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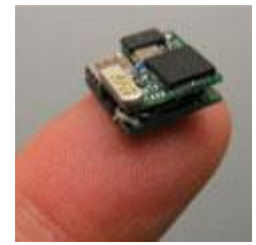
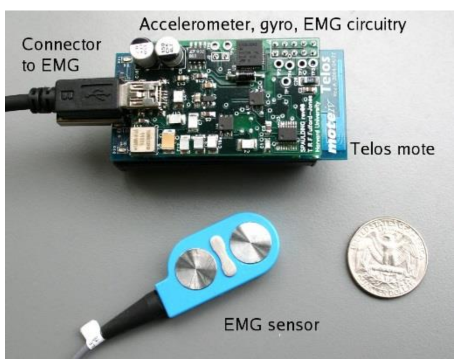


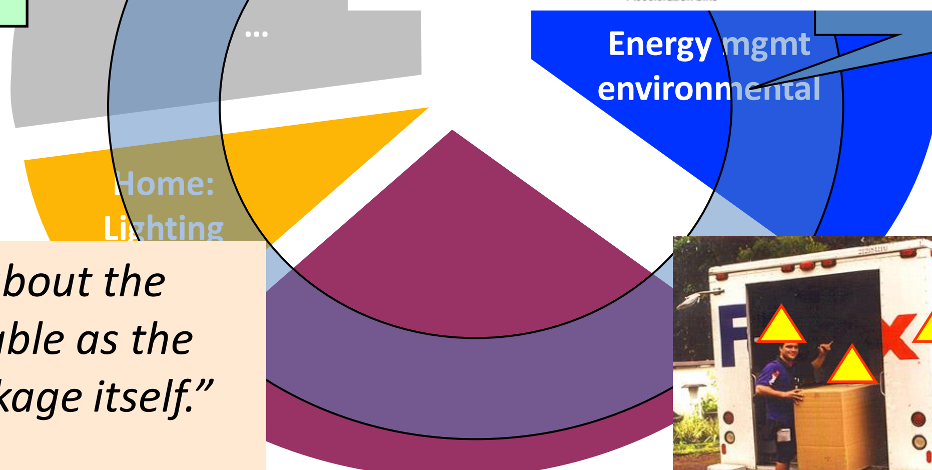


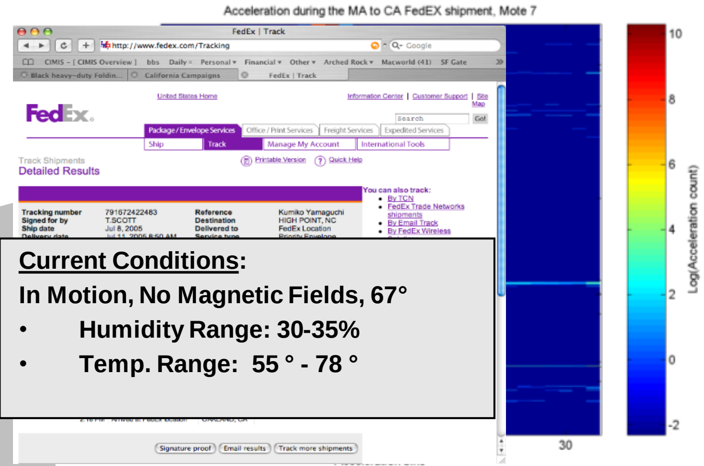
Wireless module

Millennial Net
Wireless Sensor Networking…Anywhere

Proximity, Tracking, Compliance

Safety:
Chemical-to-chemical safety alerts
Human-to-chemical safety alerts





Current Conditions:
In Motion, No Magnetic Fields, 67°
- **Humidity Range: 30-35%**
- **Temp. Range: 55 ° - 78 °**

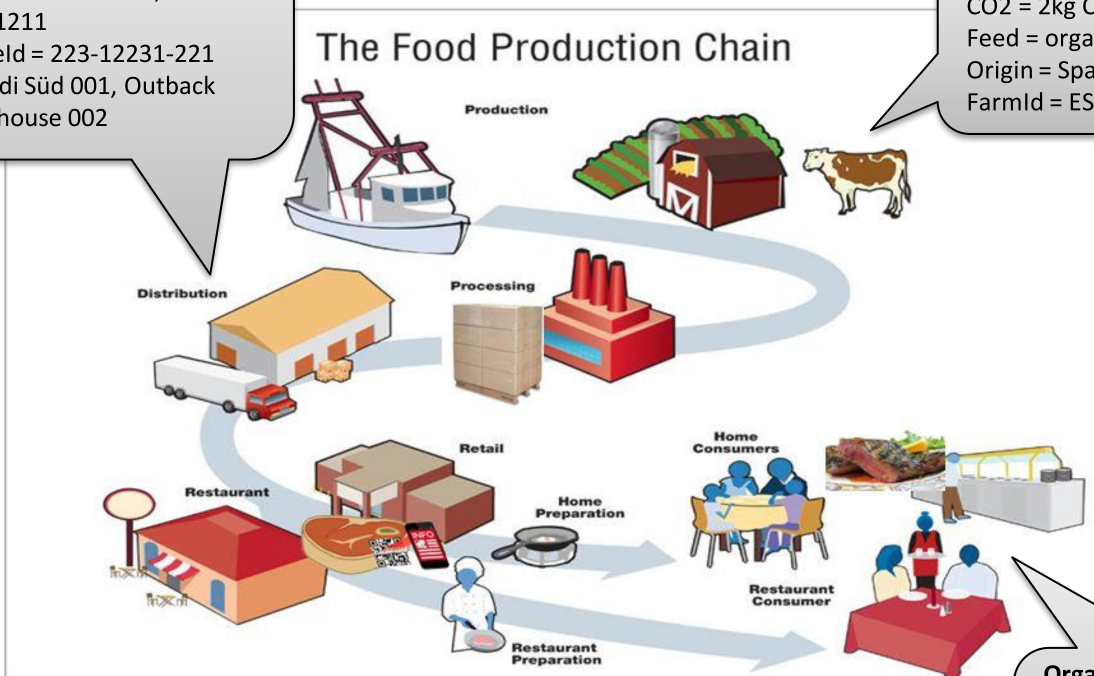
...pping QoS:
...ion threshold
...ature/humidity
...hreshold

"The information about the package is as valuable as the delivery of the package itself."

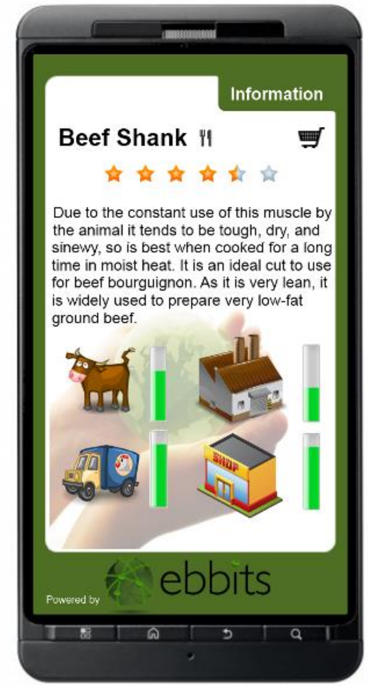
-Fred Smith
CEO, FedEx

Food traceability

Organic T-Bone Steak
CO_2 = 15kg CO_2/kg
FarmIds = ES123312, DE121211
PalateId = 223-12231-221
To=Aldi Süd 001, Outback Steakhouse 002



Weight = 150 kg
CO_2 = 2kg CO_2/kg
Feed = organic
Origin = Spain
FarmId = ES123312



Organic T-Bone Steak
CO_2 = 17kg CO_2/kg
Born In Spain, Raised In Free Farmvile Germany
100% organic grass fed
Rating = 4.5/5

Interaction Monitoring Characteristics

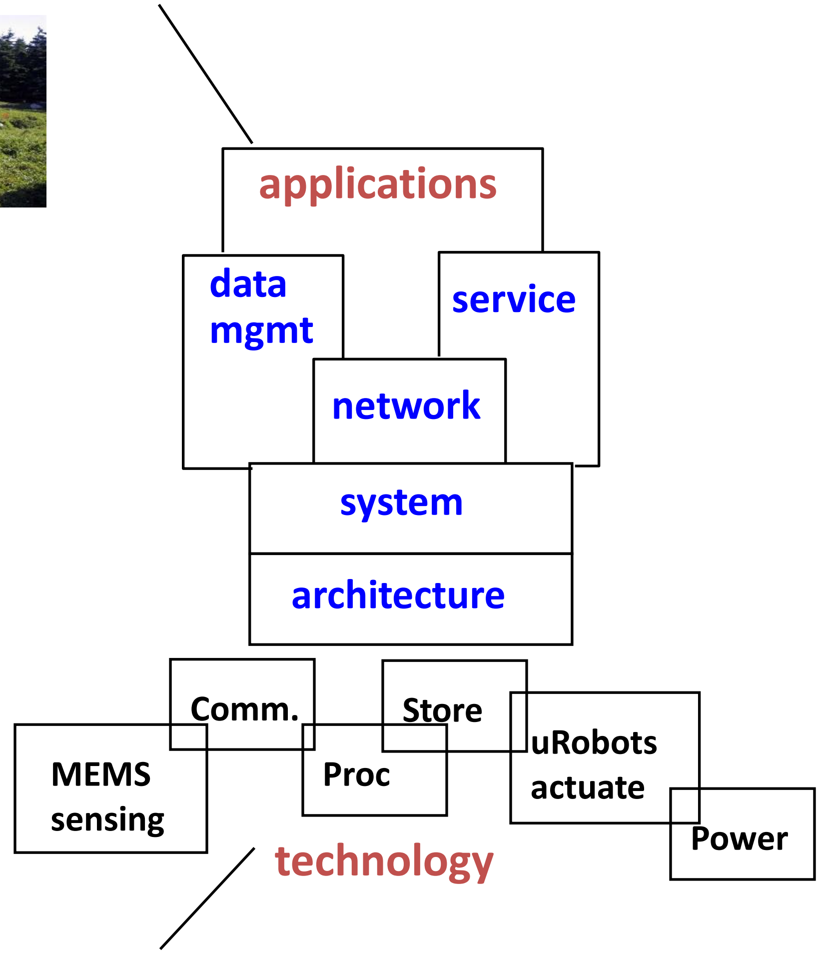
- Many different forms of monitoring
  - Untagged vs tagged items
- Mobility is central
  - Mobile nodes moving through stationary networks
  - Networks moving through networks
  - Proximity detection and action
- Wide range of communication patterns
  - Mobile-mobile routing
- Adaptive protocols
- Sophisticated routing
- Reliability through custody transfer
- Deep interactions with IT infrastructure

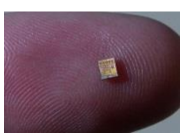
Core Challenges

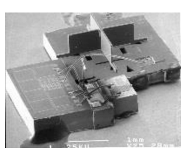
- Long-lived, unattended, reliable operation
  - Power: wireless often means self-powered
    - Batteries
    - Ambient sources (light, current, vibration, heat, …)
  - Limited Memory
  - Self-organization and Management
  - Error, fault, noise mitigation
- Ease of broad application development
  - New forms of information
  - Integration into enterprise processes and actions
  - Extracting value from vast, novel sources of information

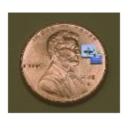
A System Challenge

Monitoring & Managing Spaces and Things









Miniature, low-power connections to the physical world