Standards-Based Wireless Sensor Networking Protocols for Spaceflight Applications

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Overview

- **Standards-based wireless sensor network (WSN) protocols show promise for spaceflight applications**
  - much previous R&D for reliable wireless sensor data transport can be leveraged
  - standards-based WSN protocols already being used for mission-critical industrial process control in difficult RF environments
- **Three main standards of interest derived from IEEE 802.15.4:**
  - ZigBee (first to market but limited uptake in industrial control)
  - WirelessHART (more robust, recently come on to market)
  - ISA100.11a (next-generation, combines benefits of WirelessHART and ZigBee)
- **NASA-JSC evaluation of protocols:**
  - common hardware platform needed to meaningfully compare protocols
  - R&D sensor node designed modularly to allow different standards-based radio modules and application-specific sensor packages to interface through common microcontroller motherboard

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Benefits of Wireless Sensor Networks (WSNs)

- **Freeing sensors from wires offers many advantages:**
  - removing wires/connectors reduces launch weight
  - sensors can be added, relocated without expensive re-design and during missions
  - sensor nodes can be re-cycled from spent vehicles (e.g., Altair lander) to in-service vehicles (e.g., lunar habitat, LER)
  - sensors can be placed where running wires prohibitive
- **Potential applications:**
  - MMOD, leak location systems
  - structural monitoring (e.g., stress/strain)
  - radiation, gas, fire, airborne contaminant (e.g., lunar dust) detection
  - temperature, light, etc. monitoring/control
  - flexible prototyping of next-gen EVA suit sensor systems
- **Potential problems:**
  - nodes must be very low power for years-long service lifetimes
  - reliable RF comm. difficult with low-power radios (channel access, multi-path reflections, other RF sources)

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Benefits of Standards-based WSNs

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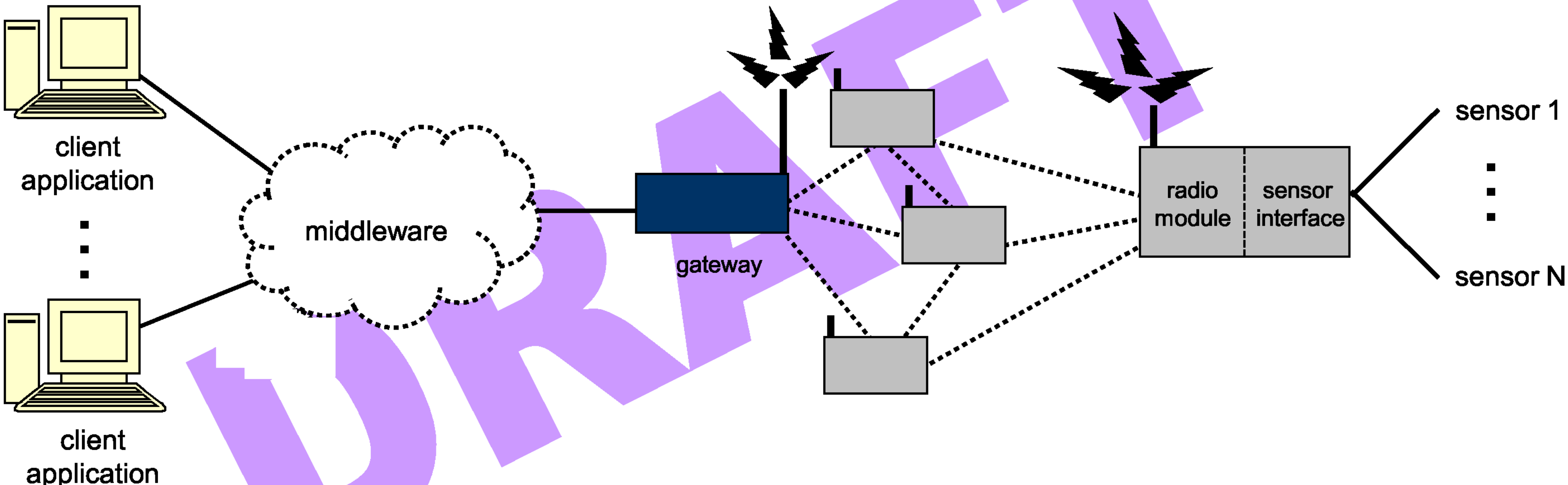
A standardized wireless sensor system offers significant benefits:

- Increased reliability through mesh network transport – many possible paths for data to reach control systems
- Scalability/Expandability – mesh network routing automatically discovers new sensor nodes
- Reusability – many sensors/sensor applications can use the same network to route data to command systems: applications *co-operate* rather than *compete*
- Vendor selection – designing to open standard allows sourcing from multiple vendors, prevents vendor lock-in

General WSN Model



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Standards Overview: IEEE 802.15.4

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- **802.15.4 (2003) specifies the following:**
  - Physical (PHY) layer – typically direct-sequence spread spectrum in 900 MHz or 2.4 GHz
  - Medium Access Control (MAC) layer – contention-based carrier sense medium access with collision avoidance (CSMA-CA)
- **Subsequent standards required to define network (NWK) and application (APP) layers**

Standards Overview: ZigBee

- **Developed by ZigBee Alliance; first major 802.15.4-based, low-power, low-datarate standard**
  - Uses both 802.15.4 PHY and MAC layers
  - Supports star, tree, and mesh topologies at network layer
  - Simple ZigBee End Devices run applications: can frequently sleep.
  - ZigBee Routers run apps, route traffic: can sleep rarely or never (depends on MAC settings)
  - Industrial adoption has been slow, partly due to criticism of end-to-end reliability of MAC (carrier sense multiple access with collision avoidance: CSMA-CA)
  - ZigBee PRO stack in ZigBee-2007 release attempts to provide greater reliability, though MAC still CSMA-CA (with some frequency agility)

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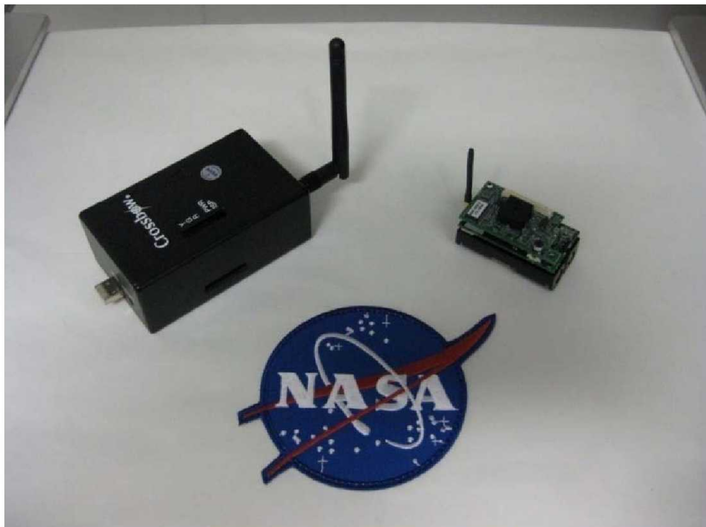
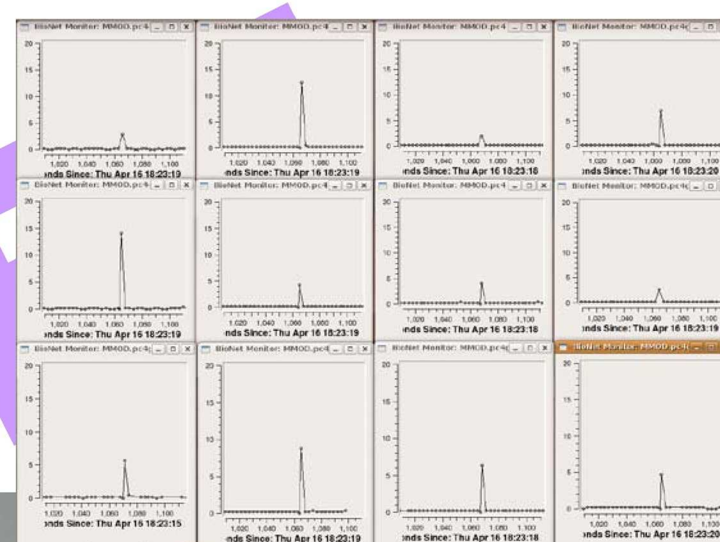
Experimental Setup: ZigBee





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Standards Overview: WirelessHART

- **Developed by HART Communication Foundation for harsh industrial environments**
  - Uses 802.15.4 PHY
  - Uses time-division multiple access (TDMA) as alternative to 802.15.4 MAC
  - MAC based on network-wide clock synchronization:
    - allows aggressive duty-cycling of all nodes
    - allows application timestamping/synchronization
  - MAC diversity through channel hopping (frequency) and multiple next-hop route choices (spatial)
  - Blacklisting of bad channels supported
  - NWK topology is full mesh with all nodes acting as routers
  - Focused on reliable transport: normally > 99.9999998% reliable delivery
  - Ratified in 2007, compliant products shipped in 2008

Experimental Setup: WirelessHART

Standards Overview: ISA100.11a

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- **Currently in development by International Society of Automation (ISA) - based results of U.S. Department of Energy study**
  - Extends WirelessHART capabilities to provide single wireless backhaul for multiple processing monitoring/control applications
  - Uses 802.15.4 PHY
  - Uses either TDMA or CSMA-CA MAC based on quality of service requested by application
  - Working with WirelessHART; targeting inter-operability of standards (dual-boot option)
  - Likely ratified 2009; draft standard compliant parts in development

NASA-JSC Work on WSN Standards

Investigating feasibility of IEEE 802.15.4 wireless infrastructure for multiple applications (leak location, MMOD impact detection, env. monitoring, etc.):

– Work to date highlights some problems with 802.15.4/ZigBee MAC (Crossbow)
  - can be susceptible to RF interference

– Currently developing flexible COTS testbed for evaluating WirelessHART/ISA100.11a :
  - WSN protocol stack, transceiver in radio module
  - Separate microcontroller in sensor interface board handles sensing/processing; sends/receives packets to/from modem as needed
  - Additional hardware (A/D for faster sampling, DSP for more processing) added to sensor board as needed

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NASA-JSC Sensor Node Architecture

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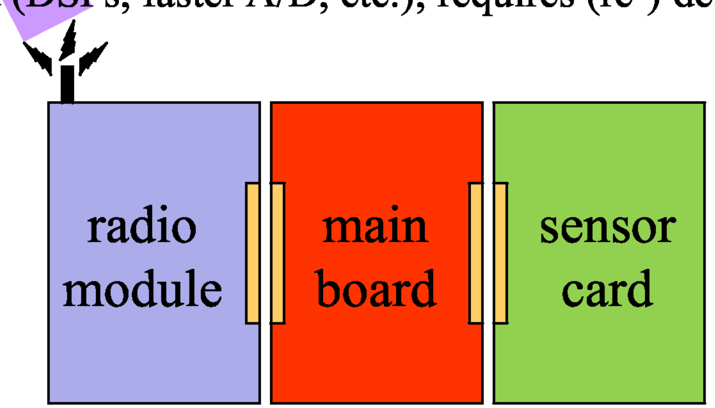
Sensor nodes composed of three basic components…

- **main board:**
  – contains application processor (TI MSP430 microcontroller), memory, power supply; responsible for sensor data acquisition, pre-processing, and task scheduling; re-used in every application with growing library of embedded C code
- **radio module:**
  – COTS radio module implementing standardized WSN protocol (e.g, WirelessHART, ISA100.11a); treated as WSN "modem" by main board
- **sensor card:**
  – contains application-specific sensors, data conditioning hardware, and any advanced hardware not built into main board (DSPs, faster A/D, etc.); requires (re-) development for each application



WSN Standards Forward Work

JSC lunar habitat mockup provides representative environment for WSN testing. Issues to investigate include:

- RF issues
  - Data delivery reliability – resistance to multi-path, interference, noise
  - Data throughput rate
  - Interoperability – assess impacts on 2.4 GHz 802.11 WLAN
- Power issues
  - Radio/networking component
    - Low power, full mesh networking
  - Sensing/processing component
    - Scheduled sensing
    - Event-driven sensing
- Application issues
  - Feasibility of sensing transient events
  - Usefulness of MAC-derived application time synchronizatoin
- Protocol issues:
  - extending past WirelessHART/ISA100.11a to future protocols (e.g., next-gen, more robust ZigBee release)

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Conclusions

- Emerging WSN standards show significant promise for spaceflight applications
- Work remains to compare standards and validate performance in relevant environments:
  - interoperability with other wireless device must be demonstrated
  - extended lifetimes with battery operation must be shown
- Modular hardware platform is necessary for WSN R&D:
  - use different networking stack modules with same application processor/sensors for meaningful protocol comparisons
  - allow new sensor suites to be paired with common application processor, networking stack for applications research

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