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
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)
Benefits of Standards-based WSNs

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
Standards Overview: IEEE 802.15.4

• **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-data-rate 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)
Experimental Setup: ZigBee
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

- 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
NASA-JSC Sensor Node Architecture

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 synchronization

- Protocol issues:
  - extending past WirelessHART/ISA100.11a to future protocols (e.g., next-gen, more robust ZigBee release)
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