NASA-JSC Wireless Sensor Network Activities Update

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April 16, 2012
Agenda

• Update on ZigBee Pro, ISA100.11a co-existence studies

• Update on JSC Modular Wireless Instrumentation (“SSIART-NASA”)

• Update on JSC High-Speed Wireless Instrumentation Needs
Update on ZigBee Pro, ISA100.11a
Co-Existence Studies
802.15.4, 802.11 Co-existence

802.11b/g/n
ch .1

802.11 b/g/n
ch .6

802.11 b/g/n
ch .11

802.15.4
ch .11

802.15.4
ch .17

802.15.4
ch .26
Two representative interference patterns:

- Wi-Fi ch. 6 interferes with ZigBee ch. 17 near its center frequency
- Wi-Fi ch. 4 interferes with ZigBee ch. 17 in its sideband
ISA100, 802.11 Coexistence Investigated

• One representative interference pattern:

–Wi-Fi ch. 6 interferes with ISA100.11a ch. 17/18 near its center frequency, ch. 16/19 in its sideband
ZigBee, ISA100 Performance Evaluation Methodology

• Primarily concerned with performance under RF interference conditions:
  – measure message delivery rate (related to goodput)
  – configure 5 nodes in star topology (primarily tests MACs)

• IEEE 802.11g router used as interference source:
  – traffic generated between laptop (wireless to router) and workstation (wired to router) using Iperf
  – flows considered: 0 Mbps, 5 Mbps, 10 Mbps, 20 Mbps
  – also considered maximum single-flow (~ 30 Mbps)

• Maximum-length packets sent using each protocol at several periodicities:
  – Packet lengths: 76B
  – Packet periodicities: 1 s/packet, 5 s/packet, 10 s/packet
  – Experiment duration: 1 hour
  – Averaged over 3 trials
  – ~ +3 dBm output power selected for both WSN platforms
ZigBee, ISA100 Performance Evaluation Hardware

• JSC WSN node (ISA100.11a):
  – Nivis VN210 radio, TI MSP430-F5438 microcontroller

• TI MSP430 Experimenters Board (ZigBee Pro):
  – TI CC2530 radio (ZigBee Pro stack), TI MSP430-F5438 microcontroller
  – looks identical to custom ZigBee JSC node from application code point of view
  – low-cost stand-in for custom hardware
Testbed Environment

JSC wireless habitat test bed:

- Provides representative, crewed environment for controlled studies
- Good isolation from external RF environment, high level of internal multipath
- Allows interferers to be selectively introduced
Test Hardware Layout

legend:
• GW – WSN gateway
• N1-N5 – WSN nodes
• WFR – Wi-Fi router
• WFC – Wi-Fi client
ZigBee – Direct Interference

![Graph showing delivery rate (%) vs. Wi-Fi Interference (Mbps) for different packet transmission rates (10 s/packet, 5 s/packet, 1 s/packet).]
ZigBee – Sideband Interference

![Bar chart showing delivery rate (%) against Wi-Fi Interference (Mbps) for different packet rates.](chart.png)
ZigBee – Direct Interference
(outliers removed)

![Graph showing delivery rate (%) vs. Wi-Fi Interference (Mbps) for 10 s/packet, 5 s/packet, and 1 s/packet.]
ZigBee – Sideband Interference
(outliers removed)
Comparison Summary

<table>
<thead>
<tr>
<th></th>
<th>Cost</th>
<th>Network Setup</th>
<th>Throughput</th>
<th>Latency</th>
<th>Interference Tolerance</th>
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<td>centralized optimization</td>
<td>lower</td>
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ZigBee – Direct Interference
(-3 dBm)

![Bar chart showing delivery rate (%) vs. Wi-Fi interference (Mbps) with various packet intervals.
- Gray bars represent 10 s/packet.
- Black bars represent 5 s/packet.
- Dark gray bars represent 1 s/packet.

The chart illustrates the decrease in delivery rate as Wi-Fi interference increases, with different packet intervals showing varying levels of interference impact.]
ZigBee – Sideband Interference
(-3 dBm)

![Graph showing delivery rate (%) vs. Wi-Fi Interference (Mbps) with three different packet intervals: 10 s/packet, 5 s/packet, and 1 s/packet. The graph compares the delivery rate under varying levels of Wi-Fi interference.]
Conclusions

• Completed first head-to-head comparison of ZigBee Pro, ISA100.11a presented in the literature

• Found that both ZigBee and ISA100.11a have their places
  – ZigBee: inexpensive, fast network formation, better throughput, good at lower interference levels
  – ISA100.11a: better latency guarantees, more robust at higher interference levels

• Uncovered occasional ZigBee Pro node disconnections
  – sometimes intermittent, sometimes permanent
    – ~1% of time at +3 dBm output power
    – ~15% of time at -3 dBm output power
  – correlated most strongly with high interference, but happened on occasion at lower interference levels
Forward Work

• Further characterize ISA100.11a performance:
  – performance with two or more 802.11 interferers?
  – maximum achievable throughput in closed environment?

• Further characterize ZigBee Pro performance:
  – maximum achievable throughput in closed environment?
  – what causes orphaning?

• Compare ZigBee multi-hop routing approach (AODV) with ISA100 (graph)

• Explore effects of 802.11n interference
Update on JSC Modular Wireless Instrumentation ("SSIART-NASA")
JSC Modular Instrumentation (MI) Architecture

- **Power Module**
  - battery
  - energy harvesting (e.g., solar, vibration)
  - mains (wired)

- **Communication Module**
  - handles data transport to C&DH system
  - forms common network with other nodes
  - can be wired or wireless

- **Controller Module**
  - manages data acquisition
  - processes sensed data as needed
  - formats data for transport to C&DH

- **Sensor Interface Module**
  - provides application-specific sensors, sensor conditioning
  - only custom-designed component
JSC MI Components

ZigBee Pro radio
(TI CC2530 ZNP)

ISA100.11a radio
(Nivis VN210)

processor
(TI MSP430-F5438,
MSP430F5438a)

power
(9V wall, AA battery x2)

photos by Mary Lynne Barends, NASA-JSC
Modular Instrumentation Stack

side view
(with sensor package)

scale view
(with sensor package)

photos by Mary Lynne Barends, NASA-JSC
Interface Specification:

• board dimension user-defined
• mounting hole locations pre-defined
• data connector location, pin assignments defined
• power connector location, pin assignments defined
• I/O connector types, locations user-defined
Modular Instrumentation Mechanical Interface

Board Clearance:

• Power, Data bus connector dimensions define board clearances
• Mounting hole locations pre-defined
• Data connector location, pin assignments defined
• Power connector location, pin assignments defined
• I/O connector types, locations user-defined

Expected Total Height = 1.982 in
Oversized Components:

- L-shaped adaptor can provide greater inter-board clearance
Oversized Components:

- Extending boards past nominal footprint can provide unconstrained vertical component space

Expected Total Height = 1.982 in
Update on JSC High-Speed Wireless Instrumentation Needs
Deep Space Habitat (DHS) Project

- **Project description**
  - Define and mature a DHS element that will enable human exploration beyond earth orbit (BEO)
  - Focus and Infuse habitat-related exploration technologies
  - Transition habitat-related products into the Habitat Demonstration Unit (HDU) prototype for integrated systems and mission testing

- **Current wireless capability**
  - ISA100.11a low-power, low data-rate WSN
    - Currently used for environmental monitoring and control
    - Primarily temperature and pressure data
  - EPCGlobal, Gen 1, Class 2 RFID
    - Inventory, tool, and sample tracking

- **Projected high data-rate wireless applications**
  - High frequency phenomena
    - Impact/leak detection and localization
    - Vibration/load monitoring during launch and docking
    - Structural health monitoring (shape and vibration)
    - Power transient monitoring
    - Non-destructive evaluation (NDE)
  - Real-time audio and HD video streams
  - Medical monitoring (very high priority)
    - Real-time telemedicine
    - Mobile crewmember monitoring
  - Increased security requirements to ensure privacy and data integrity
Project Morpheus

• **Project description**
  – Morpheus is a vertical test bed vehicle demonstrating new green propellant propulsion systems and autonomous landing and hazard detection technology

• **Current wireless capability**
  – 900 MHz, low data-rate command and telemetry ground link
  – 2 redundant UHF links for abort commanding

• **Projected high data-rate wireless applications**
  – Monitor high frequency phenomena on-board
    • Vibration/load monitoring during flight
    • Power transient monitoring in control systems
  – Real-time HD video streams
  – Stream full-bandwidth telemetry during flight
    • Enables real-time transient and diagnostic monitoring
    • Archive data to prevent total loss of data on vehicle malfunction
  – Wireless sensors for Autonomous Landing and Hazard Avoidance Technology (ALHAT)
Backup
## ZigBee – Direct Interference

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<th>Interference Bandwidth:</th>
<th>Seconds Between packets</th>
<th>Test 1:</th>
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<th>Test 3:</th>
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802.15.4, 802.11b/g/n Co-existence

802.11n (40 Mhz)
ch .6

802.11b/g/n
ch .1

802.11 b/g/n
ch .6

802.11 b/g/n
ch .11

802.15.4
ch .11

802.15.4
ch .17

802.15.4
ch .26

2.405 2.410 2.415 2.420 2.425 2.430 2.435 2.440 2.445 2.450 2.455 2.460 2.465 2.470 2.475 2.480
WSNs in the Wild

ISA100.11a node
Modular Instrumentation Stack

4 board stack
(incl. sensors)

3 board stack