Techniques for Improving Reliability of Wireless Sensor Networks in Flight Applications

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Agenda

• Company Background
• Introduction
• Methods for Improving Reliability
  – Hardware Methods
  – System Design Methods
  – Communication / Networking Methods
• Conclusion
Invocon, Inc. Background

• Founded in 1986
• Located in Conroe, Texas
• Veteran-owned Small Business
• Applications:
  – Aircraft / Spacecraft Test and Evaluation
  – Missile-Defense
  – Civil Structural Monitoring
  – Industrial Monitoring
  – Automotive Testing
• Flight Opportunities:
  – 22 Shuttle flights, including 14 unique systems
  – 4 systems aboard the International Space Station
  – 3 Flights - Navy Target Missiles
Flight Systems

- Self Contained
- Reduced Weight
- Low Integration Costs
- Short Turnaround Time
- Potential Uses:
  - Development Flight Instrumentation
  - Retrofit Flight Instrumentation
  - Integrated Vehicle Health Monitoring
  - Payload/Cargo Instrumentation & Control
  - Backup Control Systems
  - Vehicle Ground Inspections
A Goal for Wireless Sensors and Controls

• To maximize the probability that the overall system will meet the given requirements within cost and size/mass constraints – *System Dependability*
  
  – Reliability
    • Probability that a component will not fail during some period
  
  – Availability
    • Probability of failure plus recovery time
  
  – Redundancy
Understanding System Requirements

• Understanding of system requirements is the most important factor in improving system dependability
  – Optimum methods for meeting requirements often radically different for distributed wireless system versus a centralized wired system
  – Considerations:
    • What data is needed?
    • Who needs the data?
    • When do they need it?
    • What relationship does this data have with other parameters?
    • What are the acceptable performance degradation scenarios?
Methods for Improved System Dependability

• Hardware Methods
  – Watchdogs and Monitors / System Health Monitoring
  – Redundant Hardware within Node
  – Reducing Power
  – Easing the Environmental Extremes

• System Design Methods
  – Redundant Components / Cross Strapping
  – Reducing Communication Requirements
  – Reducing Real-time Requirements

• Networking / Communication Methods
  – Monitoring of Communication Link Parameters
  – Autonomously Configurable Communication Settings
  – Routing and Autonomous Network Configuration
System Example –
Wing Leading Edge Impact Detection System
Watchdogs and Monitors / System Health Monitoring

- Secondary microcontroller used for variety of watchdog functions
  - Current monitoring for radiation-induced latchup
    - Automatically cycles system power
  - “Jabber Control”
    - Resets system if unit transmits via RF or RS-485 inappropriately
    - *Unique to Wireless: A stuck-on transmitter can potentially bring down an entire system*
- System health monitoring information gathered and returned
  - Unit temperature
  - Battery voltage
  - Remaining battery life
- Analysis of acquired data can help to determine node health
  - Off scale
  - Noise level (either too high or too low)
  - Many others
- *Unique to Wireless: Once a remote node fails to communicate, it is impossible to determine the cause without accessing the unit*
  - Health information needs to be gathered continuously and tracked
Redundant Hardware within Node

• Including redundant circuit elements within a particular node can be done
  – For example, multiple signal conditioning channels or radio transceivers that can be switched in upon failure of a particular string
• Relatively large additive cost in terms of complexity, size, and per unit cost
  – Options at the die level are often efficient
• Can make system multi-fault tolerant
• Thus far, we have found it more efficient to employ redundancy at the node level
Reducing Power

- Dead batteries are a major cause of node failure and take considerable time to replace

  “Astronauts have better things to do that replace 200 batteries a month”

- Even for powered systems, the complexity and cost of power electronics can be minimized through low-power design techniques
Easing the Environmental Extremes

• Tradeoffs between mounting locations must be made
  – Environments for components
  – Installation costs
  – Impacts to vehicle

• Often short cables to sensor locations limit temperature and vibration
  – Also minimizes loading
Redundant Components
- **Unique to Wireless** – Wireless Systems provide unique opportunities for cross strapping systems with minimal effort
  - Every node can communicate with every other node
Costs of Redundancy

- Installation and integration time and cost
- System costs
- Mass and volume penalties
Reducing Communication Requirements

- During ascent, the entire system acquires 3.2Gbytes of data
  - Unreasonable to transmit all data via RF
- Data reduction algorithms are often required to minimize the quantity of data that must be transmitted.
  - However, care must be taken to not diminish the amount or quality of information contained in the returned data.
  - **Peak G’s**
    The system is able to generate a summary list of the highest raw acceleration values and the associated timestamps to be downlinked.
  - **Root Mean Square (RMS) Peaks**
    Sliding window RMS calculation on the raw data
  - **Relative RMS Peaks**
    Removes the background noise-floor level from the RMS calculation above.
    - SRB ignition, etc., can be removed
    - All data is maintained in memory at the node until post-flight
  - **It can be very difficult to convince engineers that remote data reduction is acceptable**
Reducing Communication Requirements

Raw Flight Data Set (Prior to Adding Impact Signals).

RMS Peaks Algorithm Results with Impact Signatures Added

Relative RMS Peaks Algorithm Results with Impact Signatures Added
Reducing Real-time Requirements

• Maximum latency requirement for data reception is a critical specification
  – Particular monitoring and control applications require low and deterministic latencies
    • Stricter requirements for RF data link
      – Many applications can handle days or months
  • Minimum level of synchronization between multiple nodes also critical
    – For distributed systems, often only the timing information needs to be transferred during acquisition
      • Data can be stored locally along with synchronization information
Reducing Real-time Requirements

• NASA Dryden Wireless Flight Control System
  - PURPOSE: Define and demonstrate a prototype wireless control system that can be tested and flown on the F-18 NASA test aircraft.
Reducing Real-time Requirements

- Shuttle Rollout Accelerometer System
  - Synchronized between multiple wireless sensors to within ±4μs.
  - Flexible dual basestation design with relaying synchronization and IRIG timing
Monitoring of Communication Link Parameters

• Returning, tracking, and storing RF link parameters is highly desirable
  – Error rates
  – Received Signal Strength
  – Link Quality
• Valuable for links in both directions
Autonomously Configurable Communication Settings

- Configurable settings available in newest low-power RF transceivers
  - Output Power
  - Frequency
  - Modulation
  - Data Rates
- Optimization of performance in varying environments is possible
  - Multipath fading
  - Mobile nodes
  - Variable sources of interference
- Fall back to reduced performance levels during intermittent periods of interference, etc.
- Considerable network coordination necessary for all settings changes (except maybe output power)
Routing and Autonomous Network Configuration

- Routing via multi-hop communication improves reliability
- However, compromises are made in:
  - Power consumption
  - System response time
  - Throughput
  - Software complexity
  - Non-deterministic behavior
Conclusion

• Understanding overall system requirements in the various areas described is the key to optimizing System Dependability for Wireless Instrumentation Applications

• Based on the system requirements, many methods and techniques for system optimization are possible:
  – Hardware Methods
  – System Design Methods
  – Communication / Networking Methods
Questions?

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