Net-centric System Modeling

Amitabha Ghosh
Luis Pereira
Sujit Das

Eaton Corporation
Innovation Center
Milwaukee, WI
Agenda

- Wireless Sensor Network
- Wireless Sensornet Design Challenges
- Requirements for Sensornet Systems
- Modeling the Sensornet with AADL
- Proposed AADL extensions for Wireless Sensornets
Wireless Sensor Network

- Resource constrained (battery, memory), tiny, embedded devices
- Unreliable communication infrastructure (Wireless, IR, Optical…)
- Autonomous ad hoc networks
- Distributed processing

Application Domains:
- Industrial plants monitoring & control
- Smart Homes (Home Heartbeat)
- Structural health monitoring (SHM)
- Healthcare, Wildlife habitat monitoring etc…
Industry Standards

- Zigbee Alliance – www.zigbee.org
- IEEE 802.15.4 - http://www.ieee802.org/15/
- Wireless Industrial Network Alliance – www.wina.org
- ISA Wireless Systems for Automation Standards – SP-100
Wireless Sensor Network Challenges

**Wireless**
- Unreliable wireless (RF) links
  - Noisy
  - Asymmetric
  - Interference, Multipath, Shadowing

**Network**
- Lack of a-priori topological info.
- Routing
- Medium Access Control (MAC)

**Sensor**
- Resource constrained (memory, battery, CPU)
- Large scale deployment (100s to 1000s)
- Heterogeneous nodes
- Lack of a-priori topographical knowledge
Mobius Integration For Dependability Analysis

Möbius
An Extensible Modeling Tool for Quantifying Reliability, Availability, Security, and Performance

Tod Courtney, William H. Sanders
University of Illinois
www.mobius.uiuc.edu
tod@crhc.uiuc.edu, whs@uiuc.edu

Möbius Overview

• Discrete event system modeling and analysis tool used to model the behavior of complex systems

• Traditionally used for dependability and performance analysis of computer, communication, and network systems
  – Metrics: reliability, availability, safety, time to failure, throughput…
  – Design trade-off and model parameter sensitivity studies

• Current usage has broadened to include:
  – Security validation

Model Representation

• Multiple modeling languages available:
  – Stochastic Activity Networks (‘SANs’, advanced stochastic Petri nets)
    PEPA (textual-based process algebra), Markov chains, Fault trees
  – Parameters of the model can be specified variables and set at analysis time.

• Facilitate modeling of hardware, software, protocols, and application in a unified manner
Specific Requirements for Network Centric Applications (Sensornets)

- **Latency**
  - Average end-to-end pkt delay while traversing from a node to the sink
    - Network size, Buffer size, Processing & Queuing delay, Comm. Channel

- **Network Lifetime**
  - Average time until the network is operational within performance limits
    - Frequency of sensing, processing
    - Battery
    - Efficiency of Routing and MAC protocols

- **Throughput**
  - Average # pkts reaching the sink per unit time
    - Bottleneck, hotspots
Specific Requirements for Network Centric Applications (*Sensornets*)

- **Reliability & Robustness** (*3 dimensions*): Consistently perform a given task to the desired result despite all changes to environmental behavior without fail.

  - Hardware (sensing nodes)
    - Calibration, Failure rates, Probability distribution

  - Software (protocols)
    - Error detection, removal

  - Communication Infrastructure (wireless RF links)
    - Asymmetric links
    - Transitional region
    - Multi-path, shadowing, interference, noise
Reliability in Sensornets

- **Latency Analysis:**
  - End-to-end latency: depends on # of hops, bandwidth, processing delay, buffer size

- **Network Lifetime Analysis:**
  - Average energy consumption per unit time (or per flow)
  - Average residual battery energy per node
  - Identification of battery depleted nodes (maybe to replenish or replace)

- **Robustness Analysis:**
  - Average # of lost packets: depends on buffer size, measurement frequency, BW
  - Average # of faulty measurements: due to depleted battery energy, noise, dead nodes
  - Average good put: ratio of # of packets received at sink to # of packets sent by all sensors
  - Identification of faulty nodes, deadlocks
  - Identification of bottlenecks, hotspots
**Sensornet Components: High Level View**

- **Sensor nodes**
  - Sensing unit
  - Processing unit
  - Transceiver unit
  - Power unit

- **Transmission media**
  - Communication infrastructure (wireless, optical, IR, aqueous)

- **Software Agents**
  - Efficient, energy-aware routing protocols
  - Resource-aware MAC protocols
  - Transport, Physical, and Application layer protocols (e.g. data aggregation, target classification)
AADL Components & Sensor Internal View

- **Software category**
  - Process
  - Subprogram
  - Data
  - Thread
  - Thread group

- **Platform category**
  - Processor
  - Memory
  - Device
  - Bus

- **Composite**
  - System

**Mapping**
- Layers: **Threads**
- Wireless Channel: **Bus**
- Sensor Channel: **Bus**
- Processing Unit: **Processor**
- Sensing Unit: **Device**
- Transceiver Unit: **Device**
- Power Unit: **Device**
- Sensor Measurements: **Data**
- Messages Exchanged: **Data, Event Ports**
The AADL Sensor Model

Main application
Transport protocol
Current sensor
Routing protocol
MAC protocol
Physical layer protocol
Processed data
Main application
Current data
Voltage data
Current sensor
Voltage sensor
Radio
Connected to other nodes
Battery
Wireless
Memory
CPU
The AADL Sensor Model: Failures

- Overall system error behavior is composed of individual component’s error behavior

- Some of the errors in a sensornet and their propagation in the system can be modeled by the AADL Error Model Annex
  - Hardware Error
    - (Fixed failure probability or probability distribution using specific hardware lifetime)
    - Sensing devices
    - Radio
    - CPU
  - Software Error
    - Error in the code: Specific software error model and applying them to the software components

- Specific wireless communication failures due to environmental factors cannot be modeled using the Error Model Annex (details in following slides)
Proposed AADL Extensions

- **Replication of sensing nodes: Multiplicity**
  - Typically deployed in few 100s or 1000s, differing maybe only in node ids
    - Multiplicity of nodes
  - One wireless link quality is (possibly) different than another
    - Multiplicity of buses allowing inheritance

- **Modeling the deployment region: Topology Construction & Maintenance**
  - Operations in a sensornet are highly dependent on network topology
  - Communication infrastructure depends on efficient (coverage, connectivity) topology construction
  - Data gathered by nodes are spatio-temporarily correlated (requires sibling or parent-child relationship for routing)

- **Example:**
  - How to specify in AADL model the neighbors of node A?
  - How to specify in AADL model a particular deployment distribution (e.g. uniform, normal)?
  - How to specify topographical information (presence of obstacles, 2D or 3D deployment) and their properties?
Proposed AADL Extensions

- **Modeling the Unreliable Wireless Communication Channel: Extension to the Error Model Annex**
  - *Asymmetric Links:* Asymmetric buses (?)
  - *Transitional Region:* No direct dependence on link quality on distance (mostly due to multi-path effects and obstacles)
    - How to model link quality and apply it to buses?
  - Wireless link failure rates depend on several factors, such as: noise, interference, multi-path, obstacles and shadowing effects. Their combined effect leads to a particular channel model and channel error rate.
    - How to model a given empirical or analytical failure model that does not conform to any well known distribution?

- **Nodes joining or leaving the network or node mobility**
  - Dynamically incorporate in the executable model when
    - Node failures
    - New nodes join
    - Nodes moving around (mobile nodes)
Q/A?

Thanks!