Net-centric System Modeling

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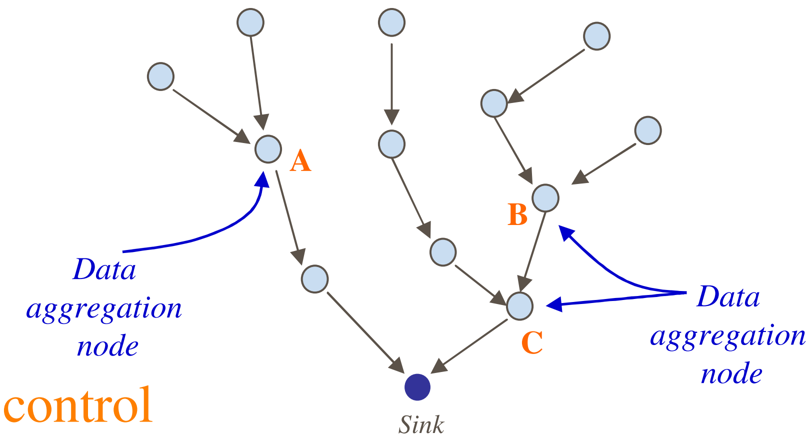
Agenda

- 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…



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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

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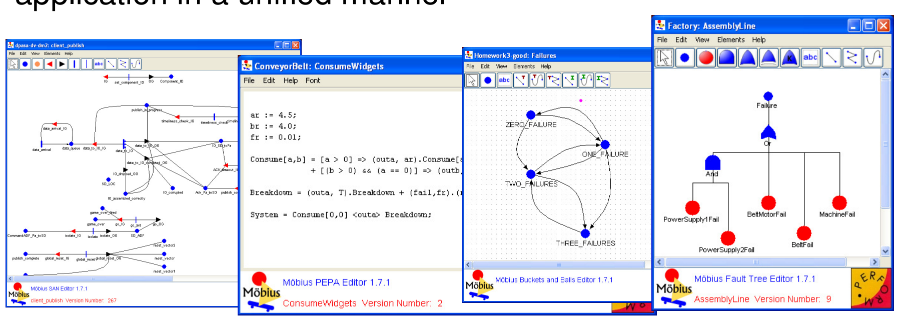
Möbius Overview

- 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
  - …hemical reactions

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



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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

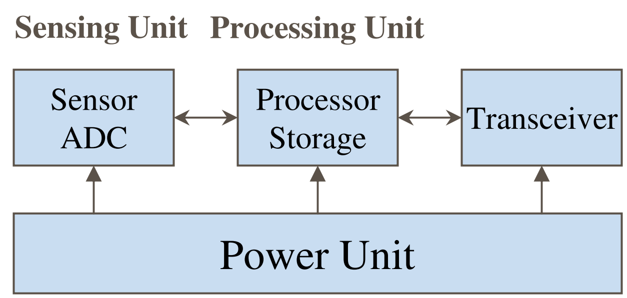
- Latency Analysis:
  - End-to-end latency: depends on # of hops, bandwidth, processing delay, buffer size

- 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

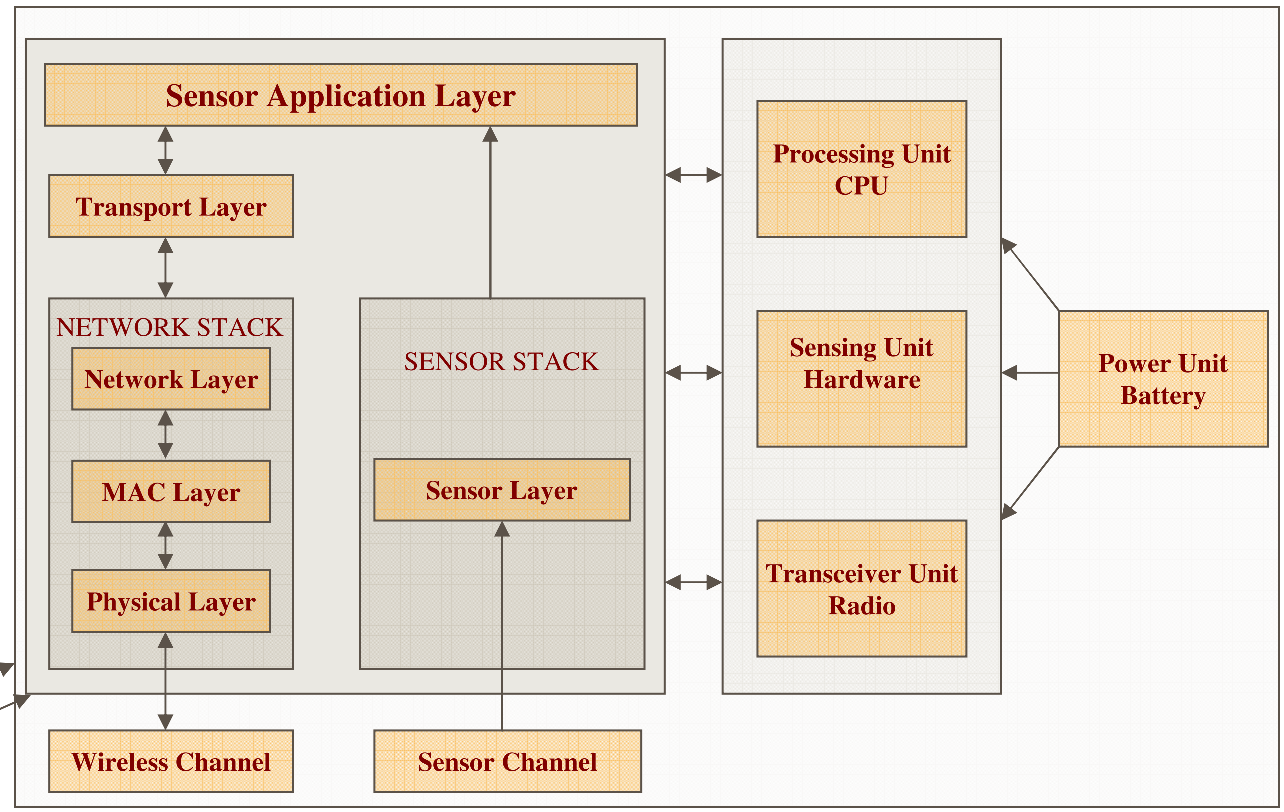


- Transmission media
  - Communication infrastructure (wireless, optical, IR, aqueous)

- 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



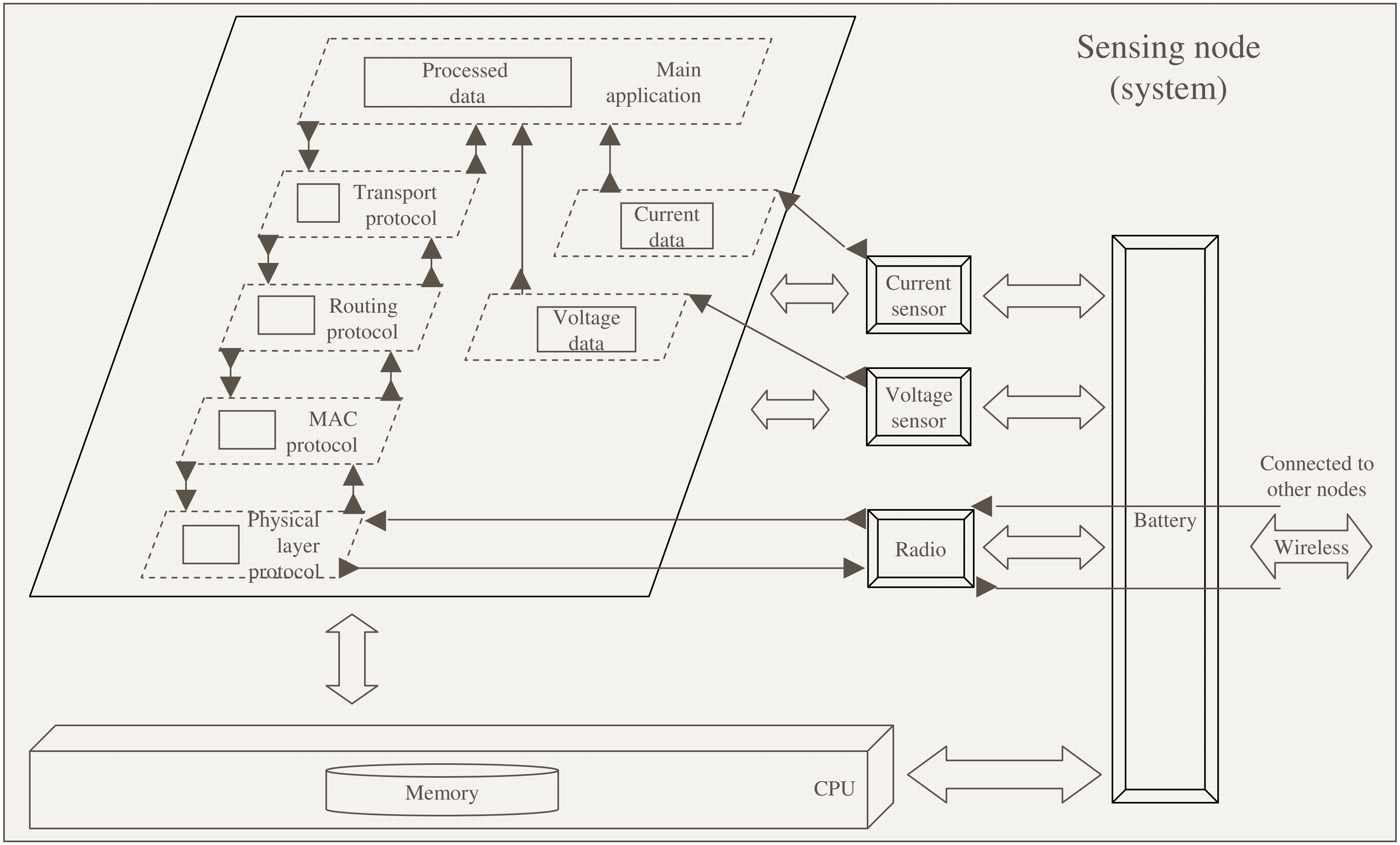
System

Process

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



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

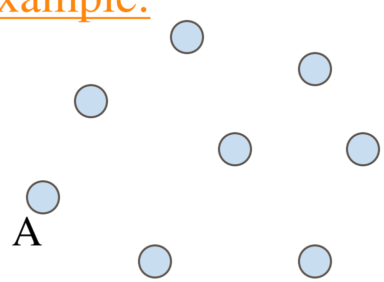
- Specific wireless communication failures due to environmental factors cannot be modeled using the Error Model Annex *(details in following slides)*

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?*

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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!