Data-Driven Dependability Analysis Using AADL for Wireless Sensor Networks

Ting Yan, Hui Cao, Sujit R. Das, and Luis Pereira

Innovation Center, Eaton Corporation

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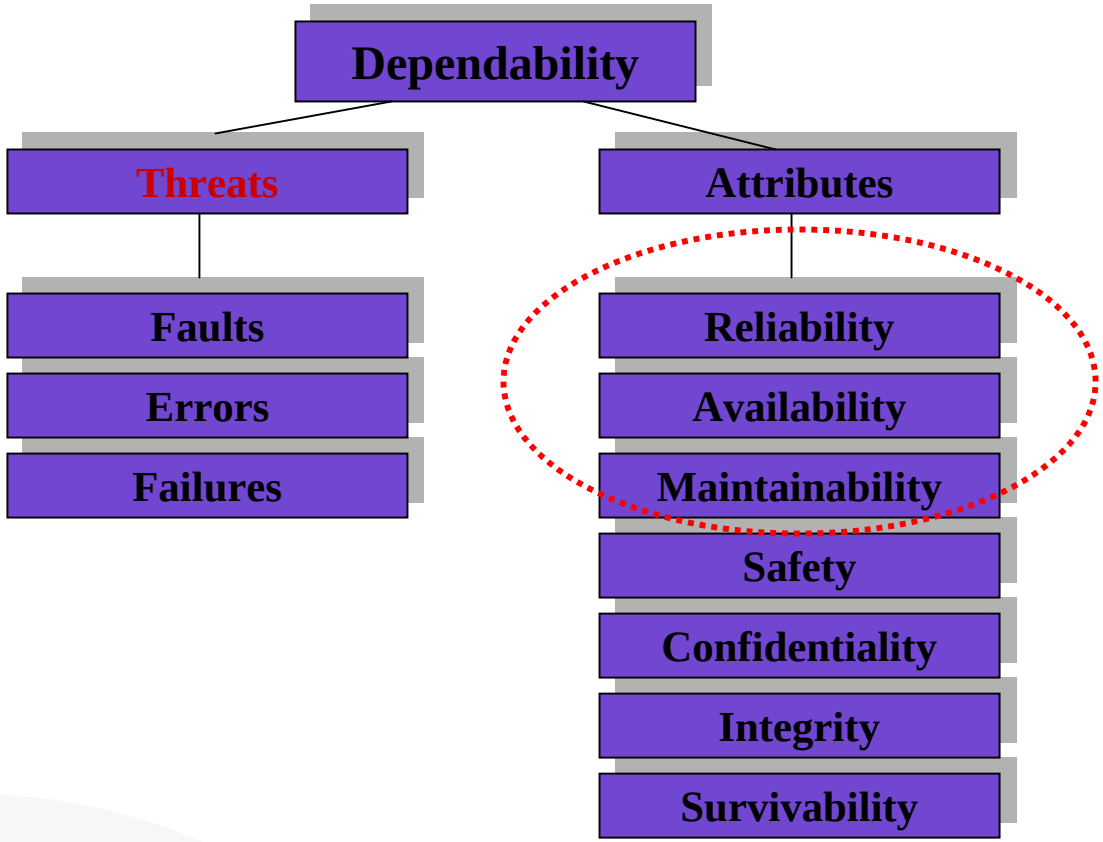
Dependability

Dependability = Ability to deliver a trusted service

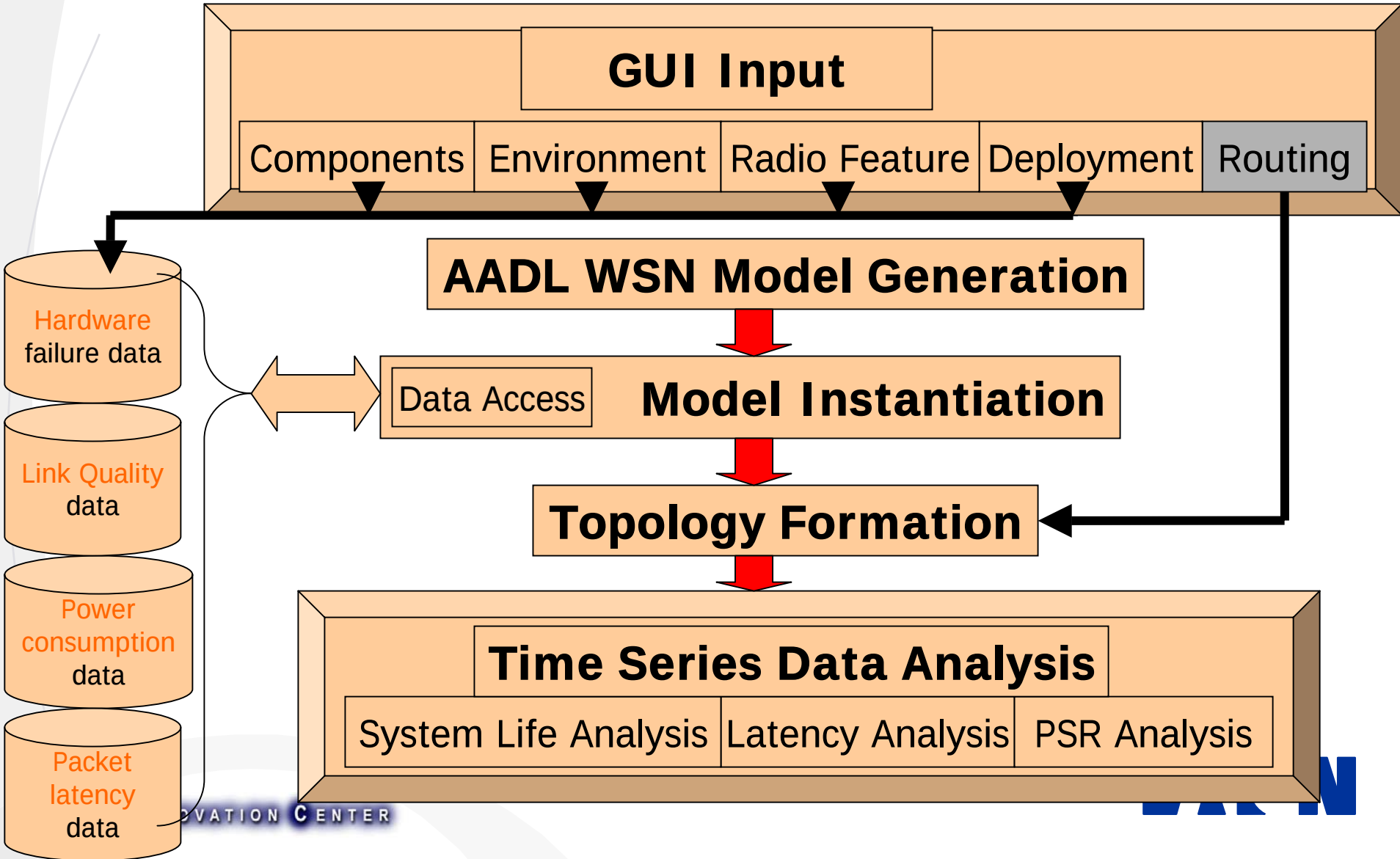


Dependability metrics for WSN

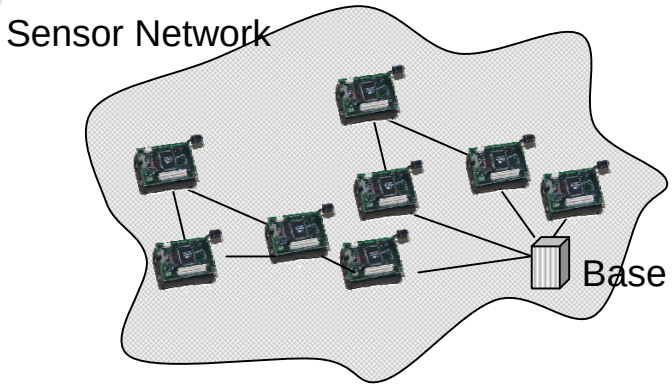
- *Average Packet Success Rate* → *Reliability*
- *Average Latency* → *Availability*
- *Average System Life* → *Availability*, *Maintainability*

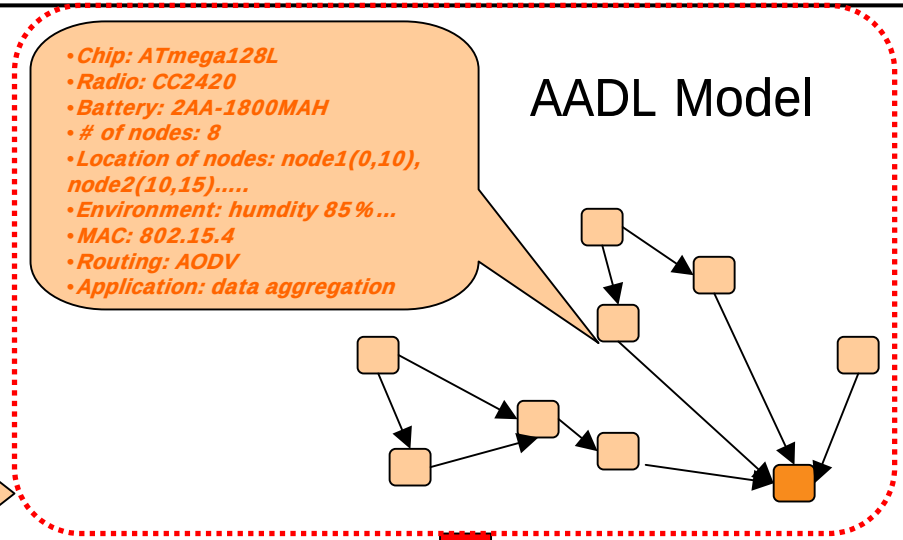
Note:
Those values are averaged across all the nodes and over a period of time

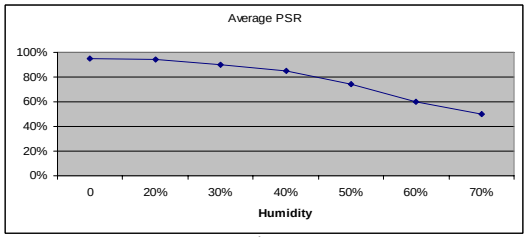
AADL Dependability Analysis Tool Design

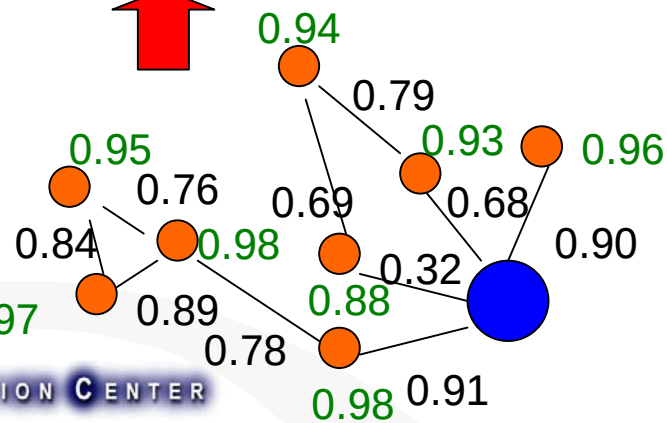


System to model and analyze









Hardware Data

Communication Link Data

R(t) = 0.97

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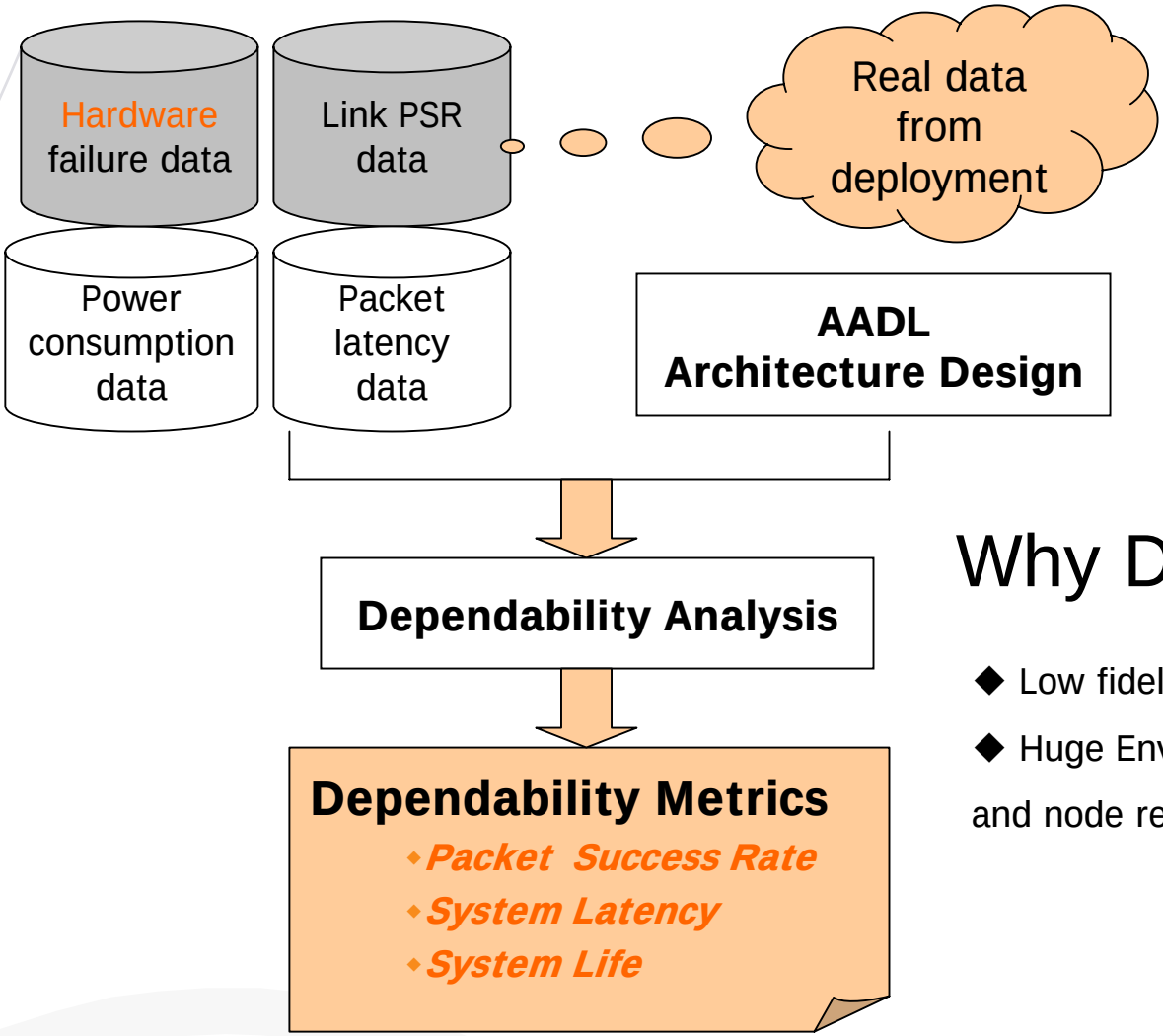
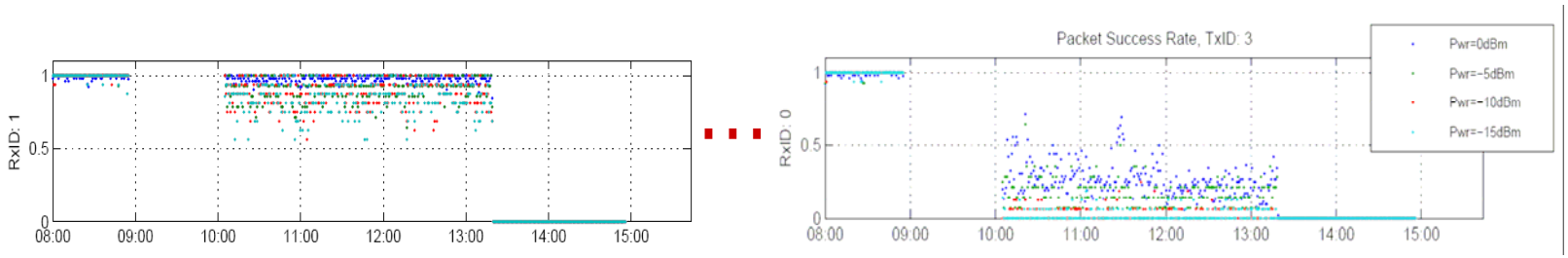
Data driven Dependability Analysis



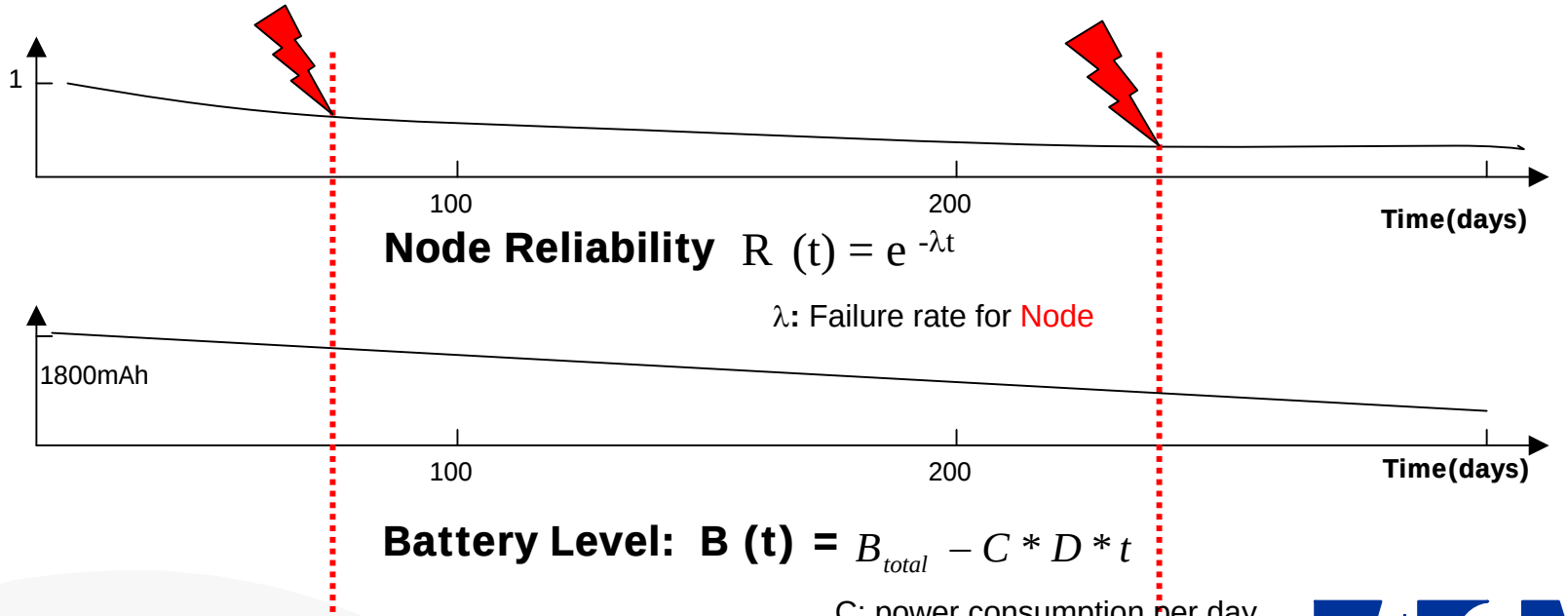
Why Data driven?

- Low fidelity of wireless channel model
- Huge Environment impact on link quality and node reliability

Time Varying Dependability Analysis



Link Quality: retrieved from Link Data



Node Reliability $R(t) = e^{-\lambda t}$

λ: Failure rate for Node

Battery Level: B (t) = $B_{total} - C * D * t$

C: power consumption per day
D: duty cycle

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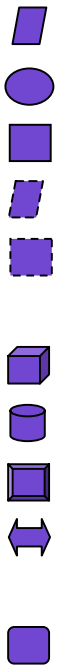
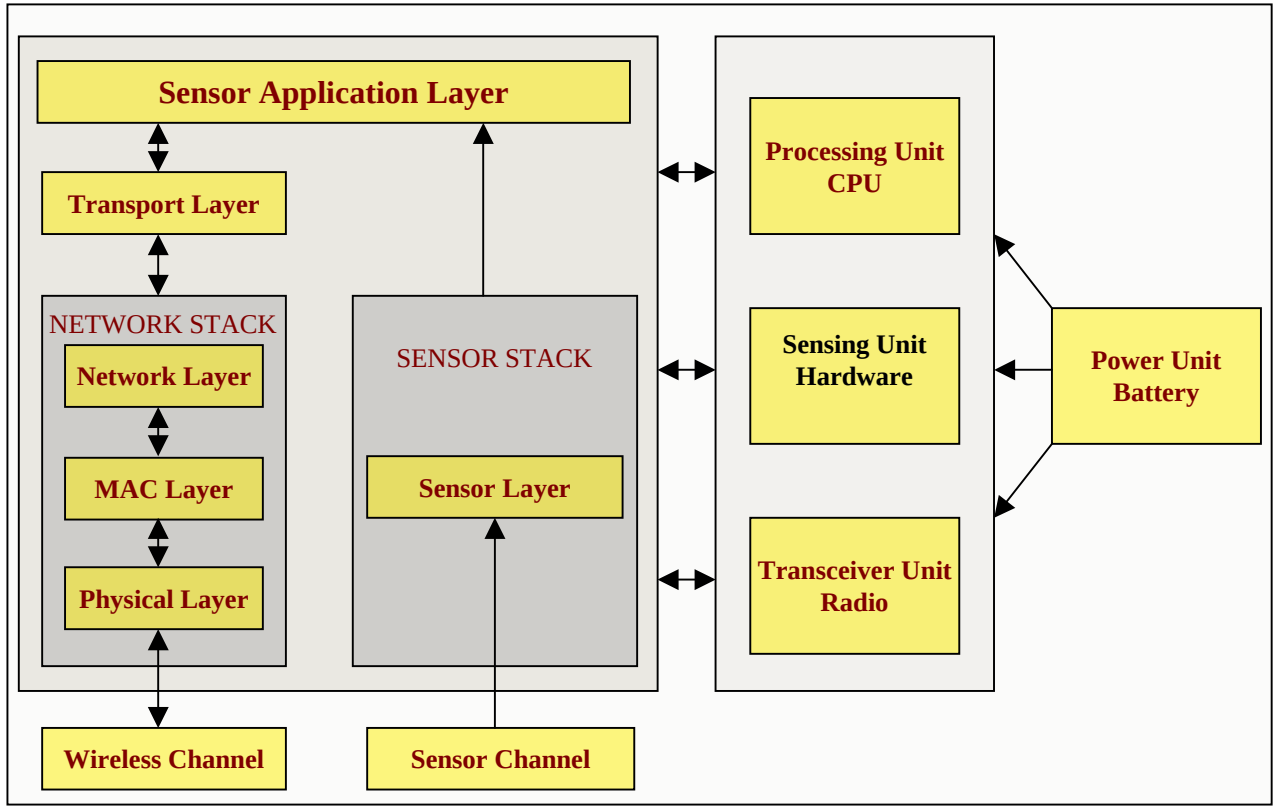
Modeling a Sensornet

AADL Constructs:

- 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**

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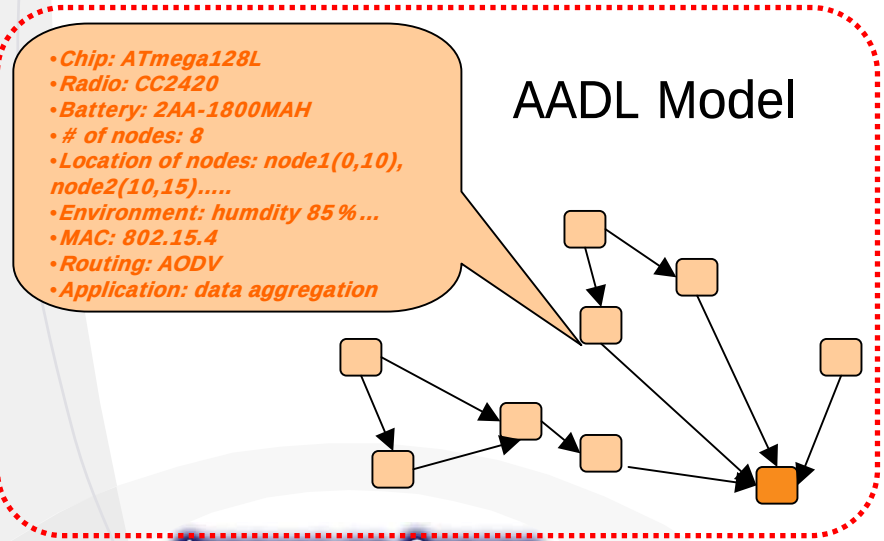
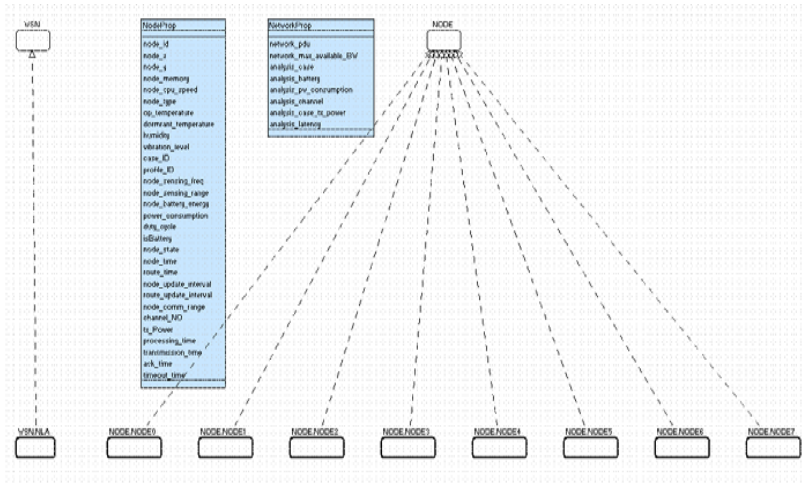
AADL Model - Network

- **Network**
  - **Sets of Nodes**
  - **Routing policy:**
    - **Neighbor Table**
    - **ZigBee AODV routing policy**
  - **Radio Channel**
    - **Channel No.**
  - **Data Source**
    - **Link Quality**
    - **Hardware Reliability**

```
system implementation WSN.NLA
  subcomponents
    NODE0: system NODE.NODE0;
    NODE1: system NODE.NODE1;
    NODE2: system NODE.NODE2;
    NODE3: system NODE.NODE3;
    NODE4: system NODE.NODE4;
    NODE5: system NODE.NODE5;
    NODE6: system NODE.NODE6;
    NODE7: system NODE.NODE7;
  properties
    NetworkProp::network_channel => 13;
    NetworkProp::network_LinkData=>“\c\dev\psr1.txt”;
end WSN.NLA;
```





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AADL Model - Node

- **Node**
  - **Node Type: RFD, FFD**
  - **Location (x,y)**
  - **Hardware Components**
    - **CPU**
    - **Memory**
  - **Environments**
    - **Temperature**
  - **Operating Profiles**
    - **Duty Cycle**
  - **Power Unit:**
    - **Battery Capacity**
    - **Power consumption**
  - **Radio Channel**
    - **Tx Power level**

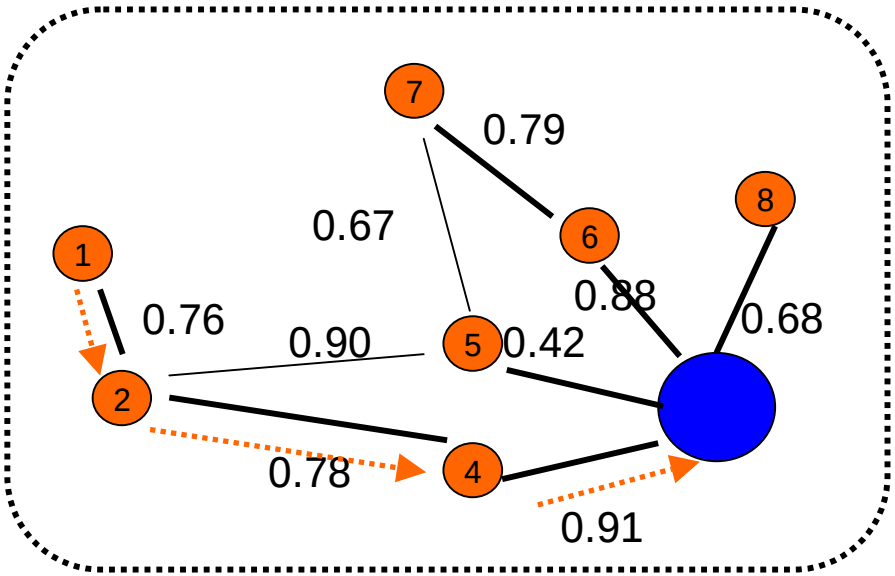
```
system implementation NODE.NODE0
  properties
    --Location Properties
    NodeProp::node_id => 0;
    NodeProp::node_x => 0.0;
    NodeProp::node_y => 0.0;
    --Hardware Components Properties
    NodeProp::node_memory => 1000.0;
    NodeProp::node_cpu_speed => 1000.0;
    --Environments Properties
    NodeProp::op_temperature => 30.0;
    NodeProp::dormrant_temperature => 40.0;
    --Operating Profiles Properties
    NodeProp::humidity => 20.0;
    NodeProp::vibration_level => 0.0;
    NodeProp::case_ID => 0;
    --Battery Properties
    NodeProp::isBattery => 0;
    NodeProp::node_battery_energy => 2100.0;
     --Node state
    NodeProp::node_time => 0.0;
end NODE.NODE0;
```

Dependability Analysis: Mains-Powered

ZigBee routing policy

AODV Link Cost:

$$C\{l\} = \begin{cases} 7, \\ \min\left(7, \text{round}\left(\frac{1}{p_l^4}\right)\right) \end{cases}$$



Base station

Sensor Node 1

Method: Monte Carlo Simulation

Step 1: Update Node reliability

Step 2: Decide whether Node is alive or not

Step 3: Update Link Quality

Step 4: AODV routing policy

Reliability of node 1:

$$R_{12} * R_{24} * R_{40}$$

Latency of node 1:

$$L_{12} + L_{24} + L_{40}$$

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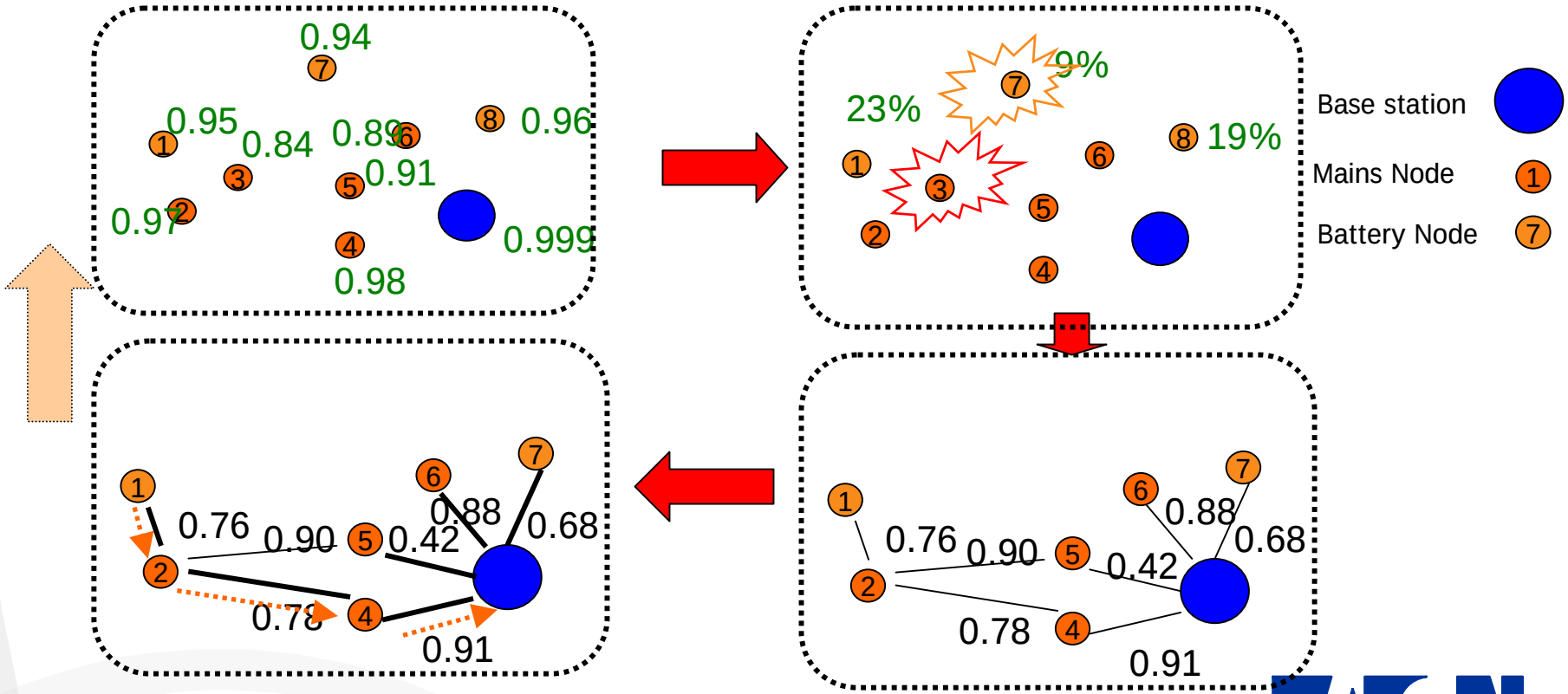
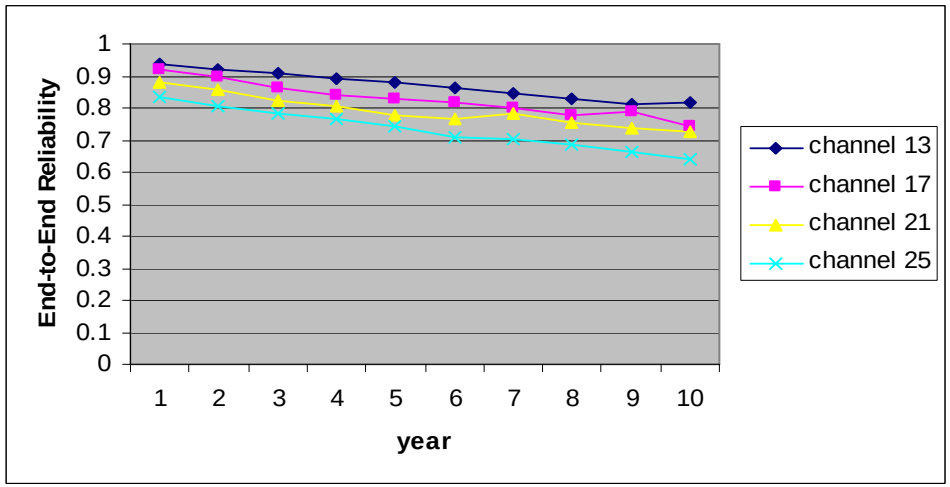
Dependability Analysis: Battery-Powered

- Node battery life: Node can work properly until certain voltage level
  - Only for RFD or end devices

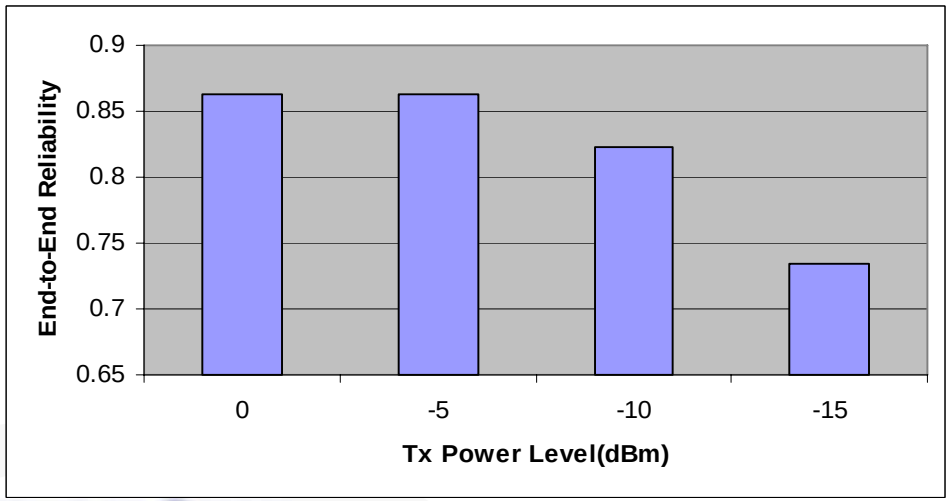


Results – System PSR

- Average Packet Success Rate (PSR)



Channel has impact on reliability of WSN

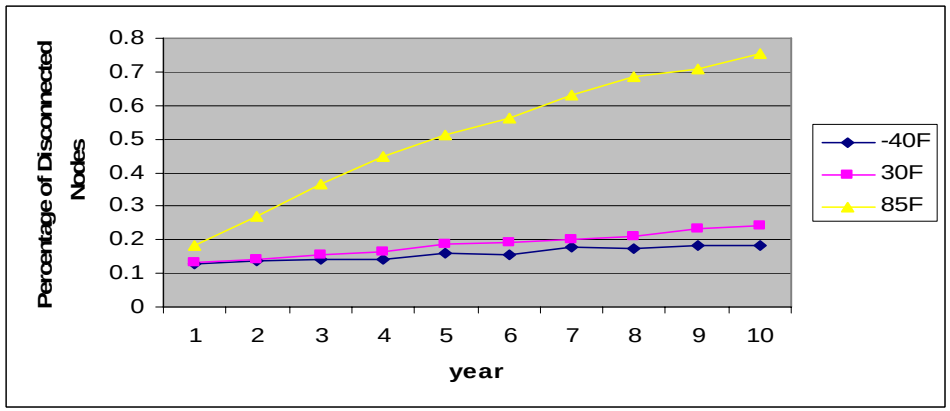


Transmission power level also affects reliability

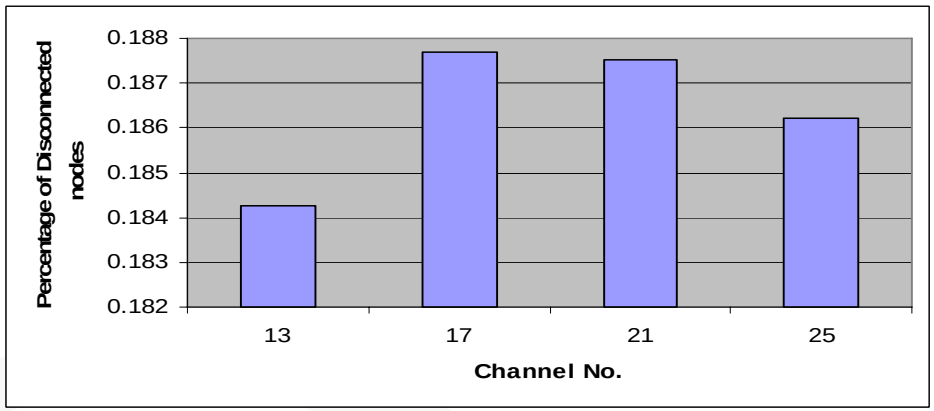
Note: Average over 10 year

Results – System Life

- System life:
  - Measured by percentage of disconnected nodes



At higher temperature, more nodes are disconnected



Channel affects the system life also

Note: Average over 10 year

Lessons learned

- AADL is the choice for modeling WSN architecture:
  - Flexibility in language extensions
  - OSATE plug-in support
- Node or link level dependability ≠ WSN dependability
- Needed more AADL support for WSN:
  - Represent large scale WSN topologies
  - Import empirical/experimental data into the system model
  - Represent time-variant properties
  - Represent node-level state machines

Proposed Publications

- AADL tutorial for Embedded System Design magazine
- WSN modeling approach using AADL – Conference
- AADL for ZigBee – ZigBee conference

Issues for WSN Modeling

- What features are not there for effectively modeling wireless sensor networks in the current version of AADL?
  - Effective and flexible means
    - to represent large scale WSN topologies
    - to import empirical/experimental data into the system model
    - to represent time-variant properties
    - to represent node-level state machines

WSN Topology Specification

- It is painful to specify each individual node location and link manually for a large scale WSN
- Various ways to manage the issue
  - Fixed topologies – need means to read topology from files
  - Topologies with patterns – grids, uniformly random, …
    - Specify with patterns and parameters, such as Grid with grid size 10 meters, and have the plug-ins automatically generate the topologies

Specification of Links

- Number of links exceeds that of nodes, therefore it is not realistic to have them entered manually for a system with > 100 nodes
- Automatically generate links based on simple models with plug-ins
  - Given the node topologies, base the on/off of links on a circular model with random fluctuations
- Gather link information with experiments, and then import the experimental data into the system

Specify Time-Variant Properties

- Some properties are time-variant, e.g., RSSI and LQI, which cannot be specified with the syntax/semantics of the current version of AADL
- Specify time-variant properties
  - Model based specification
  - Import empirical data from experiments

Specify Node-Level State Machines

- State machines on each WSN node are necessary to describe system behavior, which is missing in the current version of AADL
  - For example, the communication sub-system of a single node may have states such as SENDING, RECEIVING, WAITING_FOR_ACK, …
  - Need notions of state, transition, …

Two Patterns

- Need to import data from separate files
  - Node locations, link qualities, …
- Need various levels of details – for example:
  - First level – Grid deployment with density of 1/100m^2
  - Second level – Locations (0m, 0m), (10m, 0m), (20m, 0m), (0m, 10m) …
  - Use plug-ins to automatically generate the second level model from the first level model