On-line self-diagnosis based on power measurement for a wireless sensor node

Van-Trinh HOANG, Nathalie JULIEN, Pascal BERRUET

Lab-STICC Research Center, University of South-Brittany

Oral presentation in HARSH Workshop
24 February 2013
Outline

1. Background
   - Introduction
   - Background

2. Our approach for on-line self-diagnosis
   - Failure detection
   - Failure localization

3. Simulation
   - Simulation tools
   - Availability simulation
   - Energy simulation

4. Conclusions and Perspectives
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4. Conclusions and Perspectives
Application fields of WSN

Advantages
- Easy deployment.
- Self-organisation.
- Reconfigurability.
- Portability.
- Low cost.

Application fields
- Area and Environment monitoring.
- Health monitoring.
- Home automation.
- Industrial monitoring.
- Military monitoring.
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Additionally, energy is wasted if failing element is still supplied that leads to shorten the node lifetime because wireless sensor node is powered by battery.
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- **Soft-failure** during data sensing, or data processing, or data transmission.
- Element is down due to **hard-failure**.
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Context

When WSN is deployed in harsh environment, human intervention is very difficult in case of hardware failure of node element.

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Wireless sensor node can encounter the failure issues of element as follows:

- **Soft-failure** during data sensing, or data processing, or data transmission.
- **Element is down due to hard-failure.**

Objectives

To propose an on-line self-diagnosis that can detect and localize the failing element of wireless sensor node.
Hardware configuration of wireless sensor node

**IAS** : *Interface of Actuator and Sensor*

**RTM** : *Radio Transceiver Module*
**Hardware configuration of wireless sensor node**

IAS: *Interface of Actuator and Sensor*

RTM: *Radio Transceiver Module*
Hardware configuration of wireless sensor node

IAS: Interface of Actuator and Sensor
PAM: Power Availability Manager
RTM: Radio Transceiver Module
The complementary devices are added in sensor node:

- **PAM Block** is considered as intelligent part to reduce energy consumption and react against the issues.
- **FPGA** enhances availability and performance for sensor node.

<table>
<thead>
<tr>
<th>Issues</th>
<th>Software and Hardware causes</th>
<th>Energy causes</th>
<th>Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dead Processor</td>
<td>Dead Ram</td>
<td>Dead IAS</td>
</tr>
<tr>
<td>Dead Node</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Malfunctioning Node</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **PAM enables FPGA processor to replace main processor**
- **PAM enables FPGA memory to replace RAM/Flash memory**
- **Wait for recharging battery**
- **PAM changes mode of operation to relay point**
- **PAM changes mode of operation to local processing**
- **Processor reboots**
- **PAM selects consistent mode of operation and waits for battery recharge**

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FSM model for mode modeling

Performance and Energy Manager

Deep Sleep
- Processor: deep sleep
- Energy < 5% → Energy >= 10%
- Energy < 15% & Sleep Period
- Observation Period

Sleep
- Processor: sleep
- Energy < 15%
- Energy >= 20% & Observation Period

Observation
- Processor: sleep
- Receiver: on
- Sensor 1: on
- Energy >= 20%
- Energy < 15%

On-Duty
- Processor: on
- Sensor 1: on
- Camera: on/off
- Ram: on
- FPGA: on/off
- Receiver: on
- Transmitter: on

Enhance
- Processor: on
- Sensor 1: on
- Sensor 2: on/off
- Camera: on/off
- Ram: on
- FPGA: on
- Receiver: on
- Transmitter: on

Counter > timeout → Task completes

Monitoring
- Processor: on/off
- FPGA: on/off
- Ram: on/off
- Sensor 1: on
- Sensor 2: on/off
- Camera: on/off
- Operation completes
- Alarm Detection & Dead_Ram & Dead_Pro

Dead Processor
- Sensor 1: on
- Sensor 2: on/off
- Camera: on/off
- Ram: on
- FPGA: on
- Receiver: on
- Transmitter: on

Dead Ram
- Processor: on
- Sensor 1: on
- Sensor 2: on/off
- Camera: on/off
- FPGA: on
- Receiver: on
- Transmitter: on

Dead Node
- Processor: on/off
- FPGA: on/off
- Ram: on/off
- Sensor 1: on
- Sensor 2: on/off
- Camera: on/off
- Transmitter: on

Local Processing
- Processor: on/off
- FPGA: on/off
- Ram: on/off
- Sensor 1: on
- Sensor 2: on/off
- Camera: on/off
- Dead_IAS
- Dead_RTM

Dead_IAS
- Processor: on/off
- FPGA: on/off
- Ram: on/off
- Sensor 1: on
- Sensor 2: on/off
- Camera: on/off
- Transmitter: on

Relay
- Processor: on/off
- FPGA: on/off
- Ram: on/off
- Receiver: on
- Transmitter: on

Alarm Detection & Dead_Ram & Dead_Pro

|| (Dead_Ram & Dead_FPGA_Mem)
|| (Dead_Pro & Dead_FPGA_Pro)
Dead_RTM

Dead_IAS
- Processor: on/off
- FPGA: on/off
- Ram: on/off
- Sensor 1: on
- Sensor 2: on/off
- Camera: on/off
- Transmitter: on

Dead Node
- Processor: on/off
- FPGA: on/off
- Ram: on/off
- Sensor 1: on
- Sensor 2: on/off
- Camera: on/off
- Transmitter: on

Availability Manager

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Availability is the ability of an entity to be able to accomplish a required function under given conditions and at a given time.
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1 Background

2 Our approach for on-line self-diagnosis
   - Failure detection
   - Failure localization

3 Simulation

4 Conclusions and Perspectives
On-line self-diagnosis is applied to:

- Detect hard-failure based on power consumption.
- Then localize correctly the failing element in order to take an appropriate corrective solution.
Failure detection based on power consumption

The application of hazardous gas detection for area such as harbor or warehouse is used to illustrated our failure detection method.

<table>
<thead>
<tr>
<th>Element</th>
<th>Power (mW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIC24FJ256GB110</td>
<td>36</td>
</tr>
<tr>
<td>M48T35AV memory</td>
<td>150</td>
</tr>
<tr>
<td>Oldham OLCT 80</td>
<td>867</td>
</tr>
<tr>
<td>Miwi Radio transmitter</td>
<td>130</td>
</tr>
<tr>
<td>Miwi Radio receiver</td>
<td>70</td>
</tr>
<tr>
<td>Core8051s</td>
<td>26</td>
</tr>
<tr>
<td>PAM block</td>
<td>0.1</td>
</tr>
</tbody>
</table>
The application of hazardous gas detection for areas such as harbors or warehouses is used to illustrate our failure detection method.
Petri Net modelling for discrete-event systems

**Definition**

A *Timed Stochastic Petri Net graph* (TSPN) is a weighted bipartite graph \((P, T, A, w, Ti, Pb)\), where:
- \(P\) is the finite set of places,
- \(T\) is the finite set of transitions,
- \(A\) is the set of arcs from places to transitions or from transitions to places,
- \(w\) is the set of the multiplicities of the arcs,
- \(Ti\) is the set of the firing times of the transitions,
- \(Pb\) is the set of the firing rates of the transitions.

\[
\begin{array}{|c|c|}
\hline
\text{λ} & 1-\lambda \\
\hline
\text{NotCap} & \text{Cap} \\
\hline
\text{WaitCapture} & \text{AskDataCapture} \\
\hline
\text{CapData} & \text{WaitData} \\
\hline
\text{ProcessData} & \text{OK, NotOK} \\
\hline
\end{array}
\]

**Nondeterministic model**

**Deterministic model**
A functional test is applied to check the state of sensor as follows:

- Check the state of capturing buffer.
- Make a request of capturing data if capturing buffer is still empty during a time interval $T_2$.
- If data arrive into capturing buffer, sensor is still available. Otherwise it is down.
A functional test is applied to check the state of processor as follows:

- The PAM block sends a beacon signal to processor and wait its response.
- If our PAM does not receive any feedback from the processor, the processor is considered as failed.
A functional test is applied to check the state of RAM as follows:

- To check the availability of RAM memory, the PAM block writes a testing data of 32 bits in an address of memory space.
- Then, PAM reads the writing data at the same address.
- The reading data is compared with the original data. If they are similar, Ram memory is still available, otherwise it is down.
A functional test combined with physical test is applied to check the availability of radio module as follows:

- Check the state of reception buffer.
- Make a request of data transmission to a neighbor node if this buffer is still empty during a time interval $T_4$. This step is called as the **functional test**.
- The transmission power is measured by an embedded electronic device, and then is compared to a power threshold using a Schmitt trigger. If the output result of this trigger is true, the radio is still available, otherwise it is down. This step is called as the **physical test**.
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   - Energy simulation

4. Conclusions and Perspectives
In our approach, two different constraints of availability and energy are simulated by two different tools.

1. **Capnet-PE tool for energy simulation**
   CAPNET-PE tool is created by Nicolas Ferry and al. at Lab-STICC laboratory, in the project with Eryma company.
   
   This tool allows to:
   - Predict the node autonomy.
   - Provide energy consumption of node based on business scenario.
   - Predict energy harvested from the environment based on the weather forecast.

2. **SPNP tool for availability simulation**
   This tool is created by Prof. Kishor S. Trivedi and al. at Duke University in Durham NC, USA.
   
   This tool allows to:
   - Model the node system using Petri Net.
   - Perform the concurrent operations and asynchronous events of node system.
   - Provide the failure prediction features.
Mean Time To Failure

Definition

Mean Time To Failure (MTTF) is defined for non-repairable systems to indicate the average functioning time from instance 0 to the first appearance of failure.
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Mean Time To Failure (MTTF) is defined for non-repairable systems to indicate the average functioning time from instance 0 to the first appearance of failure.

The availability of each element is given by :

\[ R(t) = e^{-\int_0^t \lambda(x) \, dx} = e^{-\lambda \cdot t} = A(t) \] (1)

The failure probability of each element is given by :

\[ F_{sensors} = (1 - A_{sensor1}) \ast (1 - A_{sensor2}) \] (2)

\[ F_{processor} = 1 - A_{processor} \] (3)

\[ F_{ram} = 1 - A_{ram} \] (4)

\[ F_{radio} = 1 - A_{radio} \] (5)

<table>
<thead>
<tr>
<th>Component</th>
<th>Failure rate ($\lambda$)</th>
<th>MTTF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor</td>
<td>$1/30000 , hour^{-1}$</td>
<td>3.4 years</td>
</tr>
<tr>
<td>Processor</td>
<td>$1/262800 , hour^{-1}$</td>
<td>30 years</td>
</tr>
<tr>
<td>RAM</td>
<td>$1/83220 , hour^{-1}$</td>
<td>9.5 years</td>
</tr>
<tr>
<td>RTM</td>
<td>$1/100000 , hour^{-1}$</td>
<td>11.4 years</td>
</tr>
<tr>
<td>FPGA memory</td>
<td>$1/80000 , hour^{-1}$</td>
<td>9.1 years</td>
</tr>
<tr>
<td>FPGA processor</td>
<td>$1/131400 , hour^{-1}$</td>
<td>15 years</td>
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Background
Our approach for on-line self-diagnosis
Simulation
Conclusions and Perspectives

Simulation tools
Availability simulation
Energy simulation

Failure localization model for sensor node

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Remark

- The obtained curves are consistent to the above equations of computation of failure probability.
- The sensors are the most critical elements due to their low reliability (the smallest MTTF), because their circuitry is very complex.
- This simulation result allows to validate our localization method of failing element.
Energy results

The consumption of wireless sensor node is simulated with the application of detection of hazardous gas using Capnet-PE tool during seven days.

<table>
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<tr>
<th>Elements</th>
<th>Energy 1(J)</th>
</tr>
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<tbody>
<tr>
<td>Ram memory</td>
<td>5510</td>
</tr>
<tr>
<td>Processor</td>
<td>7203</td>
</tr>
<tr>
<td>Radio</td>
<td>7630</td>
</tr>
<tr>
<td>Gas sensor 1</td>
<td>16124</td>
</tr>
<tr>
<td>Gas sensor 2</td>
<td>523</td>
</tr>
<tr>
<td>Camera</td>
<td>71</td>
</tr>
<tr>
<td>FPGA Core8051s</td>
<td>6.1</td>
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<td>FPGA PAM block</td>
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<td>FPGA PAM block</td>
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Remark

The consumptions of PAM block and FPGA Core8051s are very small compared to other node elements.
Conclusions :
A on-line self-diagnosis is proposed for wireless sensor node with its efficient implementation in term of energy that can :

- Detect hard-failure based on power consumption.
- Then localize correctly the failing element in order to take an appropriate corrective solution.

The simulation results allow us to validate and evaluate our on-line self-diagnosis.
**Conclusions**
A on-line self-diagnosis is proposed for wireless sensor node with its efficient implementation in term of energy that can:

- Detect hard-failure based on power consumption.
- Then localize correctly the failing element in order to take an appropriate corrective solution.

The simulation results allow us to validate and evaluate our on-line self-diagnosis.

**Perspectives**

- Implement our approach in real material for evaluating.
- Measure the energy overhead when using the additional electronic devices for power measurement.
Bibliography

[1] Van-Trinh Hoang, Nathalie Julien and Pascal Berruet
IEEE International Conference on Design and Architectures for Signal and Image Processing (DASIP), October 2012.

Dependability evaluation of a fault-tolerant processor by gspn modeling.

Snif : Sensor network inspection framework.

Detection and diagnosis of data inconsistency failures in wireless sensor networks.


Distributed Fault Detection of Wireless Sensor Networks.
Thank for your attention!

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Van-Trinh HOANG, Nathalie JULIEN, Pascal BERRUET
Lab-STICC/University of South-Brittany, Research Center, BP 92116
56321 Lorient cedex, France