Analyzing WSN-based IoT Systems using MDE Techniques and Petri-net Models

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1. Introduction

IoT and WSN relation:

-Home appliances smart buildings, Industry 4.0 applications, and Digital Twin systems.

- Benefit from (WSN) to make their communication topology more flexible
- increase the coverage of the resulting IoT system
- Without a need for a direct Internet connection.

This causes Complexity, because:

-Require more components such as source nodes, sink nodes, and gateways

- The resulting system is complex with these additional components
- Complexity makes the design and analyses of these systems time-consuming ,costly, and cumbersome.
- It can be addressed with MDE by automatically synthesize and transform the system artifacts.

1. Introduction - 2

What should we do ?

- Design models can be used for the early analyses and validation of the system to reduce the number of errors in the SUD.

-Fast development process, saves development cost and effort.

What should we use ?

-As these multi-component systems work based on message passing to fulfill their tasks,

-Their behavior can be represented by the Petri-net models (M2M Transformation).

Which feature can be applied?

- K-boundedness can be used for power consumption, bottleneck, and first crashing node.

2. Analyzing IoT systems with Petri-net models

How to map the elements ?

- Generation rules both for LoLA and PIPE
- PIPE for GUI
- LoLA for k-boundedness

DSML Element	Petri-Net Element	DSML Element	Petri-Net Element
Tag (Sensor Nodes)	Place	Node messages	Token
ESP8266	Place	ESP Messages	Token
IoT Log Manager	Place	Element Relations	Transition
RaspberryPI	Place	Element Relations	Arcs

Mapping table: DSML4Contiki elements to Petri-net model elements,

2. Analyzing IoT systems with Petri-net models - 2

[for (l:LogMan | IoTSys.logman)]

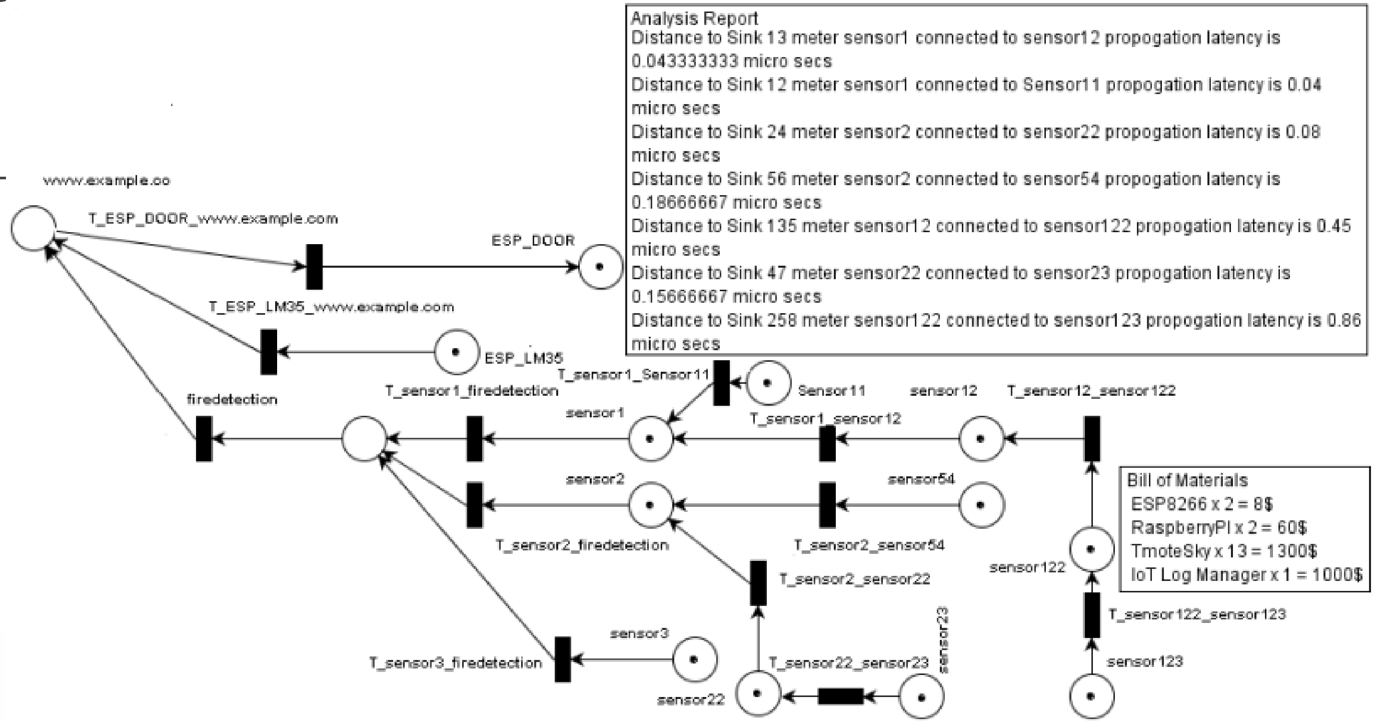
- [for (e:ESP | IoTSys.esp)]
- [e.Name/]**,**
- [/for]
- [for (t : Tag | tag)]
- [t.Name/]**,**
- [/for]

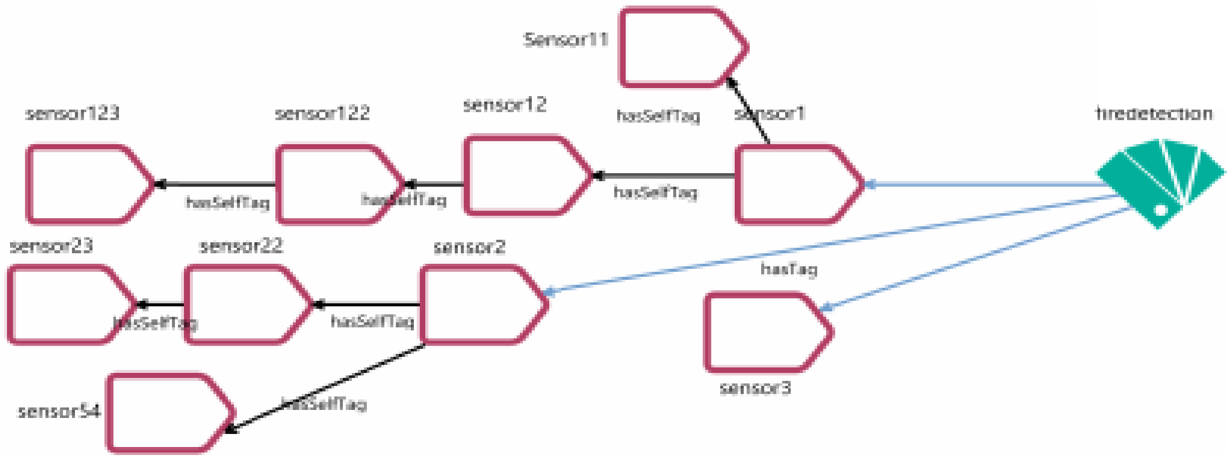
[/for] **;**

```
PLACE s1, s2, s3, s4;

MARKING s1: 1;

TRANSITION t1
CONSUME s1: 1;
PRODUCE s1: 1, s2: 1;

TRANSITION t2
CONSUME s1: 1;
PRODUCE s3: 1;

TRANSITION t3
CONSUME s3: 1;
PRODUCE ;

TRANSITION t4
CONSUME s3: 1, s2: 1;
PRODUCE s3: 1, s4: 1;
```

Code generation codes are written based on LoLA's and PIPE's syntax.

3. Topology viewpoint to Petri-net model





- User designs a topology.
- Inputs distance parameter for each node.
- Token is delivered to neighbor node.
- Only one neighbor (Routing Protocol Constraint)

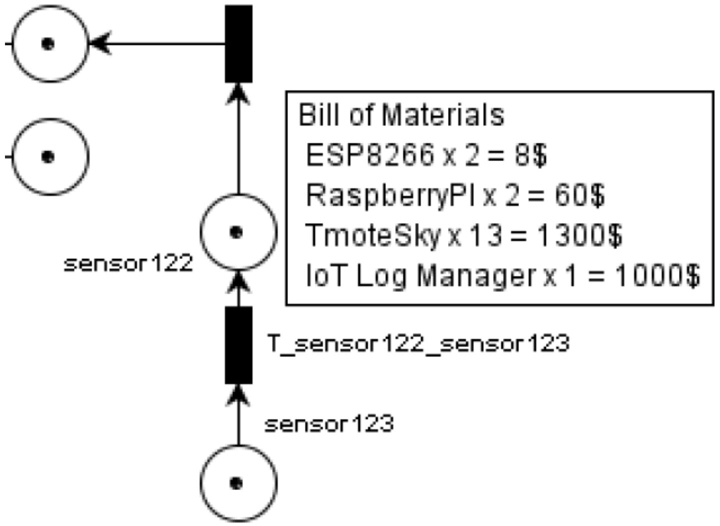
4. Additional Reports:
Bills of Materials & Propagation Delays

- The generated BOM represents components that are used in the design and their total cost.

- It is easily made using the Acceleo.

- It is important when you try to ease the bottleneck.

- It is important when you try to increase battery cap.




```
[for(t:String|calcDist)] TmoteSky x [aIoTSystem.logman.tag->size()/]=  [100*aIoTSystem.logman.tag->size()/]$
...
```

4. Additional Reports: Bills of Materials & Propagation Delays – 2

- **For the time and power constraint systems:**

 - Message transmission delays.

 - What happens if the distance to the sink node is too far in a multi-hop network,

  -Propagation delay for may cause time-violation.

- -If the distance increases, the propagation delay increases.

 - Processing delay trivial amount of time comparing to the message transmission time so can be ignored

- **Propagation delay and power and time constraints**

- Worst case needs to be calculated with respect to the node which has the furthest distance

- Trade-off analyses can be done by the user using

- Automatically calculated propagation delays help the user to handle trade-offs

4. Additional Reports: Bills of Materials & Propagation Delays - 3

```
calcDist(Collection tag)
{
for(int i=0; i<aTag.size(); i++)
        {
         for(int j=0; j<aTag.get(i).getSelftag().size(); j++)
                  aTag.get(i).getSelftag().get(j).setDistance(aTag.get(i).
                           getSelftag().get(j).getDistance()+aTag.get(i).getDistance());
        }
}
```

- Java Service used to calculate total distances
- Travels all Tag elements and sums the distances (calculates using speed of light formula).

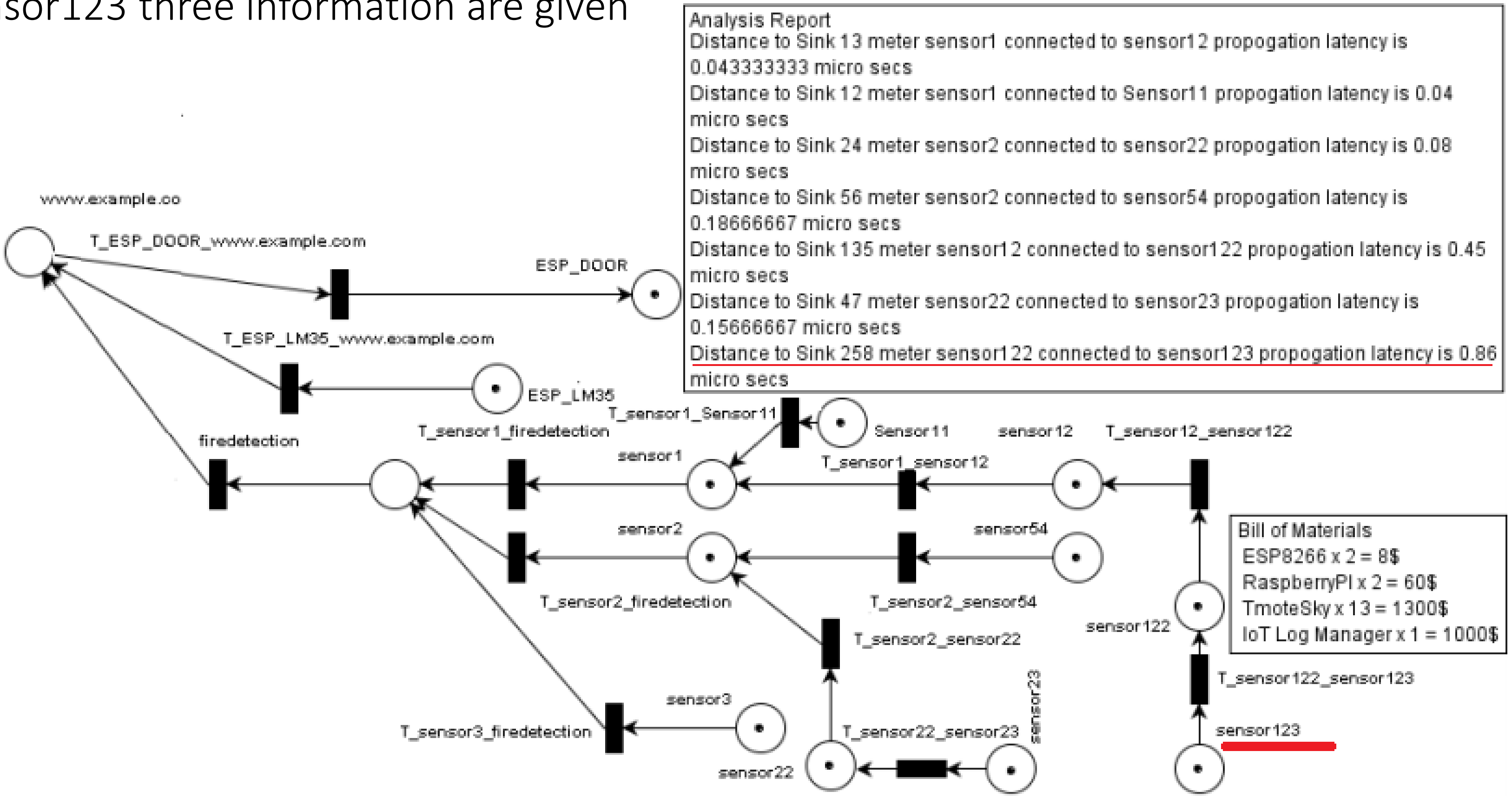
4. Additional Reports:
Bills of Materials & Propagation Delays - 4

As It can be seen that for the node named sensor123 three information are given

1-) It's parent is node named sensor122.

2-) It is 258 meter away from the sink node.

3-) Propagation latency is 0.86 micro-seconds



5. How to use k-boundedness ?

- **What is k-boundedness?**
- K-boundedness feature checks a place in a Petri-net compares tokens that are passed in that place and given k value.
- k increases bottleneck gets intense and power consumption increases at a node.
- If the power is depleted in a node, a part of the network may be disconnected.
- **What should be done ?**

```
lola --formula=AG sensor1 < 5 IoTSystem.lola : lola:result:no
```

- Optimal k value must be found by the designer.
- The topology design must be made considering this value.
- The number of the tokens pass through a place must be below this k value.
- One way to reduce the k value is by adding extra nodes to decrease message traffic (extra cost)
- Another way is increasing battery capacity (also extra cost)

6. Analyzing the Fire Detection System with Petri-net

-To keep the planned life-time of the network, the bottleneck problem must be analyzed before development

-The k value must be found to provide the desired life-time with planned battery capacity.

-Messages which are received and transmitted in a node should be considered.

-Send and receive two operations.

-Adds 1 more operation (node’s own sampling data).

$$NumberOfOperations = (2 * k) + 1$$

7. Power Consumption

- Power consumption depends on the number of operations for each node.

- The network must be bounded by k value.

- The user decides node lifetime, the battery cap. and message sending period .

- The power consumption of a send and receive operation is averaged (RxT xAvgmA).

- T represents the number of using antenna in an hour (unit of battery capacity is mAh).

-. if the system's lifetime is determined then k value can be found to analyze the Petri-net.

$$NumberOfOperations = (2 * k) + 1$$

$$LifeTime_{hour} = \frac{BatteryCapacity_{mAh}}{(NumberOfOperations) * (RxTxAvg_{mA}) * T}$$

$$T = \frac{3600}{SamplingPeriod_{seconds}}$$

8. Conclusion & Future Works

- The current study extends DSML4Contiki by automatic generation of the Petri-net using k-boundedness.

-Network lifetime (first crashing nodes), bottleneck, and power consumption analyses in the early design phase.

In the future;

-Raise the level of abstraction to PIM. (including RiotOS and TinyOS)

-This will be achieved using the M2M.

- Moreover, we aim to use Multi-agent Systems in the modeling, analysis , and implementation of IoT systems.
- PIM -> MDE4IoT special issue in SoSyM journal

Thanks for your attention.

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