

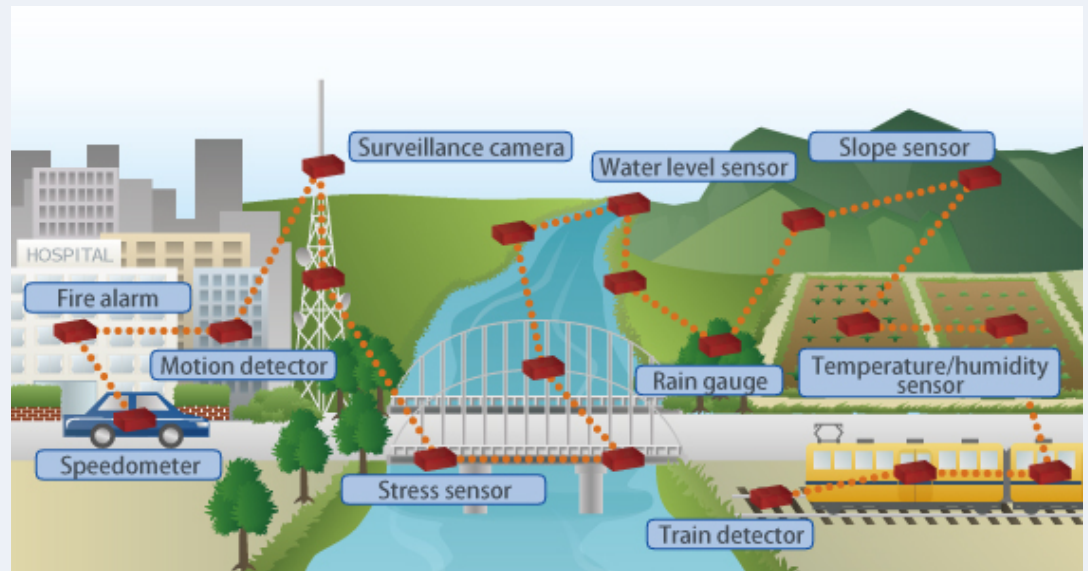
**Emil Sekerinski**  
**Department of Computing and Software**



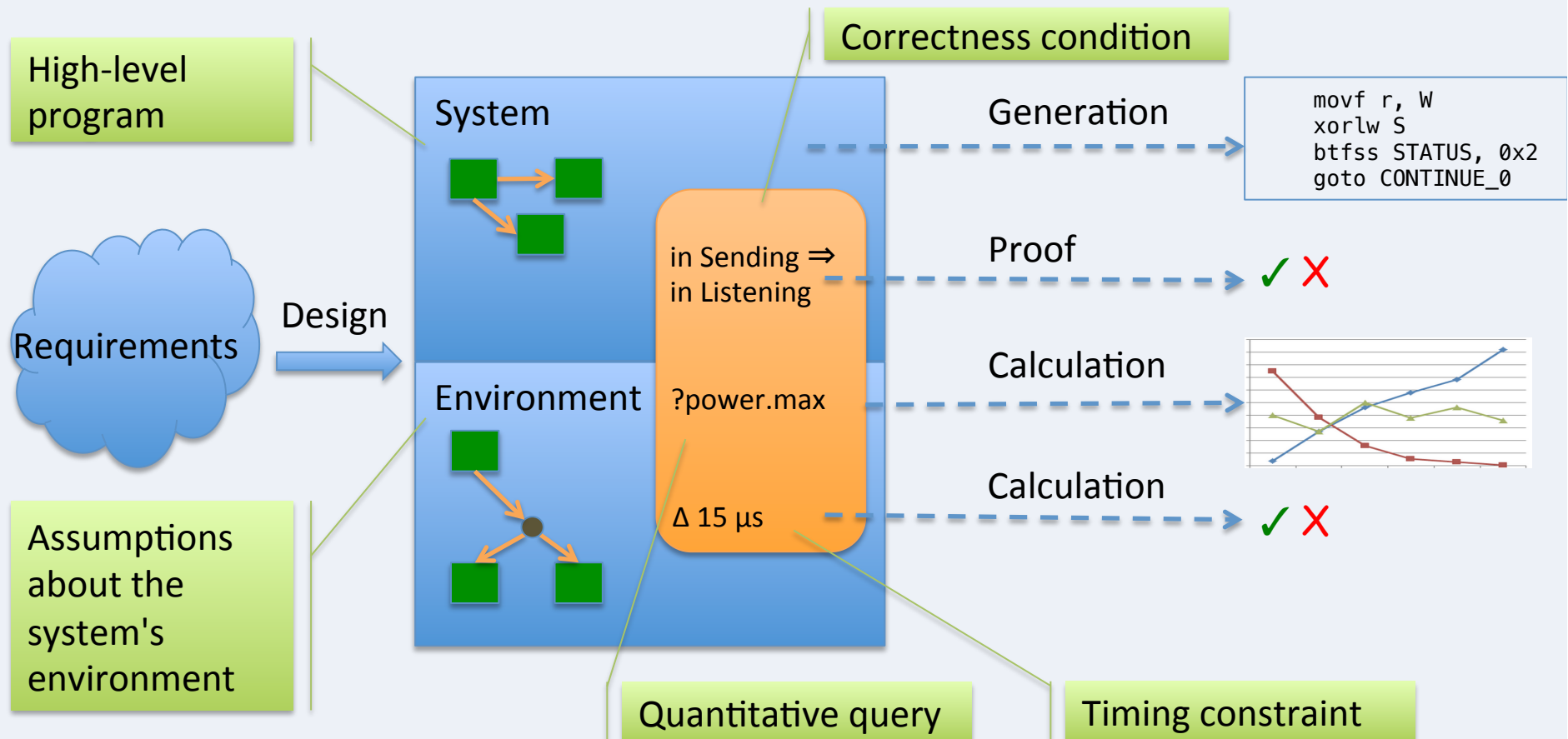
What makes **Sensor Network** – or **Internet of Things (IoT)** – nodes different?

- Software correctness a must
- Unreliable communication, changing topology
- Limited power supply
- Low frequency processors  
 $pow \propto freq^3 \rightarrow$  e.g. 4 MHz
- Low power / sleep modes
- Limited memory  
e.g. 4KB code, 256 bytes data

Credit: Fujitsu Intelligent Society Solution – Smart Grid Communications



## pState: a Holistic Approach to Embedded System Development



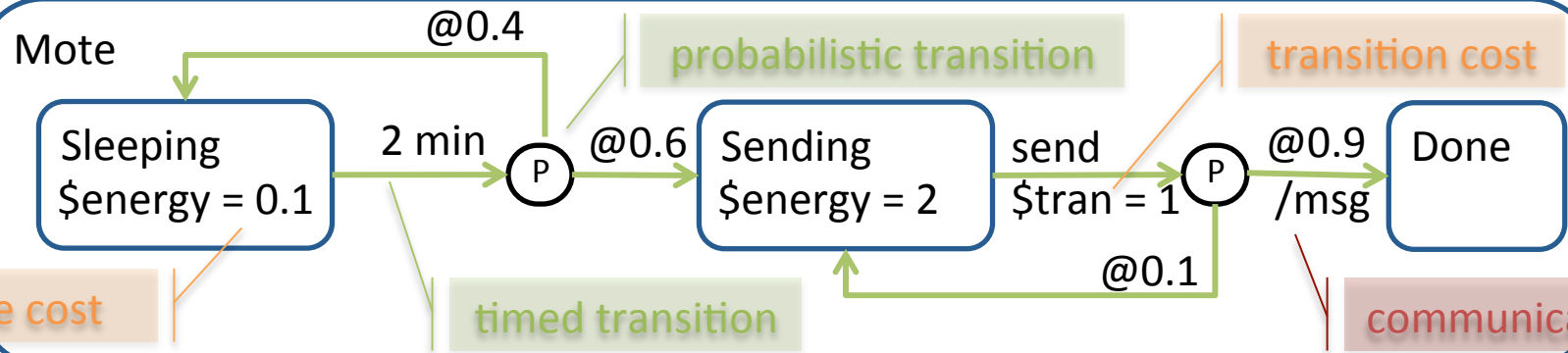
Model-driven Development: Properties of the system are deduced from the combined System + Environment model, without testing or measuring.

## pCharts: a probabilistic & quantitative modeling language

invariant?

hierarchy

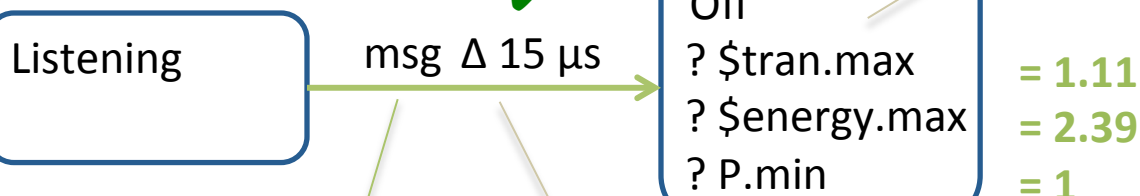
WaterMonitoring | in Sending  $\Rightarrow$  in Listening ✓



Gateway

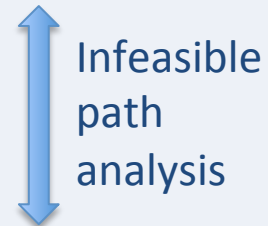
quantitative query?

concurrency

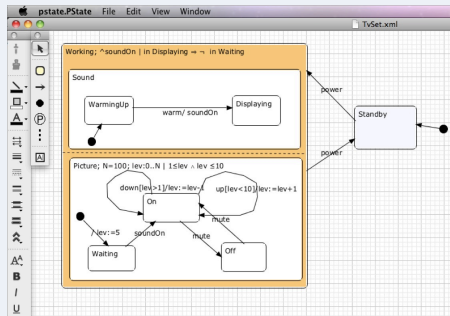


## pState Architecture & Integrated Tools

SMT solver (Yices, SRI)



Visual representation



Probabilistic guarded  
commands with priority

```
send =
(mote = Sending →
0.1: mote := Sending ⊕
0.9: mote := Done)
// skip
```



Probabilistic model checker  
(PRISM, U Oxford)

Assembly code

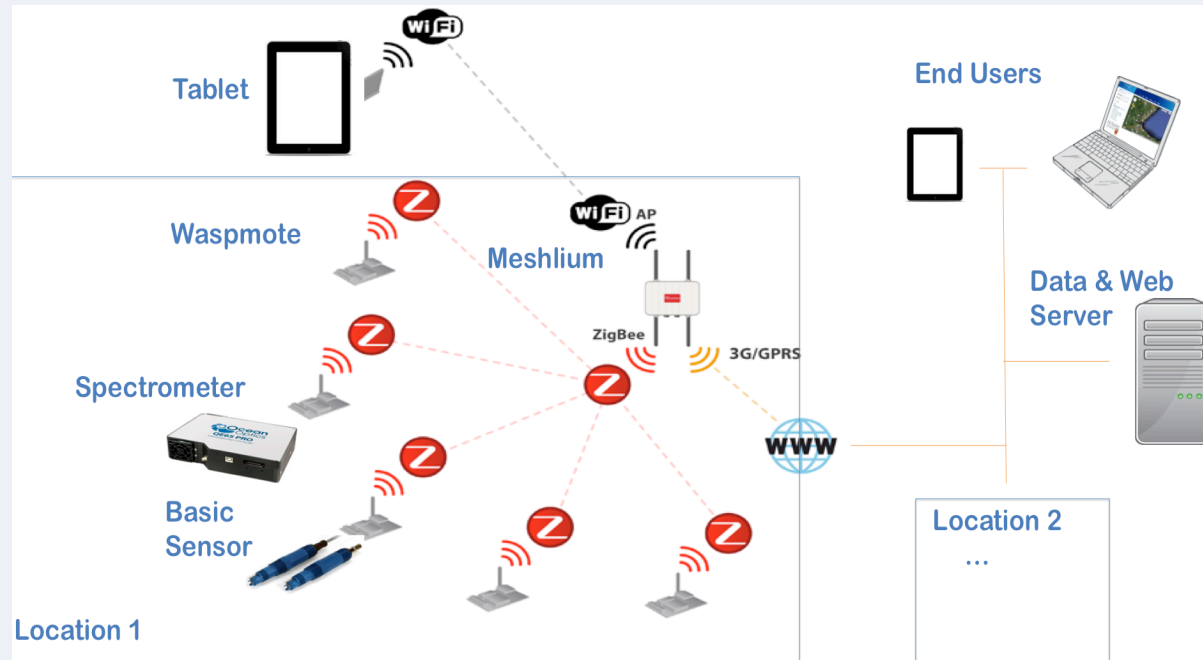
```
movf r, W
xorlw S
btfss STATUS, 0x2
goto CONTINUE_0
```

C code

```
void pH0n(long t){
    if(ph == pH0ff) {
        pHTurnOn();
        ph = pHSensorOn;
        schedule(&exactly3, 5, 1);
    }
}
```

...

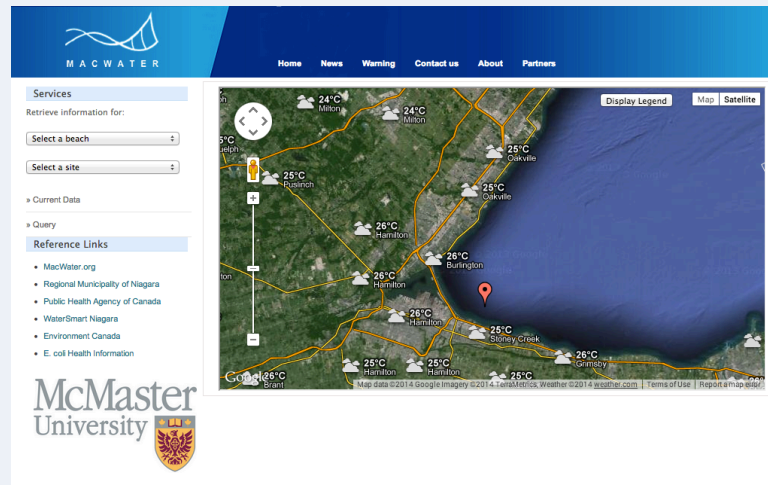
# re:mote – The MacWater Mesh Network



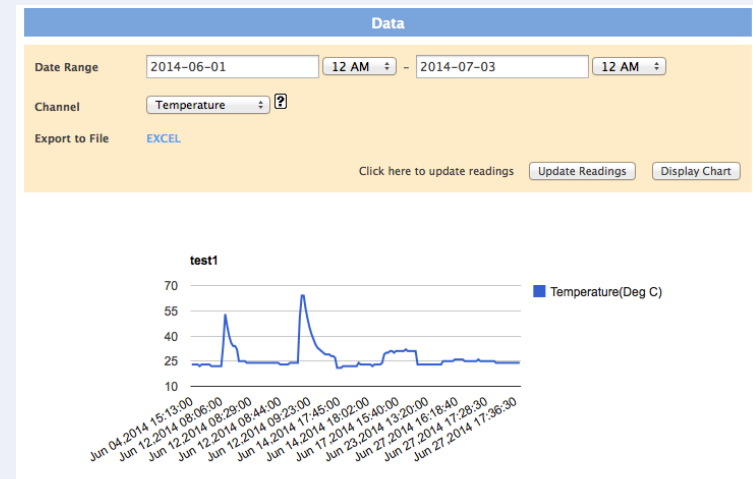
An economical, real-time water quality monitoring system for temperature, conductivity, biological, chemical and optical sensors

- using the low power, highly reliable, open, secure **Zigbee** protocol
- readily available motes by Libelium based on open source **Arduino** boards
- motes interface to **MacWater** developed sensors

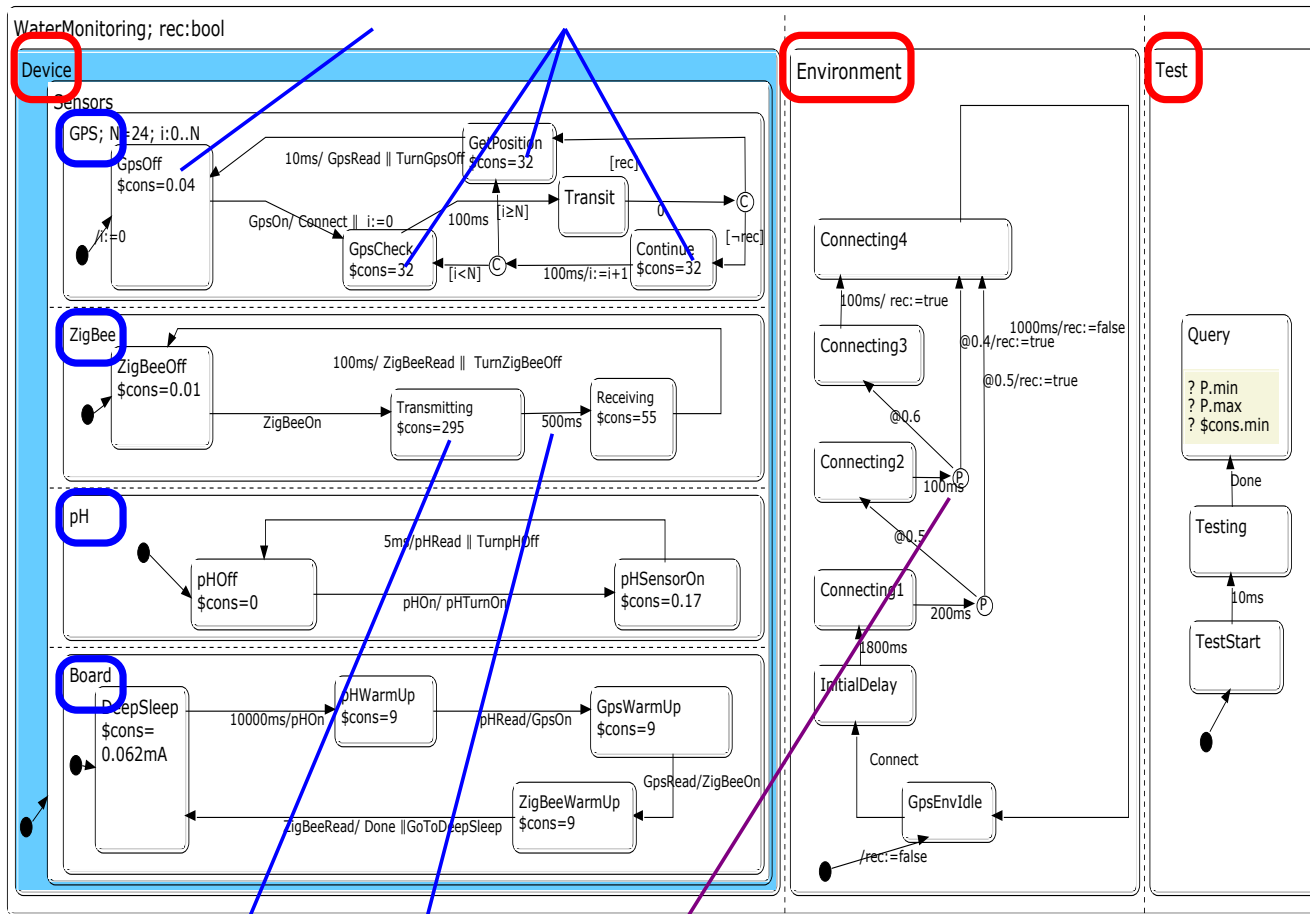
## Data & Web Server



- based on common standards: http, html, php, JavaScript, Linux
- MySQL or DB2 for storage
- Integration with publicly available environmental data, e.g. weather



Off (0.04mA), Working (32mA)



pState calculates  
average power  
consumption  
= 19.39 mA



With battery of  
6600 mAh,  
expected lifetime  
= 340 h

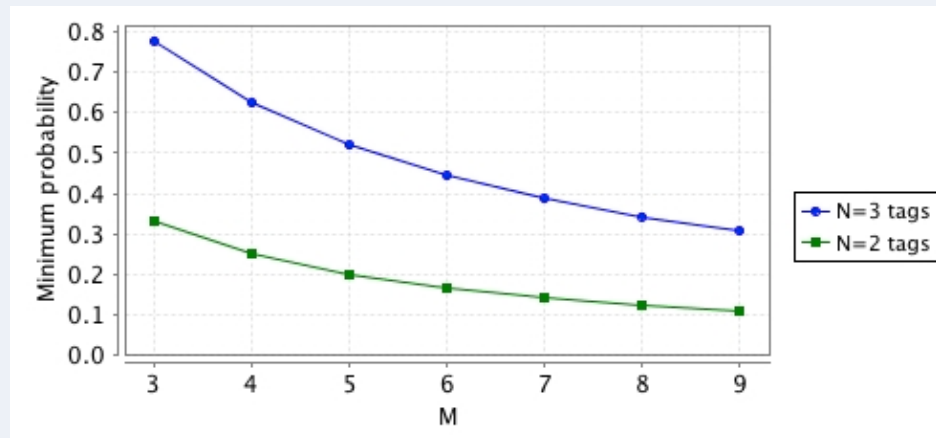
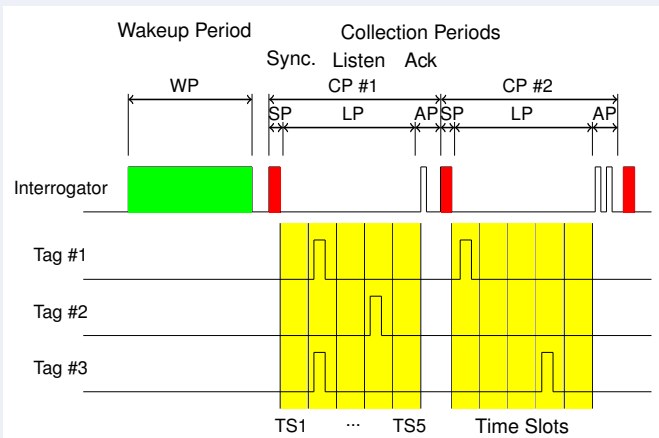
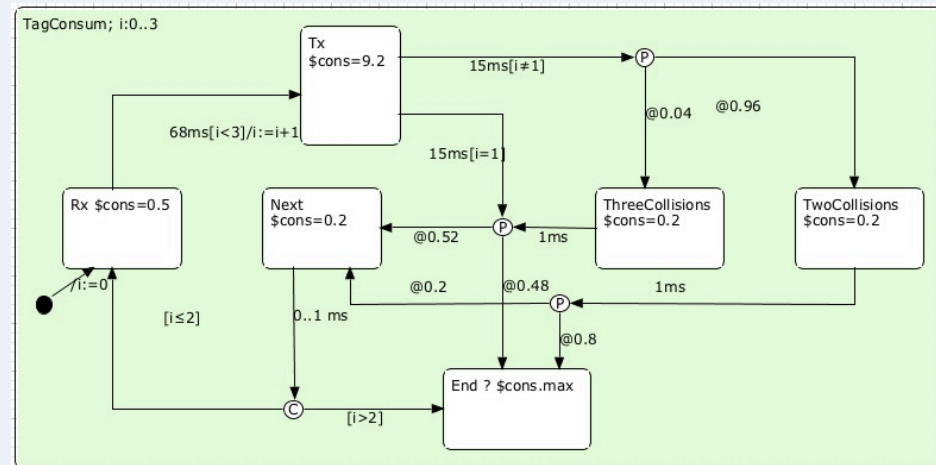
Transmitting; 295mA in 500ms Probability of GPS connection in 2100ms



## pState Examples



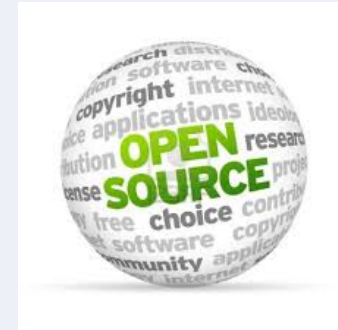
### Contention Resolution in DASH-7 for RFID Asset Management





## Ongoing Work (by end of 2016):

- Open-sourcing pState
- Tutorial with case studies
- Cyclic executive scheduler with sleep modes



## Future Work:

- Improved probabilistic model-checking
- Support for ultra-low power applications with energy harvesting:
  - ➔ intermittent computation



## Contributors

- Alex Sukhov, Mohamed AbouElNaga, Bojan Nokovic, Vincent Marois (re:mote)
- Xu Zhang, Gang Qi, Yang Cui, Jordan Lowes, Junaid Syes, James Priebe, Shucaï Yao

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- Ministry of Research and Innovation  
Ontario Research Fund (re:mote)
- Lyngsoe Systems Ltd, NSERC IPS (pState)



## Posters and Demonstration

- re:mote – Software Infrastructure for Water Quality Motes and Water Quality Visualization
- Modelling Power Consumption and Transmission Reliability of Motes