Piles réseau économes en énergie dans les Réseaux de Capteurs sans Fil

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Internet of Things

Internet today

- Not only interconnected computers
- Mobile Internet (smartphones, tablets)
- Interconnected objects (sensors, automation, monitoring)

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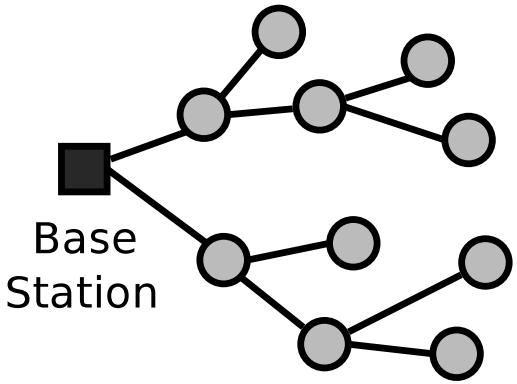
Definition

- The **Internet of Things** is a concept which seeks to integrate physical objects to Internet thanks to an adressing system which can uniquely identify them.
- These objects are generally equipped with *sensors* and *actuators* in order to interact with their environment and they have *limited* processing capabilities $\rightarrow$ *smart objects*.

Wireless Sensor Network

Features

- Wireless nodes
- Interconnected
- Common task



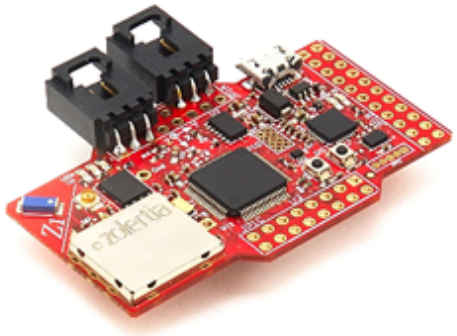
Application domains

- Environmental monitoring [11]
- Industrial applications [14]
- Health care [7]
- ...

$\Rightarrow$ **No single WSN design!**

Source: Automated irrigation [9]

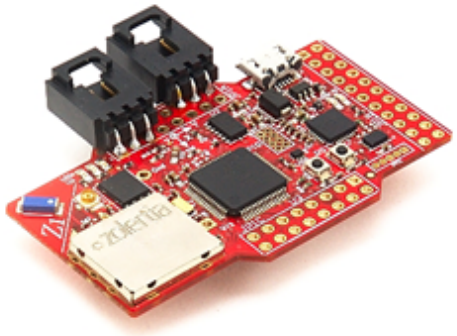
Typical wireless node



	Node	Smartphone
CPU	20 MHz	1000 MHz
RAM	8 kB	1 GB
Lifetime	years	days
Cost	10 €	200 €

Source: http://zolertia.sourceforge.net

Typical wireless node



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Problems

- Limited resources
- Energy constraints
- Single application

Need an optimized and modular network stack

Source: http://zolertia.sourceforge.net

Lifetime

How can we achieve years of longevity?

- Low-power micro-controllers and radio
- Energy harvesting techniques
- *Energy aware communication protocols*

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  - **Link layer:** RDC, dedicated MAC [12, 3, 6]
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  - **Routing:** RPL [15]
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- *Energy aware task scheduling*

Radio Duty Cycle

Radio dominates node power consumption

- Transmission and reception $\approx$ 25 mA
- Battery 2500 mAh $\rightarrow$ only 4 days lifetime
- Sleep mode $\approx$ 1 μA

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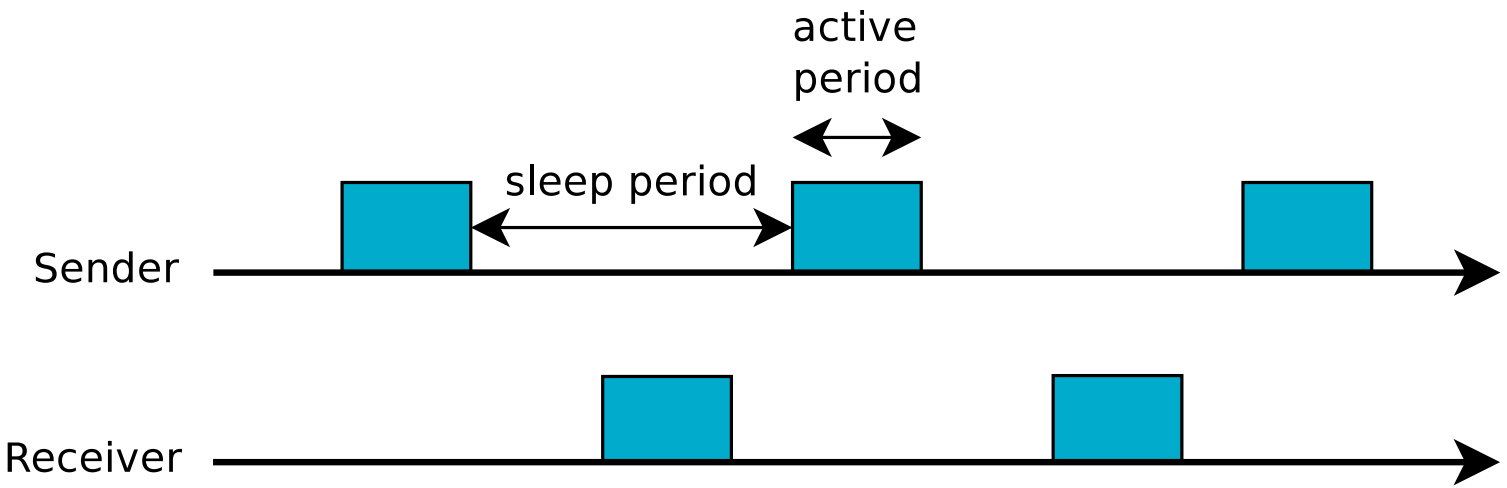
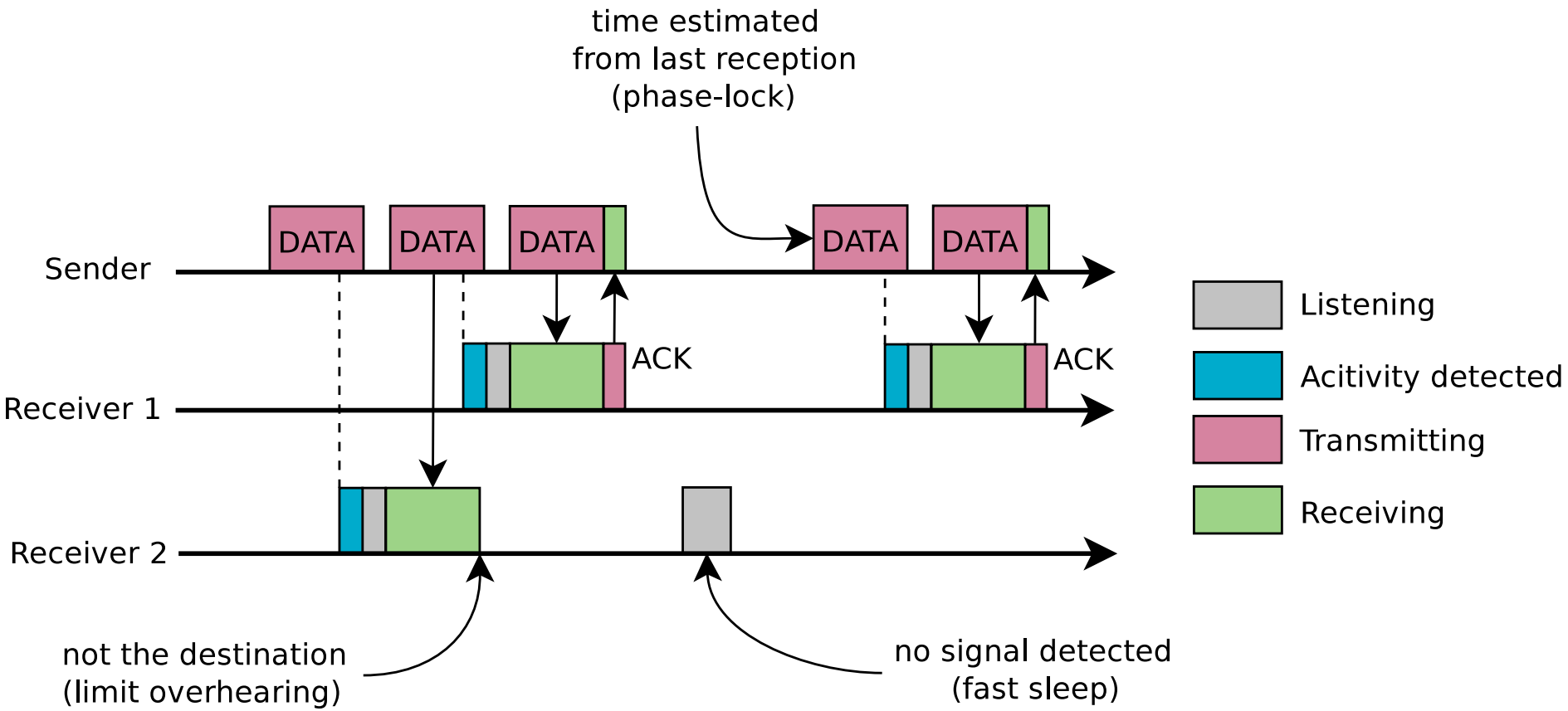
Solution : leverage the sleep mode $\rightarrow$ Radio Duty Cycle



Phase lock

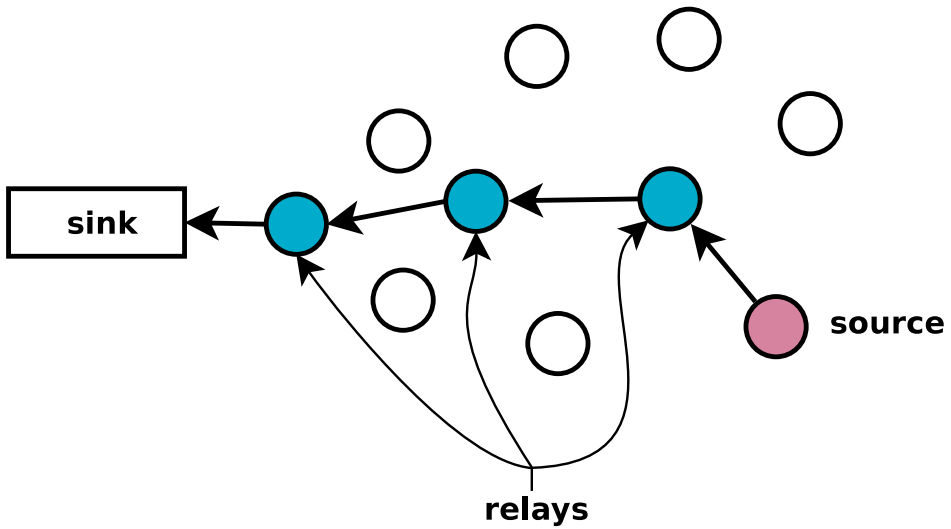
How to talk with a neighbor that sleeps 99% of time?



Multi-hop Routing

Transmit messages over longer ranges

- Low-power radio $\rightarrow$ limited range
- Nodes can act as *relay* for other nodes
- Routing $\rightarrow$ compute lowest cost paths



What is the cost of a path in WSN ?

Interoperability

How to connect these wireless nodes to Internet?

- Physical and link layer $\rightarrow$ IEEE 802.15.4
- Network layer $\rightarrow$ ZigBee or network IP (IPv6)
- Upper layers $\rightarrow$ dedicated framework, CoAP or TCP/UDP/ICMP

Source: http://compixels.com

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We use IPv6 on top of the IEEE 802.15.4 standard

Source: http://compixels.com

6LoWPAN

Network layer IPv6

- Very large number of adresses ($2^{128} \approx 3.4 \times 10^{38}$)
- Directly exposed to Internet

Problems

The IPv6 network is optimized for use with efficient links (Ethernet, Wi-Fi, ...). This poses harsh contraints on the nodes used within a wireless sensor network.

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Solution $\rightarrow$ 6LoWPAN [10]

- Adaptation layer between IPv6 and IEEE 802.15.4
- Adjust the IPv6 network to the performances of smart objects

RTOS

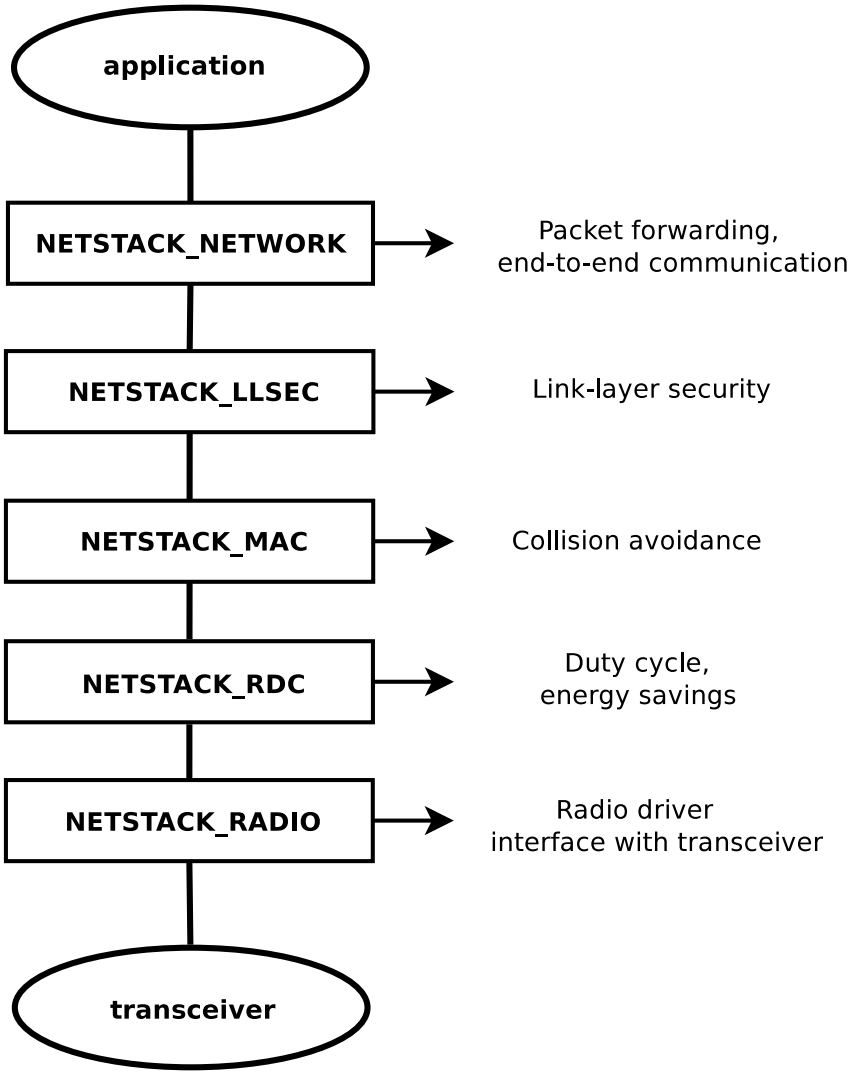
RTOS

The nodes of a wireless sensor network are programmed using specialized Real Time Operating Systems (RTOS) among which the most popular, Contiki [1] and TinyOS [2].

Example: Contiki

- Support IPv4, IPv6, 6LoWPAN, several MACs
- Lightweight network layer for IoT, RIME
- Event-driven cooperative scheduling
- Modularity
- Implemented in C

The Contiki network stack



Problems

- Limited Modularity
- Modules developed separately
- Complex code (low-level)

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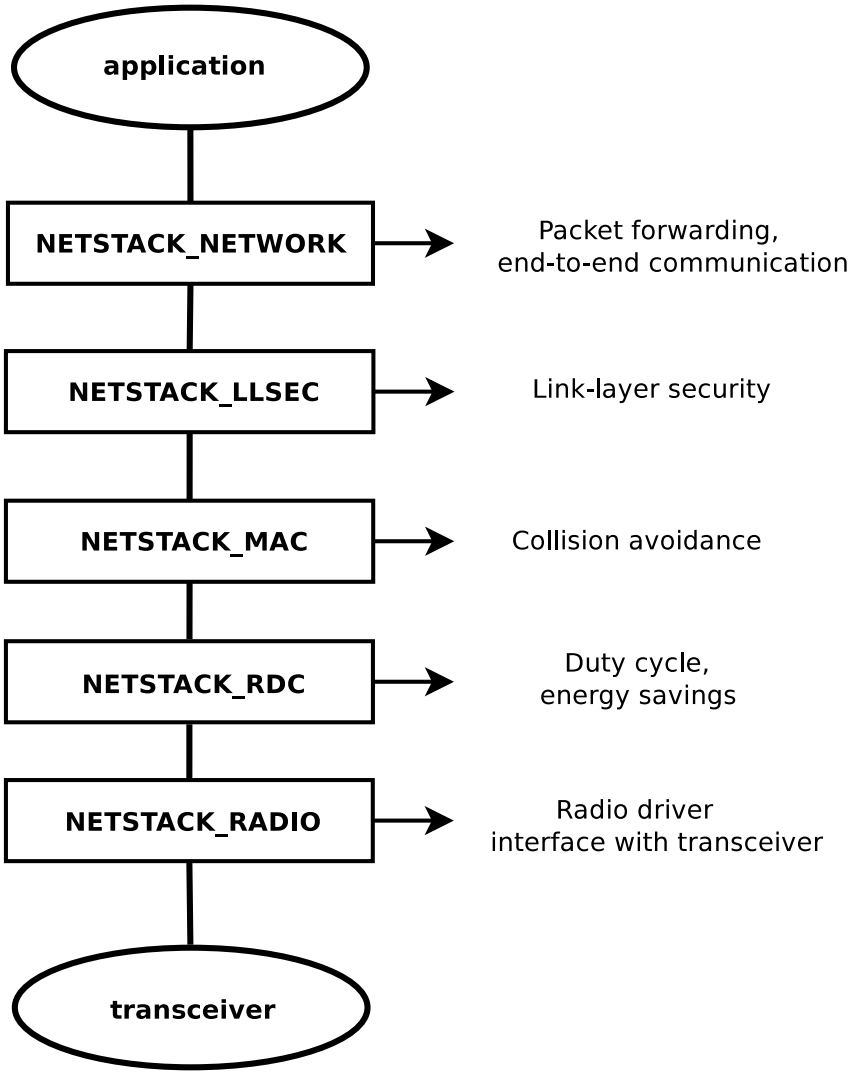

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How can we optimize?

Complexity: the RIME layer

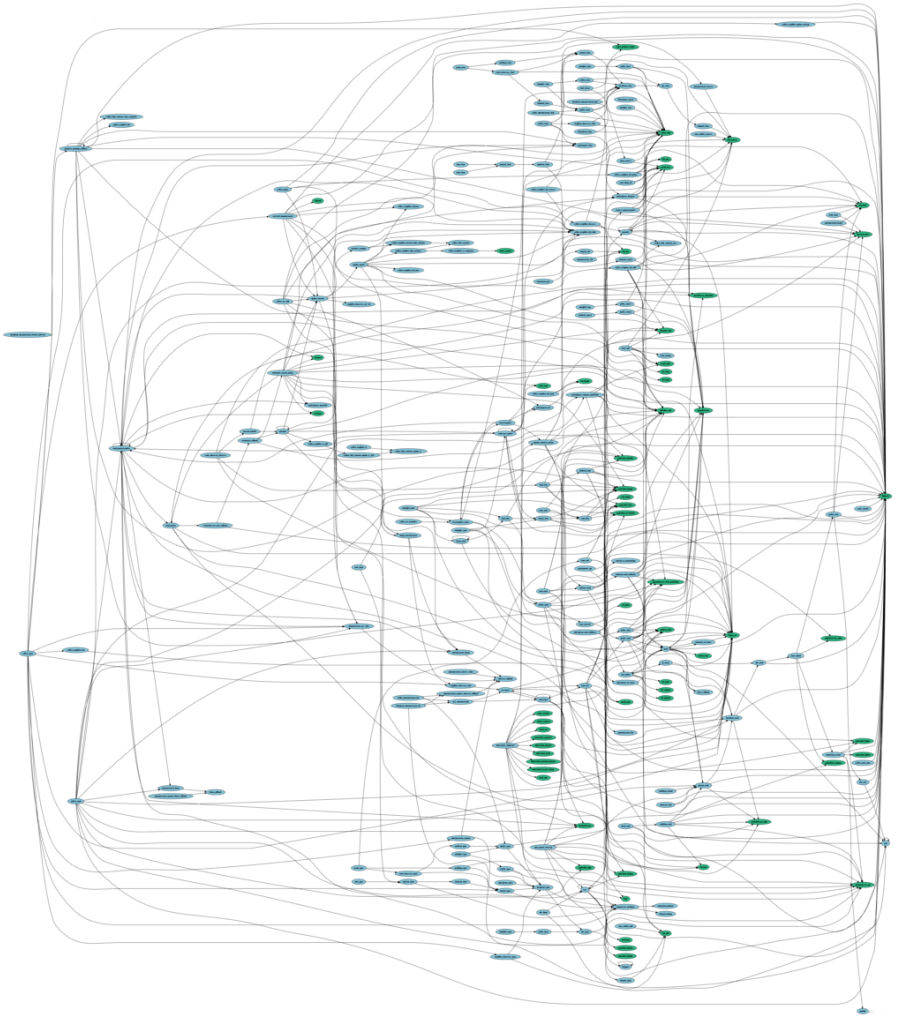


Figure: The RIME callgraph

Higher-level approach

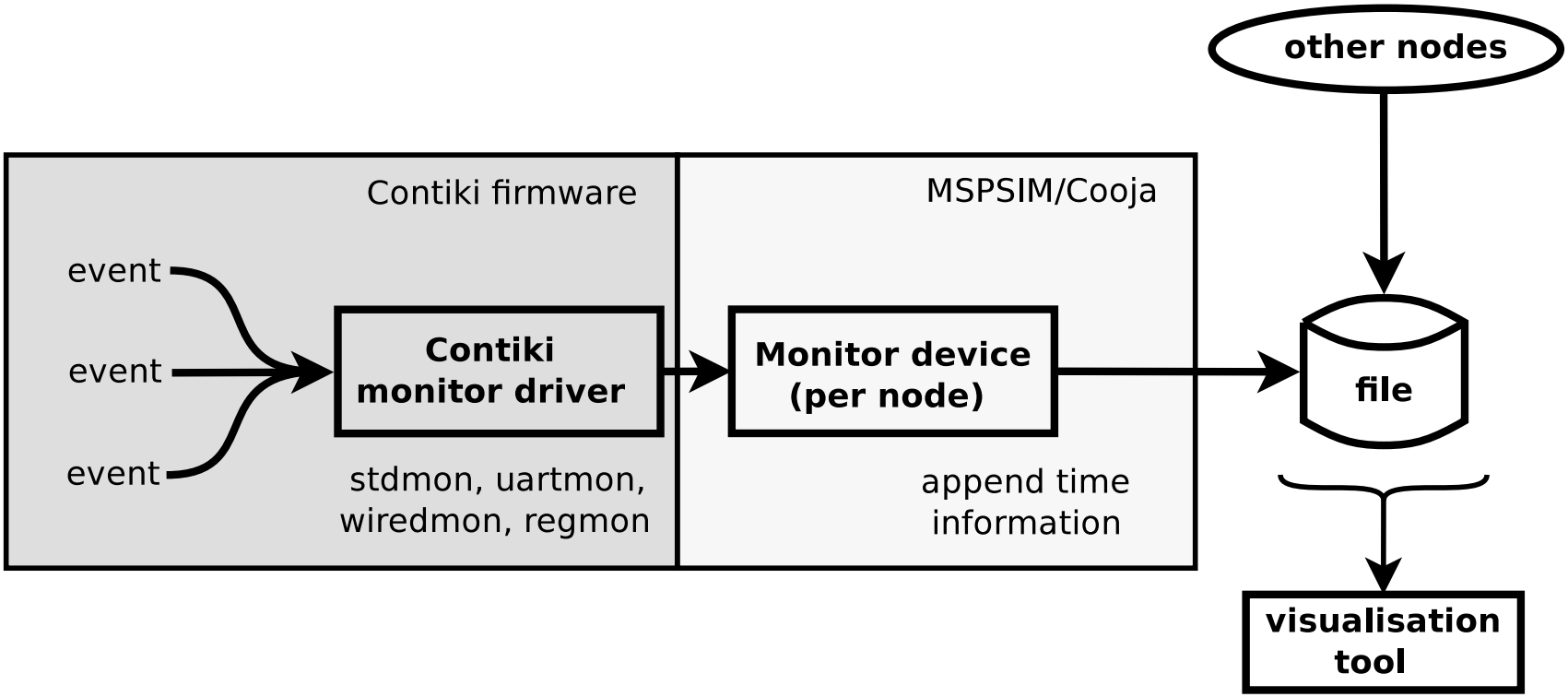
Need an inside view of the RTOS

- Monitor events in the RTOS
- Record the time of each event
- Correlation between events in different modules
- Better understanding of the network stack

Two approaches:

- *Hardware*: monitor devices changes in MSPSIM [4, 8]
- *Software*: monitor the firmware (and the netstack)

Monitor device



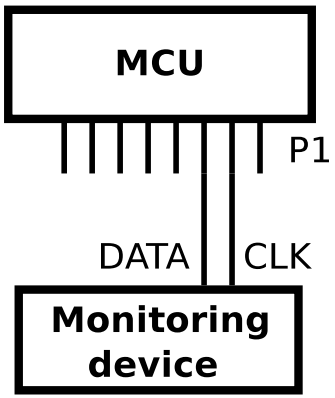
- Reference clock
- Minimize in-firmware time
- Find exact moment when an event occured

WiredMon and RegMon

Two implementations on MSP430 emulator MSPSIM

WiredMon

- Implemented like a real device
- 2-wires interface to monitoring device
- Quite slow



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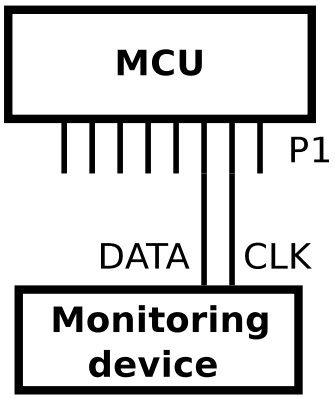
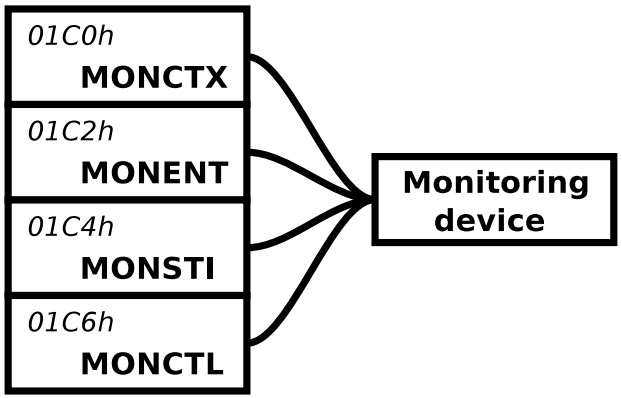
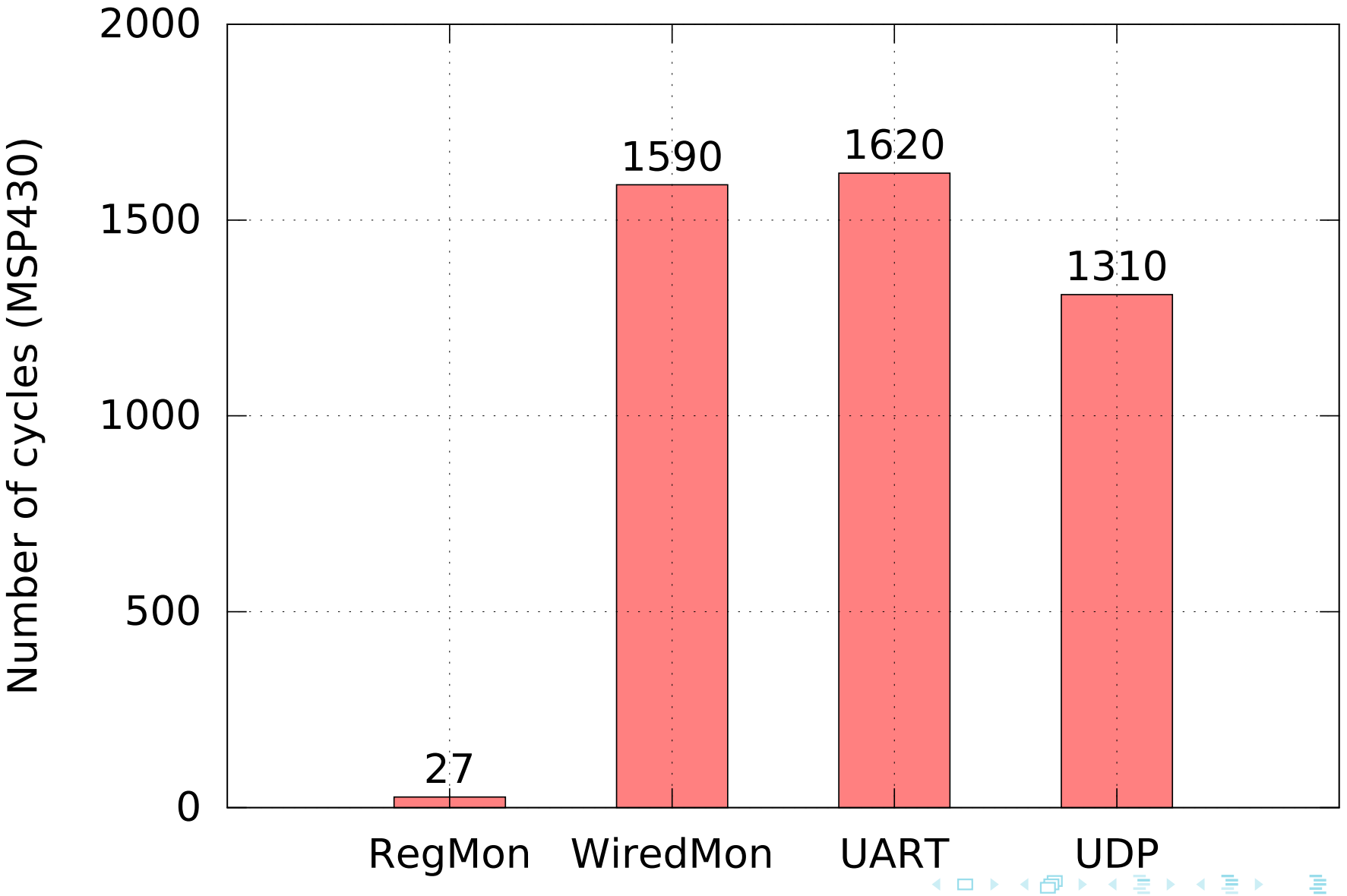


RegMon



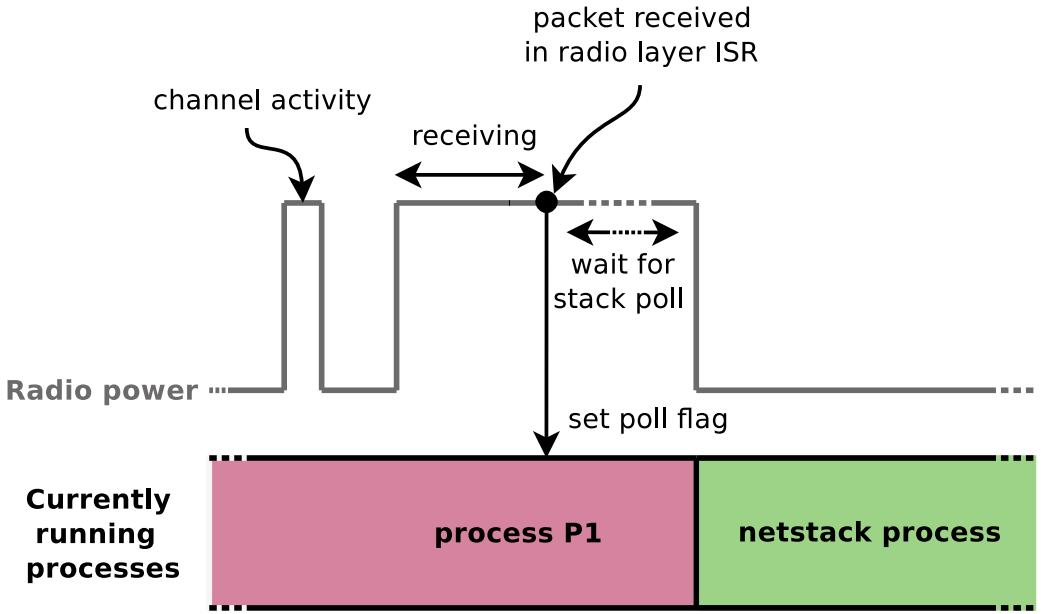
- Hack of the MSP430f1611
- 4 extra memory registers
- Really fast

Speed comparison



Example: delayed sleep

Receiving a packet in ContikiMAC



- Radio layer set poll flag on the stack process
- Poll flag checked after currently running process relinquishes CPU
- Radio stays on while currently running process still running

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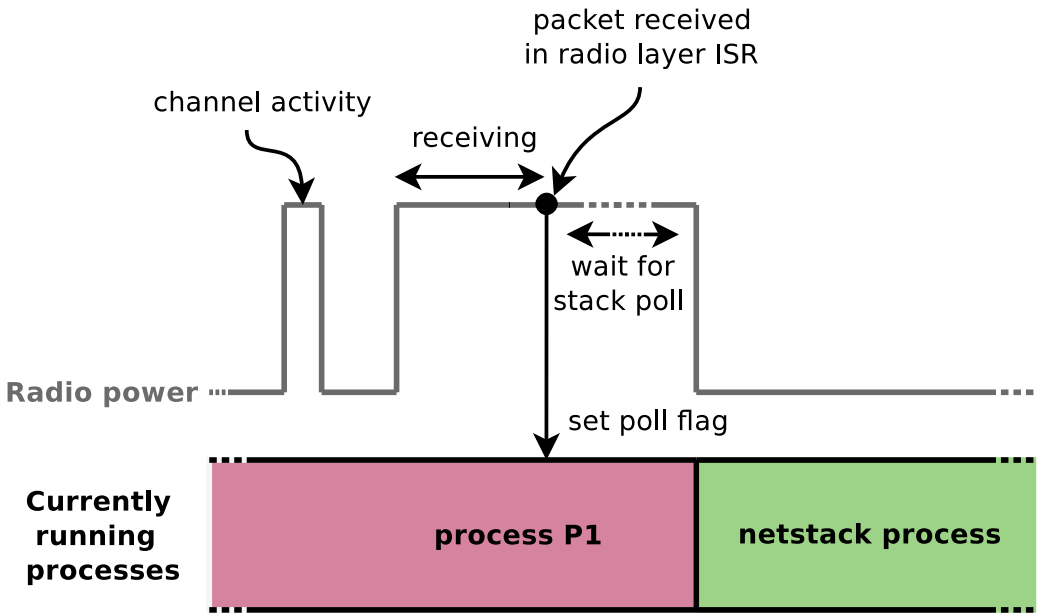

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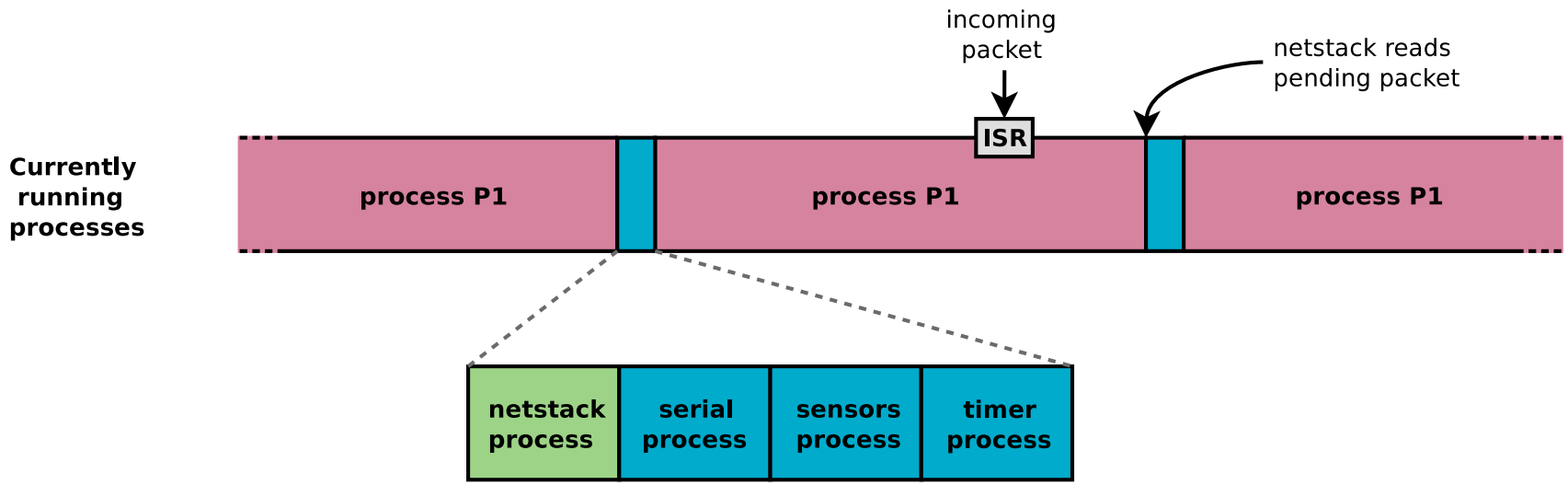
Solution $\Rightarrow$ cross layer optimization (RADIO/RDC layers)

Experiment

Delayed sleep experiment

- Two nodes: transmitter and receiver
- Transmitter sends one packet per second
- Receiver does some processing with process *P1*



Sleep delayed in average by half the working time of P1

Other optimizations

Pack short packets

- ContikiMAC imposes a lower bound on the frame size
- Short packet $\rightarrow$ padding
- Queue short packets and pack them together
- Reduce the number of transmissions

Optimistic timer

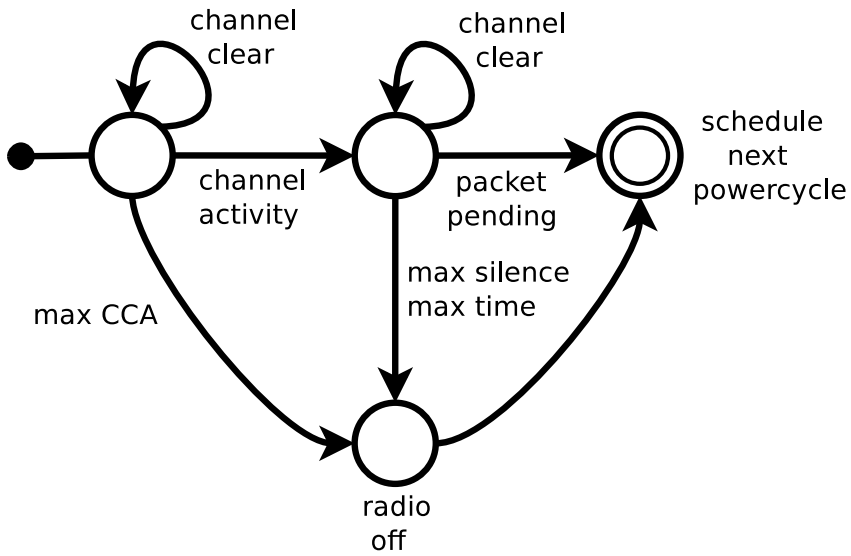
- Scheduler not aware of duty-cycle
- Trigger events at appropriate time
- Schedule timers with min/max time
- Allow the node to sleep for longer periods

Higher level approach

Monitor and visualisation tools → extract higher level model

network stack implementation (Contiki, TinyOS, ...)

extract higher level model from implementation



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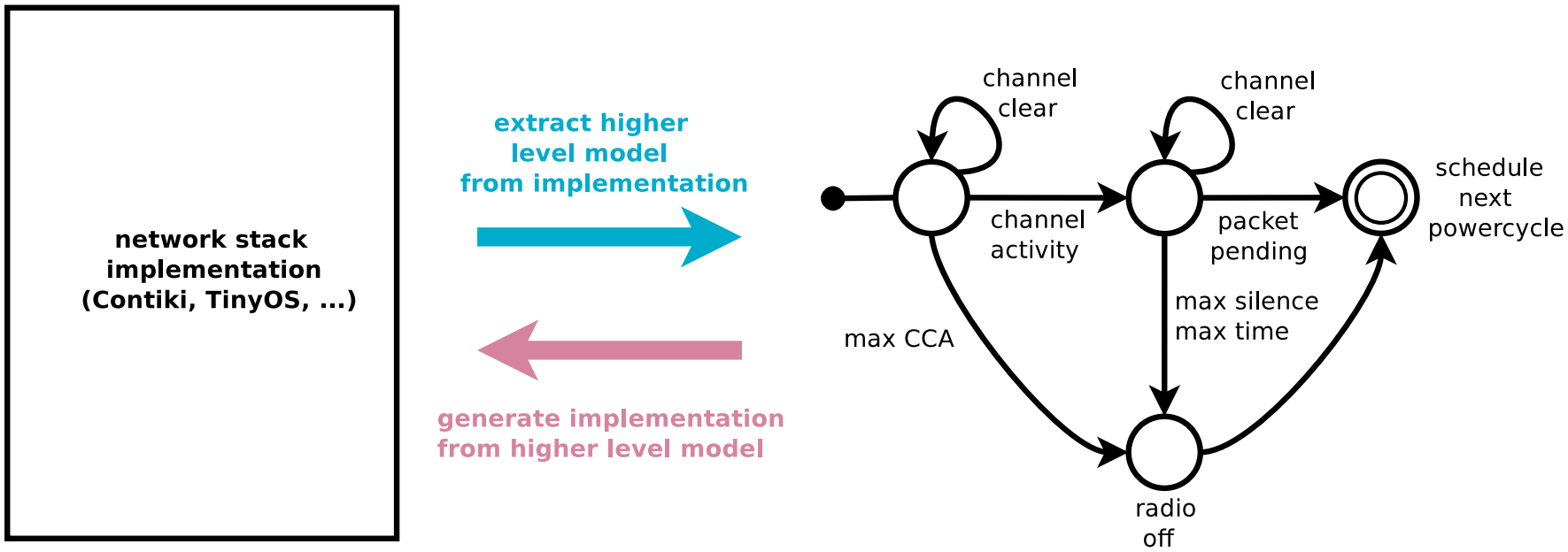

Can we generate the implementation from a higher level model ?

Conclusion

WSN

- RTOS complex and low-level
- Energy constraints
- Need a higher-level approach for netstack optimization

Monitor

- Hardware and software approach
- MSP430 emulation in MSPSIM
- RegMon approach really fast
- WiredMon for real nodes but slow
- Visualisation tools

Conclusion

Optimizations

- Possible optimizations derived from the visualisation tools
- Delayed sleep
- Short packets
- Optimistic timer

Further work

- Generate implementation from higher level model
- Derive implementations from DSLs

Conclusion

Internet of Things

- Also data mining, security, ...
- Still many technical challenges
- 50 billions devices in 2020

Chances are that you will be developing code for the Internet of Things in the future!

Questions?

- **E-Mail:**

  david.hauweele@umons.ac.be
- **Site:**

  http://www.hauweele.net/~gawen
- **Slides:**

  http://www.hauweele.net/~gawen/files/sem-umons2016.pdf

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