Peripheral State Persistence for Transiently Powered Systems

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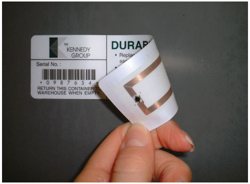
Context: *Transiently Powered Systems*

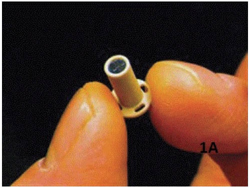
Internet of Tiny Things

- Internet of Things ▶ networked embedded systems
- no battery ▶ must harvest power from the environment

smart cards



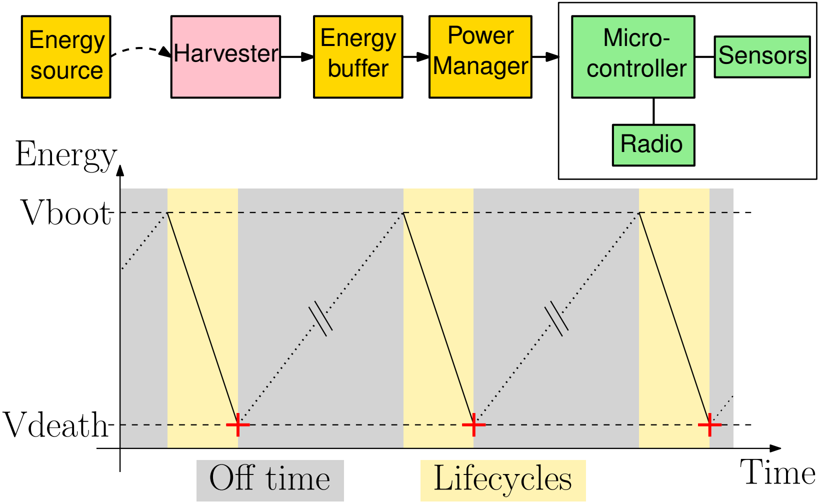
RFID tags



wearable sensors

▶ wearable computing, home automation, environment monitoring, parking assistance, supply chain control...

Transient power = frequent power failures



SW baseline: bare-metal application programming

Program=app+libs+drivers

```
ISR deviceA_interrupt()
{ ... }
ISR deviceB_interrupt()
{ ... }

void main(void){
   hardware_init();
   __enable_interrupts();
   hardware_access_1();
   compute_step_1();
   hardware_access_2();
   compute_step_2();
   ...
}
```

Application must run to completion within one “lifecycle”

Software architecture

- no OS support
- `main()` + interrupt routines + hardware accesses

Problem statement

Industrial Approach:

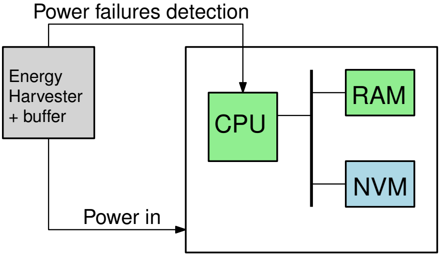
- Application software must run to completion in one lifecycle
- SW and HW are codesigned : one platform per application

How to run arbitrary code despite frequent, unexpected reboots?

Academic approach:

- Spread execution across multiple lifecycles

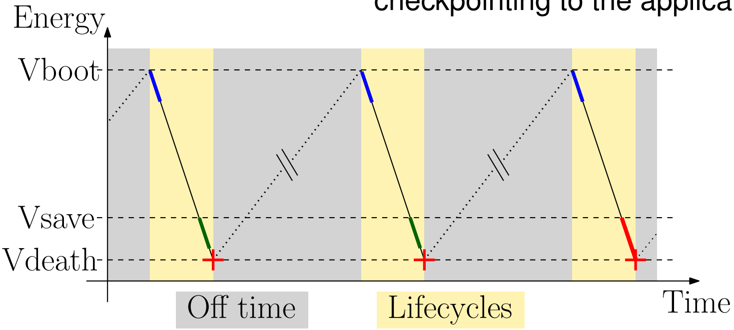
State of the art: program checkpointing



Program Checkpointing:

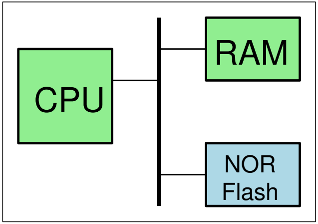
- Anticipate power failures
- Save program state to a non-volatile memory
- Restore state on next boot

▶ Idea: add “OS” code to hide checkpointing to the application



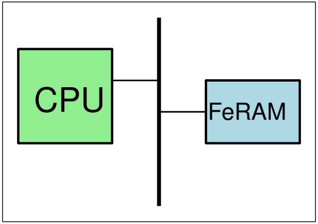
Checkpointing for Transiently Powered Systems

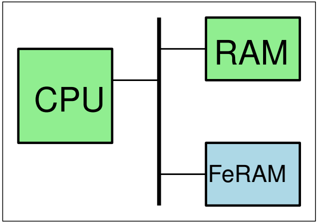
[Ransford *et al* ’13]



[Lucia & Ransford ’15]

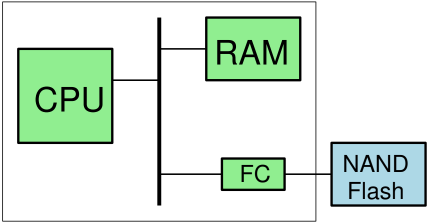
[Jayakumar *et al* ’14]





[Balsamo *et al* ’15, ’16]

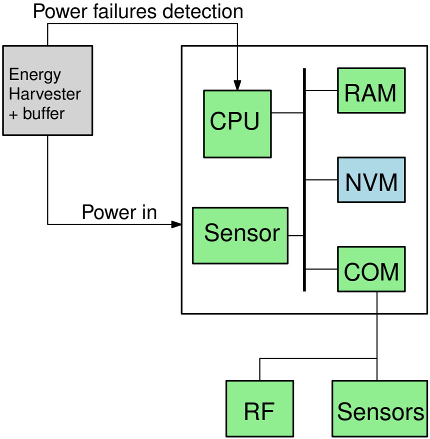
[Ait Aoudia *et al* ’14] (previous work)



[Bhatti & Mottola ’16]

Outline

This paper: Making peripherals persistent, too



Non trivial initialization

- timing, polling, ordering constraints

Non trivial access

- not mapped in memory

Most peripherals don’t support "resuming"

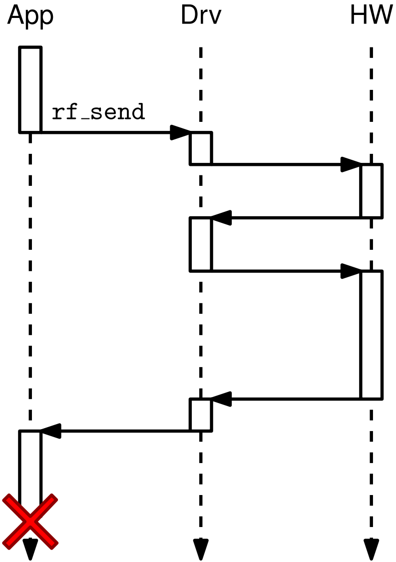
Program checkpointing is not enough

The Peripheral State Volatility Problem

Application code

```
void main(void){
   sensor_init();
   rf_init(myconfig);

   for(;;){
     v = sensor_read();
     rf_send(v);
     ...
  }
}
```



Restoring memory content will not restore device state

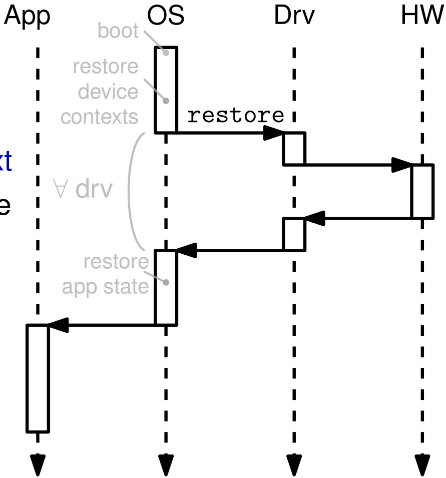
Our approach: distinct roles for OS and drivers

Each driver:

- Adds a `restore()` function

  `init()` + transitions to saved state
- Put its variables into a device context

  Description of a “restore()-able” state



Operating System:

- Persists device context
- Calls every `restore()` functions
- Persists application state

The Peripheral Access Atomicity Problem

Application code

```
void main(void){
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   rf_init(myconfig);

   for(;;){
     v = sensor_read();
     rf_send(v);
     ...
  }
}
```
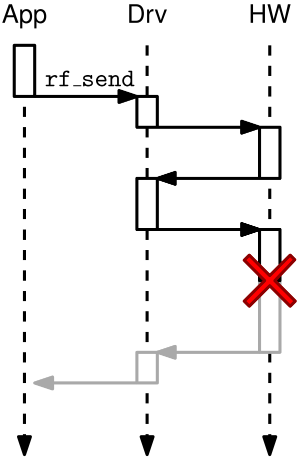



In most cases, resuming execution in the middle of a hardware access does not make sense

Our approach: make driver calls atomic

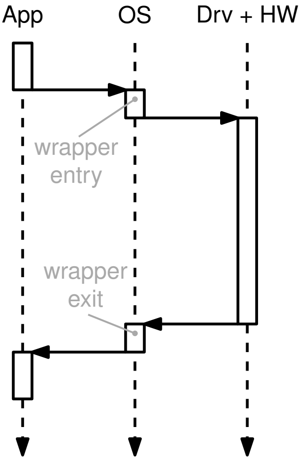
encapsulate driver functions into OS wrappers.

On wrapper entry:

- save arguments + function called
- switch to volatile stack

On wrapper exit:

- save device contexts
- clear arguments
- switch back to main stack



Interrupted driver calls are retried and not just resumed.

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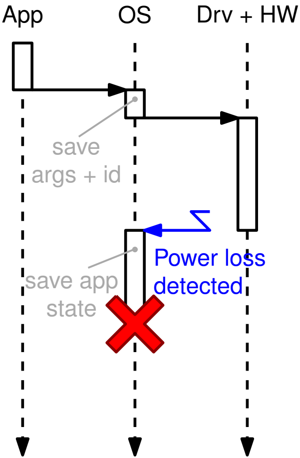
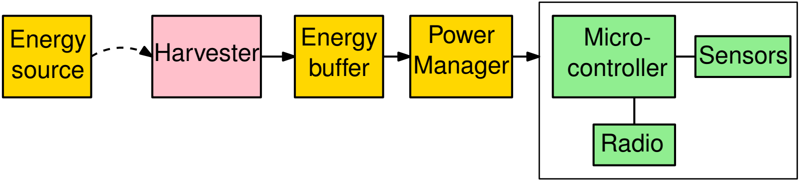


Interrupted driver calls are retried and not just resumed.

Outline

Sytare Evaluation Setup



Energy source

Harvester

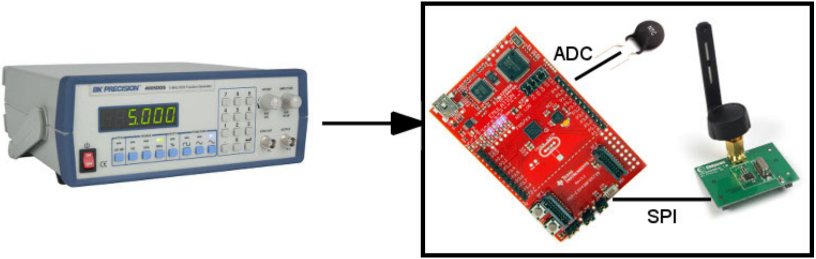
Energy buffer

Power Manager

Micro-controller

Sensors

Radio



- μcontroller: 16-bit CPU 24MHz, 1kB SRAM, 15kB FeRAM
- RF transiever: 2.4 GHz transciever, 64B packets

Sense and send example application

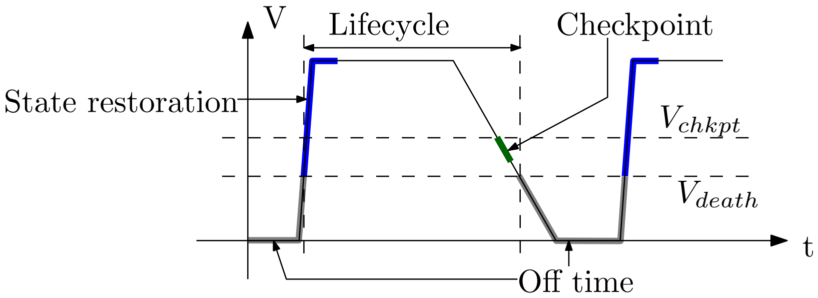
Original Application

```
void main(void){
   sensor_init();
   rf_init(myconfig);

   for(;;){
     v = sensor_read();
     compute();
     rf_send(v);
     ...
  }
}
```

Adapted Application

```
void main(void){
   syt_sensor_init();
   syt_rf_init(myconfig);

   for(;;){
     v = syt_sensor_read();
     compute();
     syt_rf_send(v);
     ...
  }
}
```

Evaluation methodology



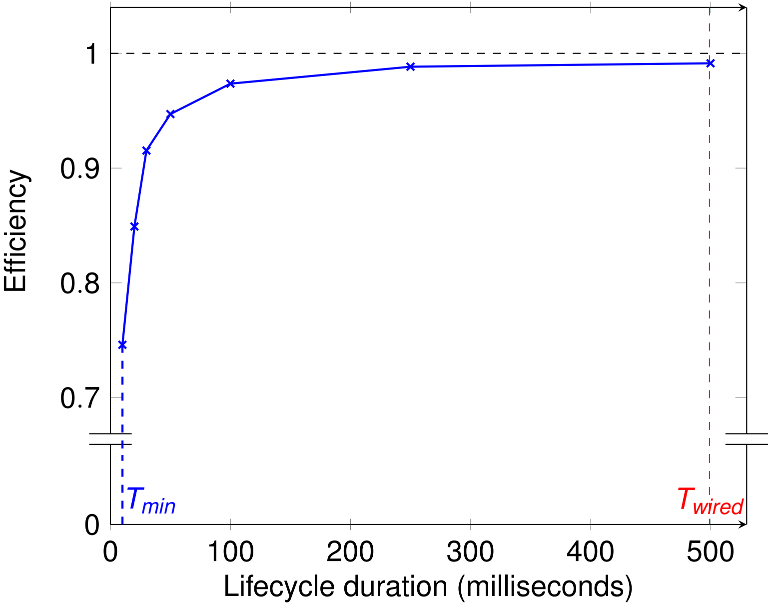
Experimental setup

- Lifecycle: ON for a duration T, then OFF (and then repeat)
- Measure efficiency for various values of T

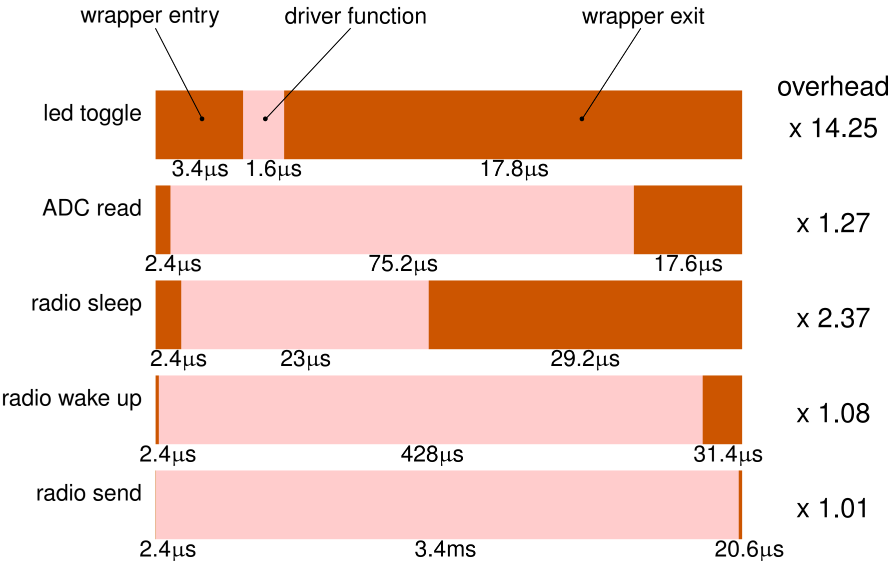
Performance metrics

- Duration of shortest usable lifecycle
- Execution temporal efficiency w.r.t. bare-metal baseline

Results for Sense and Send scenario



Results: Driver calls overhead



Outline

Introduction: Context and State of the Art

Peripheral State Persistence
  Peripheral State: Volatility Problem
  Peripheral Access: Atomicity Problem

Experimental Results

Conclusion and Perspectives

Conclusion and Perspectives

Peripheral State Persistence for Transiently Powered Systems

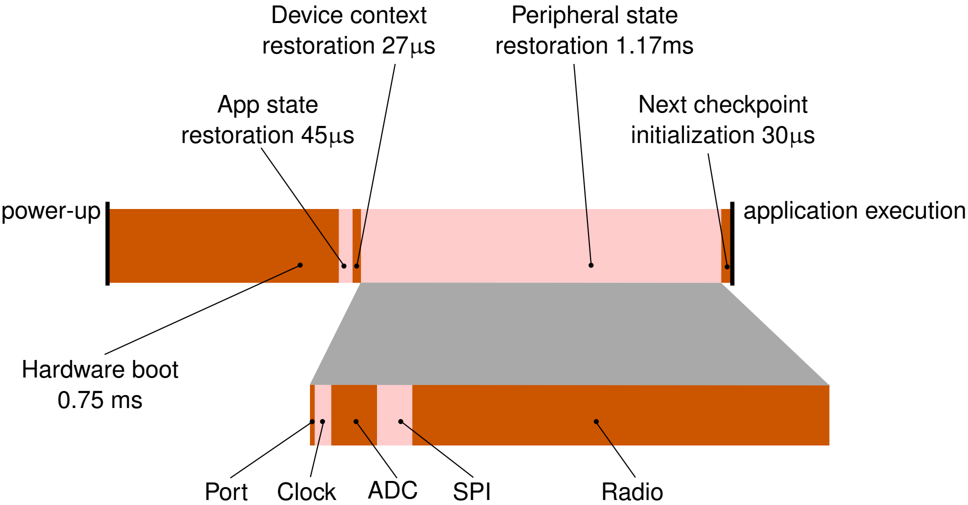
- Volatility: device contexts + `restore()` methods
- Atomicity: retry VS resume

Project sources available at: `https://gitlab.inria.fr/citi-lab/sytare`

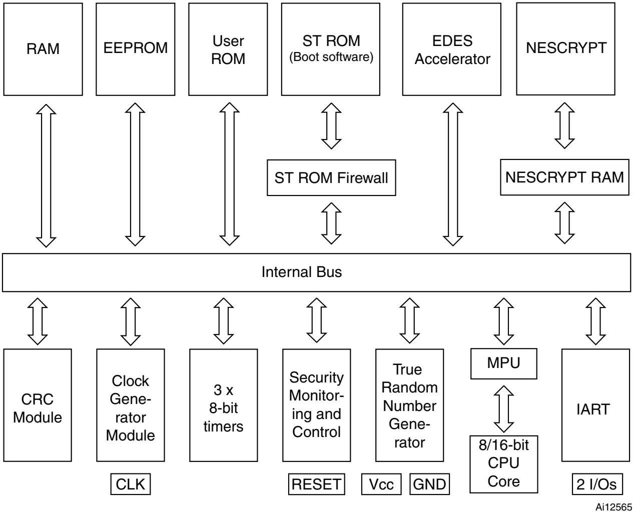
Perspectives: Look at programming abstractions for transient power

- Expose interrupts to application code
- Add delay-tolerance to driver calls
- Energy based decision making
- Design networking stacks and protocols
- Reduce overhead on driver calls

System boot sequence



TPS example architecture : ST23ZL48 microcontroller



RAM
EEPROM
User ROM
ST ROM (Boot software)
EDES Accelerator
NESCRYPT
ST ROM Firewall
NESCRYPT RAM
Internal Bus
CRC Module
Clock Generator Module
3 x 8-bit timers
Security Monitoring and Control
True Random Number Generator
MPU
8/16-bit CPU Core
IART
CLK
RESET
Vcc
GND
2 I/Os
Ai12565

- 16-bits CPU (27MHz)
- 8kB RAM
- 300kB ROM
- 48kB EEPROM

`http://www.st.com/en/secure-mcus/st23zl48.html`