Underlying

work

Project extent

Tool Chain

Protocol im-

Physical Layer Coding

Reculto

Future Work

Daisy Chain Protocol Development in Force-Guiding Particle Chains for Shape-Shifting Displays Network Protocol Implementation

Raoul Rubien rubienr@sbox.tugraz.at

Institute for Technical Informatics Graz University of Technology

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Introduction

Underlying work

Underlying work

Project extent

Tool Chain

Simulation

plementation Physical

Physical Layer Coding

Result

_ ...

What this session covers

the development tool chain simulation protocol implementation

Introduction Underlying

Underlying work

Project extent

Tool Chai

Protocol im-

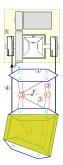
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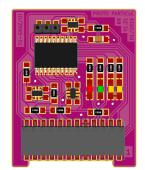
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Future Wor

Underlying work

Force-Guiding particle Chains for Shape-Shifting Displays[1] development board grid board





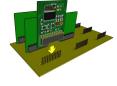


Figure 1: underlying work

Underlying work Underlying work

Project extent

Tool Chair Simulation

Physical ...

Physical Layer Coding

Results

Future Wor

Project extent

daisy chain protocol development (OSI)

Physical Layer, Data Layer, Network Layer
actuation scheduling and execution
time synchronization
runtime compensation of RC-oscillator discrepancy

Project constraints

exploit actuation wires for protocol communication single communication entry point to the network daisy chained network

Introduction
Underlying
work

work

Project exten

Approach
Tool Chai

Simulation

Physical Layer Coding

Results

F 14/...

Planning the development work flow

Aim	Solution
i) How to guarantee	by continuous testing
good code quality ? ii) How to test ?	by simulation
iii) How how to speed up	by using customized
development?	tool chain, i) and ii)

Tool Chain

The Tool Chain

Tool Chain

Tool chain overview

IDE independent multiple projects can be integrated CMake provides all necessary make targets such as deployment to real MCU and simulation targets

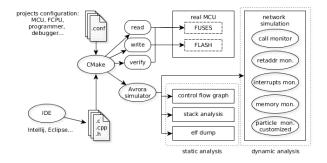


Figure 2: tool chain overview

Underlying work

Project exten

Tool Chain

Simulation

plementation

Physical Layer Coding

Result

_ ...

CMake targets in detail

CMake implementation provides various targets

```
dynamic analysis (monitoring) of:
   wires
   any SRAM register
   I/O ports
   interrupts
   function calls
   stack overflow
   statistic reports (profiling): memory writes, function calls
static analysis:
   stack maximum size
   control flow graph (code optimization)
   inspecting CPU cycles per instruction (code opt.)
```

Simulation

Introduction Underlying work

Underlying work

Project extent

Tool Chain Simulation

plementatior Physical Layer Codin

Results

Future Worl

How does a simulation framework help - I

the simulation framework simulates a whole network each node is served by a dedicated thread any node is defined by an abstract PCB model (platform) each platform is associated with the firmware, whereas the firmware is the same as for a real MCU

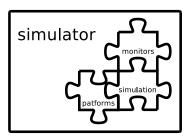


Figure 3: simulator structure

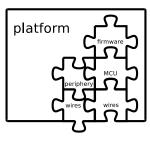


Figure 4: platform structure

How does a simulation framework help - II

the simulation output is inspected by JUnit tests interpreted by the developer used to visualize signals, wires, variables, state changes and much more

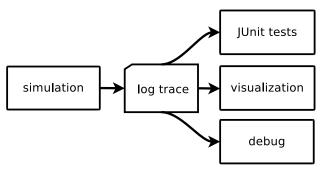


Figure 5: work flow

```
Avrora<sup>1</sup> simulation trace
may also be used in other tools such as:
   friction simulation
   network visualization
```

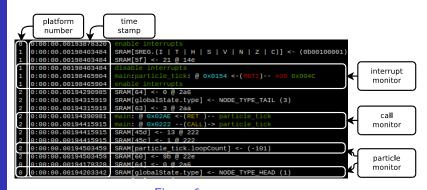


Figure 6: simulation trace

¹http://compilers.cs.ucla.edu/avrora 4 日 5 4 周 5 4 3 5 4 3 5

Trace visualization

 (2×2) network (interactive chart example [1] or [2]): wire signals, arbitrary uint8_t debug output, internal global variables

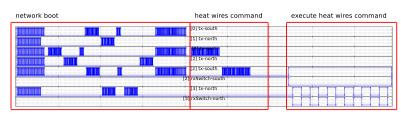


Figure 7: node visualization

Control flow graph

code otimizing helper inline vs. call prove expected inlining result

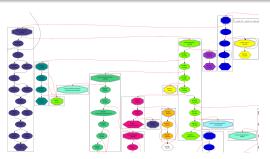


Figure 8: control flow graph snippet

square: interrupt double octagon: procedure hexagonal: blocks with return edges: jumps, branches red edges: calls dotted: indirect calls or jumps

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Underlying work

Project exten

Tool Chair

Simulation

Protocol im-

Physical Layer Codin

Results

Future Worl

Profiling

customized memory profiling interrupt profiling

```
219/218
globalState.state 5/4
                             variable particle state:
 globalState.type 2/1
                              5 writes, 4 changes
 globalState.nodeId 1/0
 globalState.northRxEvents 14/13
 globalState.southRxEvents 14/13
 globalState.flags( - | - | - | - | RECORD_RX_SOUTH | RECORD_RX_NORTH |) 1/6
 globalState.rxNorthByte1 1/0
 globalState.rxNorthByte2 1/0
 globalState.rxSouthBvte1 1/0
 globalState.rxSouthByte2 1/0
 globalState.rxBitCounter 1/0
 dirD.(D7 | D6 | STH RX | D4 | D3 | NRTH RX | D1 | D0) 0/0
 portD.(D7 | D6 | STH RX | D4 | D3 | NRTH RX | D1 | D0) 1/1
 MCUCR.(SM2 | SE | SM1 | SM0 | ISC11 | ISC10 | ISC01 | ISC00) 1/1
 dirA.(TP | STH SW | A5 | STH TX | LED | A2 | NRTH TX | NRTH SW) 1/1
 portA.(TP | STH SW | A5 | STH TX | LED | A2 | NRTH TX | NRTH SW) 175/175
 GCIR.(INT1 | INT0 | INT2 | - | - | - | IVSEL | IVCE) 2/2
 SREG.(I | T | H | S | V | N | Z | C) 115/1
1 RESET
                                                    interrupt statistics
                      43 353,5476
                                    10 232558
```

Figure 9: Avrora profiling monitors example

Code optimization helper

inspecting cycles per instruction example

```
case STATE TYPE PREPARE FOR SLEEP:
        if (ParticleAttributes.directionOrientedPorts.north.txPort->isTransmitting | |
26ca:
             e0 91 be 01
                               [LDS -> 211
                                              r30, 0x01BE
            f0 91 bf 01
26ce:
                                              r31, 0x01BF
                                IDS -> 21
26d2:
            85 85
                                              r24, Z+13
                                                               ; 0x0d
26d4:
            80 fd
                              [[SBRC -> 1/2/3]]
                                                       r24, 0
26d6:
             37 c0
                              [[RJMP -> 2]]
                                              .+110
                                                               ; 0x2746 <particleTick+0x288>
            ParticleAttributes.directionOrientedPorts.east.txPort->isTransmitting
26d8:
               91 cc 01
                              [[LDS -> 2]]
                                              r30, 0x01CC
26dc:
             f0 91 cd 01
                              [[LDS -> 2]]
                                                           SBRC @ 26d4 takes 1, 2 or 3 cpu cycles
                                              r31, 0x01CD
        break;
```

Figure 10: cycles per instruction inspection

Underlying

Underlying work

Project extent

Tool Chair

Simulation

Protocol implementation

Physical Layer Coding

Doculto

_ ...

Protocol Implementation

Recall objectives

What is needed?

A daisy chain protocol capable of executing commands synchronously at a given time using actuator wires.

Underlying

Underlying work

Project extent

Tool Chair

Protocol implementation

Physical Layer Coding

Result

Future Worl

That means roughly

- 1) Layer 0
- 2) Layer 1
- 3) Layer 2

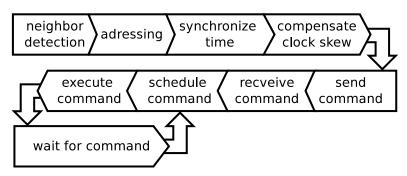


Figure 11: Layer 2: protocol process

```
Underlying
work
```

Underlying work

Project extent

A ------

Simulation

Protocol implementation

Physical Laver Coding

Danulan

Future Work

```
State driven process implementation

void main() {
    // state machine call
    while(true) { process(); }
}
```

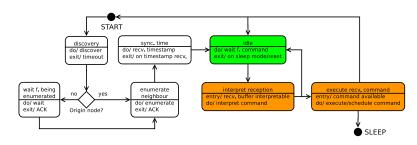


Figure 12: protocol states

Introduction Underlying work

Underlying work

Project extent

Tool Chain Simulation

Protocol implementation

Physical Layer Codin

Result

Future Worl

Firmware sequence diagram

reception, transmission and processing are independent may occur effectively concurrent

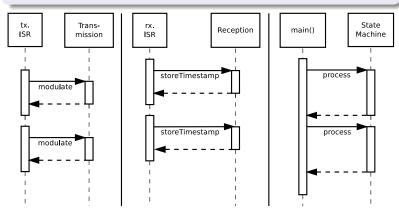


Figure 13: firmware sequence diagram

Physical Layer Coding

Encoding

opted for Manchester coding no common tx/rx clock needed can be exploited to calculate clock skew simple to implement

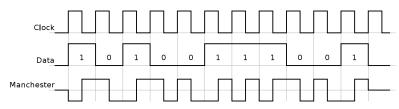


Figure 14: Manchester coding: $data = clock \oplus manchester$

Project extent

Tool Chair

Protocol implementation

Physical Layer Coding

Result

Future Work

Decoding implementation

store timestamp of signal flank

to circular buffer

timestamp: 16bit timer-counter value

decoder removes from buffer, stores to decoded buffer

interpreter: interprets on interpret-able decoded buffer

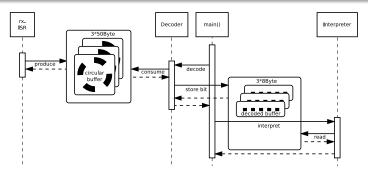


Figure 15: decoding sequence diagram

Physical Layer Coding

Network boot example

 1^{st} phase: neighbor discovery 2^{nd} phase: address assignment 3^{rd} phase: enumeration finished 4^{th} phase: time synchronization

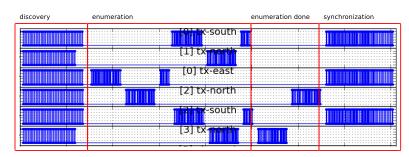


Figure 16: network boot visualization

Physical Layer Coding

Addressing example

1st phase: network discovery and address assignment 2^{nd}

send "heat wires at specific time" command phase:

3rd phase: execute command

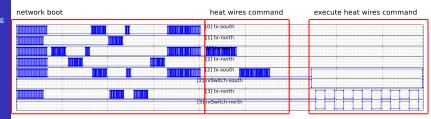


Figure 17: "execute command" network visualization

Underlying work

work

Project exten

Tool Chair Simulation

Physical

Layer Codir

Results

Future Worl

Results

- i) An extend-able daisy chain network protocol that
- ii) executes actuation commands at a given time synchronously, and
- iii) a development tool chain that sustains:
- iii.a) simulation,
- iii.b) debugging and
- iii.c) JUnit testing.

Underlying

Underlying work

Project exten

Approac

Tool Chair Simulation

Protocol implementation

Physical Layer Codin

Results

Future Worl



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Underlying

Underlying work

Project exten

Tool Chair Simulation

Physical

Layer Coding

Results

Future Work

Future work

Phy. Layer: considering partially implemented parity bit

Network Layer: fault detection, fault tolerance actuation: power adjustment (PWM tuning)

time commencetion, and notion of collegation of

time compensation: evaluation of calibration accuracy

firmware replication: customize boot loader

forward/backward shaping of 1st row

Introduction

Underlying work

Underlying work

Project exten

Approac

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Protocol im-

Physical Layer Coding

Results

Future Work



M. Lasagni and K. Römer, "Force-guiding particle chains for shape-shifting displays," *CoRR*, vol. abs/1402.2507, 2014.