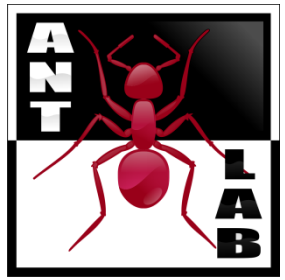
Politecnico di Milano

Advanced **N**etwork **T**echnologies **Lab**oratory



Internet of Things

Hands on activities

Calendar

- March 18 - TinyOS 1 + **Home challenge #1**
- March 25 - TinyOS 2 + **Home challenge #2**
- April 15 - CoAP
- April 28 - MQTT + **Home challenge #3**
- May 5 - Node-RED + **Home challenge #4**
- May 13 - IoT pipeline + **Home challenge #5**

- Edoardo Longo
- DEIB Building 20 - Ground Floor - ANTLab

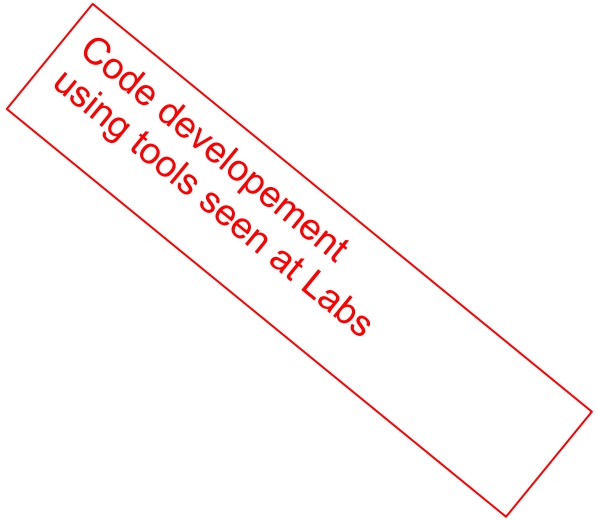
- Email: edoardo.longo@polimi.it
- Phone: 02 2399 9614

Classes Objective

- Giving you an overview on the software used in the IoT community
- Stimulating your curiosity
- Providing you with basic tools to develop simple IoT applications
- Classes time is limited -> Play with these tools on your own!
- Use the forum

Projects

- Home projects
  - Home assignment
  - Delivery approx in 1 week
  - Groups of max 3 students



- Final project
  - Home assignment
  - Delivery within the end of June/July exam session
  - Groups of max 3 students

Grading

- **Grade Composition**
  - Written Exam: up to 25 points (75%)
  - Home/Classes projects: up to 5 points (15%)
  - Final project: up to 3 points (10%)

Project info

- Team must work remotely
- Github, bitbucket, gitlab, etc. are strongly encouraged and appreciated

Project info

- The team can change during the semester
- If you don’t have one, use the forum to find a mate
- Grade if you’re alone is the same if you’re together

Hands On Activities

- Operating Networks of Embedded Devices
  - Playing with TinyOS/NesC
  - Playing with CoAP/MQTT
  - Playing with ThingSpeak/NodeRed
- Calendar

  (TBD, keep checking web site!)

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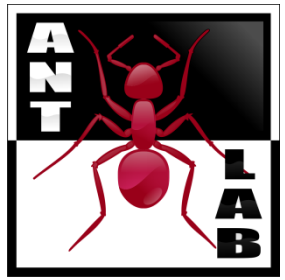

TinyOS

Agenda

- Playing with TinyOS
  - Programming and components
  - Blink Application
- Using the Radio
  - RadioCountToLeds Application

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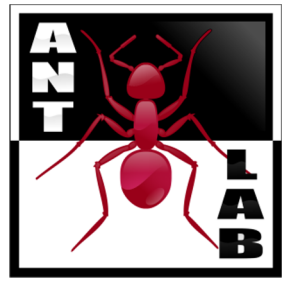
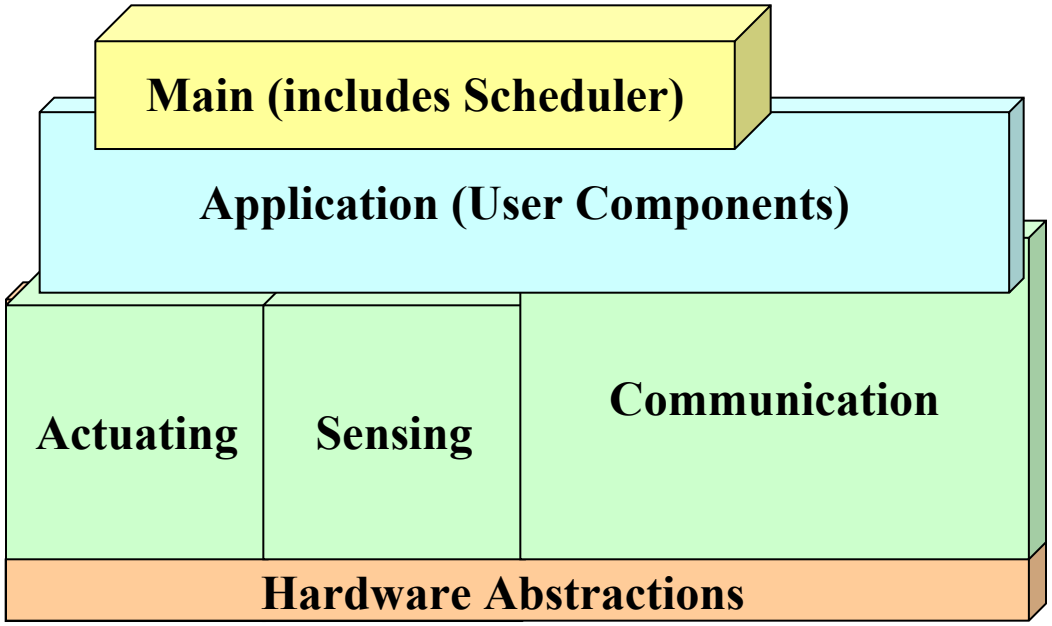


"TinyOS is an *open-source operating system* designed for *wireless embedded sensor networks*"

http://www.tinyos.net/

TinyOS Overview

- Event-driven architecture
  - OS operations are triggered by hardware interrupt (asynchronous management)
- Single shared stack -> no dynamic allocation
- No kernel/user space differentiation



TinyOS "Ingredients"

- TinyOS is not an OS in traditional sense
- Provides a programming framework to build application-specific OS instances
- Programming Framework made of:
  - Scheduler (always there)
  - Components
  - Interfaces

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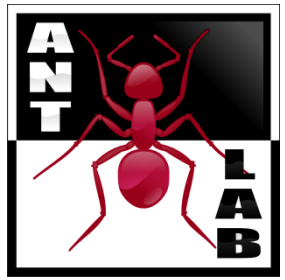


Internet of Things

TinyOS Programming and Cooja

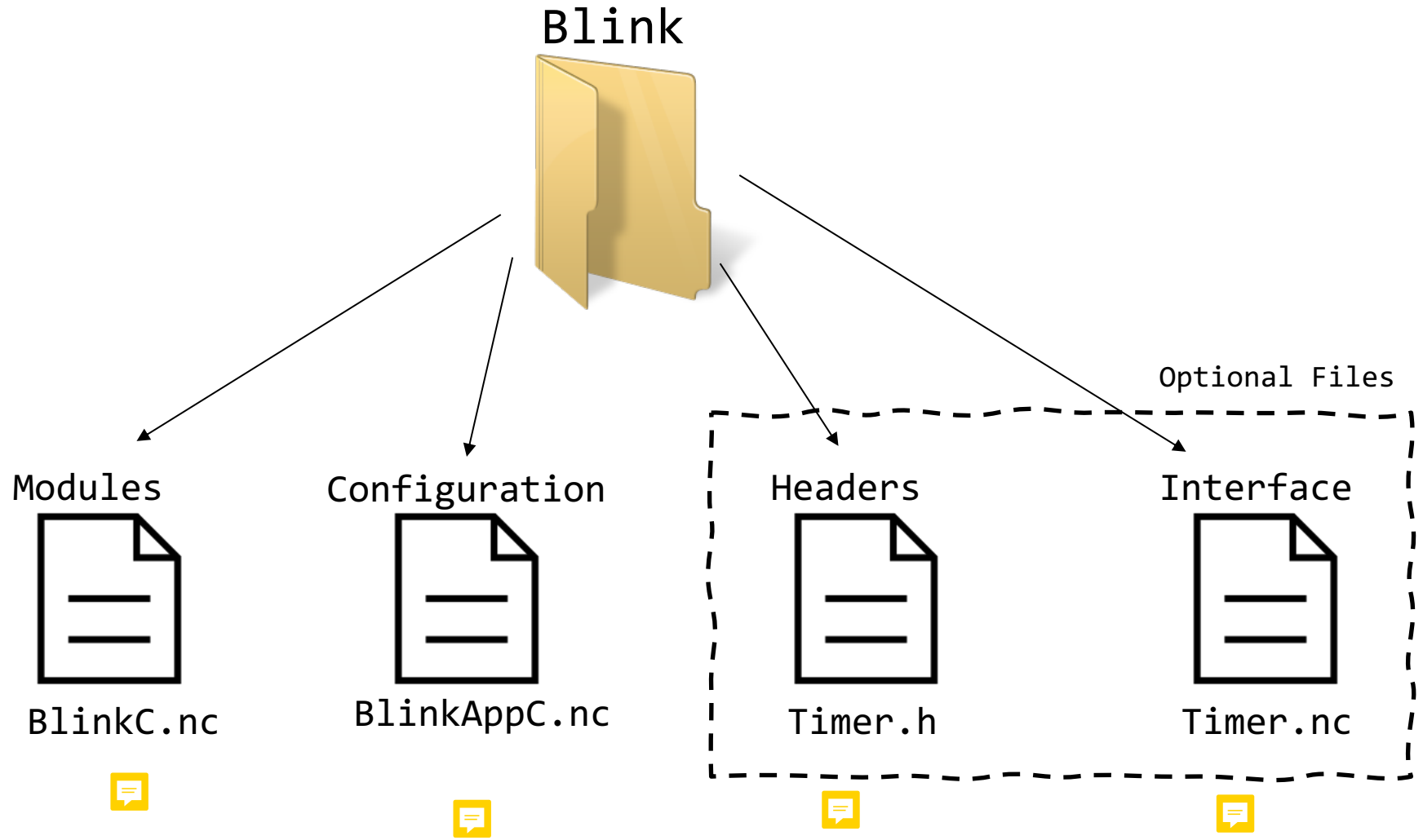
Programming TinyOS

- TinyOS is written in a C "dialect" *nesC*

http://csl.stanford.edu/~pal/pubs/tinyos-programming.pdf

- Provides syntax for TinyOS concurrency and storage model
  - commands, events, tasks
  - local frame variable
  - static memory allocation
  - no function pointers
- Applications:
  - just additional components composed with the OS components

Folder structure



Components

- Modules (*BlinkC.nc* files)
  - provide code that implements one or more interfaces and internal behavior
- Configuration (*BlinkAppC.nc* files)
  - link together components to yield new component
- Headers (*Timer.h* files)
  - Define parameters
- *Interface* (*Timer.nc* files)
  - logically related set of commands and events

StdControl.nc

```
interface StdControl {
command result_t init();
command result_t start();
command result_t stop();
}
```

Timer.nc

```
interface Timer {
 command result_t start(char type,uint32_t
interval);
 command result_t stop();
 event result_t fired();}
}
```

Applications in TinyOS

- Configurations *(BlinkAppC.nc)*:
  - Used to configure applications
  - Used to wire components through interfaces
- Modules *(BlinkC.nc)*:
  - Used to implement components, call commands, events, and tasks.

Example 2: Blink

- Operation: the application keeps three timers at 1 [Hz], 2 [Hz] and 4 [Hz], upon timer expiration a LED is toggled.

- Application Files:
  - BlinkAppC.nc, configuration
  - BlinkC.nc, module

Blink Application - Demo

- Test applications are in tiny-os/apps
- Compile the code for real-motes platforms
  - Open the terminal and move to the code folder (cd tiny-os/apps/Blink
    - Compiling commands:
      - **`make micaz`**

        or
      - **`make telosb`**
    - **`Telosb and Micaz are two different type of motes`**
      - Look at the *makefile* for more information

BlinkC.nc

```
#include "Timer.h"

module BlinkC {
     uses interface Leds;
     uses interface Boot;
     uses interface Timer<TMilli> as Timer0;
     uses interface Timer<TMilli> as Timer1;
     uses interface Timer<TMilli> as Timer2;
}
implementation {
     event void Boot.booted() {
          call Timer0.startPeriodic( 250 );
          call Timer1.startPeriodic( 500 );
          call Timer2.startPeriodic( 1000 );
     }
     event void Timer0.fired() {
          call Leds.led0Toggle(); }
     event void Timer1.fired() {
          call Leds.led1Toggle(); }
     event void Timer2.fired() {
          call Leds.led2Toggle(); }
}
```

Used Interfaces

Timer Initialization

Events of timer expiry

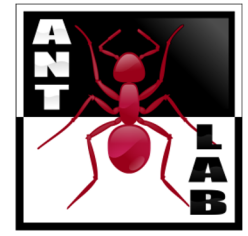
Note:
- NO interfaces provided to other components
- NO commands defined
- NO tasks needed

BlinkAppC.nc

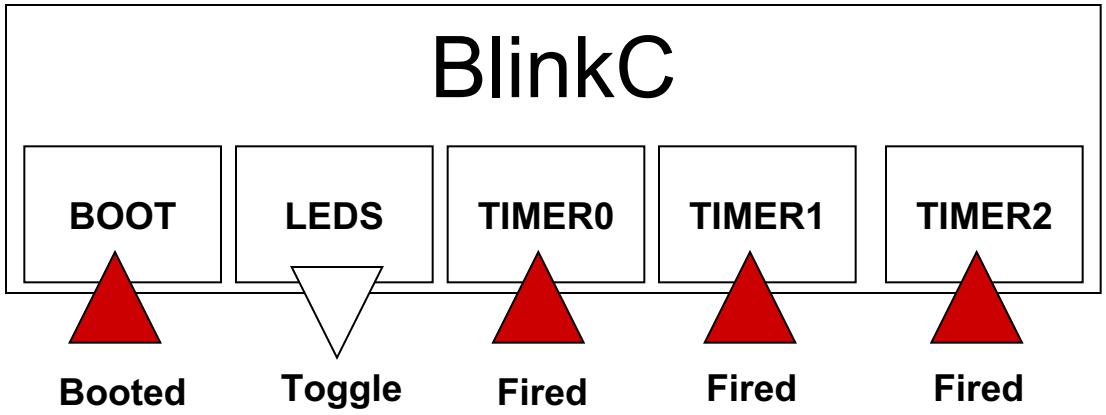
```
configuration BlinkAppC {
}
Implementation {
    components MainC, BlinkC, LedsC;
    components new TimerMilliC() as Timer0;
    components new TimerMilliC() as Timer1;
    components new TimerMilliC() as Timer2;

    BlinkC.Boot -> MainC.Boot;
    BlinkC.Timer0 -> Timer0;
    BlinkC.Timer1 -> Timer1;
    BlinkC.Timer2 -> Timer2;
    BlinkC.Leds -> LedsC;
}
```

List of components implementing Blink applications

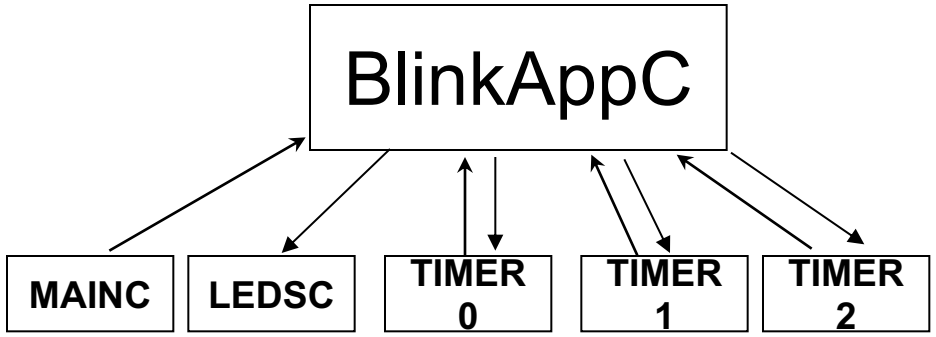
Components Wiring



Blink – Interfaces, Events and Commands



BlinkC interfaces:
- Fired and Booted events
- Toggle command



BlinkAppC components:
- TimerN.Timer and MainC.Boot
- LedsC.Toggle

Documentation

- The best way to understand which module must be used is check the documentation

- Documentation path in the VM:

`tiny-os/main/doc/nes/telosb/index.html`

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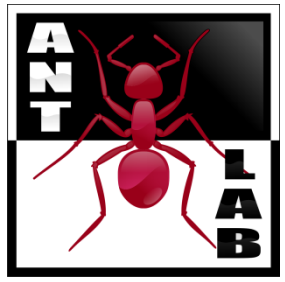

WSN Simulation

Using Cooja

WSN simulation: why?

- WSN require large scale deployment
- Located in inaccessible places
- Apps are deployed only once during network lifetime
- Little room to re-deploy on errors

TinyOS Blink on Cooja

- Compile blink for Telosb
  - make telosb
- Open Cooja and create a new simulation
- Create a new Sky mote
- Select the main.exe file as firmware (located in the Blink build/telosb directory) and create the mote
- Watch the leds blink!

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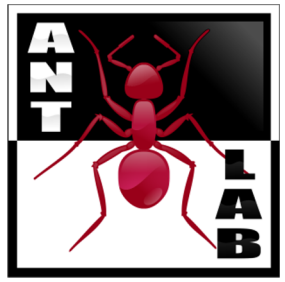
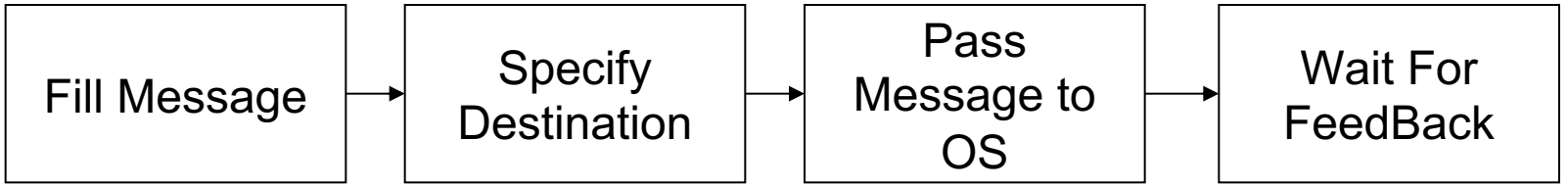


Using the Radio

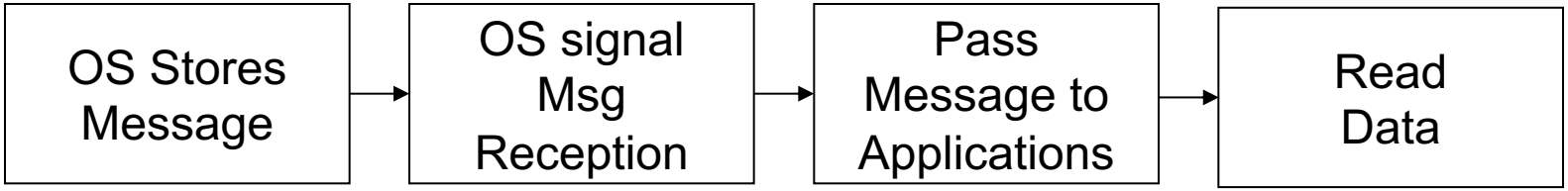
Creating/Sending/Receiving/Manipulating Messages

General Idea

SENDER



RECEIVER



Message Buffer Abstraction

- In tos/types/messages.h

```
typedef nx_struct message_t {
   nx_uint8_t header[sizeof(message_header_t)];
   nx_uint8_t data[TOSH_DATA_LENGTH];
   nx_uint8_t footer[sizeof(message_header_t)];
   nx_uint8_t metadata[sizeof(message_metadata_t)];
} message_t;
```

- Header, footer, metadata: already *implemented* by the specific link layer
- Data: *handled* by the application/developer

Message.h


```
#ifndef FOO_H
#define FOO_H

typedef nx_struct FooMsg {
      nx_uint16_t field1;
      nx_uint16_t field2;
      ….
      nx_uint16_t field_N;
    } FooMsg;

enum { FOO_OPTIONAL_CONSTANTS = 0 };

#endif
```

Header and Metadata


```
typedef nx_struct cc2420_header_t {
    nxle_uint8_t length;
    nxle_uint16_t fcf;
    nxle_uint8_t dsn;
    nxle_uint16_t destpan;
    nxle_uint16_t dest;
    nxle_uint16_t src;
    nxle_uint8_t network; // optionally included with 6LowPAN
    layer
    nxle_uint8_t type;
} cc2420_header_t;

typedef nx_struct cc2420_metadata_t {
    nx_uint8_t tx_power;
    nx_uint8_t rssi;
    nx_uint8_t lqi;
    nx_bool crc;
    nx_bool ack;
    nx_uint16_t time;
} cc2420_metadata_t;
```

Interfaces

- Components above the basic data-link layer MUST always access packet fields through interfaces (in /tos/interfaces/).

- Messages interfaces:
  - AMPacket: manipulate packets
  - AMSend
  - Receive
  - PacketAcknowledgements (Acks)

Sender Component

- AMSenderC

```
generic configuration AMSenderC(am_id_t id)
{
    provides {
        interface AMSend;
        interface Packet;
        interface AMPacket;
        interface PacketAcknowledgements as Acks;
    }
}
```

Receiver Component

- AMReceiverC

```
generic configuration AMReceiverC(am_id_t id)
{
    provides{
        interface Receive;
        interface Packet;
        interface AMPacket;
    }
}
```

An Example - RadioCountToLeds

- Create an application that counts over a timer and broadcast the counter in a wireless packet.

What do we need?

- Header File: to define message structure (RadioCountToLeds.h)
- Module component: to implement interfaces (RadioCountToLedsC.nc)
- Configuration component: to define the program graph, and the relationship among components (RadioCountToLedsAppC.nc)

Message Structure

- Message structure in RadioCountToLeds.h file

```
typedef nx_struct radio_count_msg_t {
    nx_uint16_t counter;  //counter value
} radio_count_msg_t;

enum {
    AM_RADIO_COUNT_MSG = 6, TIMER_PERIOD_MILLI = 250
};
```

Module Component

1. Specify the interfaces to be used
2. Define support variables
3. Initialize and start the radio
4. Implement the core of the application
5. Implement all the events of the used interfaces

Module Component

- Define the interfaces to be used:

```
module RadioCountToLedsC
{
    uses interface Packet;
    uses interface AMSend;
    uses interface Receive;
    uses interface SplitControl as AMControl;
}
```

Packet Manipulation Interfaces

Control interface

- Define some variables:

```
implementation {
    message_t packet;
    bool locked; ...
}
```

Local Variables

Initialize and Start the Radio

```
event void Boot.booted() {
    call AMControl.start();
    }


event void AMControl.startDone(error_t err) {
    if (err == SUCCESS) {
        call MilliTimer.startPeriodic(TIMER_PERIOD_MILLI
    ); }
    else {
        call AMControl.start(); }
    }

event void AMControl.stopDone(error_t err) { }
```

Events to report
Interface Operation

Implement the Application Logic

```
event void MilliTimer.fired() {
    ...
    if (!locked) {
    radio_count_msg_t* rcm = (radio_count_msg_t*)call
    Packet.getPayload(&packet,
    sizeof(radio_count_msg_t));

    rcm->counter = counter;

    if (call AMSend.send(AM_BROADCAST_ADDR, &packet,
    sizeof(radio_count_msg_t)) == SUCCESS) {
        locked= TRUE; }
    }
}
```

Creates and Set Packet

Send Packet

Implement Events of Used Interfaces


```
event void AMSend.sendDone(message_t* msg, error_t error
{
    if (&packet == msg) {
        loked = FALSE;
    }
}
```

Must implement the events referred to all the interfaces of used components.

And What About Receiving?

- We need a Receive interface

```
uses interface Receive;
```

- We need to implement an event Receive handler

```
event message_t* Receive.receive(message_t* msg, void* payload, uint8_t
    len) {
    if (len == sizeof(radio_count_msg_t)) {
        radio_count_msg_t* rcm= (radio_count_msg_t*)payload;
        call Leds.set(rcm->counter);
    }
    return msg;
}
```

- We need to modify the configuration component

```
implementation {
... components new AMReceiverC(AM_RADIO_COUNT_MSG); ... }
implementation {
... App.Receive -> AMReceiverC; ... }
```

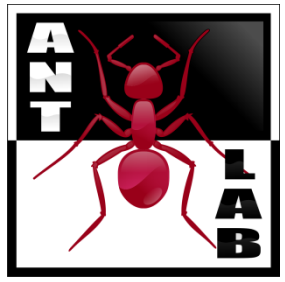
Configuration File


```
implementation {

...
components ActiveMessageC;
components new AMSenderC(AM_RADIO_COUNT_MSG);

...

App.Packet -> AMSenderC;
App.AMSend -> AMSenderC;
App.AMControl -> ActiveMessageC;
...

}
```

RadioCountToLeds - Demo

- Let’s have a look at the files
- Let’s see how it works
- Let’s try to turn off a device

- Can you do that in Cooja?



Challenge

Home challenge #1: TinyOS

Homework Rules

- Max 3 people in a group
- Deadline: Friday, March 22 - 23:49
- Score: max 1 point
- Max 3 people
- Submit through beep «Homework/Activity 1» folder
- Don’t cheat ☺

Challenge deliverable

- Zip content:
  - Source code folder:
    - fooC.nc
    - fooAppC.nc
    - foo.h
    - Other files, if needed
  - Small project report (max 2 pages)
  - Your names + ID number/matricola on top of the report
  - Repository link (if used)

Home Challenge #1

- Create a Cooja simulation with three TinyOS (sky) motes, called 1, 2 and 3.
- The three motes communicate over the radio. The message is composed by a **counter** and the **sender id**. All the messages are sent in BROADCAST.
- Messages are sent at:
  - 1 Hz for mote 1
  - 3 Hz for mote 2
  - 5 Hz for mote 3

Home Challenge #1

- Turn on/off the LEDs according the following rules:
  - Messages sent by mote 1 toggle led0
  - Messages sent by mote 2 toggle led1
  - Messages sent by mote 3 toggle led2

  - Messages with ’counter mod 10’ == 0 turn off all the LEDs
- The counter is incremented every time a message is received.

Hints

1. Start from a clean folder with clean files
2. Create the message structure
3. Identify the interfaces to use
4. Wire the interfaces in the AppC.nc file
5. Write the logic in the C.nc file

- Use RadioCountsToLed as reference
- The mote number is in the constant TOS_NODE_ID
- Compile often the code checking if all the interfaces are okay