Advanced Networking Architectures and Wireless Systems

Carlo Vallati
Assistant Professor@ University of Pisa
c.vallati@iet.unipi.it

Who’s this guy??

Carlo Vallati

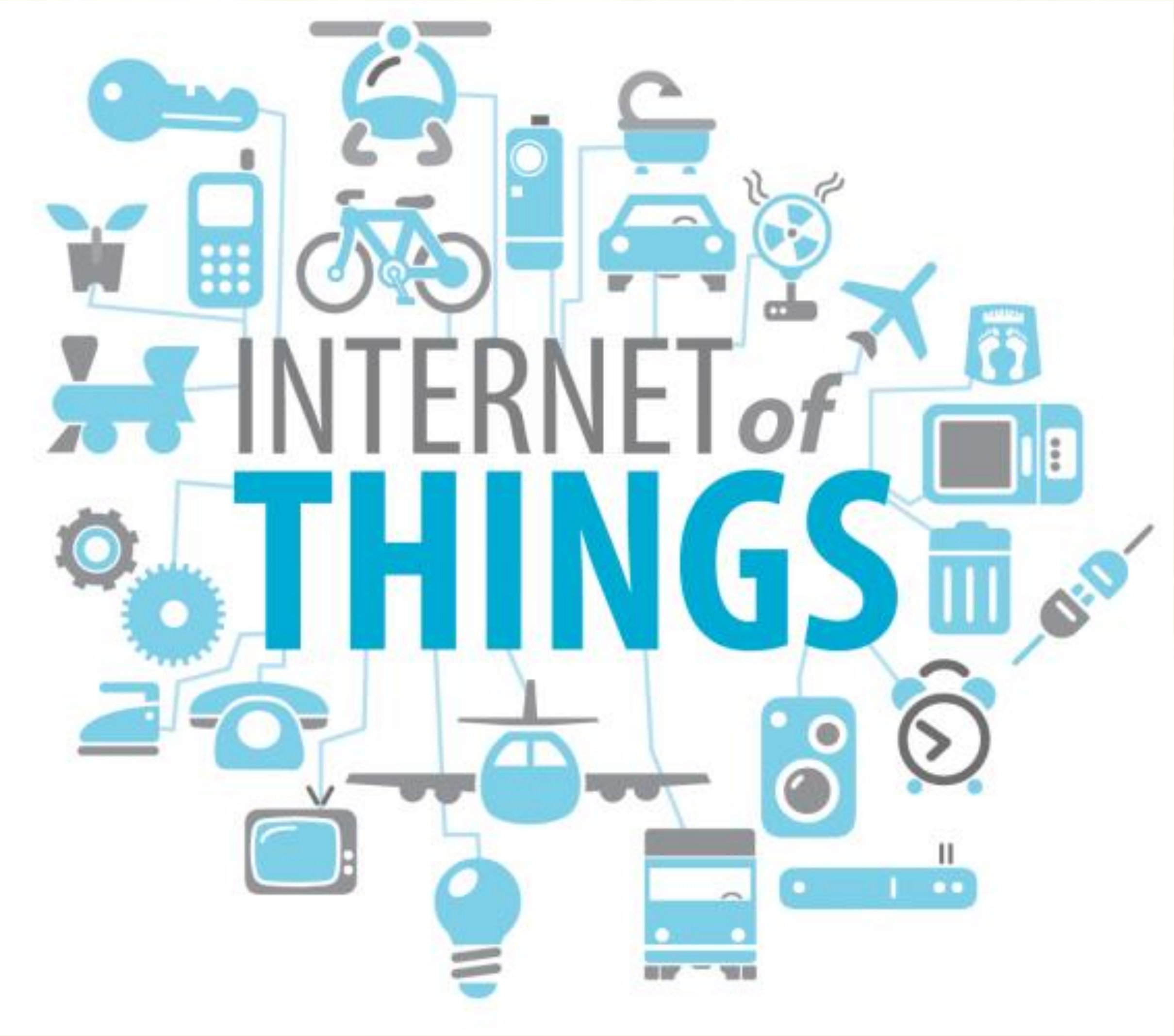
c.vallati@iet.unipi.it

http://www.iet.unipi.it/c.vallati/

Pointers

- Lab homepage:
  - http://lab-anaws.github.io/
- Lab page on github for code and slides:
  - https://github.com/lab-anaws

Internet of Things Labs



Outline

- Introduction
- IEEE 802.15.4 refreshment
- Basic network operations: IPv6+6LoWPAN and direct communication
- RPL: multi-hop communications
- CoAP

Hardware

Carlo Vallati
Assistant Professor@ University of Pisa
c.vallati@iet.unipi.it

How an IoT device look like?

TelosB - SkyMote

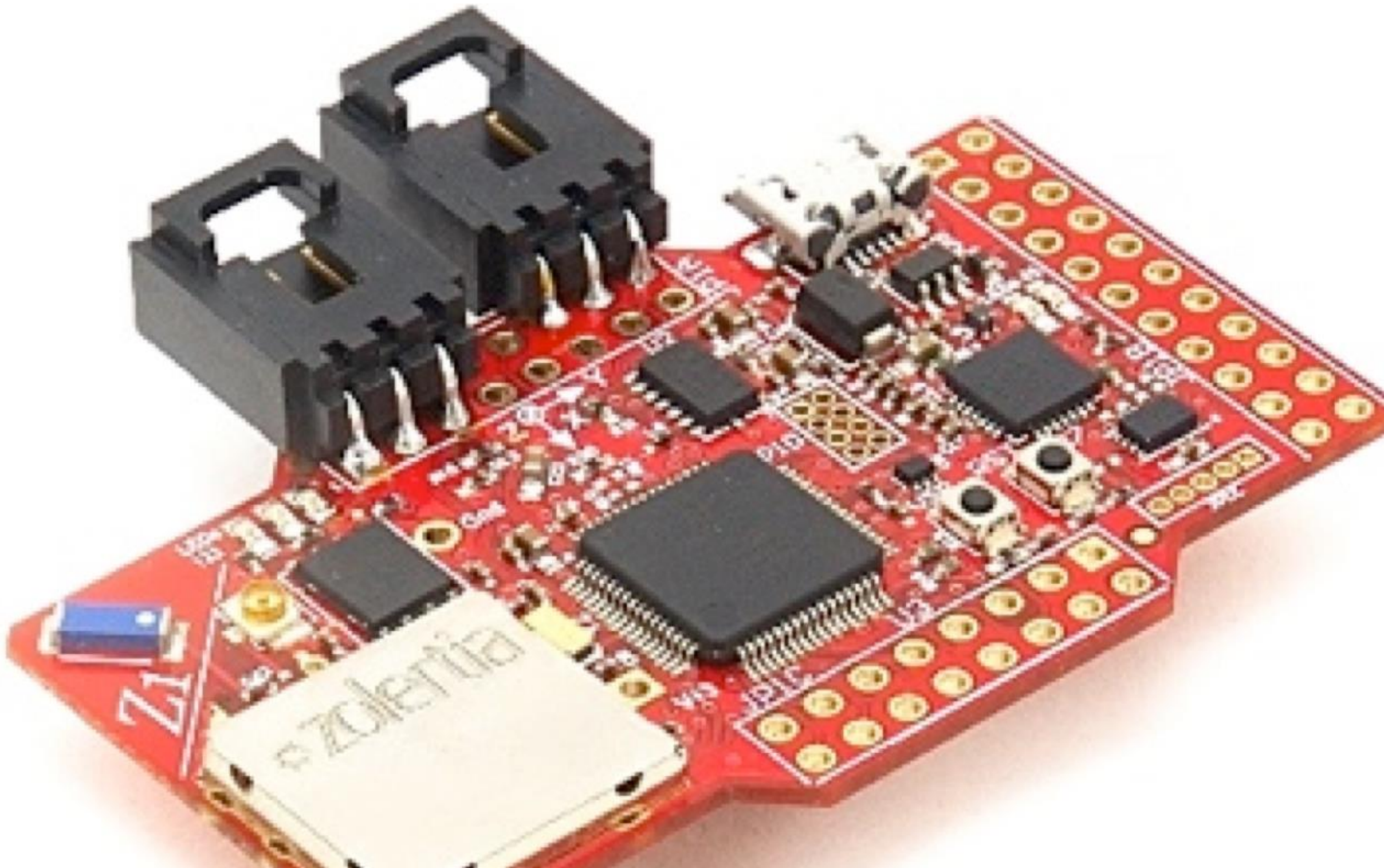
Zolertia Z1

Z1

Low-Power WSN Platform

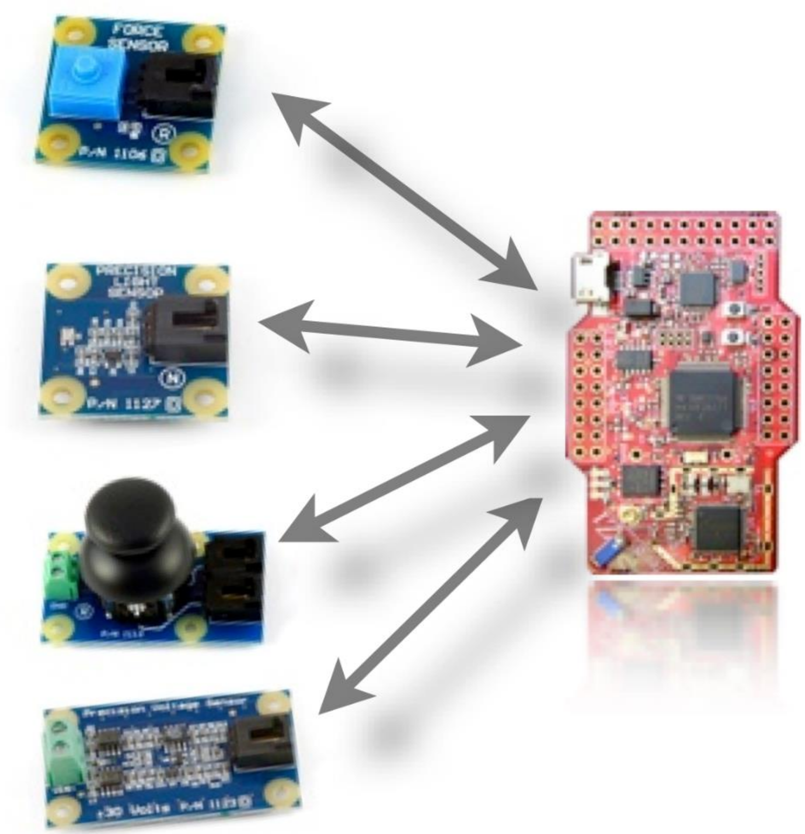
zolertia

Smarten it up



Zolertia Z1

- Out of the box support for Phidgets™

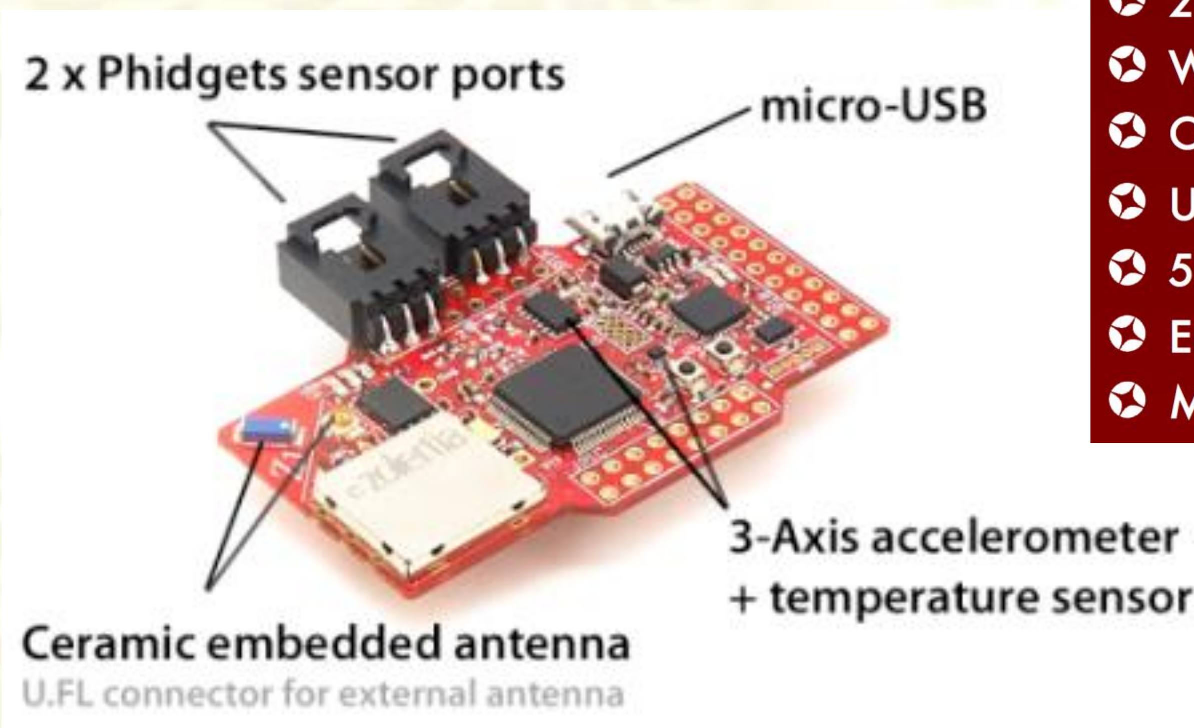


Zolertia Z1

Similar specs for the SkyMote!

Main Features

- 2.4GHz IEEE® 802.15.4 & 6LowPAN Compatible
- 2^{nd} Generation MSP430(F2617)
- Widely Adopted Radio: CC2420
- On-board Digital Sensors (x2)
- Up to 4x Analog Phidgets™
- 52-pin Expansion Connector
- Embedded or External Antenna
- MicroUSB Connector



Contiki – OS basics

Carlo Vallati
Assistant Professor @ University of Pisa
c.vallati@iet.unipi.it

WSN Operating Systems

- The OS hides many HW details
  - Simplify the programmer life
- Contains drivers to radio and sensors, scheduling, network stacks, process & power management
- TinyOS, Contiki, FreeRTOS, Mantis OS

Contiki overview

- Contiki is a dynamic operating system for constrained devices
- Event driven kernel
  - Protothreds on top of it
- Support for many platform
  - Tmote Sky, Zolertia Z1, MicaZ …
- Support for many CPU
- Programmed in C

http://www.contiki-os.org/start.html

https://github.com/contiki-os/contiki/wiki

Event vs Thread

- Event driven kernel only use events
  - Difficult to program
  - No sequential flow of control
  - Low overhead
- **Threads**
  - **Easy to program**
  - **Sequential flow of control**
  - **High overhead (each thread has its own stack)**

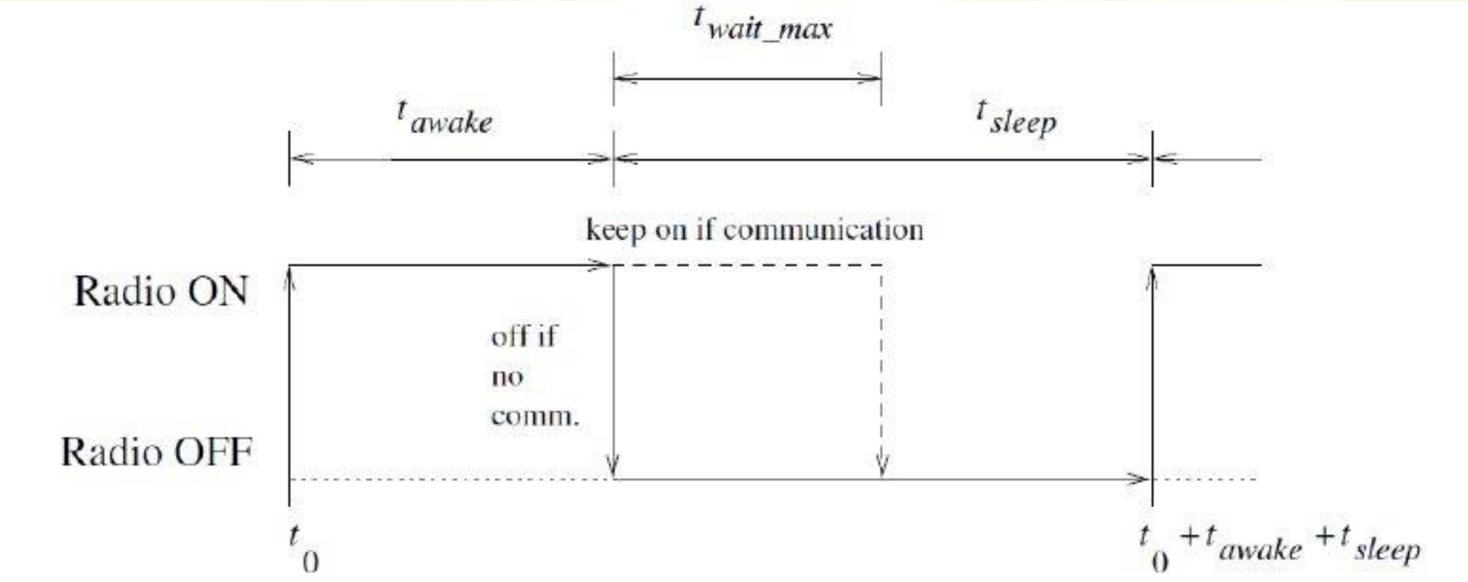
Contiki solution: Protothreads

- Contiki adopts Protothreads: threads that have event management support
- Each Protothread has a sequential flow of instructions that can be interrupted to wait for events or conditions

```
int a_protothread(struct pt *pt) {
  PT_BEGIN(pt);


  PT_WAIT_UNTIL(pt, condition1);


  if(something) {


    PT_WAIT_UNTIL(pt, condition2);


  }
  PT_END(pt);
}
```

Protothreads: usage examples

- Simple MAC protocol:
  - *Mix of sequential operations and operations triggered by events*: Turn ON radio -> Wait for end of transmission or timeout -> Turn OFF radio



Process Thread

- The code of the thread is called ***process thread***
- Each process thread contains the code of a single protothread invoked from the process scheduler and it is declared as follows:

```
PROCESS_THREAD(hello_world_process, ev, data)
{
    PROCESS_BEGIN();
    printf("Hello, world\n");
    PROCESS_END();
}
```

A process thread must start with PROCESS_BEGIN(); and terminate with PROCESS_END();

Process Thread

- Inside the process thread the instructions are defined to manage events or conditions:
  - `PROCESS_WAIT_EVENT(); // Wait for any event.`
  - `PROCESS_WAIT_EVENT_UNTIL(); // Wait for an event, but with a condition.`
  - `PROCESS_YIELD(); // Wait for any event, equivalent to PROCESS_WAIT_EVENT().`
  - `PROCESS_WAIT_UNTIL(); // Wait for a given condition; may not yield the process.`
  - `PROCESS_PAUSE(); // Temporarily yield the process.`

Main Process Thread

- Every Contiki image to run on devices must have a main process thread that runs automatically as the device boots up
- In order to make a process starting automatically the following autostart declaration must be added

```
PROCESS(example_process, "Example process");
AUTOSTART_PROCESSES(&example_process);
```

Contiki directories

- core
  - System source code
- apps
  - System apps
- platform
  - Platform-specific code
    - Default mote configuration
- cpu
  - CPU-specific code
- example
  - Lots of examples. **USE** it as a starting point.
- tools
  - Cooja and other useful stuff

Hello World

```
#include “contiki.h”
#include <stdio.h>
/* Declare the process */
PROCESS(hello_world_process, “Hello world”);
/* Make the process start when the module is
loaded */
AUTOSTART_PROCESSES(&hello_world_process);

/* Define the process code */
PROCESS_THREAD(hello_world_process, ev, data) {
   PROCESS_BEGIN(); /* Must always come first */

   printf(“Hello, world!\n”); /*code goes here*/

   PROCESS_END(); /* Must always come last */
}
```

Makefile

- The project includes a Makefile that specify how to produce the binary code:

```
CONTIKI_PROJECT = hello-world

all: $(CONTIKI_PROJECT)

CONTIKI = /home/user/contiki

include $(CONTIKI)/Makefile.include
```

project-conf.h

- An additional configuration file is usually included to override operating system default configurations
- Add to Makefile

```
CFLAGS += -DPROJECT_CONF_H=\"project-conf.h\"
```

- Example change wireless change channel

```
#undef RF_CHANNEL
#define RF_CHANNEL      26
```

- See parameters platform/z1/contiki-conf.h

Load Hello-World Program

Go to "contiki/examples/hello-world"

Select the mote, in case you have more than one mote connected

Select the architecture, z1 for Zolertia sky for SkyMote

Compile the program:

make MOTE=1 TARGET=z1 name-program

Flash the program:

name-program.sky is produced as binary

make MOTE=1 TARGET=z1 name-program.upload

In case of problems in loading the program:

sudo chmod 777 /dev/ttyUSB0

Connect to the mote

To connect to the mote to obtain the log:

make TARGET=z1 MOTE=1 login

In case the connection fails:

sudo chmod 777 /dev/ttyUSB0

Or to solve the issue permanently:

sudo usermod -a -G dialout $USER

Every mote has a node id which is used by some functions of the operating system.

To set the node id:

make burn-nodeid.upload nodeid=158 nodemac=158

Mote log

If you have some issue in connecting to the mote serial port execute the following commands:

wget https://github.com/contiki-os/contiki/blob/master/tools/sky/serialdump-linux?raw=true

mv serialdump-linux\?raw\=true serialdump-linux

chmod +x serialdump-linux

mv serialdump-linux ~/contiki/tools/sky

Do it!

- Load the hello-world program and grab the mote output

Introduction to Cooja

- Cooja is a java based emulator for contiki nodes
- The hardware of motes is emulated
- Wireless connection among motes is simulated
  - Go to “contiki/tools/cooja”
  - Launch cooja:
    - **ant run**
  - The first time you need to run the following command to download some unmet dependencies:
    - **git submodule update --init**

POST and WAIT

- `PROCESS_WAIT_EVENT();`
  - Waits for an event to be posted to the process

- `PROCESS_WAIT_EVENT_UNTIL(condition c);`
  - Waits for an event to be posted to the process, with an extra condition. Often used: wait until timer has expired
  - `PROCESS_WAIT_EVENT_UNTIL(etimer_expired(&timer));`

- `PROCESS_POST(...)` and `PROCESS_POST_SYNCH(..)`
  - Post (a)synchronous event to a process.
  - The other process usually waits with `PROCESS_WAIT_EVENT_UNTIL(ev == EVENTNAME);`

Local Variables

- Protothreads are stackless: they all share the same global stack of execution, opposed to "real" threads which typically get their own stack space
- As a consequence, the values local variables <u>are not preserved</u> in Contiki protothreads across yields:

```
int i = 1;
PROCESS_YIELD();
printf("i=%d\n", i); // <- prints garbage
```

- The traditional Contiki way how deal with this limitation is to declare all protothread-local variables as static:

```
static int i = 1;
PROCESS_YIELD();
printf("i=%d\n", i); // <- prints 1
```

Timers

- struct timer
  - Passive timer, only keeps track of its expiration time
- struct etimer
  - Active timer, sends an event when it expires
- struct ctimer
  - Active timer, calls a function when it expires
- struct rtimer
  - Real-time timer, calls a function at an exact time. Reserved for OS internals

ETimer

- etimers are usually adopted:

```
#include “sys/etimer.h” // Include etimer
static struct etimer et;   // Declare an etimer
…
etimer_set(&et, CLOCK_SECOND*4);  // Set the timer
…
// Inside the main loop
PROCESS_WAIT_EVENT(); // Block and wait for any event
// Check if the timer is expired
if(etimer_expired(&et)){
      etimer_reset(&et); // Reset the timer
}
```

Sensors

- Sensors can wait for external events generated from sensors, e.g. the user press a button:

```
#include “dev/button-sensor.h” // Add sensor library
#include “dev/leds.h” // Add led library
…
// Activate the button
SENSORS_ACTIVATE(button_sensor);
…
// In the main loop
PROCESS_WAIT_EVENT_UNTIL(ev==sensors_event &&
data==&button_sensor); // Wait until the user presses
the button
leds_toggle(LEDS_ALL); // Turn on all the leds
```

See example/sky/test-button.c

Do IT!

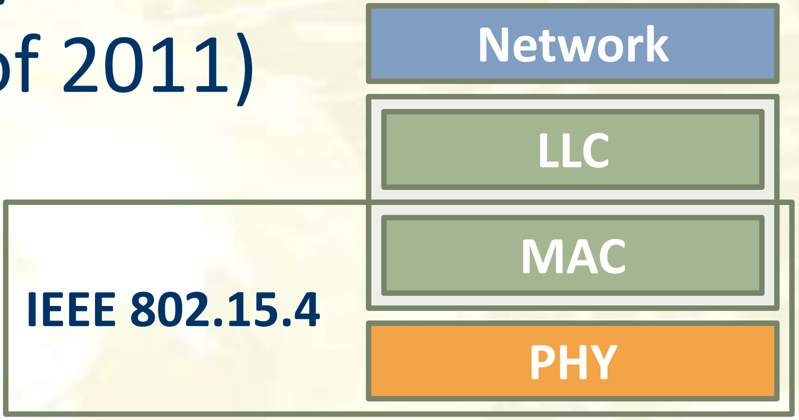
- Write a program that loops indefinitely, check if the timer has expired, and if so, prints out a message.
- Write a program that loops indefinitely, waits for an event, check if a button has been pressed, toggles LEDs and prints out “Button Press!”. If, instead, the timer has expired toggles LEDs and prints out “Timer!”

IEEE 802.15.4 Refresher

Carlo Vallati
Assistant Professor @ University of Pisa
c.vallati@iet.unipi.it

IEEE 802.15.4 standard

- Standard PHY and MAC layers for low-rate WPANs (latest release as of 2011)



- Goal
  – Defining a communication standard for constrained devices with limited computation, power (battery powered devices) and memory

Limited? how much?

IEEE 802.15.4 features

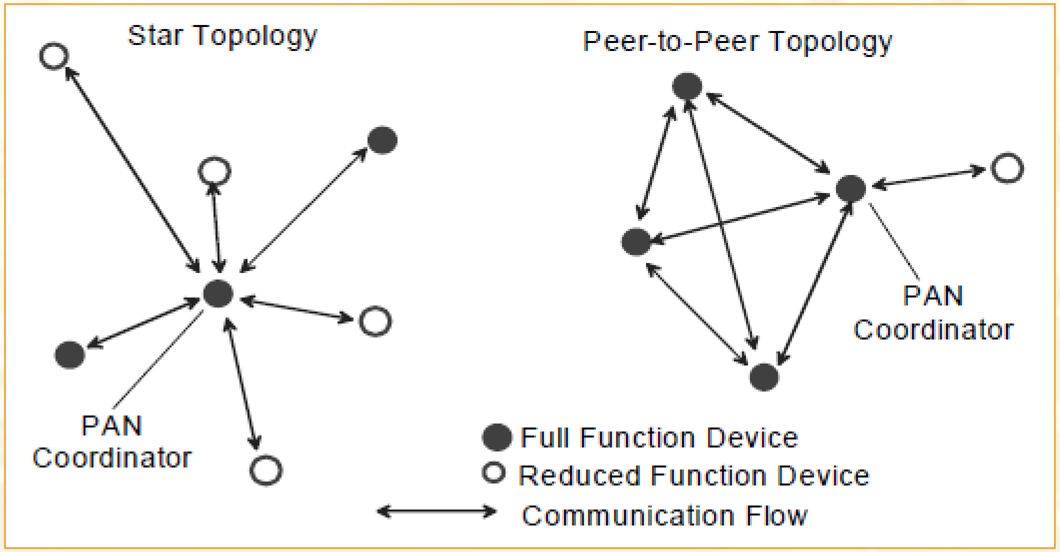
- Main features
  - Low data rate: 20-250 Kbit/s data rates
  - Pure CSMA or hybrid TDMA/CSMA MAC protocols
  - 127 bytes max frame size
  - Long (64-bit) and short (16-bit) addressing modes
  - Star and peer-to-peer network operation
  - Link layer security

IEEE 802.15.4 topologies

- Full vs. Reduced Function Devices
  - FFDs can talk to RFDs or other FFDs, while an RFD can talk only to an FFD
- An RFD is intended for applications that are extremely simple
- The RFD can be implemented using minimal resources and memory capacity
- A full-function device (FFD) has more resources and it is capable of **relaying** messages
- FFDs can operate in three modes: *regular device*, *coordinator* and *PAN coordinator*

IEEE 802.15.4 topologies

- Star vs. P2P topologies
  - **Star**: the communication is established between devices and the single *central controller*, the *PAN coordinator*
  - **P2P**: any device can communicate with any other device in range. *Mesh functionalities for multi-hop data delivery can added at the higher layer, <u>but are not part of this standard</u>*
- PAN unique id
- Coordinators provide synchronization services to other devices



IEEE 802.15.4 addressing

- 64-bit addresses based on IEEE EUI-64, a globally unique id assigned by the manufacturer

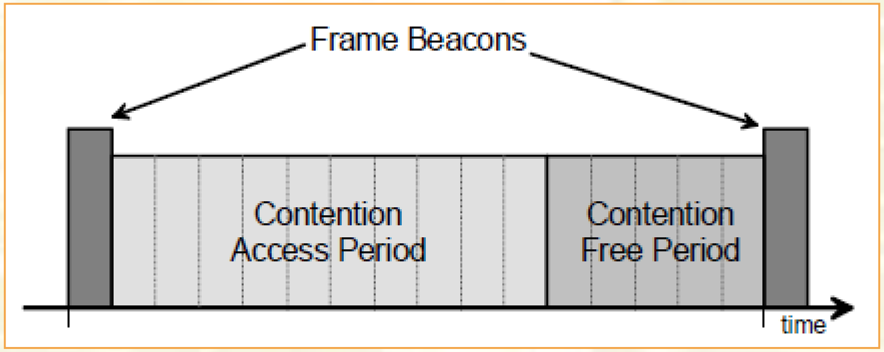
```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     OUI     |L|M|         OUI (cont.)         |               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+               +
|                     extension identifier                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

M = multicast
L = local

- Short 16-bit addresses dynamically assigned during network formation
- Source and destination addresses are augmented by the 16-bit *PAN id*

IEEE 802.15.4 operation modes

- Beaconless vs. beacon-enabled MAC operation
- Beaconless mode
  - uses a pure CSMA channel access and operates quite like basic IEEE 802.11
- Beacon-enabled mode
  - superframe structure and the possibility to reserve time-slots for critical data



IEEE 802.15.4 Frame format

- MAC frame format
  - 127 bytes max
  - 88 bytes payload in the worst case

Octets: 2	1	0/2	0/2/8	0/2	0/2/8	0/5/6/10/14	variable	2
Frame Control	Sequence Number	Destination PAN Identifier	Destination Address	Source PAN Identifier	Source Address	Auxiliary Security Header	Frame Payload	FCS
		Addressing fields						
MHR							MAC Payload	MFR