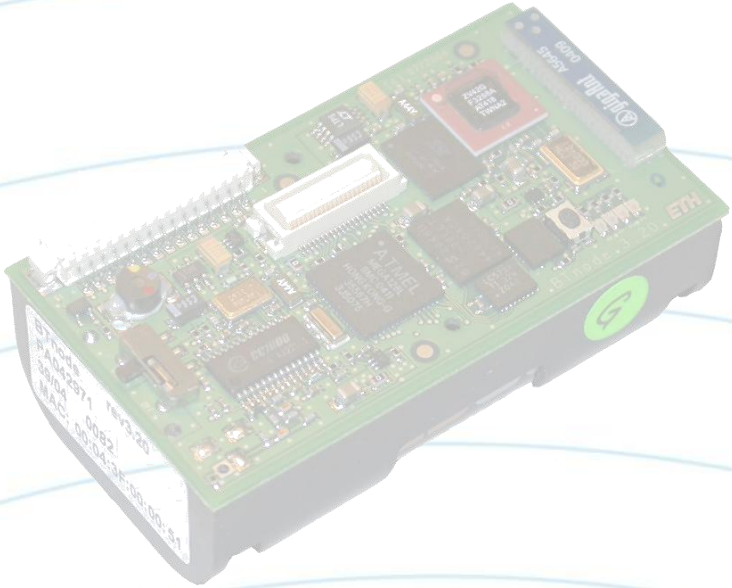


Tutorial at INSS 2007

Fast-Prototyping of Wireless Sensor Networks

Jan Beutel, ETH Zurich

with Matthias Dyer, Andreas Meier, Matthias Wöhrle and Mustafa Yücel

NCCR MICS
National Competence Center In Research
Mobile Information and Communication Systems

FNSNF
Fonds national suisse
Schweizerischer Nationalfonds
Fondo nazionale svizzero
Swiss National Science Foundation

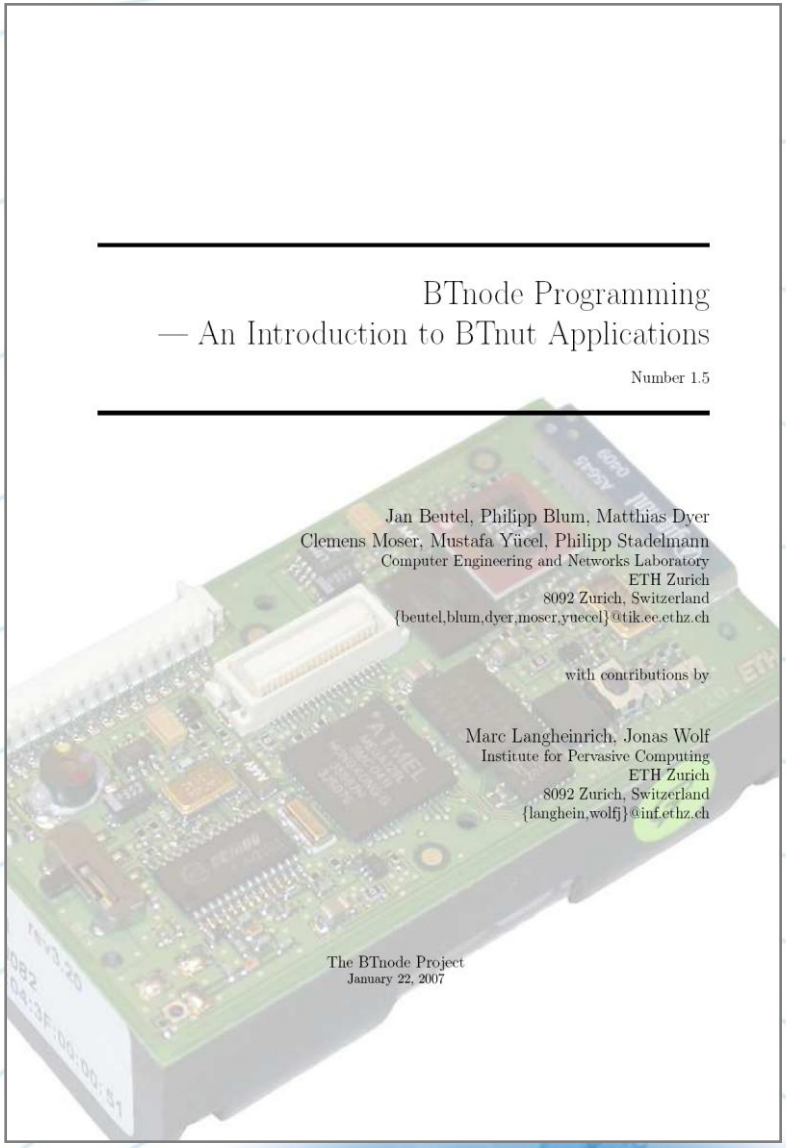
Today's Objective

Learn how to build a typical wireless sensor network application

- Get our hands dirty with "real" sensor network implementations
- Learn about their challenges and caveats
- This tutorial does not require prior experience in embedded programming and thus is suitable for researchers from all areas, e.g. people that have not yet had (extensive) platform experience
- Have fun…

BTnode Programming – An Introduction to BTnut Applications

- In-depth BTnode Tutorial
  - Originating in lectures at ETH Zurich
  - Set up in separate sessions
  - Minimum prerequisites required
  - Available online
- This tutorial uses excerpts from
  - First Steps
  - Bluetooth Multihop
  - Sensors
  - Debugging
- http://www.btnode.ethz.ch



BTnode Programming
— An Introduction to BTnut Applications

Number 1.5

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The BTnode Project
January 22, 2007

Material

- What you should have received
  - BTnode tutorial manual
  - Slide copies
  - CDROM containing software tools and doc's
  - BTnode developer kit
    - BTnode rev3
    - USBprog board
    - 2xAA rechargeable cells
    - ATAVRISP programmer
    - USB cable
    - Serial Cable
  - A Teco Particles SSMALL sensor board

- Optional
  - USB-UART transceiver + 2nd USB cable

Your Requirements as Participants

- The hands-on experience requires you to
  - Install the necessary tools on your laptop
    - root/admin access
  - Handle a build system (make)
  - (program in C)

- We suggest you
  - Work in groups of two
  - Use a Windows laptop
    - Non-windows see http://www.btnode.ethz.ch/Documentation/Installation

✪ Hands-on exercises are marked in red on the slides
  - 1st demonstration of the exercise – 2nd time for participants

Outline

- Introduction
  - Basic concepts of embedded wireless sensor network platforms
  - Overview of the BTnode platform
    - Hardware architecture
    - BTnut system software
- Hands-on
  - Installing/getting to know the development tools
  - First steps in BTnode programming
    - Plugging things together
    - Basic communication, ISP programming
    - The `bt-cmd` application – simple Bluetooth networking
  - My first BTnut multi-hop application
    - Bluetooth networking basics
    - Multihop networking
    - Sensor interfaces, packets and payload
    - Bluetooth Scatternet topology visualization

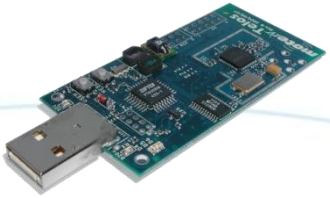
Outline continued…

- Demonstration
  - Debugging and profiling of sensor network applications
    - Embedded debugging
    - Profiling using and OS tracer
    - Testbeds – The ETH Deployment-Support Network
- Hands-on
  - Interfacing to handheld devices
    - Bluetooth RFCOMM
    - AT commands
    - Sending an SMS message using AT commands
- Question and answer
- Time to explore BTnodes…

Basic concepts of embedded wireless sensor network platforms

- "Mote class" devices
  - Microcontroller + low-power radio
  - Battery powered

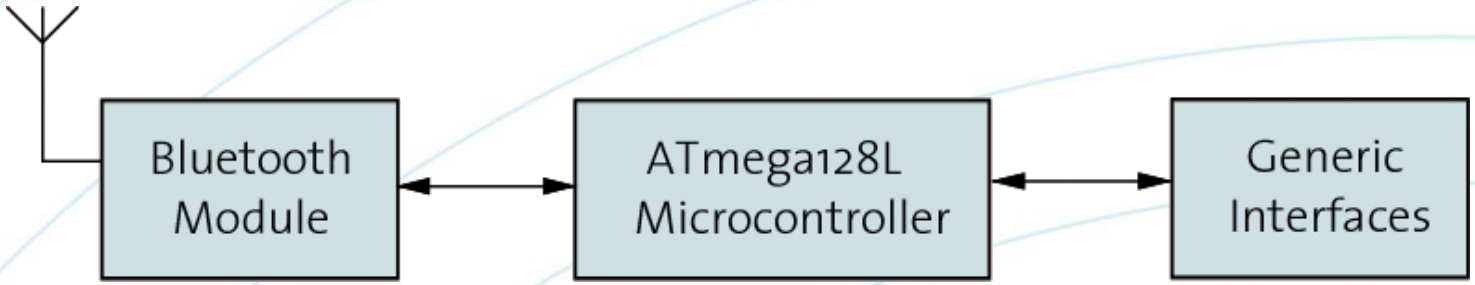
  - Many custom applications
  - Large design space, many variants



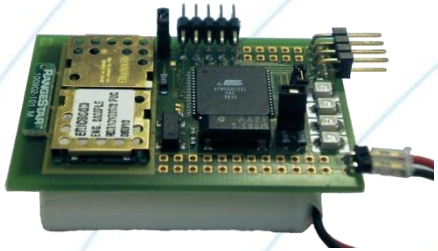
  - Most prominent examples: Mica2, Mica2Dot, Tmote Sky

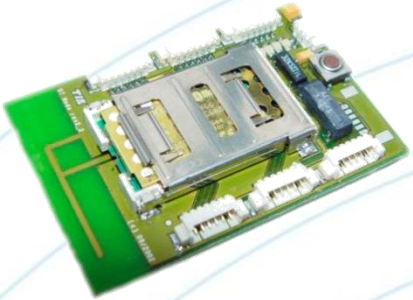
- Hardware is packaged with
  - System software and apps (e.g. TinyOS, BTnut, Contiki, Mantis, …)
  - Basestations, network access
  - Server-side solutions (backends)
  - Tools (e.g. simulators, …)

The BTnode Platform



Communication Computation IO/Peripherals





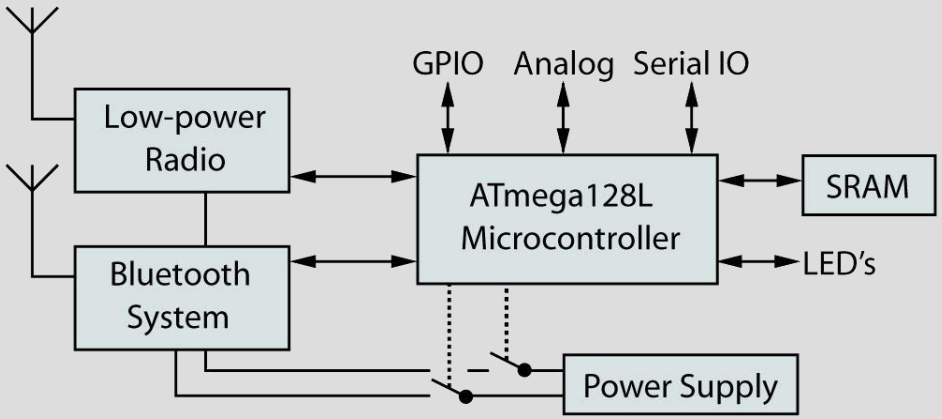
Prototype → 2nd Generation → 3rd Generation

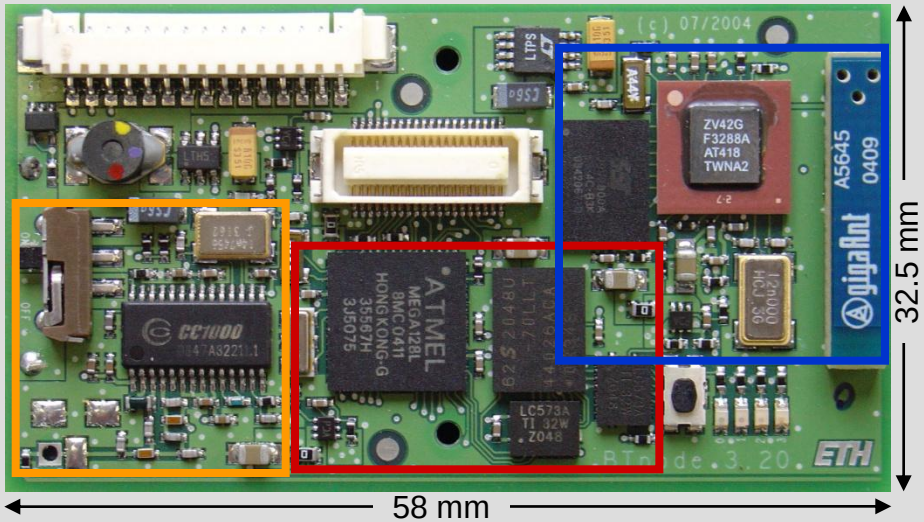
The BTnode rev3 – Architecture Details

- System core
  - Atmel ATmega128
  - 256 kB SRAM
  - Generic IO/peripherals
  - Switchable power supplies
  - Extension connectors

- Dual radio system

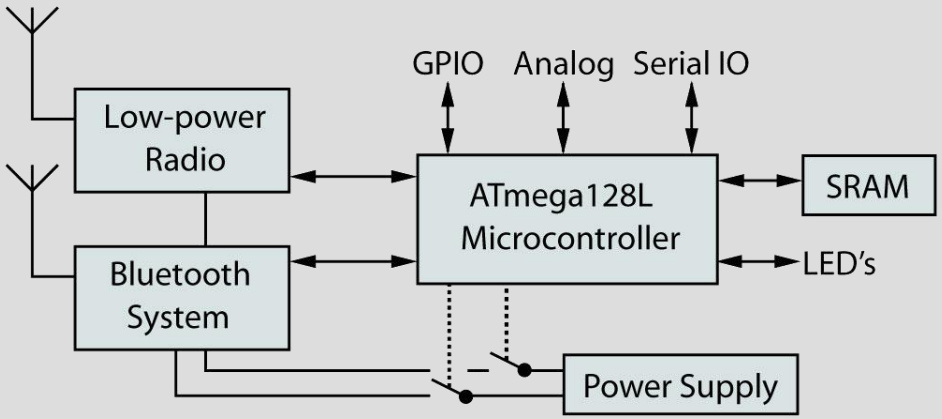
- Bluetooth radio
  - 2.4 GHz Zeevo ZV4002
- Low-power radio
  - 433-915 MHz ISM Chipcon CC1000
- On-board antennas



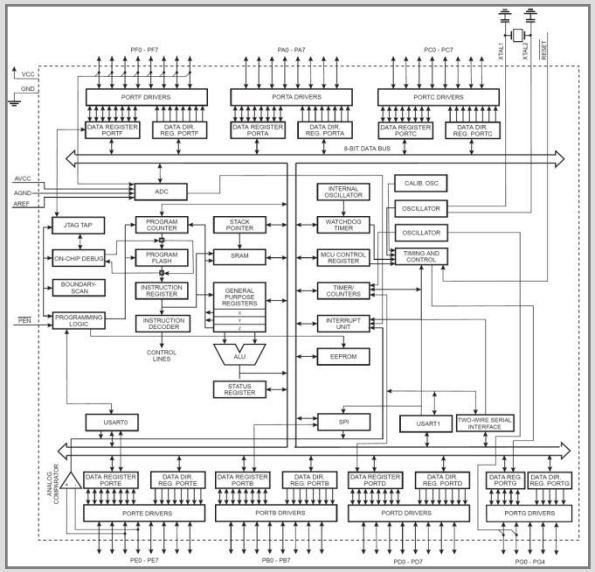


The BTnode rev3 – Atmel AVR Microcontroller Architecture

- ATmega128l
  - 8-bit AVR RISC @ 7.3 MHz
  - 64k address space
  - Integrated peripherals
  - Configurable using fuse bits

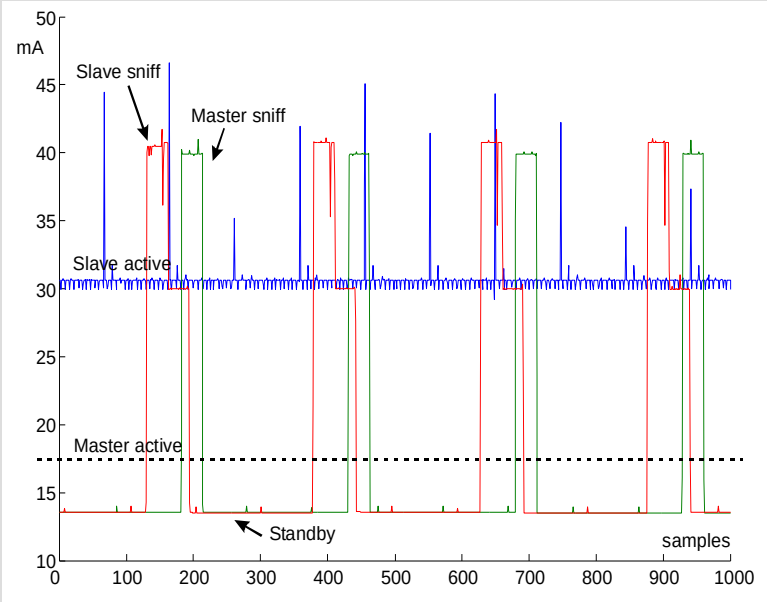


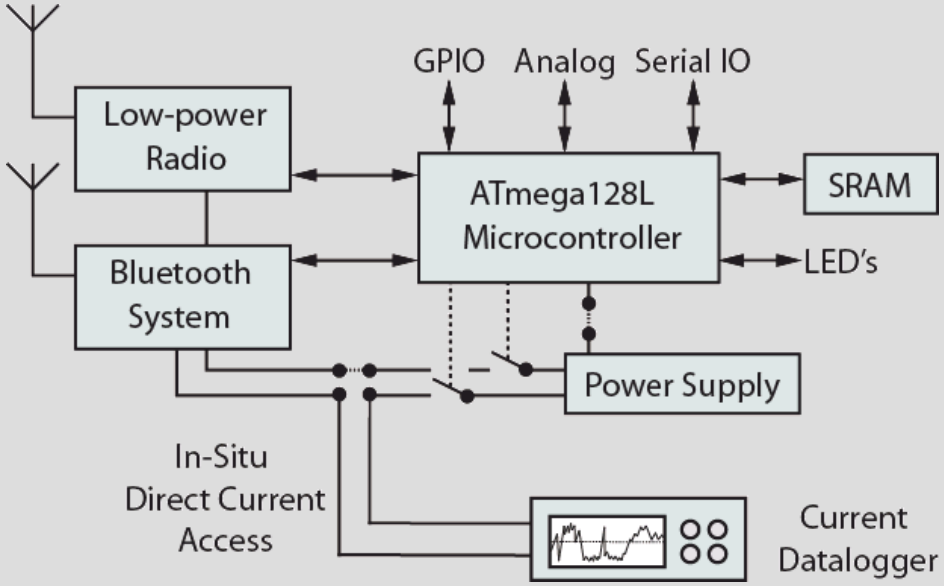
- Programs resident in flash memory
  - Max. size 128 Kbyte
  - One program at a time only

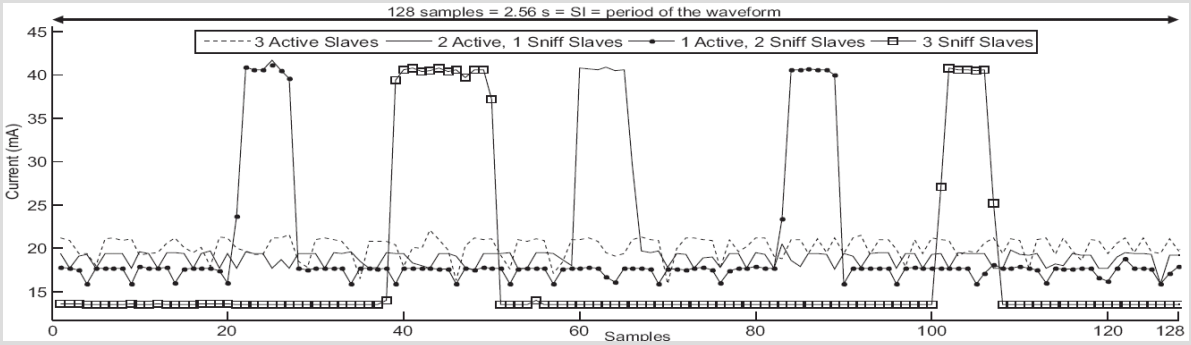


- System core – bus systems
  - UART0: Bluetooth
  - UART1: Ext. terminal, programming
  - SPI: Low-power radio, sensors

The BTnode rev3 – In-situ Power Profiling Function



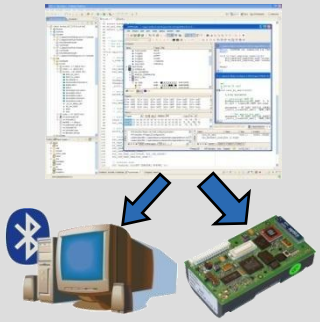




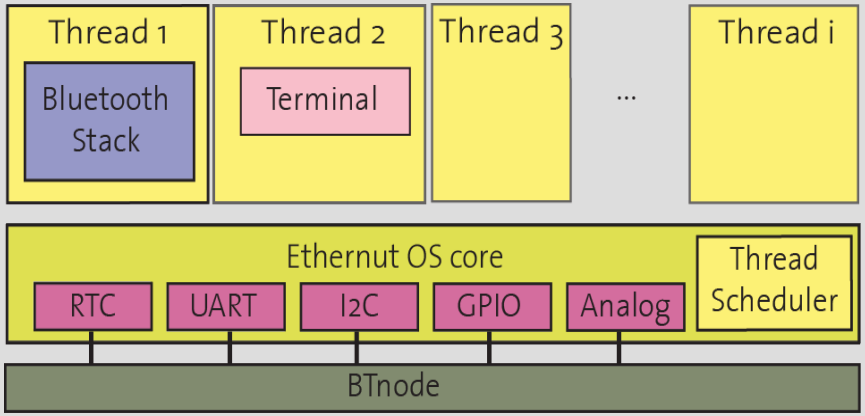
[Negri2005/2006]

The BTnut System Software

- Versatile and flexible fast-prototyping
  - Lightweight operating system support in plain C
  - Standard GNU tools, avr-libc
  - Simple demo applications and tutorial



- Built on top of multi-threaded Nut/OS framework
  - Oriented towards networking applications
  - Non-preemptive, cooperative multi-threading
  - Events, timers
  - Priorities for threads
  - Dynamic heap allocation
  - POSIX style device drivers
  - OS tracer (µsec resolution)



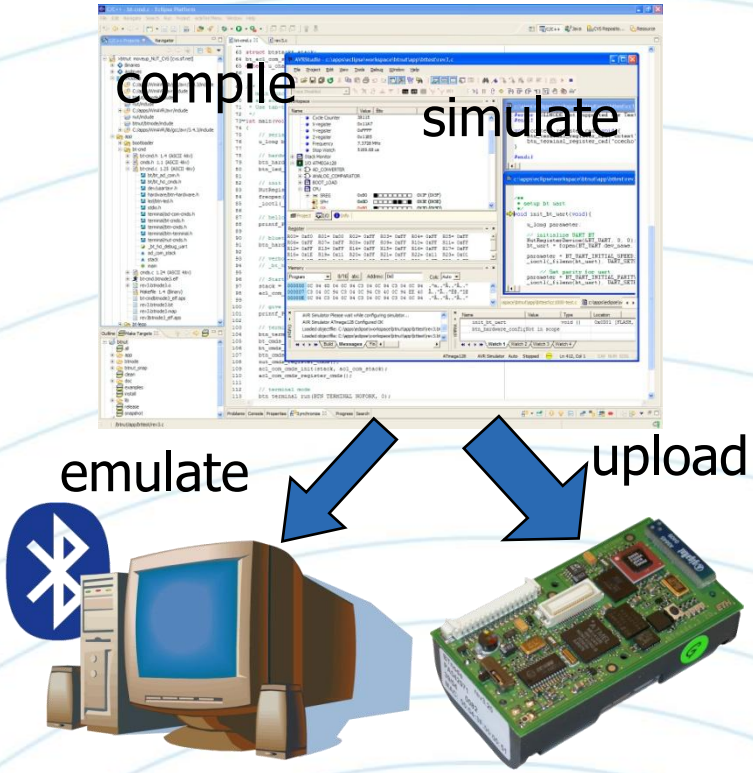
BTnut – What's the Difference to TinyOS?

- TinyOS is the de-facto standard for WSN software
- BTnut is plain vanilla C using the GNU toolchain, avr-libc
  - Less dependencies, no need for extra tools
  - No need to learn new languages/abstractions (nesC)
- BTnut offers support for concurrency through threads
  - Intuitive to program
  - No need to express all system functions using state-machines
- BTnut offers a clear and simple structure
  - Suitable for a quick jump-start and fast learning curve
  - Many features and tools target fast-prototyping

BTnodes are not targeted at ultra low-power…

… but target versatile and flexible fast-prototyping.

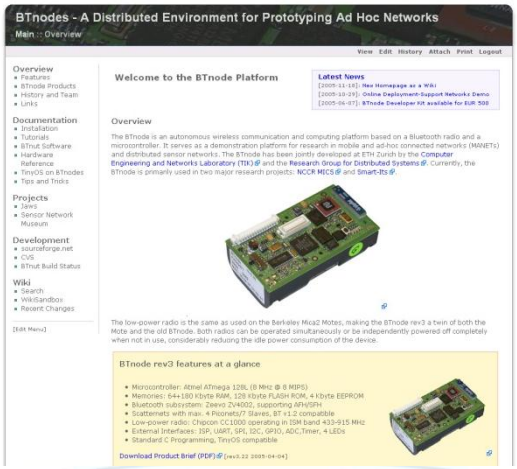
- Multi-threaded OS frame in C
  - Standard open-source tools
  - Lightweight software distribution (12.3 MB binary, 32.5 MB source)
- Rapid prototyping
  - HW emulation on Linux PC
- Demo applications and tutorial
  - Different labs for graduate lectures
  - (Multi-)day tutorials



The BTnode Platform – Beyond Hard- and Software…

- Hardware and system software don't yet make a platform…

- Documentation resources
  - Hardware: Datasheets, schematics, parts, design specifications
  - Software: API, libraries, compilers, demo apps
  - Many documented projects and applications



- The BTnode community
  - Development hosted on sourceforge.net (version control, tracker)
  - Wiki based web pages
  - Mailing list
  - Continuous integration using CruiseControl

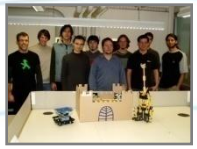
BTnode Platform Success

- Industrial technology transfer
  - Commercialization with ETH spin-off "Art of Technology"
  - Commercial replicas resulting from open source policy

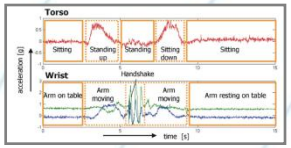
BTnode dev kit € 500

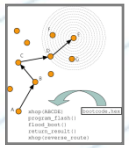
Vitronics Cobalt Blue™ Bluetooth Board

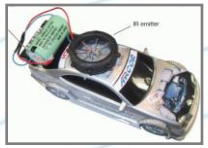
- BTnodes in education
  - Different labs and demos
  - Graduate lab in embedded systems (120 participants)
  - 50+ successful completed student projects

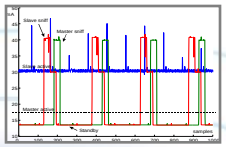


- BTnodes in research domains
  - 35+ wearable and ubiquitous computing applications and demos
  - Wireless (sensor) network research
  - 50+ scientific publications based on or related to BTnodes









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    - Multihop networking
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    - Bluetooth Scatternet topology visualization

Hands-on: Installation of the Development Tools

- Development tools
  - AVR toolchain with avr-gcc, make, avrdude, …
  - Terminal application (Hyperterm, Minicom, ZOC, …)

✪ AVR toolchain installation
  - Open the directory **`inss2007`** on the BTnode CDROM
  - Install **`WinAVR-20060125-install.exe`** into **`C:\WinAVR`**
  - Alternate instruction http://www.btnode.ethz.ch/Documentation/WinInstall

✪ Terminal application installation
  - Install **`zoc507_win_english.exe`**

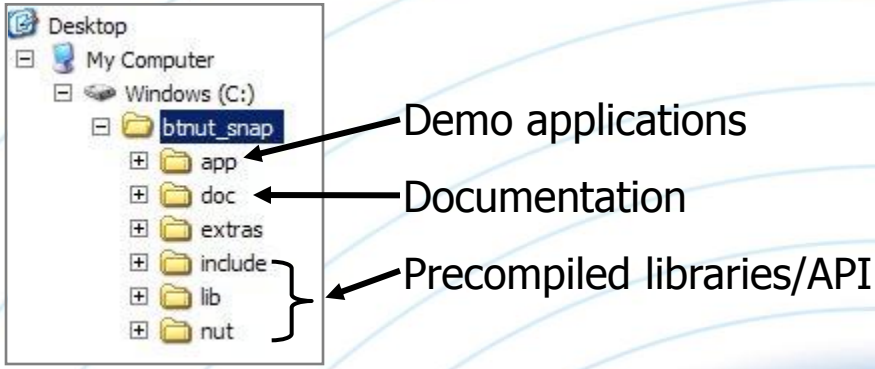
✪ Testing the installation
  - Open a cmd shell and execute **`avr-gcc --version`**

Hands-on: Installation of the BTnut Software

- BTnut software
  - Precompiled libraries
  - Demo examples
  - Documentation

✪ Installation
  - Unpack `btnut_snap_btnode3_binary_1.8.tar.gz` into `C:\btnut_snap`

- Directory structure



Hands-on: Browsing the BTnut API Documentation

- BTnut API documentation
  - Available in **`doc/html/index.html`**
  - Inline docs generated from source code using doxygen
  - Also available online
    http://www.btnode.ethz.ch/static_docs/doxygen/btnut

✪ Optional: Browsing the BTnut API – LED driver docs (Ex 2.4)

- Find **`btnode/include/led/btn-led.h`**
- Read and understand the documentation for **`btn_led_init()`** and **`btn_led_add_pattern()`**

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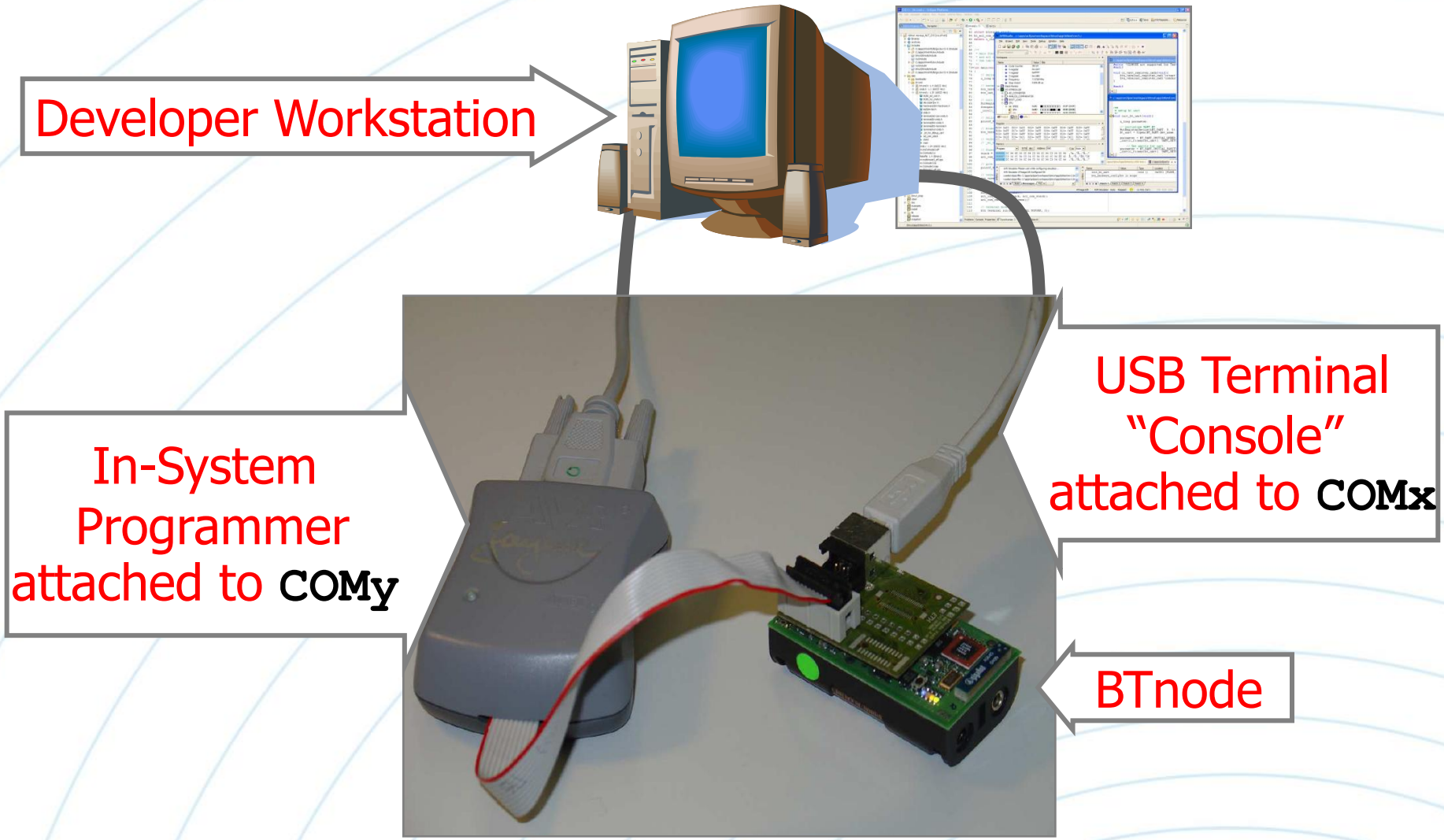
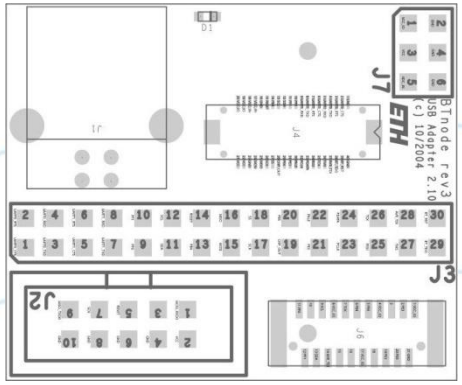
Plugging Things Together – The BTnode Development Setup



Hands-on: Plugging Things Together – The BTnode Terminal

- USBprog adapter board
  - CP2101 USB-UART transceiver
  - Power via USB
  - Breakout connectors for prototyping
  - Sensor interface connector



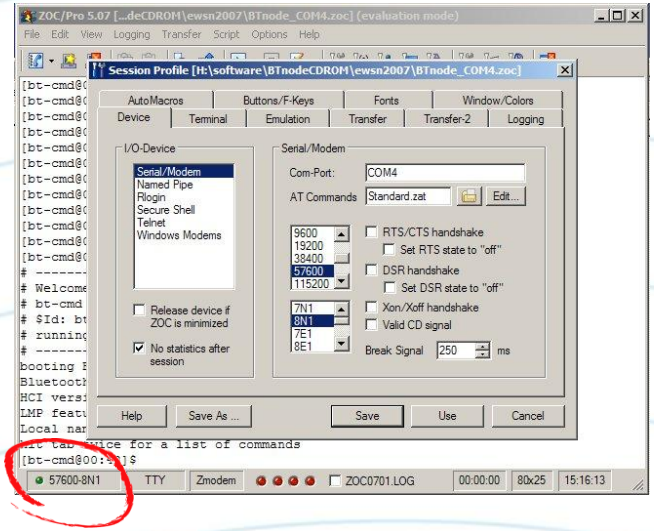
- ✪ BTnode terminal connection
  - USB cable
  - USBprog adapter board
  - BTnode

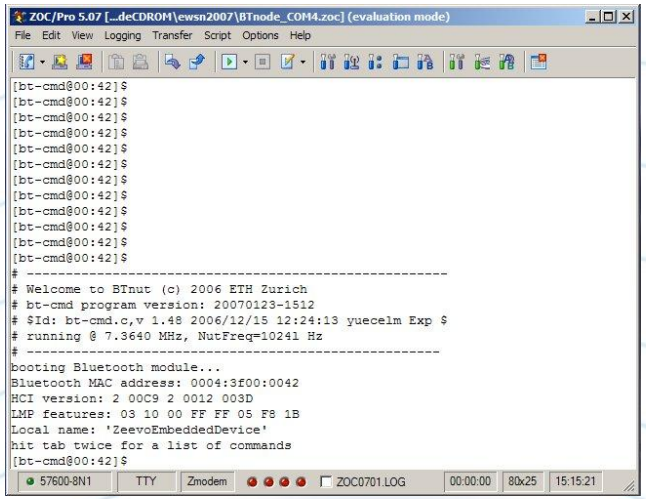
  - Watch out for the correct orientation!

- ✪ Optional: Installation of the CP2101 driver

Hands-on: BTnode Terminal – Basic Device Communication

- BTnode terminal configuration
  - Find the right **`COMx`** port
    - Start **`list_cp2101uart.vbs`**
  - Start a terminal application (e.g. minicom or ZOC) using **`57600, 8N1, no handshake`**
  - Shortcut: Start **`BTnode_COM4.zoc`** to connect to **`COM4`** (edit for other **`COMx`** ports)

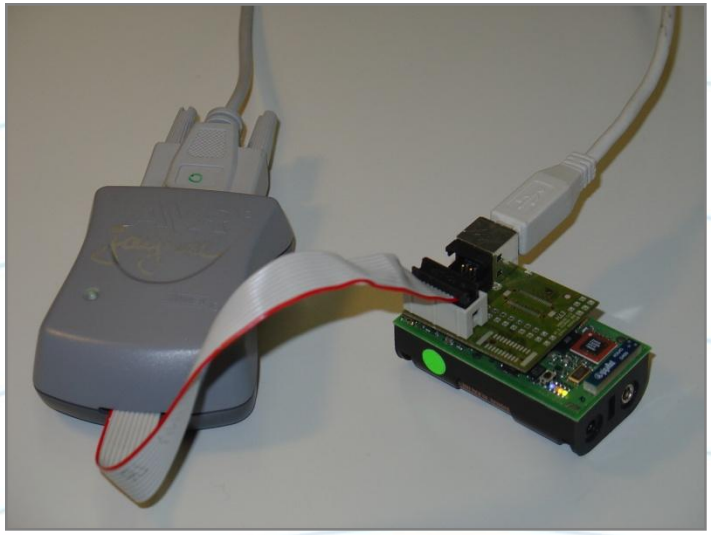




- BTnode terminal operation
  - Press the reset button on the BTnode and observe the terminal

Hands-on: Plugging Things Together – The ISP Programmer

- AVR programming
  - Programs are resident in flash memory (ATmega128l = 128 Kbyte)
  - Different AVR programming variants
    - Serial using a hardware programmer
    - JTAG
    - Bootloader
    - (Parallel)

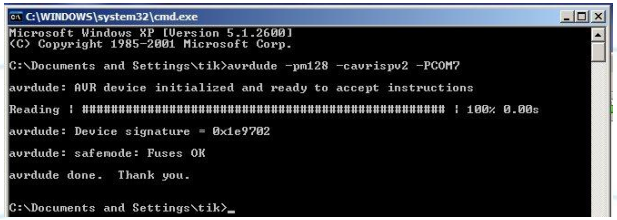


✪ ATAVRISP programmer connection
  - Connect to J2 on USBprog and a serial port on the PC
  - No serial port available? Use the USB-UART transceiver

✪ Testing the ISP programming tool installation (Ex 2.10)
  - Open a cmd shell and execute **`avrdude -h`**

Hands-on: BTnode Programming – ISP Programming

- Testing the ISP communication (Ex 2.12)
  - Find the right **COMy** port
    - Start **list_cp2101uart.vbs**
  - Open cmd shell and execute
    avrdude -pm128 -cavrispv2 -P//./COMy



The //./COMy syntax allows to map COM ports > 9 on Windows

- Programming a pre-compiled application (Ex 2.13)
  - Open a cmd shell in **inss2007** on the BTnode CDROM
  - Erase the flash memory:
    - Execute
      avrdude -pm128 -cavrispv2 -P//./COMy -e
  - Program **bt-cmd** into flash
    - Execute
      avrdude -pm128 -cavrispv2 -P//./COMy -D -V -s -U flash:w:bt-cmd.btnode3.hex:i

Hands-on: Building and Uploading BTnut Applications

- The BTnut build process
  - Automated with GNU make
    - Toplevel **`Makefile`** in **`btnut_snap/app`**
    - Global **`Makerules`** and **`Makedefs`** in **`btnut_snap`**
    - Can be overridden using environment variables

✪ Building the **`bt-cmd`** application (Ex 2.16)

- Open cmd shell in **`btnut_snap/app/bt-cmd`**
- Execute
  `make btnode3`
- Define the serial port for programming (default is **`/dev/ttyS0`**)
  `set BURNPORT=//./COMy`
- Execute
  `make btnode3 upload`

Hands-on: bt-cmd – Simple Bluetooth Networking

- Simple terminal commands
  - bt – Bluetooth radio commands
  - led – toggle LED patterns
  - bat – get the battery status
  - nut – show OS system information
  - log – BTnut logging features
  - More information on commands by pressing 2x tab

✪ Try out these terminal commands with **`bt-cmd`**

- **`led on 3`**
- **`nut threads`**

- **`bt inquiry sync`**
- **`bt rname XX:XX:XX:XX:XX:XX`**
- Try to connect to other Bluetooth devices

Hands-on: bt-cmd – A Look Under the Hood

- Open **`app/bt-cmd/bt-cmd.c`** in an editor

app/bt-cmd/bt-cmd.c

```c
/* \example bt-cmd/bt-cmd.c */

#include <hardware/btn-hardware.h>

int main(void){

    btn_hardware_init();

    // hello world!
    printf("\n# -------------------------------------------------------");
    printf("\n# Welcome to BTnut (c) 2006 ETH Zurich\n");
    printf("\nbooting Bluetooth module...\n");

    // bluetooth module on (takes a while)
    btn_hardware_bt_on();

    // terminal init
    sprintf(prompt, "[bt-cmd@"SADDR_FMT"]$ ", SADDR(addr));
    btn_terminal_init(stdout, prompt);
    bt_cmds_init(stack);
    bt_cmds_register_cmds();
    btn_cmds_register_cmds();

    // terminal mode
    btn_terminal_run(BTN_TERMINAL_NOFORK, 0);

    return 0;
}
```

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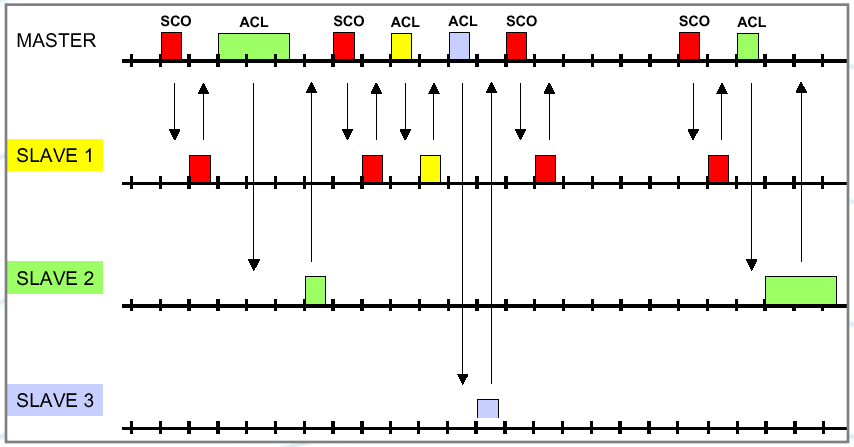
Now that you have an overview of BTnodes, the BTnut software and required tools we want to build an application

- Typical wireless sensor network application
  - Sampling on different sensors in a regular interval
  - Multi-hop networking
  - Debugging output
  - Data collection and visualization
- Hands-on exercises using an application template

Bluetooth Networking – Introduction

- Bluetooth in a nutshell
  - Low-power, low-range personal communication
  - Frequency hopping spread spectrum
  - 2.4 GHz ISM band
  - 79 channels
  - 1 Mbit/sec data rate
  - 10-100 m range
  - Connection-oriented

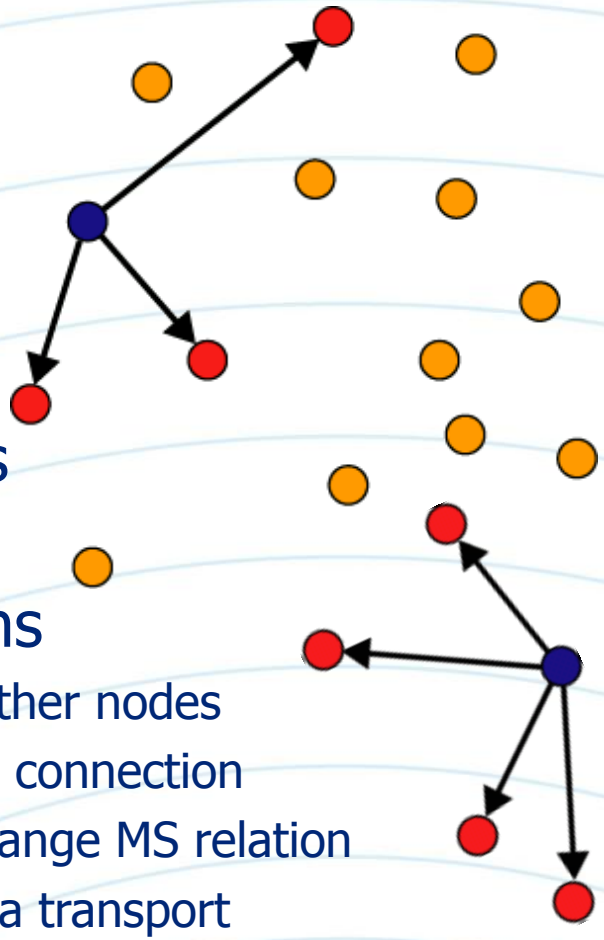


- Many high-level features built in
  - Encryption, authentication
  - Error correction
  - Flow control

- Available on many consumer devices

Bluetooth Networking – Pico and Scatternets

- Communication organized in Piconets
  - Master-slave configurations
  - Up to 7 active slaves
  - 255 inactive (parked) slaves



- Piconets can be combined in Scatternets

- Four states

  IDLE

  MASTER

  SLAVE

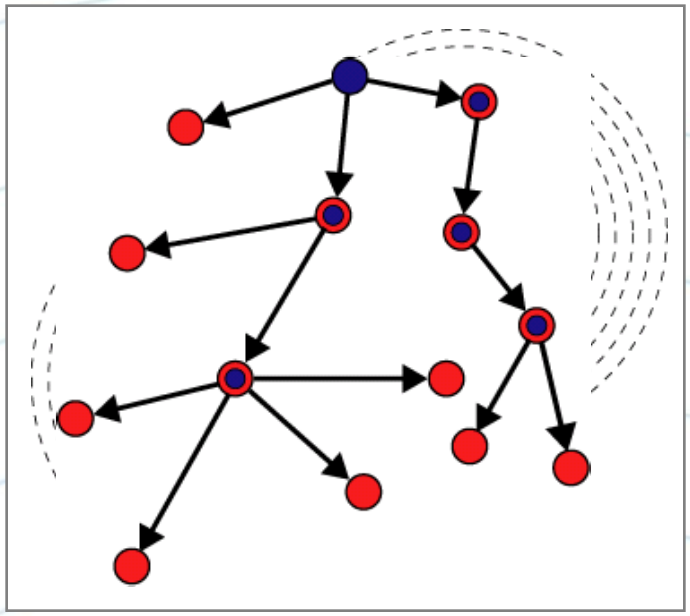
  MASTERSLAVE

- Useful operations
  - *inquiry()* – find other nodes
  - *connect()* – open connection
  - *roleSwitch()* – change MS relation
  - *sendData()* – data transport

- Detailed capabilities/features vary across Bluetooth devices

Bluetooth Networking – Simple Scatternet Tree Construction

- A simple and effective approach



[Beutel2005/2006, Dyer2007]

- Link layer connectivity
  - Random search and connect

```
loop {
 while (my_slaves < max_degree) do
   found_nodes = inquiry();
   forall nodes in found_nodes do
     connect();
  }
}
```

- Distributed coordination
  - Inquiry() and connect() operations can exhibit long delays
  - No a priori guarantee for success
  - Serialization of parallel processes

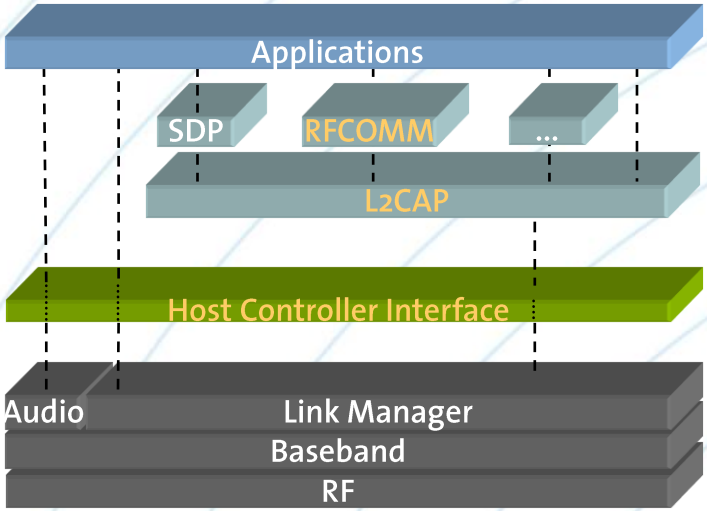
Bluetooth Networking – Host Controller Interface

- Standardized asynchronous, buffered packet interface
  - providing access to lower levels of the protocol stack

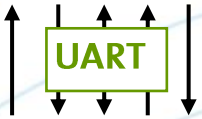
HCI_COMMAND

HCI_EVENT

DATA



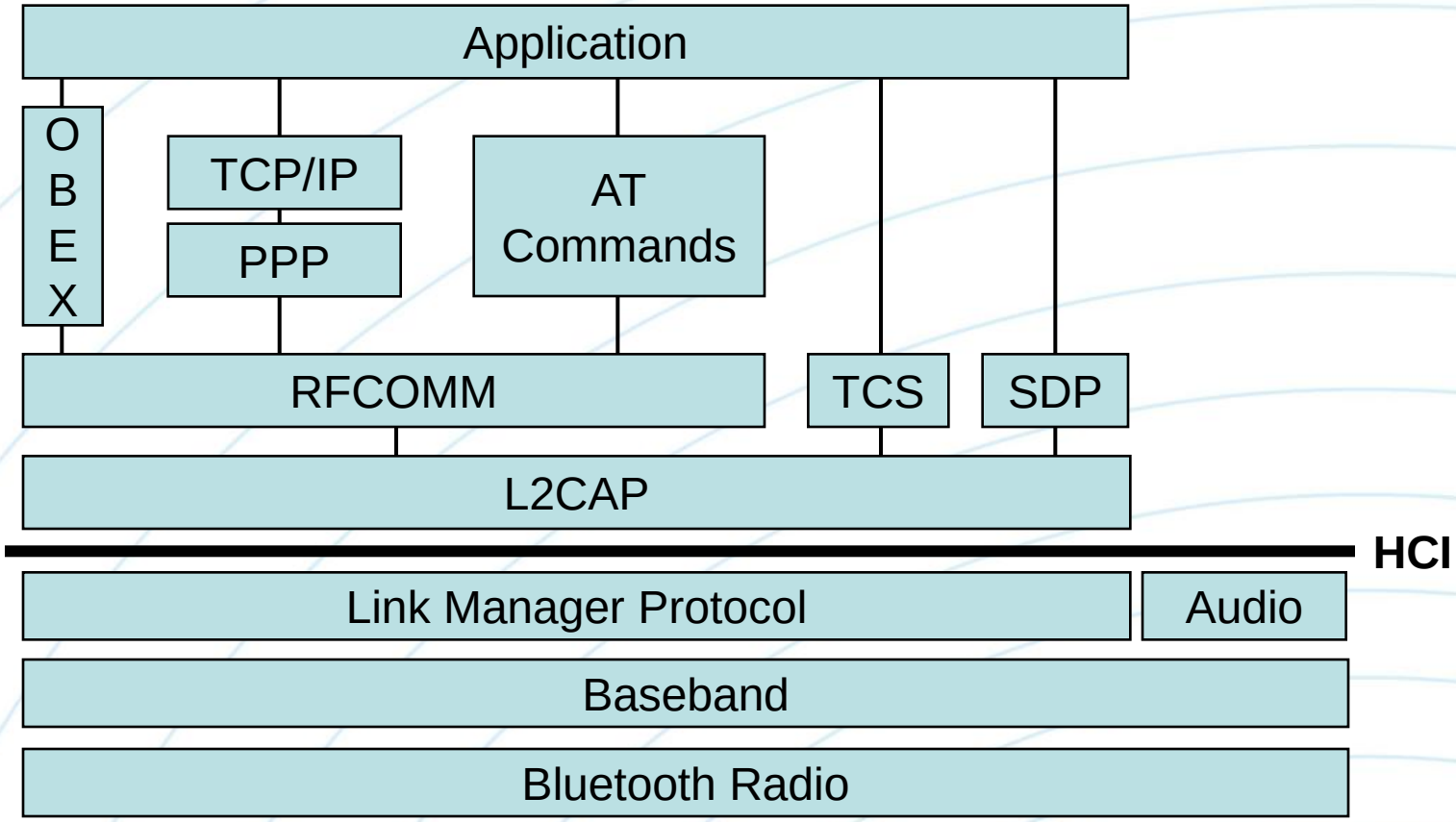
Host processor



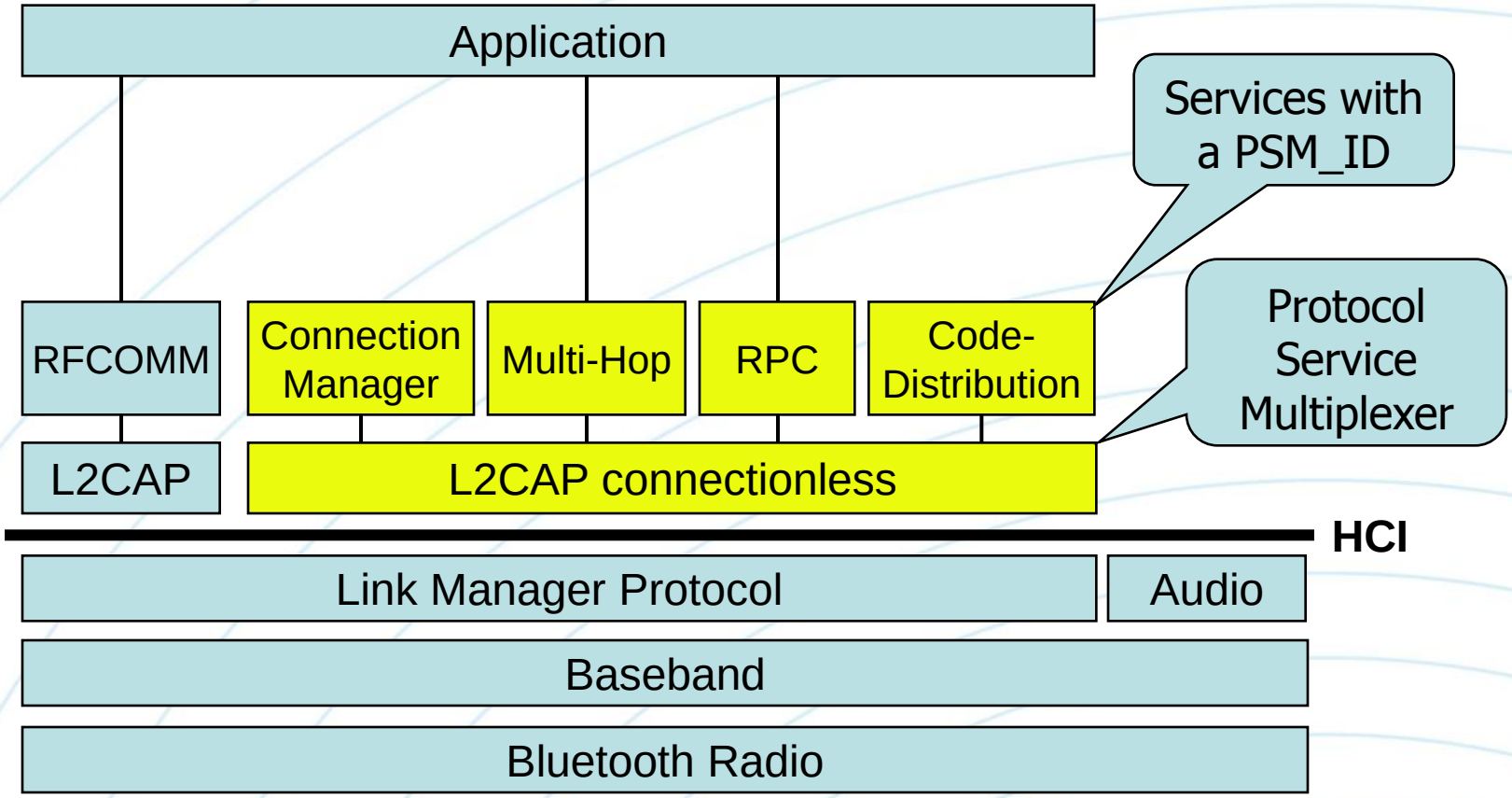
Physical interface

Bluetooth module

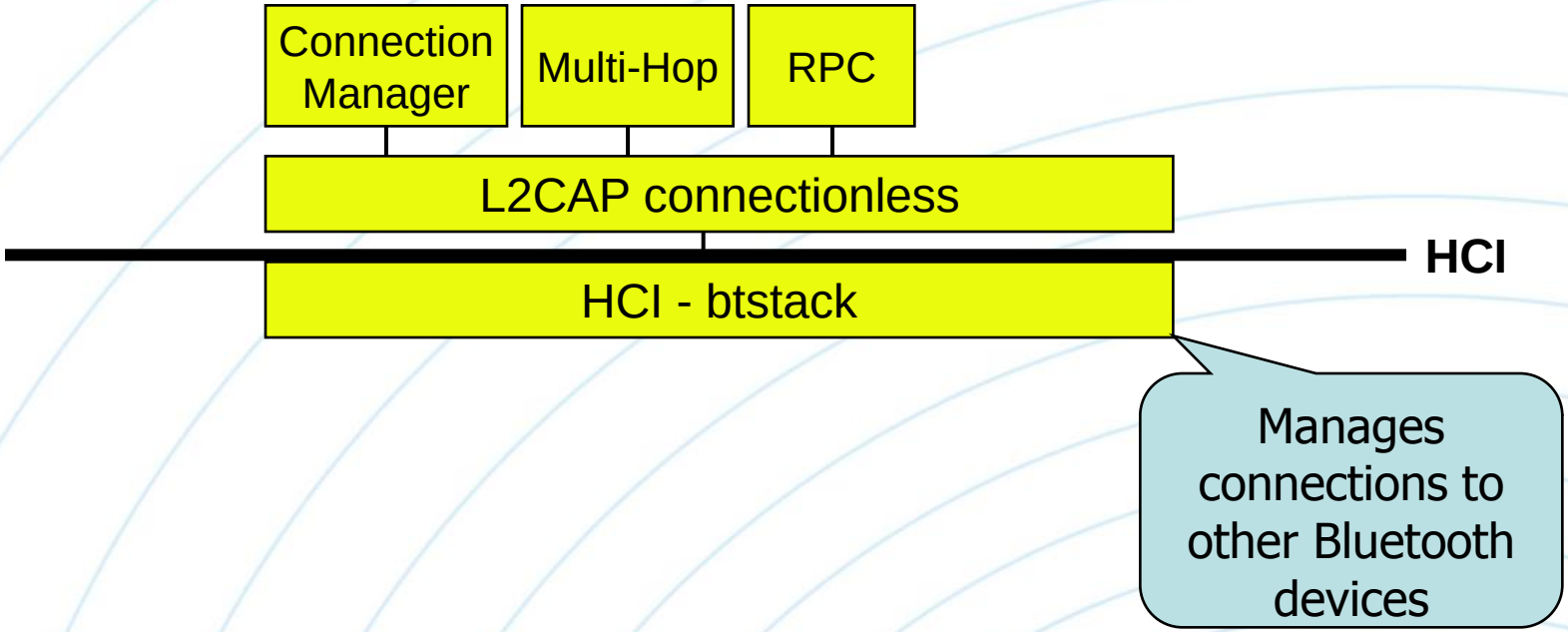
My First BTnut Application – The Bluetooth Protocol Stack



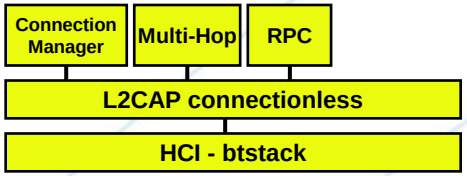
My First BTnut Application – The BTnut Protocol Stack



My First BTnut Application – The Host Controller Interface Layer

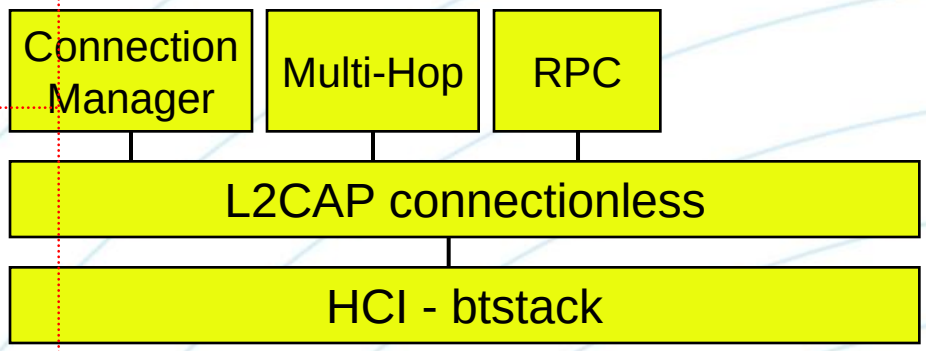


My First BTnut Application – Application Template Overview

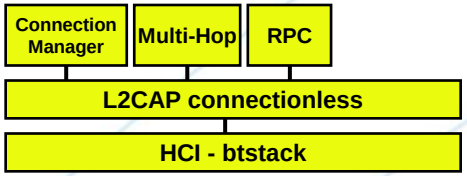



```
int main(void){
}
```

sensor-node.c



Hands-on: Application Template Overview

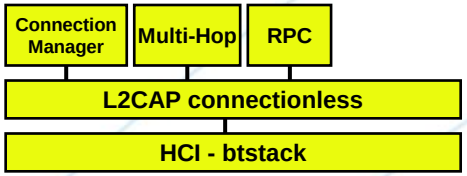



```
int main(void){
}
```

sensor-node.c

- A template **`sensor-node.c`** has been prepared for you
  - Copy the folder **`inss2007/mhop-example`** into the folder **`app`**
  - It contains **`sensor-node.c`**, **`defs.h`**, **`Makefile`** and solutions
  - Open **`app/mhop-example/sensor-node.c`** in an editor

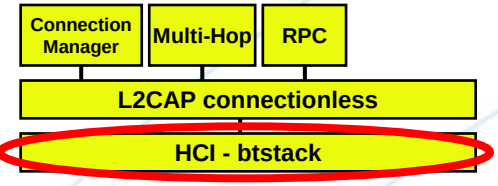
My First BTnut Application – BTnode Hardware Initialization



sensor-node.c

```
int main(void){
    // hardware init
    btn_hardware_init();
    btn_led_init(1);

    // init terminal app uart
    u_long baud = 57600;     // serial baud rate
    NutRegisterDevice(&APP_UART, 0, 0);
    freopen(APP_UART.dev_name, "r+", stdout);
    _ioctl(_fileno(stdout), UART_SETSPEED, &baud);
    btn_terminal_init(stdout, "[senso]$");

    // hello message
    printf("\n# ----------------------------------------");
    printf("\n# Welcome to INSS 2007 (c) ETH Zurich\n");
    printf("# program version: %s\n", PROGRAM_VERSION);
    printf("# ----------------------------------------");

    printf("\nbooting bluetooth module.\n");
    btn_hardware_bt_on();
    ...
}
```

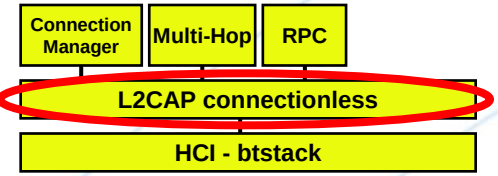
My First BTnut Application – BT Stack HCI Initialization



sensor-node.c

```
int main(void){
    ...
    struct btstack* bt_stack;
    bt_stack = bt_hci_init(&BT_UART);

    bt_acl_init(bt_stack, BT_HCI_PACKET_TYPE_DM3);

    ...
}
```

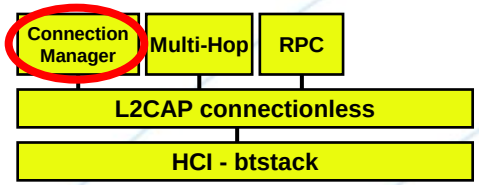
My First BTnut Application – BT Stack L2CAP Initialization



sensor-node.c

```
int main(void){
    ...
    struct btstack* bt_stack;
    bt_stack = bt_hci_init(&BT_UART);

    bt_acl_init(bt_stack, BT_HCI_PACKET_TYPE_DM3);

    bt_psm_t* psmux;
    psmux = bt_psm_init(bt_stack, MAX_NR_SERVICES,
                        NR_BUFFERS);
    l2cap_cl_init(bt_stack, psmux);

    ...
}
```

My First BTnut Application – Connection Manager Initialization

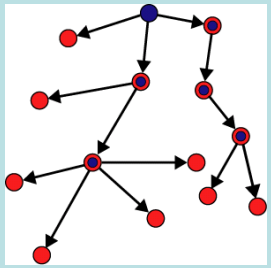


sensor-node.c

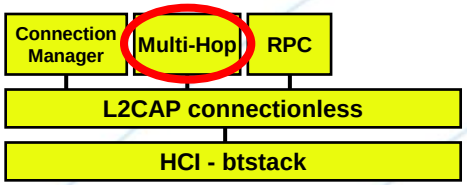
```
int main(void){
    ...
    struct btstack* bt_stack;
    bt_stack = bt_hci_init(&BT_UART);

    bt_acl_init(bt_stack, BT_HCI_PACKET_TYPE_DM3);

    bt_psm_t* psmux;
    psmux = bt_psm_init(bt_stack, MAX_NR_SERVICES,
                        NR_BUFFERS);
    l2cap_cl_init(bt_stack, psmux);

    con_mgr_init(bt_stack, psmux, CM_PSM,
                 bt_hci_register_con_table_cb, CM_COD);

    ...
}
```

PSM_ID for con_mgr service

This initializes a simple tree connection manager



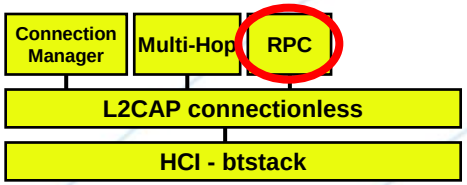
My First BTnut Application – Multi-hop Transport Initialization



sensor-node.c

```
int main(void){
    ...
    struct btstack* bt_stack;
    bt_stack = bt_hci_init(&BT_UART);

    bt_acl_init(bt_stack, BT_HCI_PACKET_TYPE_DM3);

    bt_psm_t* psmux;
    psmux = bt_psm_init(bt_stack, MAX_NR_SERVICES,
                        NR_BUFFERS);
    l2cap_cl_init(bt_stack, psmux);

    con_mgr_init(bt_stack, psmux, CM_PSM,
                 bt_hci_register_con_table_cb, CM_COD);

    mhop_cl_init(bt_stack, psmux, MHOP_PSM,NR_BUFFERS,
                 con_mgr_register_con_table_cb);

    ...
}
```

My First BTnut Application – Remote Procedure Call Initialization

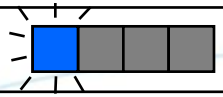
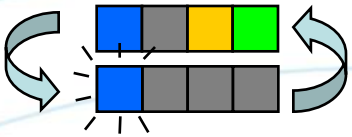
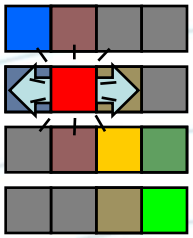


sensor-node.c

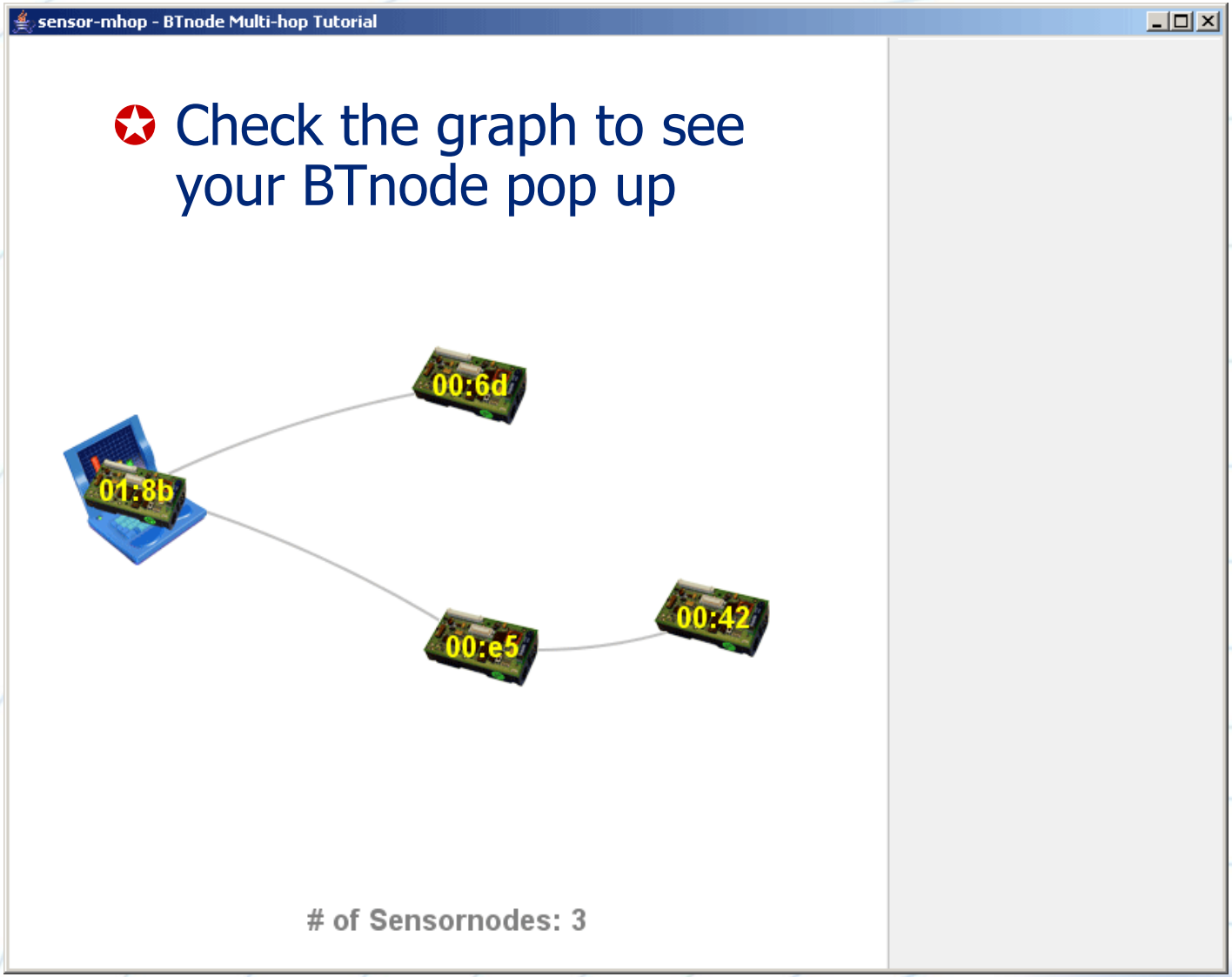
```
int main(void){
    ...
    struct btstack* bt_stack;
    bt_stack = bt_hci_init(&BT_UART);

    bt_acl_init(bt_stack, BT_HCI_PACKET_TYPE_DM3);

    bt_psm_t* psmux;
    psmux = bt_psm_init(bt_stack, MAX_NR_SERVICES,
                        NR_BUFFERS);
    l2cap_cl_init(bt_stack, psmux);

    con_mgr_init(bt_stack, psmux, CM_PSM,
                 bt_hci_register_con_table_cb, CM_COD);

    mhop_cl_init(bt_stack, psmux, MHOP_PSM,NR_BUFFERS,
                 con_mgr_register_con_table_cb);

    rpc_init(psmux, 8, RPC_PROC_PSM, RPC_RESULT_PSM);

    ...
}
```

Hands-on: Visual Control – Debugging with LEDs

- First steps with **`sensor-node.c`**
  - Understand the basic structure of the source code files
  - Compile, upload and inspect the state on the LEDs

State	LED Pattern	LEDs
Initialization	Heartbeat	
No connection	4Bit-ID+Heartbeat	
Inquiry	Knight-Rider	
Connected	4Bit-Tree-ID	
Connectivity with base station	Green LED	

My First BTnut Application – Network Topology Visualization



Hands-on: Sampling a Single Sensor

- Attach the sensor board to the USBprog
- Extend **`sensor-node.c`** with a sensor
  - Sample one sensor (microphone) every 5 seconds
  - Print the value on the terminal

```
#include <teco_ssmall/micsampler.h>
#include <dev/adc.h>
```

```
THREAD(sensorLoop, arg){        // sensor thread
    ADCInit();
    mic_init();
    for(;;){
        NutSleep(5000);
        printf("mic value = %u\n", mic_read());
    }
}
```

In **`main()`** before **`btn_terminal_run()`**

```
    btn_hardware_io_power(1); // sensor board power
    NutThreadCreate("T_senso", sensorLoop, 0, 256)
```

Hands-on: Sampling Multiple Sensors

1. Sample all 3 sensors:
   - Microphone
   - Light
   - Temperature
2. Store the sensor values in a predefined data-structure
3. Print the sampled data on the terminal

✪ Copy the code on the right into the template

```
#include <dev/twif.h>
#include <teco_ssmall/tsl2550.h>
#include <teco_ssmall/tc74.h>
```

```
THREAD(sensorLoop, arg){
    TwInit(20); // init twi with slave addr

    while(tsl_init()) NutSleep(10000); // start light sensor

    ADCInit();
    mic_init(); // init mic

    sensor_data_t sensor_data;    // see defs.h
    sensor_data_t* data = &sensor_data;
    u_char channel0, channel1;
    signed int temp;
    for(;;){
        NutSleep(5000);
        data->mic = mic_read();                // sample mic
        tsl_read(&channel0, &channel1);        // sample light
        data->light = tsl_calculate_lux(channel0, channel1);
        tc_read(&temp);                        // read temperature
        data->temp = temp;
        printf("mic = %u, light = %d, temp = %u\n",
                data->mic,
                data->light,
                data->temp);
    }
}
```

Hands-on: Multi-hop Data Transport

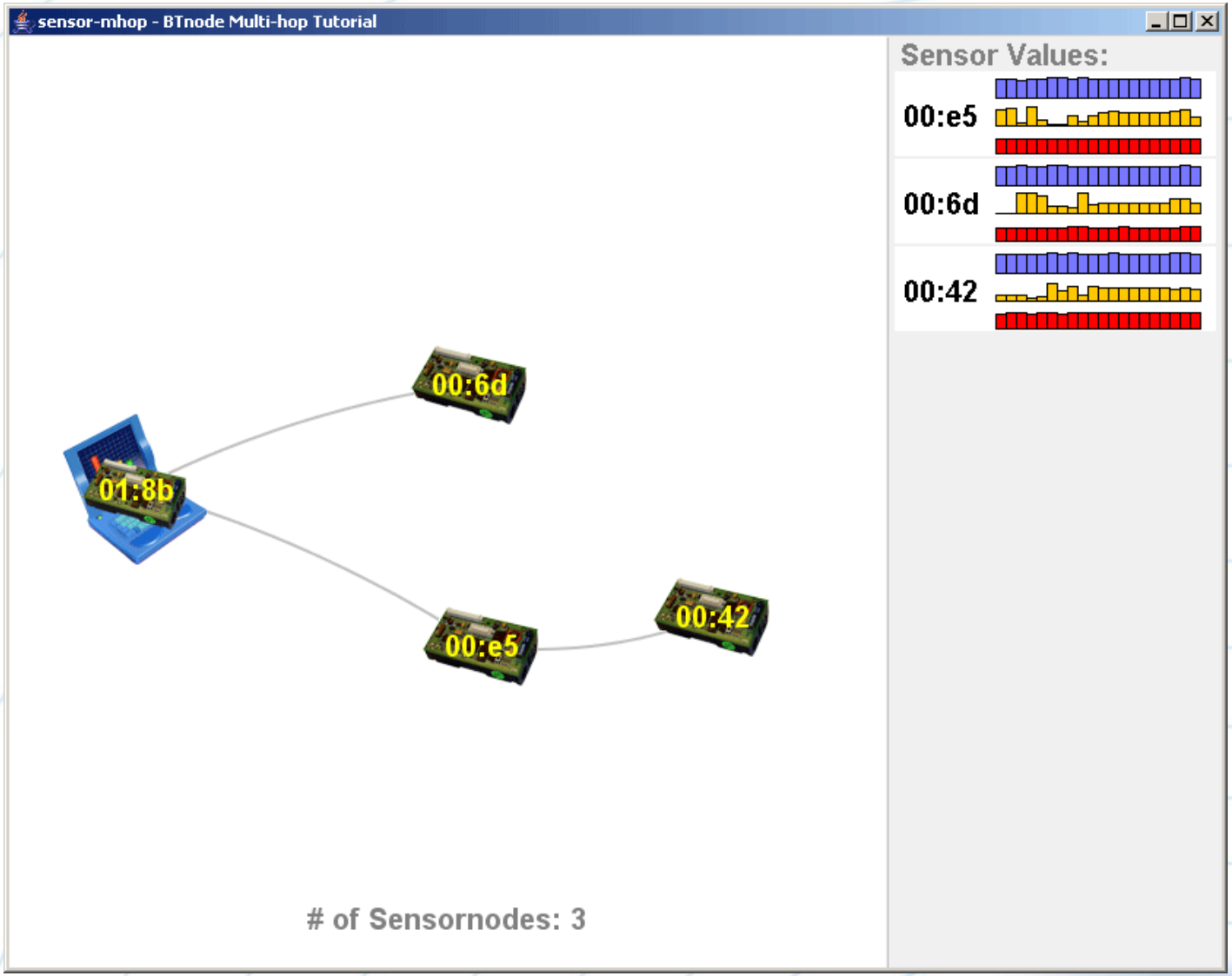
- Send the data-structure with the sensor values in a multi-hop packet to a base-station

```
// address of the base station (note: big endian)
bt_addr_t sink_addr = {0x8b,0x01,0x00,0x3f,0x04,0x00};
```

In **THREAD()** after **printf()**

```
// send packet
mhop_cl_send_pkt((u_char*)data,
                 sizeof(sensor_data_t),
                 sink_addr,
                 SENSO_PSM,
                 MHOP_CL_UNICAST, MHOP_CL_TTL_INFINITE);
```

My First BTnut Application – Sensor Data Visualization



My First BTnut Application – The Base-Station

Data-callback prints sensor values on terminal:

```
bt_acl_pkt_buf* sensor_data_cb(bt_acl_pkt_buf* pkt_buf,
                               u_char* data, u_short data_len,
                               u_short service_nr, void* cb_arg){
    u_char* source = mhop_cl_get_source_addr(pkt_buf->pkt);
    sensor_data_t* sensor_data = (sensor_data_t*) data;

    printf(":S "SADDR_FMT" %u %d %u\n", SADDR(source),
    sensor_data->mic,
    sensor_data->light,
    sensor_data->temp);

    return pkt_buf;
}
```

Data-callback is registered in main() with a PSM number:

```
bt_psm_service_register(psmux, SENSO_PSM, sensor_data_cb, NULL);
```

Congratulations!

Outline continued…

- Demonstration
  - Debugging and profiling of sensor network applications
    - Embedded debugging
    - Profiling using and OS tracer
    - Testbeds – The ETH Deployment-Support Network
- Hands-on
  - Interfacing to handheld devices
    - Bluetooth RFCOMM
    - AT commands
    - Sending an SMS message using AT commands
- Question and answer
- Time to explore BTnodes…

Beyond the Blinking LED – Embedded Debugging

- LEDs are nice but they
  - Offer a limited view inside only (e.g. Mica2Dot with one LED only)
  - Lack context/timing information (order of events?)
  - Consume lot's of power

- Other debugging techniques
  - Instruction-code simulators (with debugging capabilities)
  - In-circuit emulators (ICE)
  - Breakpoints with JTAG

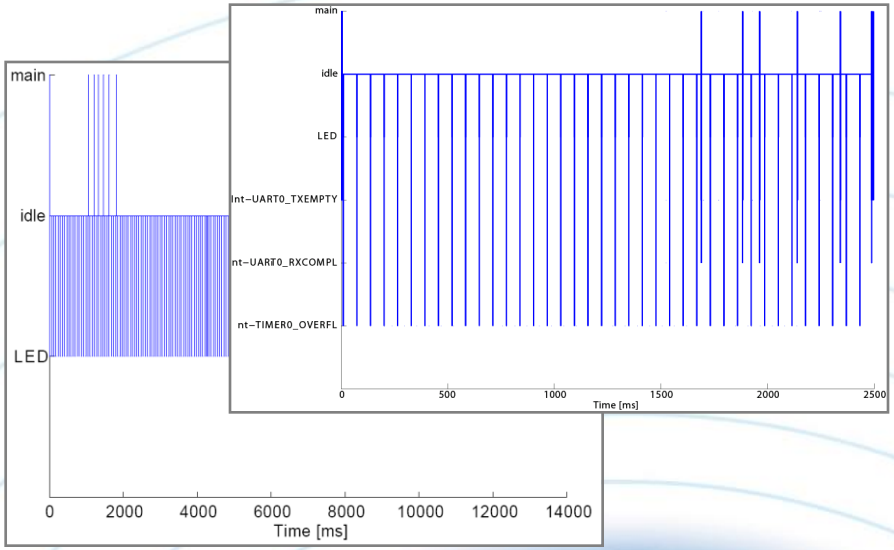
  - `PRINTF()` statements
  - Levels of verbosity, memory consumption, timing

  - Operating system monitors

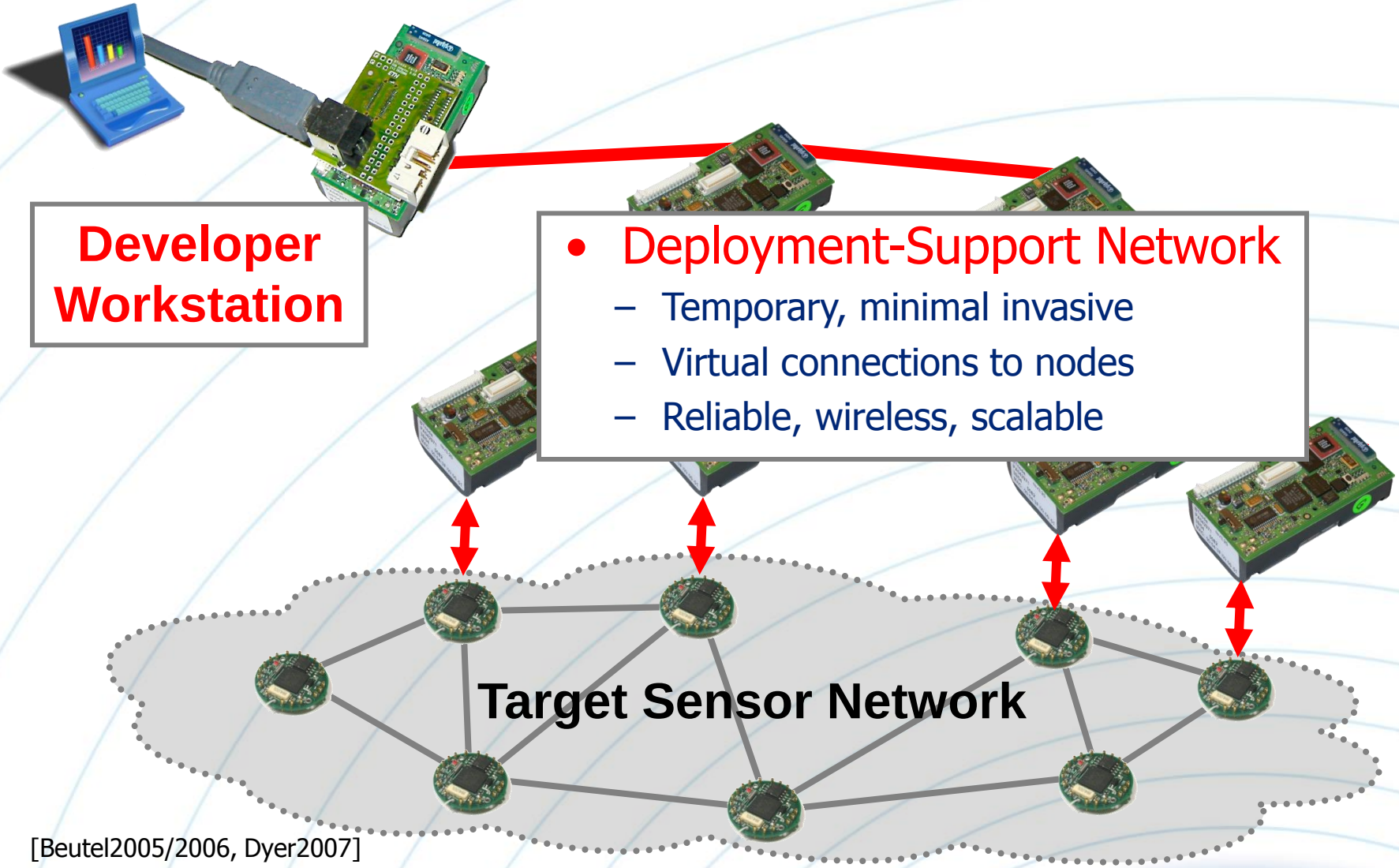
Beyond the Blinking LED – The BTnut OS Tracer

- The tracer tool is an extension to the BTnut software
  - Storage of information about important OS events
    - Thread switches, interrupts
    - Type of event, system time, additional information
  - Retrieval of information for offline analysis at a later time
  - Runtime configurable
  - Must be enabled at compile time using **–DNUTTRACER**

```
[btnode]$trace oneshot TRACE mode ONESHOT, restarted
[btnode]$trace TRACE STATUS
Mode is ONESHOT
Size is 500
contains 77 elements
[btnode]$trace print 10
TRACE contains 500 items, printing 10 items.
TAG            PC/Info   Time[s:ms:us]
-------------------------------------------------
Thread Yield   idle      13:524:336
Thread Sleep   LED       13:524:604
Thread Yield   idle      13:581:857
Thread Sleep   LED       13:582:125
Thread Yield   idle      13:639:392
Thread Sleep   LED       13:639:659
Thread Yield   idle      13:696:909
```



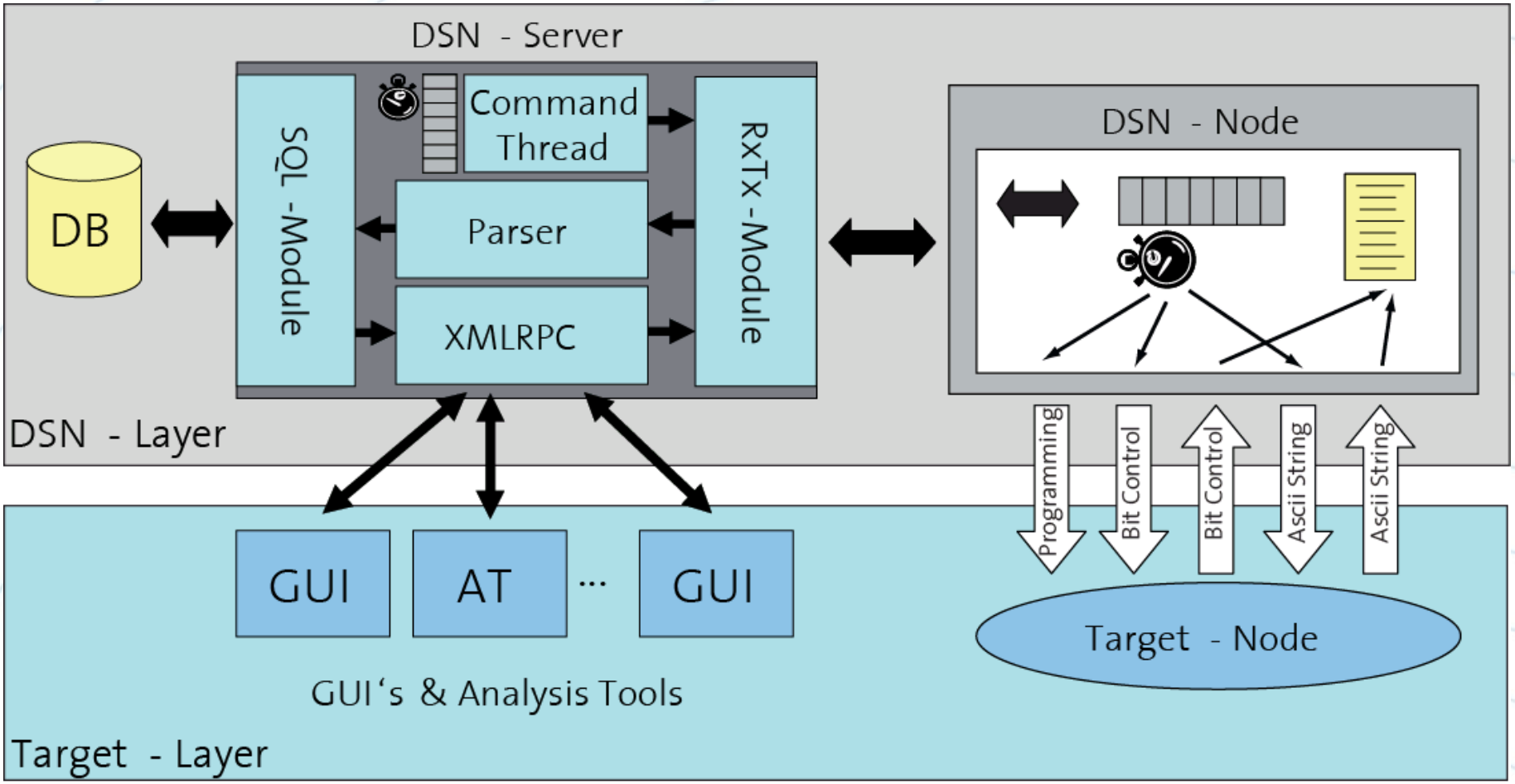
The Deployment-Support Network



- Deployment-Support Network
  - Temporary, minimal invasive
  - Virtual connections to nodes
  - Reliable, wireless, scalable

[Beutel2005/2006, Dyer2007]

Deployment-Support Network – Architecture

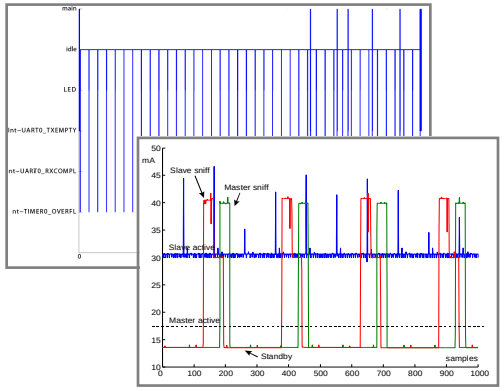


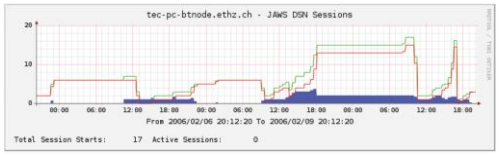
Deployment-Support Network – Application

- Characterization and validation of Smoke Detectors
  - Project in cooperation with Siemens Building Technologies

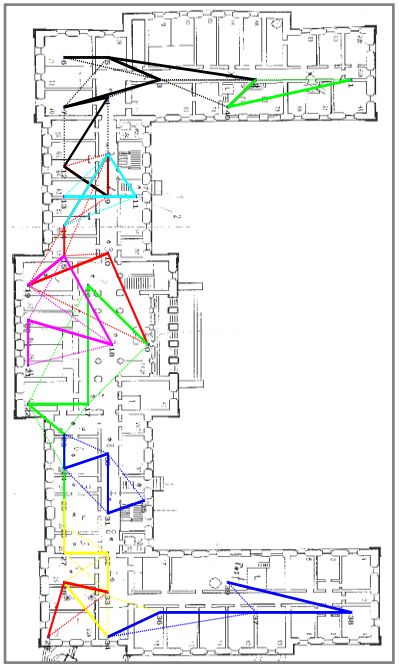
Test Setup

Development & Analysis





Field Testing



Deployment-Support Network – Analysis

Outline continued…

- Demonstration
  - Debugging and profiling of sensor network applications
    - Embedded debugging
    - Profiling using and OS tracer
    - Testbeds – The ETH Deployment-Support Network
- Hands-on
  - Interfacing to handheld devices
    - Bluetooth RFCOMM
    - AT commands
    - Sending an SMS message using AT commands
- Question and answer
- Time to explore BTnodes…

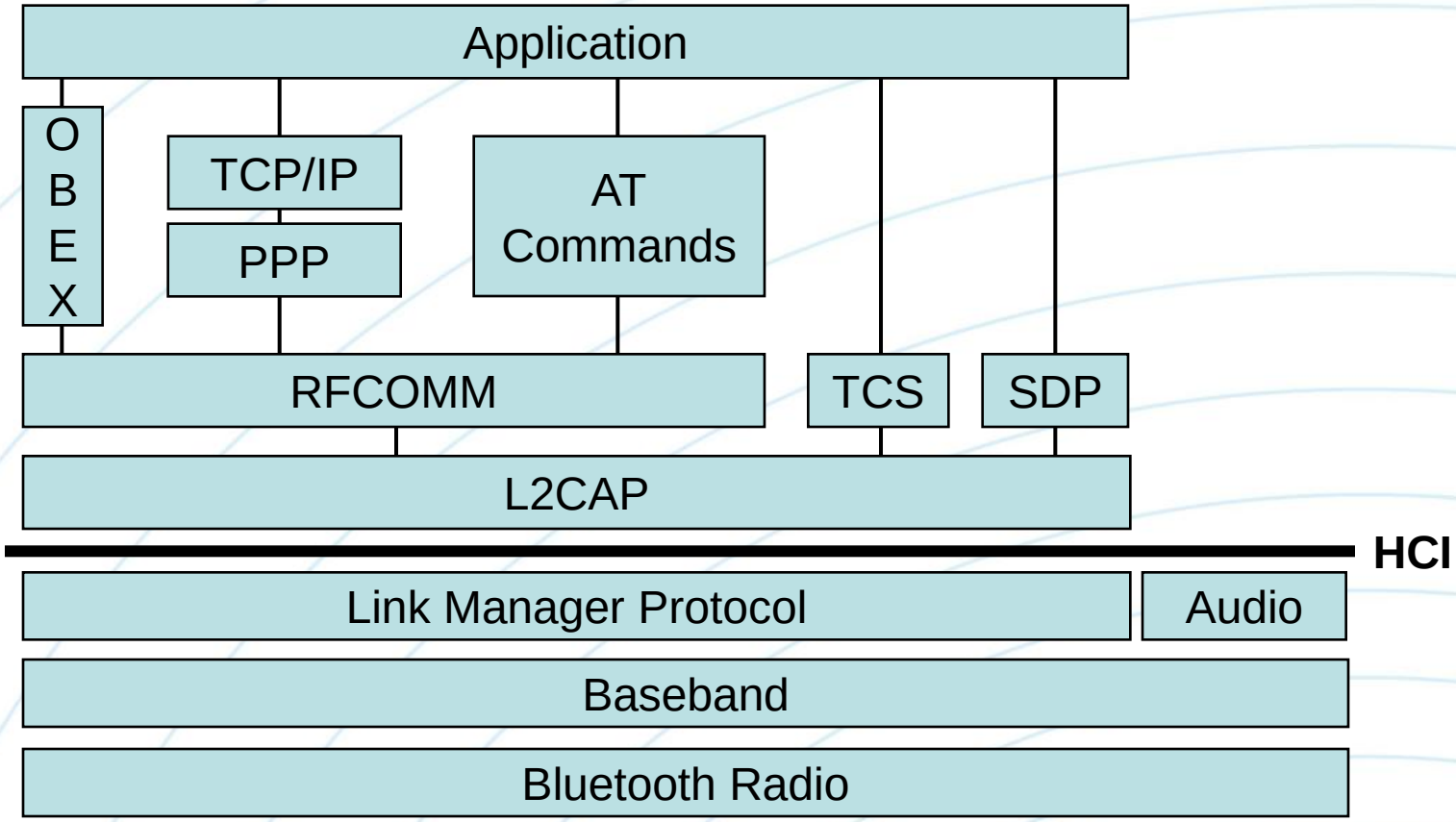
Interfacing to Handheld Devices – Overview

After creating a wireless sensor network we want to connect to a cellular phone as gateway.

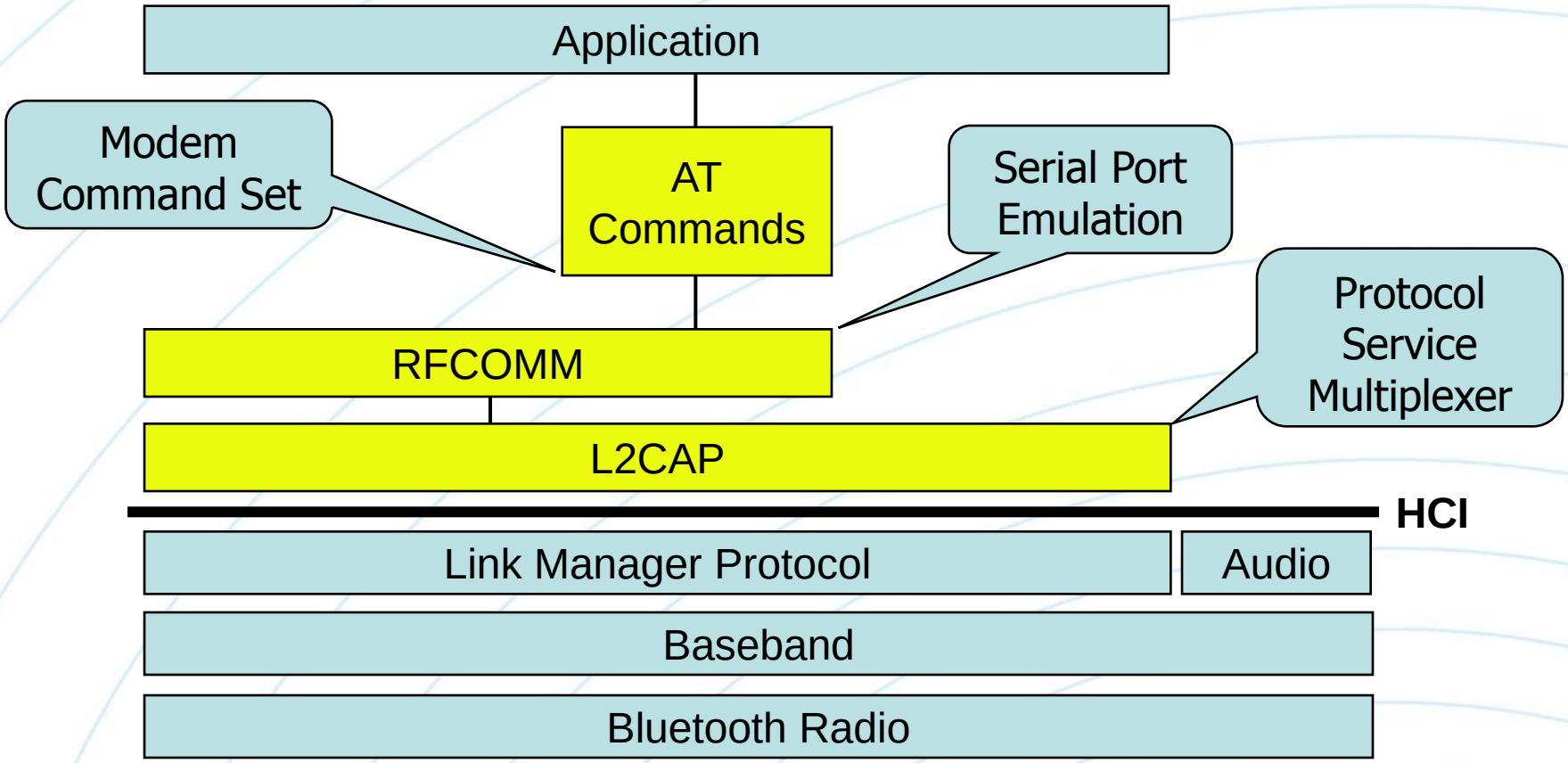
- Interfacing a sensor network to a mobile gateway
  - Internet connectivity
  - Alerting in case of events/failures
  - Independence of infrastructure

- Hands-on exercises using an application template

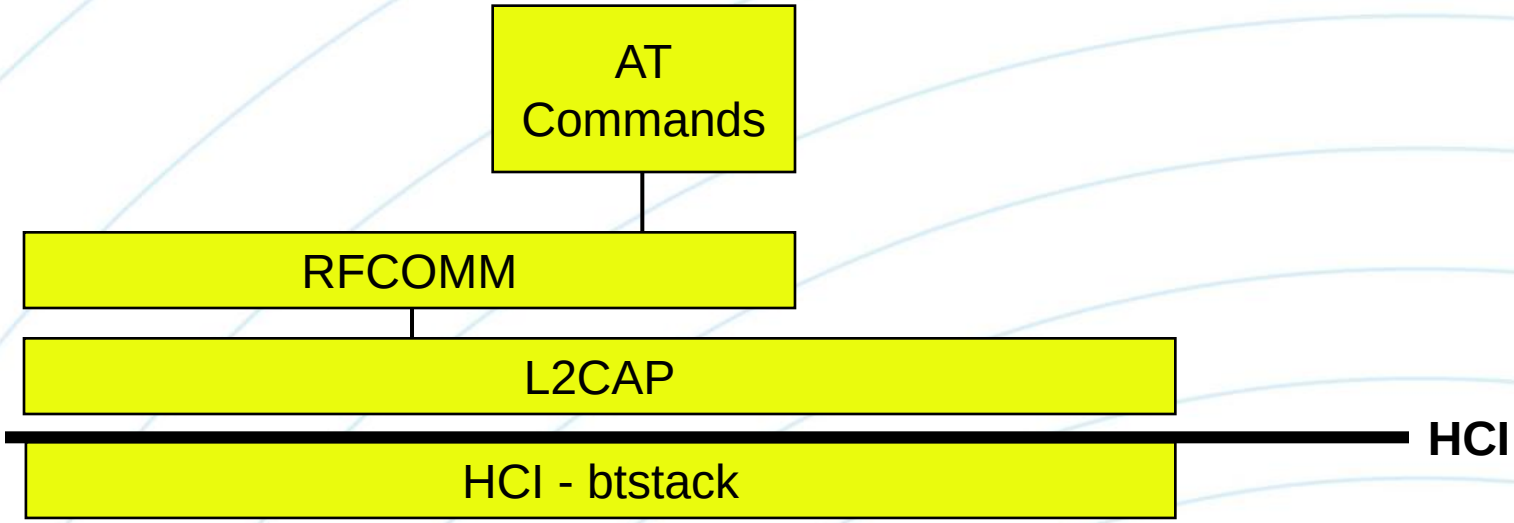
Interfacing to Handheld Devices – The Bluetooth Protocol Stack



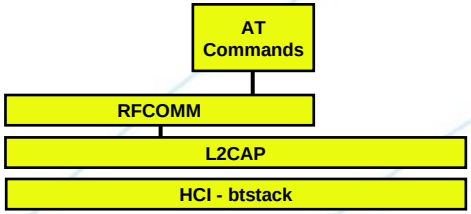
Interfacing to Handheld Devices – The Bluetooth Protocol Stack



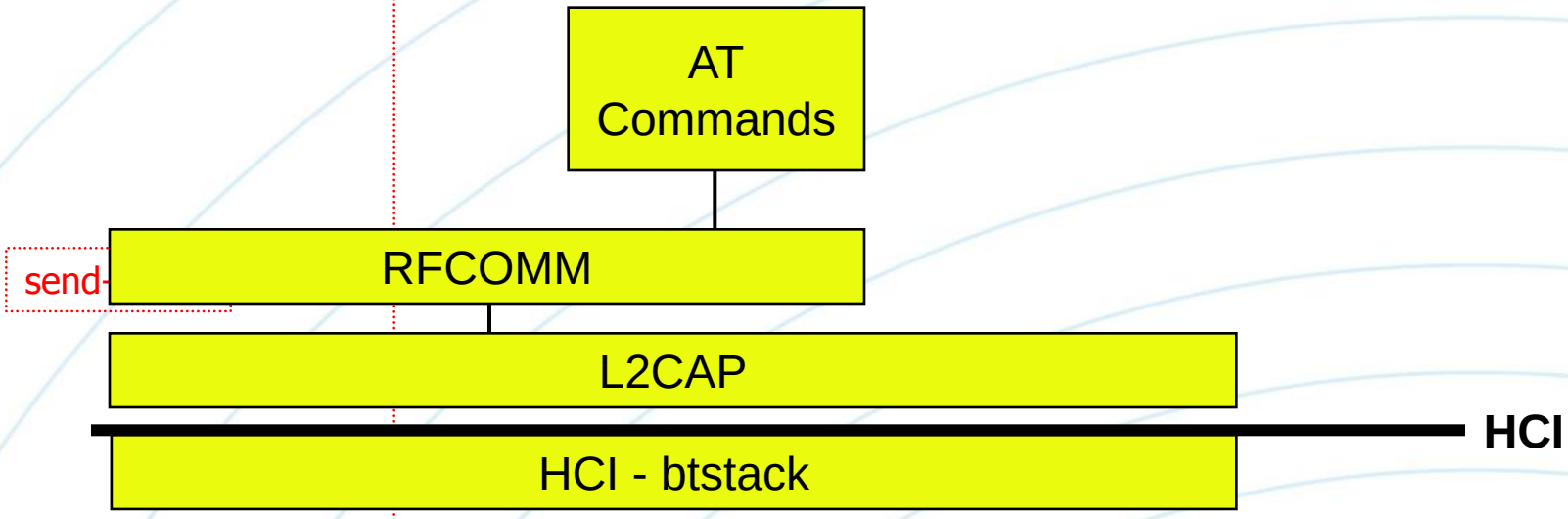
Interfacing to Handheld Devices – The Bluetooth Protocol Stack



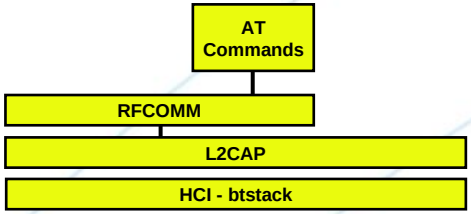
Interfacing to Handheld Devices – Template Overview




```
int main(void){
}
```



Hands-on: Application Template Overview

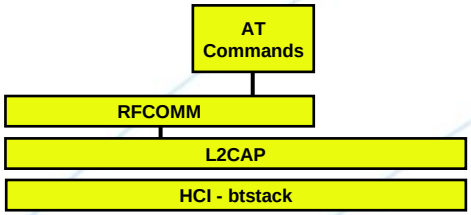



```
int main(void){
}
```

send-sms.c

- A template **`send-sms.c`** has been prepared for you
  - Copy the folder **`inss2007/send-sms`** into the folder **`app`**
  - It contains **`send-sms.c`**, **`Makefile`** and solutions
  - Open **`app/send-sms/send-sms.c`** in an editor

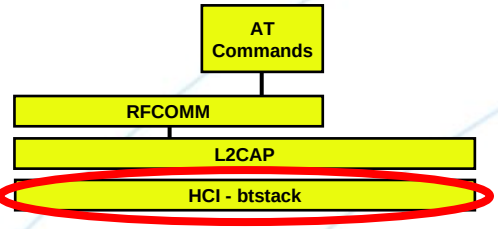
Interfacing to Handheld Devices – Hardware Initialization



send-sms.c

```
int main(void){
    // hardware init
    btn_hardware_init();
    btn_led_init(1);

    // init terminal app uart
    u_long baud = 57600;     // serial baud rate
    NutRegisterDevice(&APP_UART, 0, 0);
    freopen(APP_UART.dev_name, "r+", stdout);
    _ioctl(_fileno(stdout), UART_SETSPEED, &baud);
    btn_terminal_init(stdout, "[senso]$");

    // hello message
    printf("\n# ----------------------------------------");
    printf("\n# Welcome to BTnut(c) 2007 ETH Zurich\n");
    printf("# send-sms version: %s\n", PROGRAM_VERSION);
    printf("# configured for gateway BT MAC: ");
    printf("%.2x:%.2x:%.2x:%.2x:%.2x:%.2x\n", Btaddr ...);
    printf("# channel %x\n", channel);
    printf("# sending SMS to phone number %.15s\n", number);
    ...
}
```

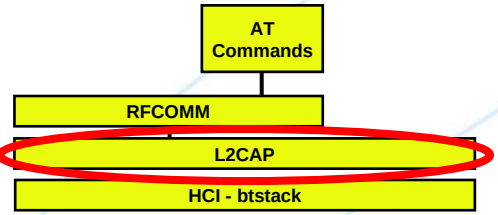
Interfacing to Handheld Devices – BT Stack HCI Initialization



send-sms.c

```
int main(void){
    ...

    // bluetooth module on (takes a while)
    btn_hardware_bt_on();

    // Start the stack and let the initialization begin
    stack = bt_hci_init(&BT_UART);
    bt_hci_write_local_cod(stack, BT_HCI_SYNC, 200);
    printf_P(PSTR("ok.\n\r"));

    // give hint
    printf_P(PSTR("hit tab twice for a list of
   commands\n\r"));

    // terminal init
    btn_terminal_init(stdout, "[send-sms]$");
    bt_cmds_init(stack);

    ...
}
```

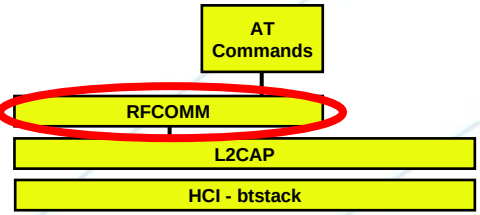
Interfacing to Handheld Devices – BT Stack L2CAP Initialization



send-sms.c

```
int main(void){
    ...

    // Start L2CAP

    l2cap_stack = bt_l2cap_init(stack, 8, 8,
   BT_L2CAP_HCI_PACKET_TYPE);

    l2cap_cmds_init(l2cap_stack, 1, BT_L2CAP_MIN_MTU,
   BT_L2CAP_MTU_DEFAULT);

    ...
}
```

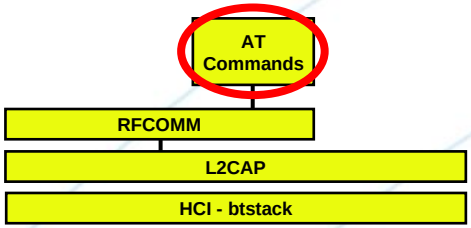
Interfacing to Handheld Devices – BT Stack RFCOMM Init



send-sms.c

```
int main(void){
    ...

    // Start RFCOMM

    rfcomm_stack = bt_rfcomm_init(l2cap_stack,
   BT_RFCOMM_DEF_MFS, 4, 5);

    rfcomm_cmds_init();

    ...
}
```

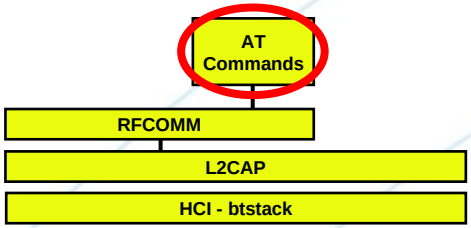
Interfacing to Handheld Devices – BT Stack Terminal Init



send-sms.c

```
int main(void){
    ...

    // Start RFCOMM

    rfcomm_stack = bt_rfcomm_init(l2cap_stack,
   BT_RFCOMM_DEF_MFS, 4, 5);

    rfcomm_cmds_init();

    bt_cmds_register_cmds();
    btn_cmds_register_cmds();
    nut_cmds_register_cmds();
    l2cap_cmds_register_cmds();
    rfcomm_cmds_register_cmds();

    ...
}
```

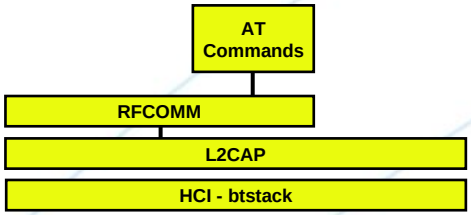
Interfacing to Handheld Devices – The Send SMS Application



send-sms.c

```
int main(void){
    ...

    // Start RFCOMM

    rfcomm_stack = bt_rfcomm_init(l2cap_stack,
   BT_RFCOMM_DEF_MFS, 4, 5);

    rfcomm_cmds_init();

    bt_cmds_register_cmds();
    btn_cmds_register_cmds();
    nut_cmds_register_cmds();
    l2cap_cmds_register_cmds();
    rfcomm_cmds_register_cmds();

    btn_terminal_register_cmd("sendsms", send_sms);

    // terminal mode
    btn_terminal_run(BTN_TERMINAL_NOFORK, 0);
    return 0;
}
```

Interfacing to Handheld Devices – Send SMS Routine Details



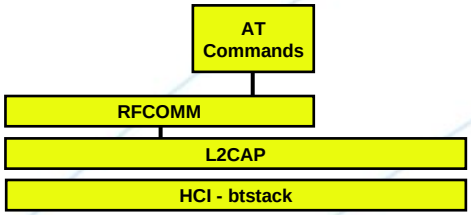
send-sms.c

```
void send_sms(char* arg){

    // the message
    char* message = NutHeapAllocClear(161);
    strcpy(message, "Greetings from the BTnode.");


    //connect
    printf("connecting to ["ADDR_FMT"]\n",ADDR(BTaddr));
    bt_rfcomm_start_session(BTaddr, 0, 0)

    NutSleep(1000);
    bt_rfcomm_connect(channel, con_cb, rcv_cb, line_cb,
   credit_cb, 10, NULL)
    NutSleep(1000);

    ...
}
```

RFCOMM session to the cell phone

RFCOMM channel setup: Callbacks necessary for the connection, reception, line status and RFCOMM credit

Interfacing to Handheld Devices – Send SMS Routine Cont.

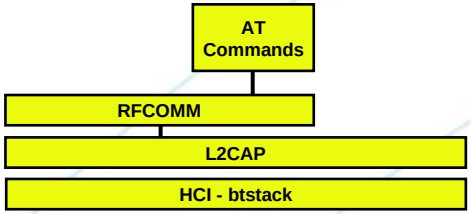


send-sms.c

```
void send_sms(char* arg){
    ...

    //general AT Commands
    bt_rfcomm_send(2*channel, "at&f\r", 5);
    NutSleep(2000);
    bt_rfcomm_send(2*channel, "at+cgmi\r", 8);
    NutSleep(1000);
    bt_rfcomm_send(2*channel, "at+cgmm\r", 8);
    NutSleep(1000);
    bt_rfcomm_send(2*channel, "at+cgsn\r", 8);
    NutSleep(1000);

    //send sms
    send_sms_pdu_mode(number, message);

    //disconnect
    bt_rfcomm_disconnect(2*channel);
}
```

A lot of string operations and text mangling…

Interfacing to Handheld Devices – Configuration



send-sms.c

```
// configure this!
// bt-address of the phone (reverse order!)
bt_addr_t BTaddr = {0x1d, 0x34, 0x05, 0x13, 0x18, 0x00};

// destination number to which sms is sent to
char number[17] = "+41774325509";

// destination channel number
u_char channel = 2;

void send_sms(char* arg){
    ...
}

int main(void){
    ...
}
```

Congratulations!

Further Reading

M. Dyer, J. Beutel and L. Thiele: **S-XTC: A Signal-Strength Based Topology Control Algorithm for Sensor Networks.** Proc. 2nd Second International Workshop on Ad Hoc, Sensor and P2P Networks (AHSP 2007), pages to appear, March 2007.

M. Dyer, J. Beutel, L. Thiele, T. Kalt, P. Oehen, K. Martin and P. Blum: **Deployment Support Network - A Toolkit for the Development of WSNs.** Proc. 4th European Conference on Wireless Sensor Networks (EWSN 2007), Lecture Notes in Computer Science Vol. 4373, Springer, Berlin, pages 195-211, January, 2007.

J. Beutel: **Fast-prototyping Using the BTnode Platform.** Proc. Design, Automation and Test in Europe (DATE 2006), ACM Press, New York, pages 977-982, March 2006.

L. Negri, J. Beutel and M. Dyer: **The Power Consumption of Bluetooth Scatternets.** Proc. IEEE Consumer Communications and Networking Conference (CCNC 2006), pages 519-523, January 2006.

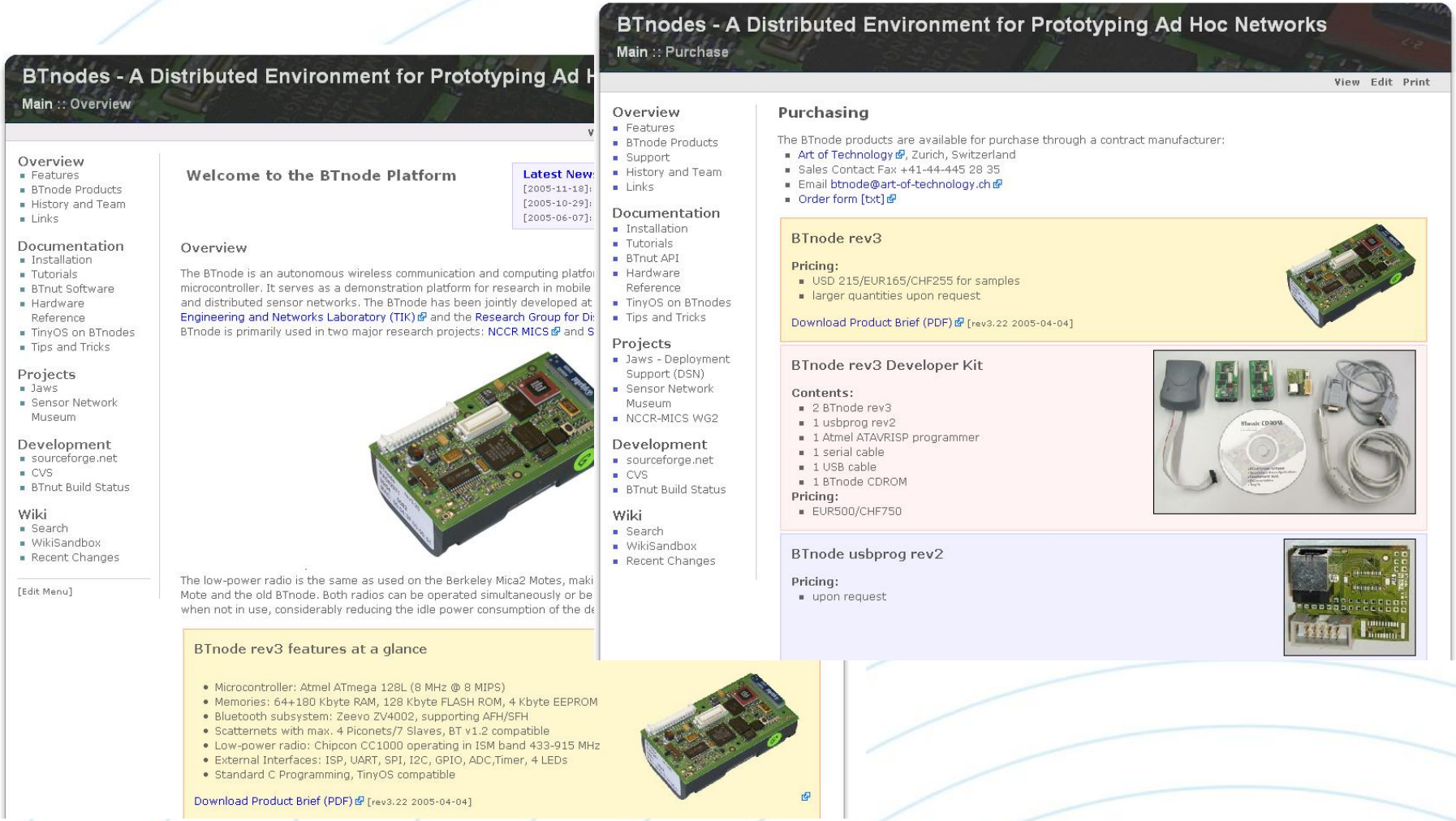
J. Beutel: **Robust Topology Formation using BTnodes.** Computer Communications, Elsevier B.V., Amsterdam, The Netherlands, Pages 1523-1530, Volume 28, Issue 13, August 2005.

J. Beutel, M. Dyer, L. Meier, and L. Thiele: **Scalable Topology Control for Deployment-Support Networks.** Proc. 4th Int'l Conf. Information Processing in Sensor Networks (IPSN '05), pages 359-363, April 2005.

J. Beutel, M. Dyer, M. Hinz, L. Meier, M. Ringwald: **Next-Generation Prototyping of Sensor Networks.** Proc. 2nd ACM Conf. Embedded Networked Sensor Systems (SenSys 2004), ACM Press, New York, 291-292, November, 2004.

J. Beutel, O. Kasten, F. Mattern, K. Römer, F. Siegemund and L. Thiele: **Prototyping Wireless Sensor Networks with BTnodes.** Proc. 1st European Workshop on Wireless Sensor Networks (EWSN 2004), Springer LNCS, vol. 2920, Berlin, pages 323-338, January 2004.

BTnode Online Resources



http://www.btnode.ethz.ch