CG4002

Computer Engineering Capstone Project

Lecture

Internal communications: Body area network over Bluetooth Low Energy

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[Slides adapted from previous CG3002 slides]

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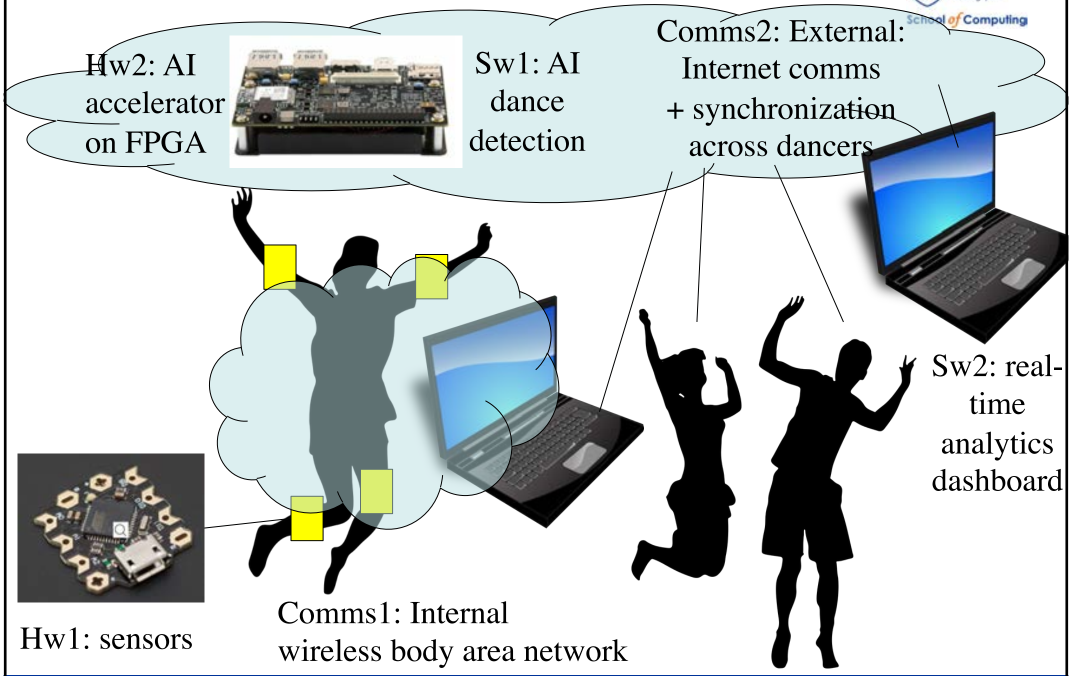
Virtual CG4002 in 6 parts:


Hw2: AI accelerator on FPGA
Sw1: AI dance detection
Comms2: External: Internet comms + synchronization across dancers
Sw2: real-time analytics dashboard
Hw1: sensors
Comms1: Internal wireless body area network

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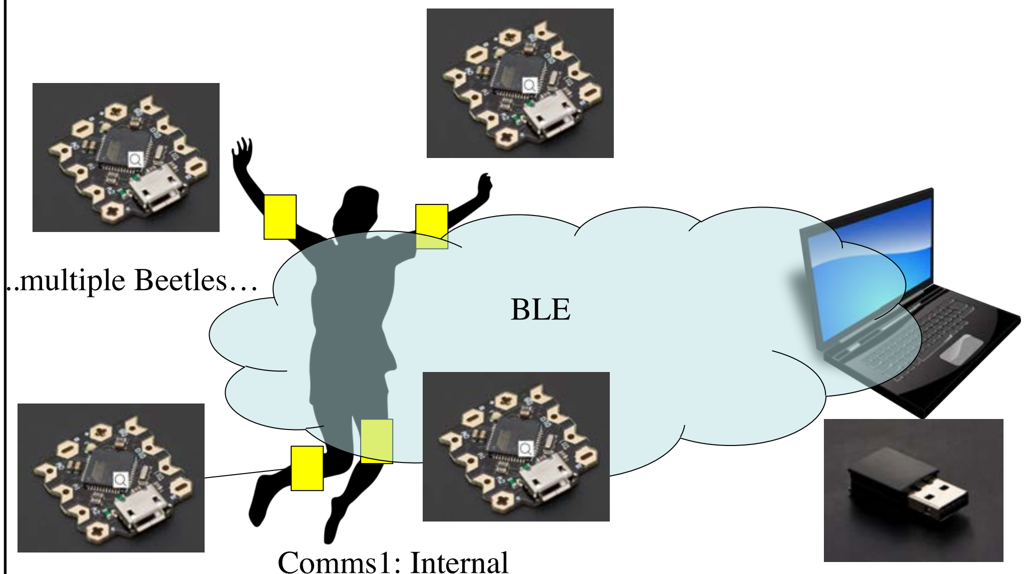
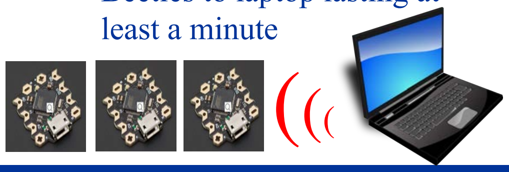
Comms Internal:



Comms1: Internal
wireless body area network

Week 7: Individual subcomponent test (20% indiv)

- **Comms1: Internal**
  - Walkthrough protocol for BLE communications
    - ✓**Handshaking**
    - ✓**Packet format**
  - Dummy sensor data
  - Demonstrate concurrent BLE connections from 3 Beetles to laptop lasting at least a minute



ARDUINO BEETLE-ULTRA96 BLE SERIAL COMMUNICATIONS

Goal: Send sensor data from Beetles to laptop reliably

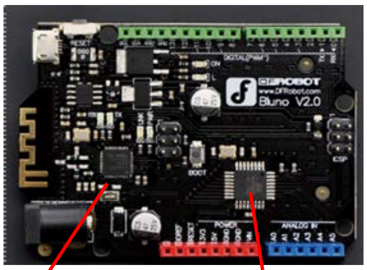
- **Burning questions…**
  - Beetle:
    - ✓**How to connect wirelessly?**
    - ✓**How to handshake?**
    - ✓**How to send?**
    - ✓**Real-time OS?**
  - Laptop:
    - ✓**How to discover the beetles?**
    - ✓**How to handshake?**
    - ✓**How to receive from multiple beetles?**
    - ✓**How to ensure reliable communication?**

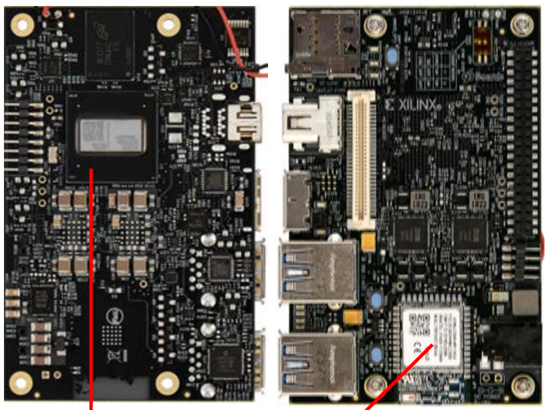
Bluetooth Low Energy (BLE)

- **Targeted for low power devices, IoT, wearables, mobiles**
- **Widely adopted**
- **Small data size, low duty cycle**
- **Range**

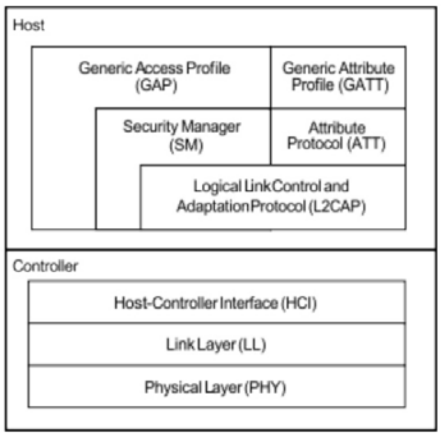
Bluetooth modules on Beetles and Ultra96

USB Bluetooth dongle




Xilinx Zynq Ultrascale+ ZU3EG
Microchip ATWILC3000 Bluetooth module

BLE Host and Controller


Host
Generic Access Profile (GAP)
Generic Attribute Profile (GATT)
Security Manager (SM)
Attribute Protocol (ATT)
Logical Link Control and Adaptation Protocol (L2CAP)
Controller
Host-Controller Interface (HCI)
Link Layer (LL)
Physical Layer (PHY)

[TI CC2540 software developer's guide]

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Setting up BLE host and controller on Ubuntu Linux

- **hciconfig**
  - print information about Bluetooth devices installed in the system.
- **/dev/wilc_bt:**
  - echo BT_POWER_UP > /dev/wilc_bt
  - echo BT_DOWNLOAD_FW > /dev/wilc_bt
  - echo BT_FW_CHIP_WAKEUP > /dev/wilc_bt
- **hciattach /dev/ttyPS1 -t 10 any 115200 noflow nosleep**
  - attach serial UART to bluetooth stack as HCI transport interface
- Configure **conn_min_interval** and **conn_max_interval** settings
- **bluetoothctl**
  - commands: list, show, connect
  - Get UUID

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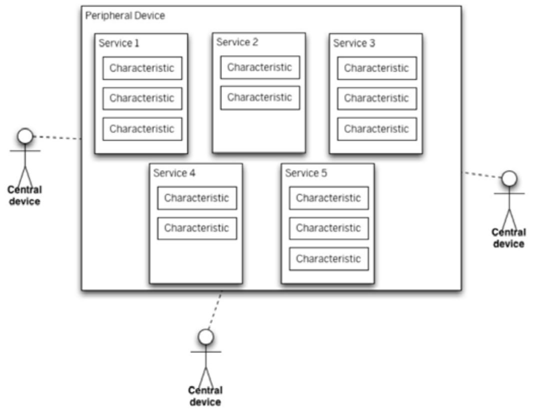
BLE basics



- **Peripherals vs Central devices**
  - ▪Peripherals publish/write data
  - ▪Central subscribes/reads data
- **Service and characteristics**

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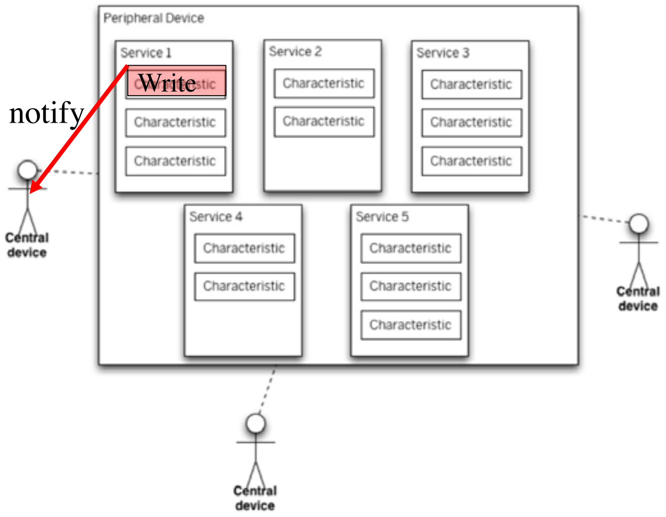
BLE basics: notifications



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How to establish BLE connections?

- **Connection = Peripheral – Central can communicate**
- **Discovery and advertising**
  - ▪Central device can scan and look for new devices
  - ▪Do you need it?
- **Handshaking**
  - ▪Need to make sure both devices are awake so you can establish connection
  - ▪How will you handshake?

BLE on Beetle: Serial Programming

- **Serial.begin**
- **Serial.available**
- **Serial.read**
- **Serial.print**

BLE on Ubuntu: bluepy? pySerial? bluez?

- **To do serial programming using Python you can use the bluepy package.**
  - github.com/IanHarvey/bluepy

- **Sample code skeleton**

```
from bluepy import btle

dev = btle.Peripheral("B0:B4:48:BF:C9:83")

p = Peripheral(MACADDRESS)
```

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Arduino Programming / Serial Communication

BUILDING A PROTOCOL

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Designing your own protocol over BLE

- **Handshaking: What do you send? Who starts handshaking?**
- **Packet format: What data do you send, in what format?**
  - BLE: Max message size? **What if data is fragmented across multiple messages?**
  - Baud rate?
- **Reliability?**
- **Concurrency?**
- **Security?**

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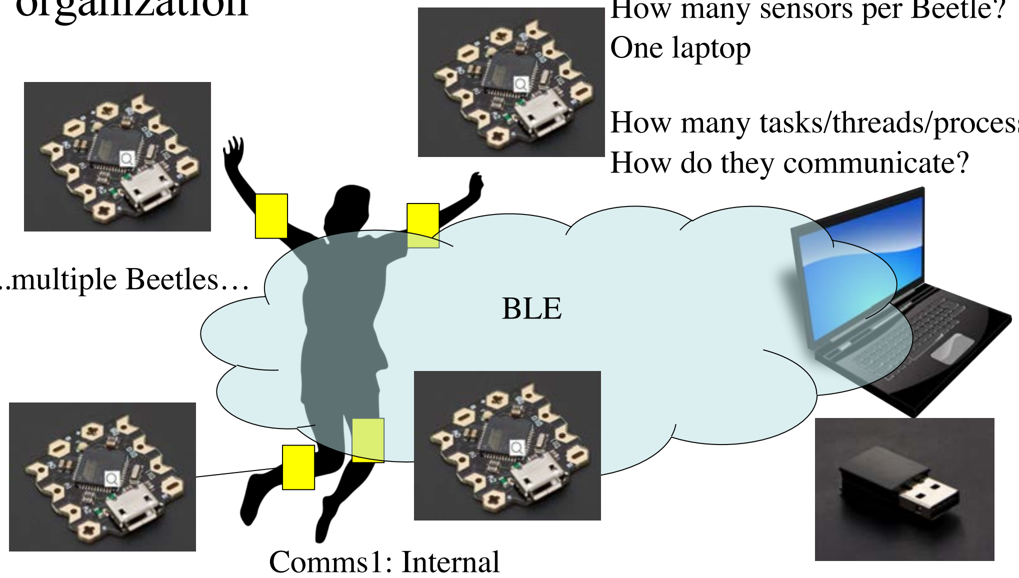
High level communications organization

How many Beetles?
How many sensors per Beetle?
One laptop

How many tasks/threads/processes
How do they communicate?



Comms1: Internal
wireless body area network

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Assign an ID to each device

- You need to be able to identify sensors (actuators) to read from (send data to).

Device ID	Device
0	Sonar 1
1	Sonar 2
2	Touch Sensor 1
3	Touch Sensor 2
4	Buzzer
5	Tactile feedback motor
...	...

- Do you have more than one sensor connected to a Beetle?

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Create Packet Types

- So both sides know what sort of packets are being sent (and the appropriate response)

Packet Type	Packet Code
ACK	0
NAK	1
Hello	2
Read	3
Write	4
Data Response	5
...	...

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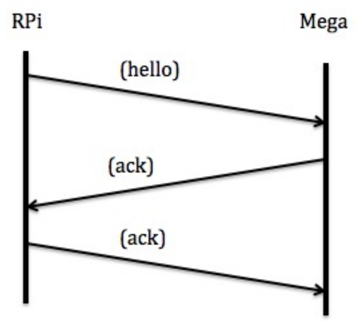
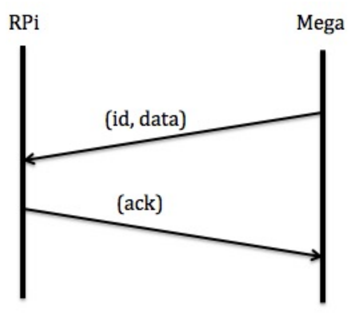
Bootup 3-way Handshake

- **Objective:**
  - ▪So both beetles and laptop know that each is ready to communicate.



  - ▪Do this at the very start of your programs on both sides

Periodic Push By Arduino?



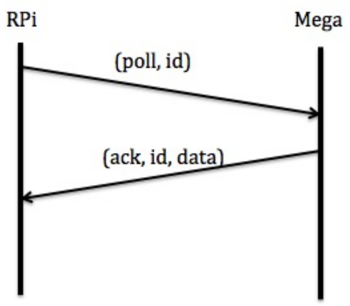
- **Arduino sends data whenever it is available.**
- **Laptop monitors and buffers data as it comes in.**

  +Arduino sends data whenever it is available.

  -Laptop needs to buffer incoming data.

  - What happens if buffer overflows?

Periodic Poll by Laptop



- **Arduino waits for poll packets from laptop**
- **Laptop requests data when it needs it.**

  +Laptop decides when it needs the data and sends poll packet.

  -If laptop doesn't poll often enough, may lose data on Arduino (Arduino has small memory).

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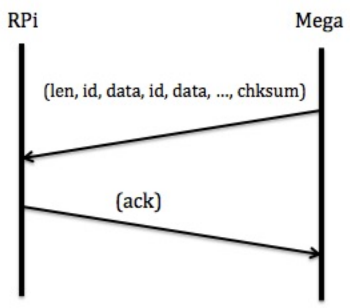
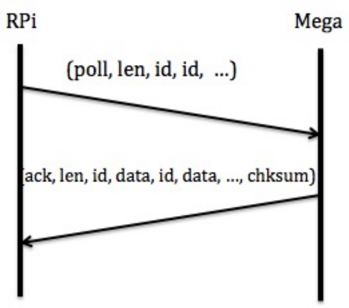
Sending Raw or Processed Data?

- **Polling/Pushing individual sensor data can be expensive.**
- **Might be better (??) to send processed?**





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Reliability: Checksums, Reconnections, Fragmentation

- **Checksums are used to check that data is received correctly.**
  - Does BLE specs support checksum?
- **Disconnections and reconnections**
- **Packet fragmentation**

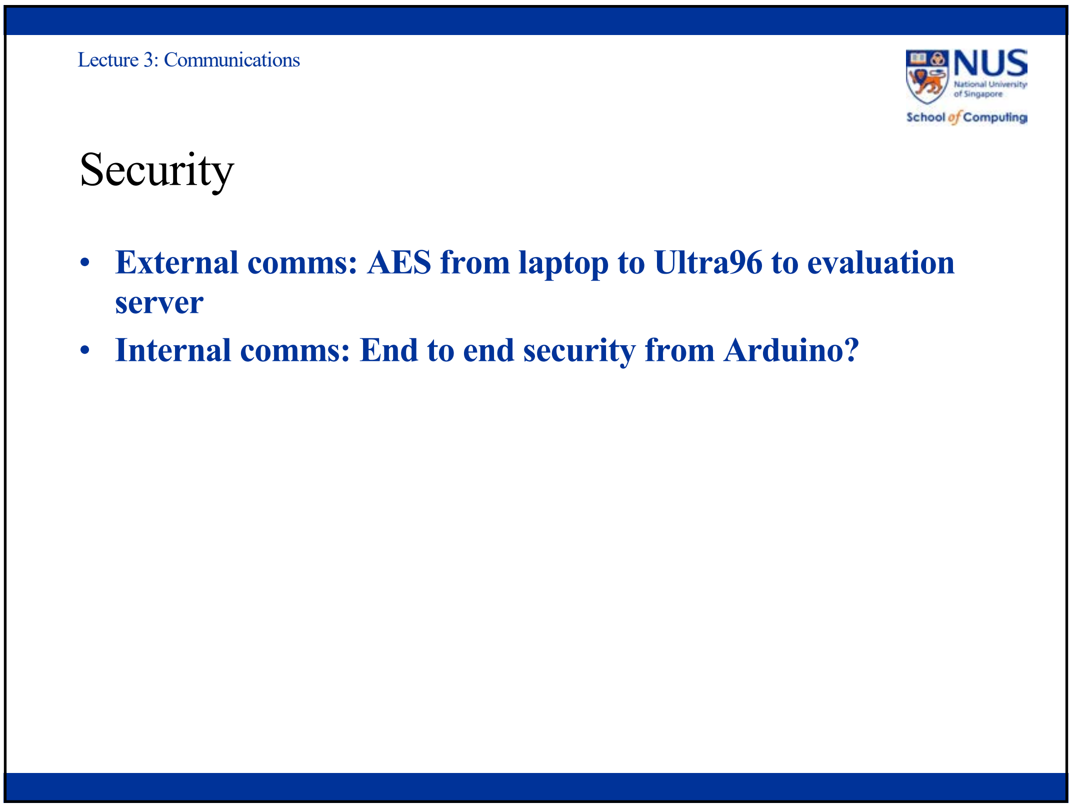
Concurrency: Tasks and processes in our project

Arduino: RTOS?

- **What are the tasks?**
- **Priorities among the tasks?**

Laptop:

- **What are the processes? Or threads?**
- **Synchronization/communication between the threads/processes?**



Security

- **External comms: AES from laptop to Ultra96 to evaluation server**
- **Internal comms: End to end security from Arduino?**

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