Distinguished lecture talk by our new AU honorary doctor Wendy E. Mackay on Creating Human-Computer Partnerships

- **Friday, 15 September, 10:15-11:00**
- **Small Auditorium, InCuba building**
- The classic approach to Artificial Intelligence treats the human being as a cog in the computer's process — the so-called "human-in-the-loop".
- By contrast, the classic approach to Human-Computer Interaction seeks to create a 'user experience' with the computer.
- We seek a third approach, a true human-computer partnership that takes advantage of machine learning, but leaves the user in control. I describe how we can create in teractive systems that are discoverable, appropriable and expressive, drawing from the principles of instrumental interaction and reciprocal co-adaptation. Our goal is to create robust interactive systems that grow with the user, with a focus on aug menting human capabilities.

Wireless Sensor Networks & Networking for IoT

Niels Olof Bouvin

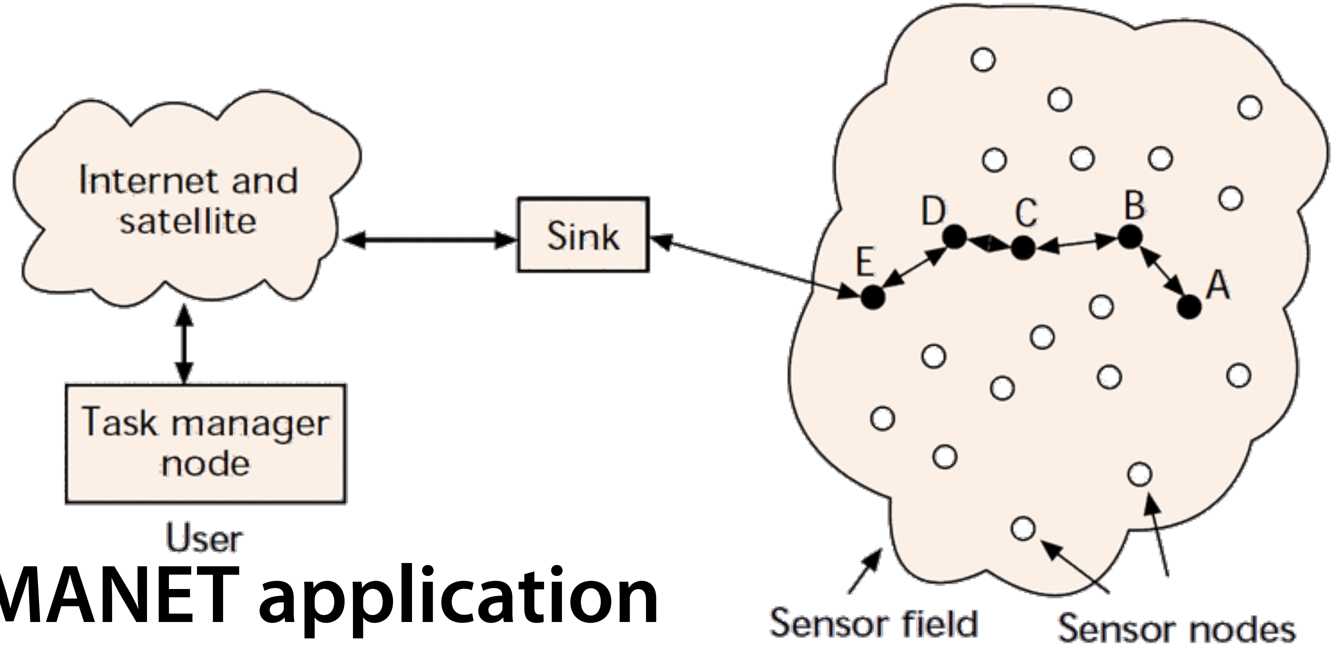
Overview

- **Wireless Sensor Networks**
- Choosing an embedded platform
- Network communication for IoT
- IoT application layer

Structure

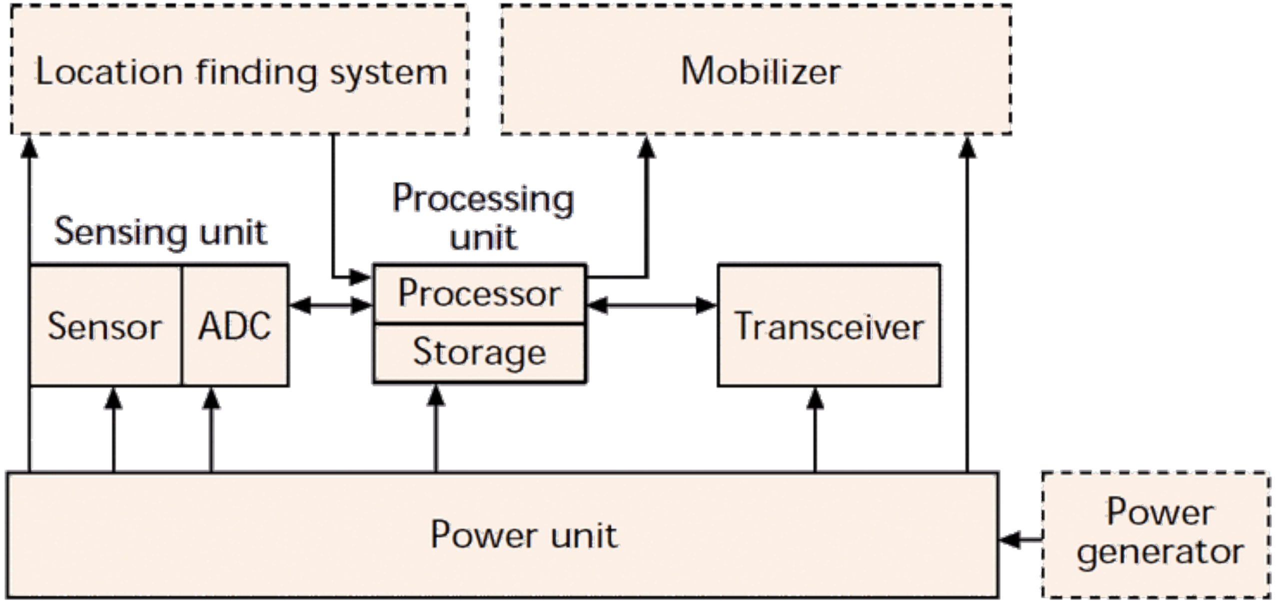
- What are wireless sensor networks?
- Challenges for WSN

What are Wireless Sensor Networks?



- **A special class of MANET application**
    - *many* nodes, cheap, small, and limited in CPU, storage, and communication
    - scattered/distributed in an ad hoc manner
    - in order to study a specific phenomenon through sensing, and
    - to report the collected data to a data sink
- **MANETs are intended to handle ad hoc communication from one arbitrary node to another**
    - WSN is about sensing, collecting, and shipping data in one direction—the *sink*

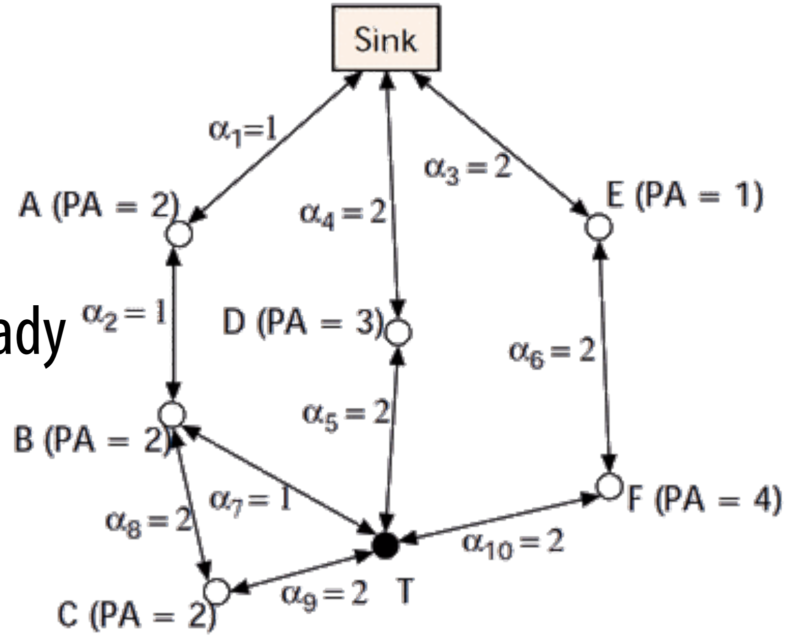
Criteria and restrictions for WSN



- **The individual node must be *cheap***
  - if the sum price for the nodes is greater than conventional sensing, it is too expensive
- **The overriding requirement is the overall survival of the sensing network—not the individual node**
  - which may not even have an unique identifier, or be expected to survive long
- **Nodes are limited in communication range**
  - but are densely distributed, which helps

Energy-concerned routing

- **Maximum PA route**
  - prefer highest total PA. Route 2 looks best, but already contains the nodes of Route 1. Route 4 wins!
- **Minimum Energy route**
  - prefer lowest total transmission cost. Route 1 wins!
- **Minimum Hop route**
  - prefer shortest path. Route 3 wins!
- **Maximum minimum PA route**
  - prefer path with the largest of the smallest PA along the route. Route 3 wins!

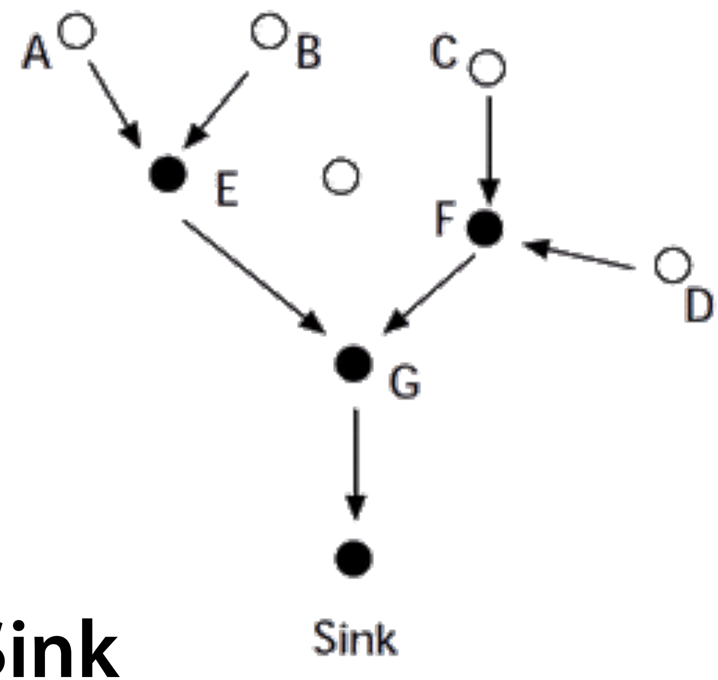


PA: Available power

α: Transmission cost

	T to Sink	∑ PA	∑ α
1	T-B-A-S	4	3
2	T-C-B-A-S	6	6
3	T-D-S	3	4
4	T-F-E-S	5	6

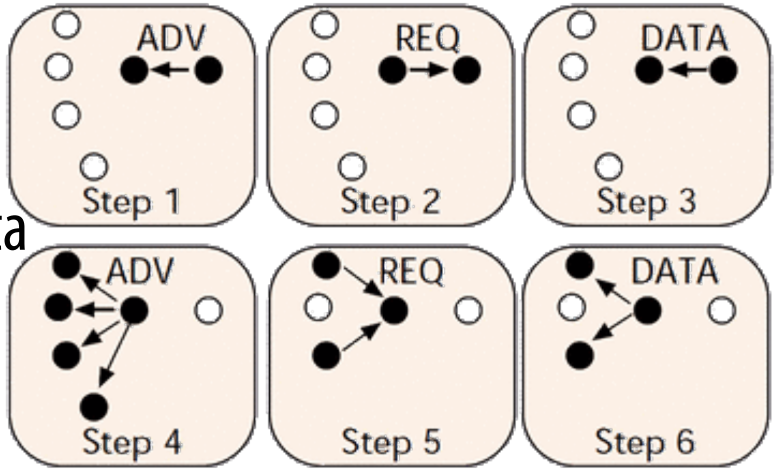
Data-aggregation



- **Data moves from sensors to the Sink**
- **In ordinary routing, each packet is treated individually**
- **In sensor networks, data can be aggregated, i.e., collected into bigger packets along the way towards the sink**
    - more much efficient

Data-centric routing

- **In ordinary MANET, we might request resource held by specific node**
- **In WSN, queries are data centred**
  - Sinks can request data matching certain attributes
    - 'data from sensors, where temperature > 35°C'
  - Nodes can advertise that they have data
    - meta-data is often cheaper to transmit than data



Summary

- Wireless sensor networks have a specific use case that sets them apart from ordinary MANET
- Advances in sensor technologies, Smart Dust™, etc, indicates a field in growth
- Many challenges and unanswered questions

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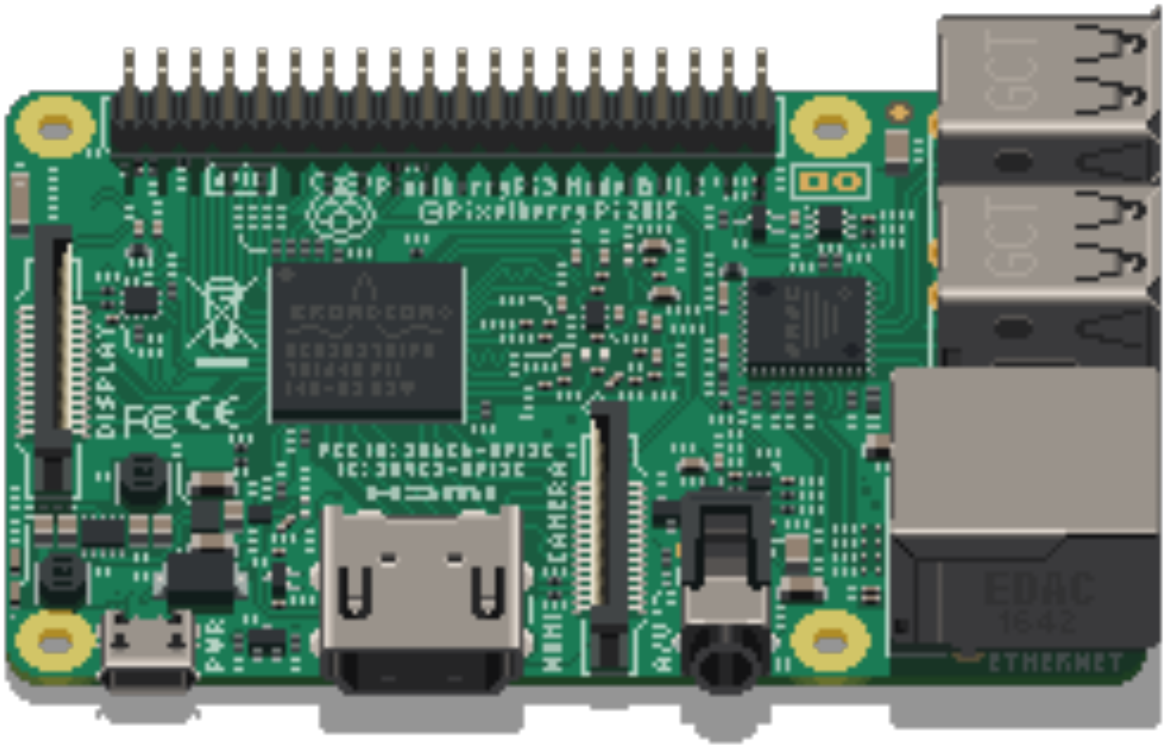
Internet of Which Things?



- **There are many different embedded platforms suited for IoT development, so why choose the Raspberry Pi?**
  - it is relatively cheap; it is fairly powerful; it comes with WiFi, Bluetooth & Ethernet; it runs Linux; it supports all kinds of development tools and frameworks; it is highly extensible through GPIO or the use of shields

Talking to GPIO

```
var onoff = require('onoff'); //#A

var Gpio = onoff.Gpio,
  led = new Gpio(4, 'out'), //#B
  interval;

interval = setInterval(function () { //#C
  var value = (led.readSync() + 1) % 2; //#D
  led.write(value, function() { //#E
    console.log("Changed LED state to: " + value);
  });
}, 2000);

process.on('SIGINT', function () { //#F
  clearInterval(interval);
  led.writeSync(0); //#G
  led.unexport();
  console.log('Bye, bye!');
  process.exit();
});

// #A Import the onoff library
// #B Initialize pin 4 to be an output pin
// #C This interval will be called every 2 seconds
// #D Synchronously read the value of pin 4 and transform 1 to 0 or 0 to 1
// #E Asynchronously write the new value to pin 4
// #F Listen to the event triggered on CTRL+C
// #G Cleanly close the GPIO pin before exiting
```

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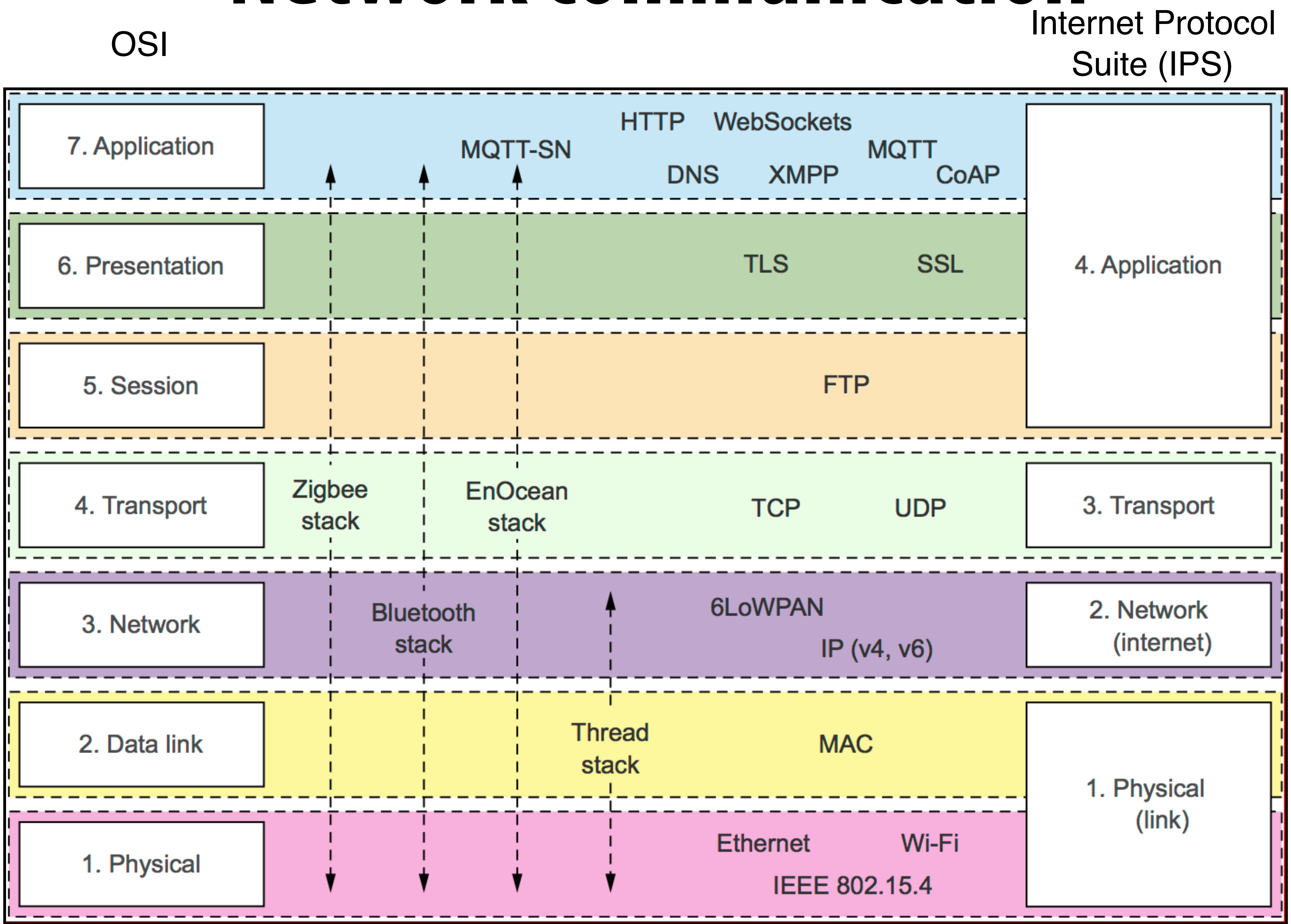
Network communication



A layered approach

- **There are multitudinous network protocols**
  - from very low level physical to high level application protocols
- **There are many different networking stacks**
  - the Internet Protocol Stack, while the most widespread, is one among many
- **Within a stack, the protocols are layered**
  - depending on the layers below
  - providing services for the layer above
- **In a well designed stack, lower layers can be replaced without affecting higher layers (if protocols are kept)**
  - your web browser does not care if you're on 4G, WiFi or Ethernet, even though these are physically quite different

Wireless communication for IoT

- **Many choices and one size does not fit all**
- **Different scales:**
  - Personal
  - Domestic or building
  - City or larger
- **Different traffic scenarios**
  - Periodic sensor data
  - High, constant data rate
  - Low latency actuator activation
- **Throughput, Range, Energy-efficient: Pick two**

Bluetooth®

- **Started out as a PAN (Personal Area Network)**
  - very widespread — few phones, tablets, or computers without it
  - quite a few different subprotocols — RFCOMM universally supported
  - pairing usually necessary to connect devices — more secure, but also a hassle
  - supports in principle general networking, but most cases are 1-to-1 connections
  - range up to 100 m, though typically much less
- **Recent revisions have expanded IoT aspects**
  - BT 4.0 Low Energy: sufficiently energy efficient to work in cell battery driven beacons
  - BT 5: enables trading range for speed in low energy communication
- **Not a part of the Internet Protocol Stack — must be bridged using, e.g., 6LowPAN (RFC 7668)**

ZigBee

- IEEE 802.15.4 specified protocol
- Low range WPAN, simpler than Bluetooth
- Datarate: <250 kb/s; highly energy efficient
- Supports star, tree, and mesh networking
  - usually controlled through a hub, though, e.g., a switch and light may connect directly
- Notably used by Philips Hue and IKEA Trådfri
  - ZigBee Light Link
  - thus, IKEA Trådfri can be paired and used with the Philip Hue hub
- ZigBee IP links to the IP stack

- **IEEE 802.11a-ac**
- **Ubiquitous in domestic or commercial settings**
  - speeds up to 1 Gbps
  - range typically well below 100 m with omni-directional antennas
- **Completely integrated with the IP stack**
- **Not especially energy efficient**
  - unsuited for battery powered sensors
  - 801.11ah designed to address this

GPRS, 3G, 4G

- **Mobile phone data network**
- **Works well with the IP stack**
- **Good, if not complete, coverage, but**
  - not energy efficient
  - expensive
- **Not really intended for a lot of devices**

LPWAN

- **Low Power Wide Area Networks**
- **Typically a star topology**
  - infrastructure may be provided by the operator
- **Great range, low bandwidth, great energy efficiency**
- **Excellent for collecting data from sensors**
  - but if we need to connect to the device, we either have high latency or low energy efficiency

sigfox

- **The existing standard for SigFox communications supports up to 140 uplink messages a day, each of which can carry a payload of 12 Bytes (Excluding message header and transmission information) and up to 4 downlink messages per day, each of which can carry a payload of 8 Bytes. [Source: Wikipedia]**
- **Hardware is cheap; SigFox (and partners) operate the infrastructure financed through a subscription model**
  - Only one operator in an area; if your area is not covered: tough
  - SigFox provides various services, including geolocation and IP connectivity

LoRa

- **Competing standard to SigFox**
  - LoRa Alliance
- **Companies may run their own infrastructure**
  - Aarhus municipality uses LoRa to collect sensor data from, e.g., garbage containers
- **While most use cases are data collection, messages can be sent back, even to battery constrained units**
  - when a device uploads data, it can listen for a little while, and the central station can use that window to send a message back
  - if low latency is required, the device must necessarily be listening

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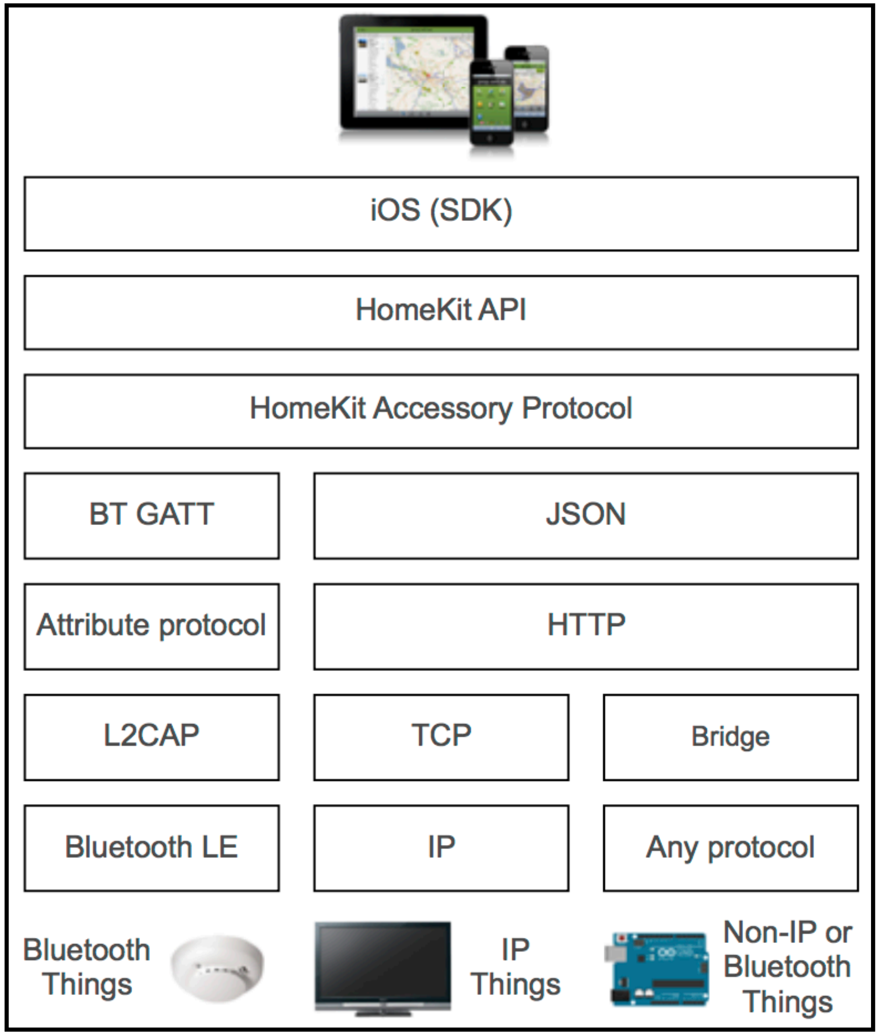
So, you want to build a system…

- **Most standards, such as Bluetooth or ZigBee have predefined profiles**
  - controlling thermostats, curtains, lights, air-conditioning, etc.
  - discovery of services
- **But, these often require specific SDKs, not necessarily widely supported across languages and platforms**

Apple HomeKit & Google Weave



- Runs on Thread
  - IEEE 802.15.4 standard like ZigBee
- Creates a mesh network
- Integrates with IP stack
- The basis for Nest

Works with Apple HomeKit

THREAD CERTIFIED COMPONENT

MQTT & CoAP

- **MQ Telemetry Transport**
- **A lightweight publish/ subscribe protocol**
  - messages are pushed to a *broker*, who then publishes to subscribers
  - if the broker is strong, this can scale very well
- **Persistent connections**
- **QoS levels**
- **FOSS available**

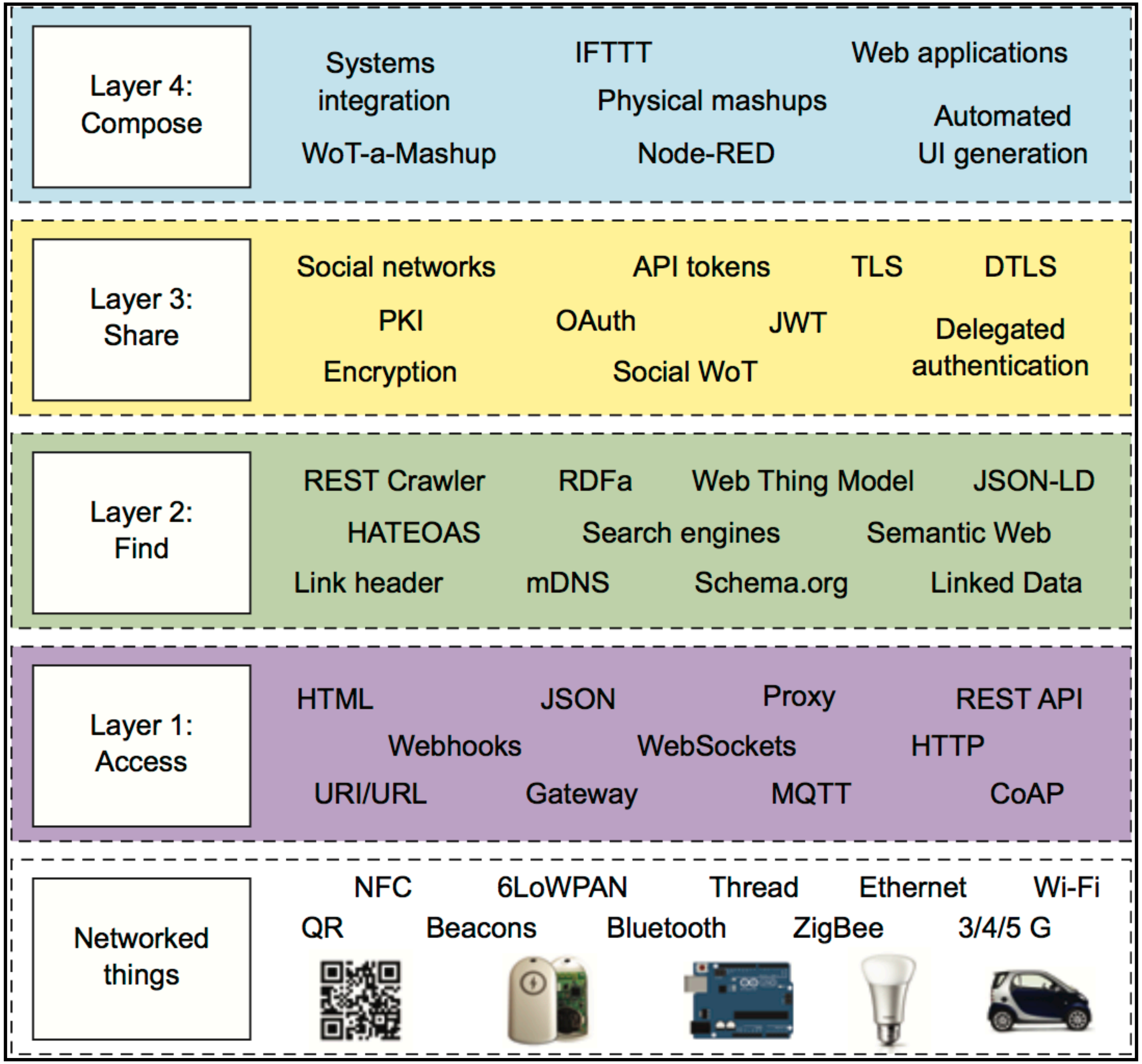
- **Constrained Application Protocol**
- **UDP based**
- **REST like protocol**
- **IKEA Trådfri uses CoAP**

The WoT perspective

- **The main advantage of a Web based architecture is the wide support from frameworks to web browsers**
- **But, the Web was not designed for embedded systems**
  - basic services such as discovery and service description must be added

- **Access**
  - using RESTful API to access devices
- **Find**
  - defining semantics of devices
  - supporting indexing
- **Share**
  - secure access to devices
- **Compose**
  - combine services

The WoT perspective



Summary

- **There are many protocols and technologies available for IoT devices**
  - some are well established, others are relatively new
  - some are proprietary, others are open
- **No solution fits all use cases, but openness to the IP stack enables higher interoperability**
  - and less vendor lock-in

Milestone 2

- Having laid the foundations of the Kademlia system, it is time to turn your attention to the WoT side. You should, using a Raspberry Pi and your sensor kit, im plement a Web application that can display the phe nomenon measured by your sensors on a Web page as well as provide a RESTful API to access them. You should also make it possible to control some aspect, e.g., turning some LEDs on and off.