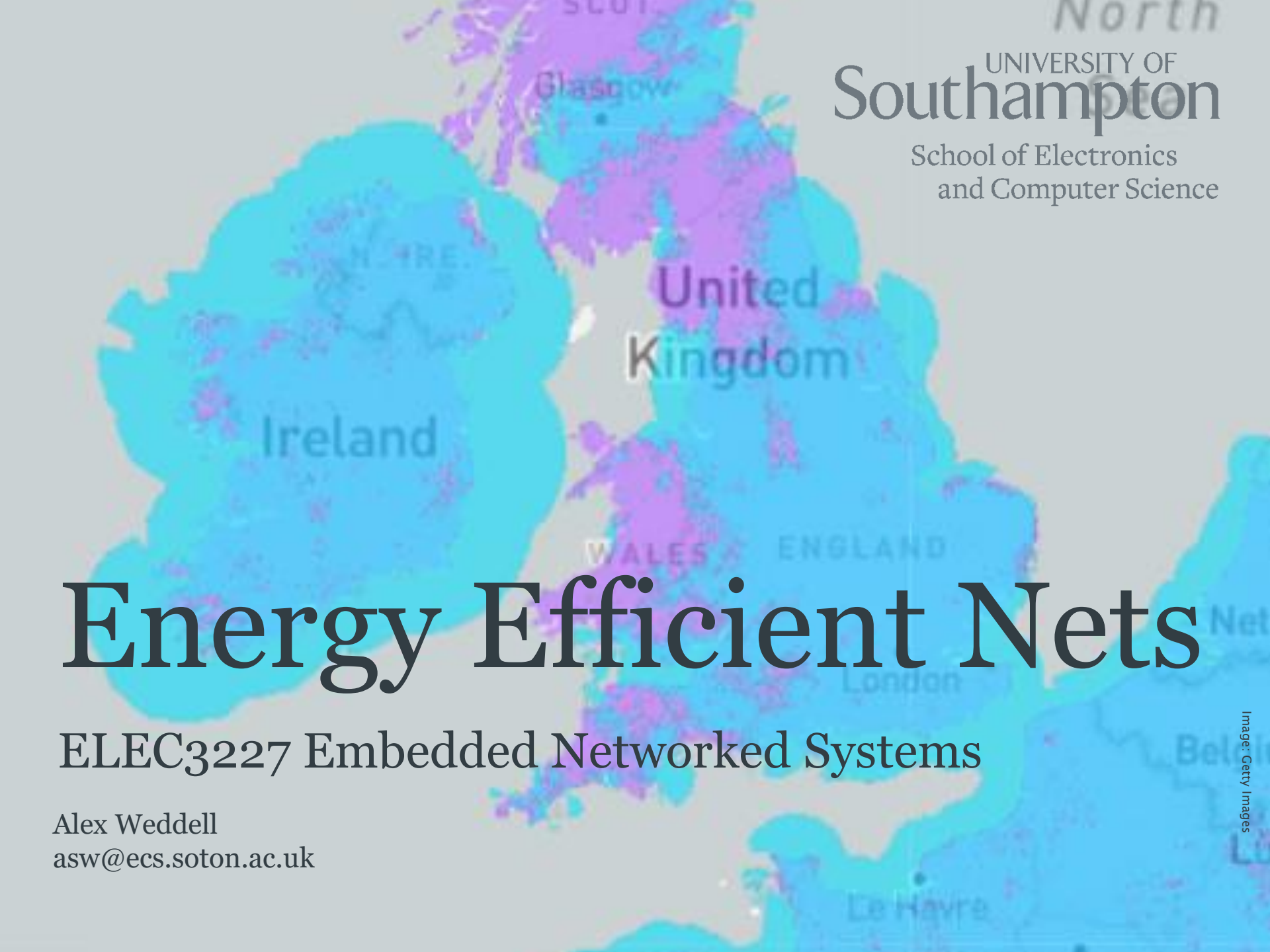

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Energy Efficient Nets

ELEC3227 Embedded Networked Systems

Alex Weddell
asw@ecs.soton.ac.uk

Overview

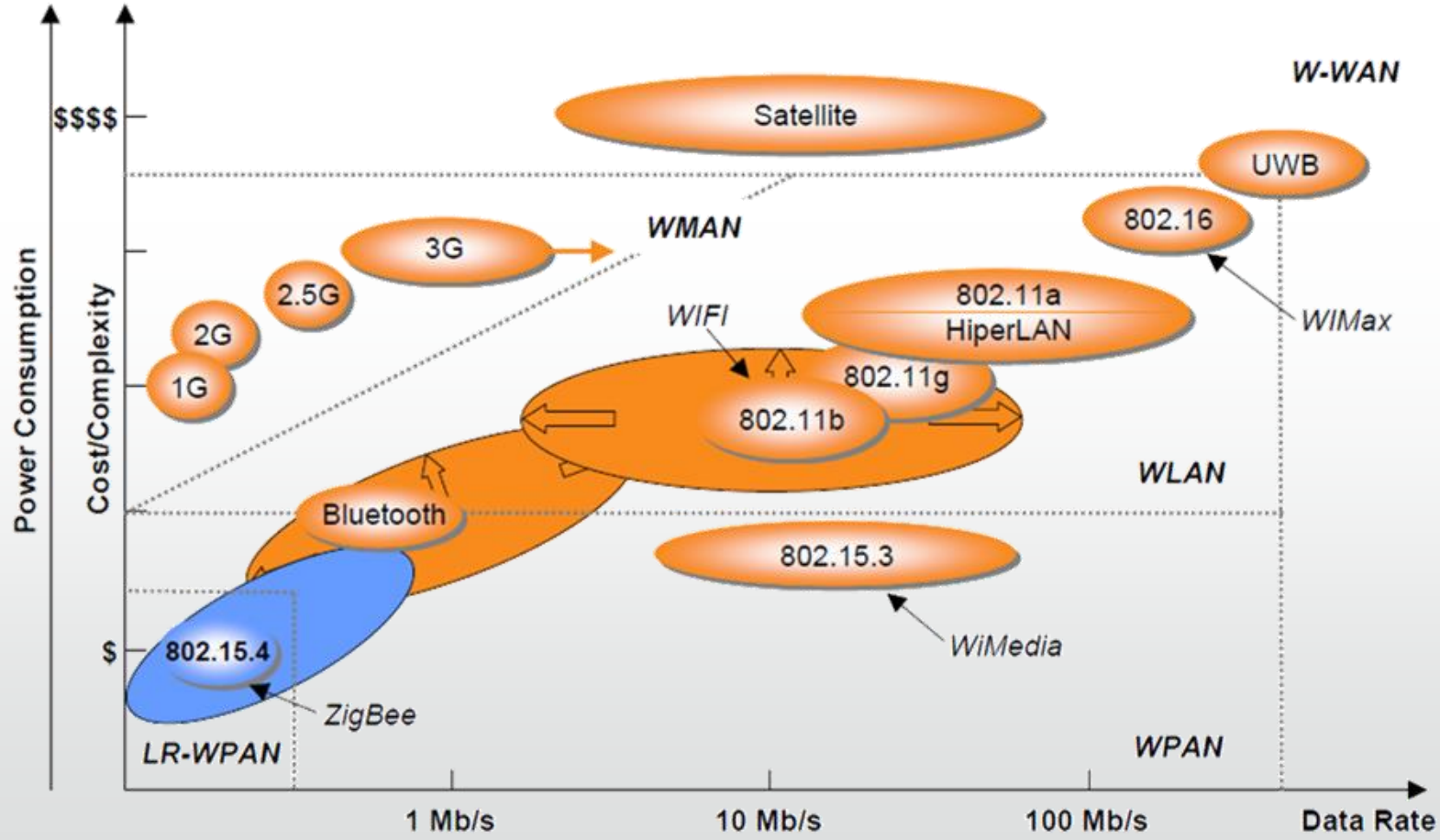
- Requirements of low-power networks.
- Personal Area Networks… Including IP on small devices
  ZigBee, Bluetooth vs. Bluetooth Low Energy, Thread (6LoWPAN), Matter.
- Wide Area Networks: LoRA, SigFox and NB-IoT.

Requirements of Low-Power Networks

- Major requirements:
  - Small, simple devices (*cheap*).
  - Easy to deploy (*cheap*).
  - Run for months or years with no maintenance (*cheap*).
  - Standardised and *sometimes* cross-compatible.
- Common applications:
  - Wearable devices (headphones, smartwatches).
  - Computer peripherals (keyboards, mice).
  - Machine-to-Machine (machinery monitoring and control).
  - Smart home (lighting, heating).
  - Environmental/building monitoring.

Options for Wireless Networks

- A (slightly dated) overview of wireless capabilities



Credit: Eaton

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Options for Wireless Networks

	802.15.4*	Bluetooth	BLE	WiFi
Range	10->100 m	~10, 100 m	~100 m	~100m
Data throughput	< 250 kbps	< 24 Mbps	<2 Mbps	<600 Mbps
Power Consumption	Low	Medium	Low	High

* The IEEE 802.15.4 standard provides the PHY and MAC layers that underpin a range of protocols, including Thread and ZigBee

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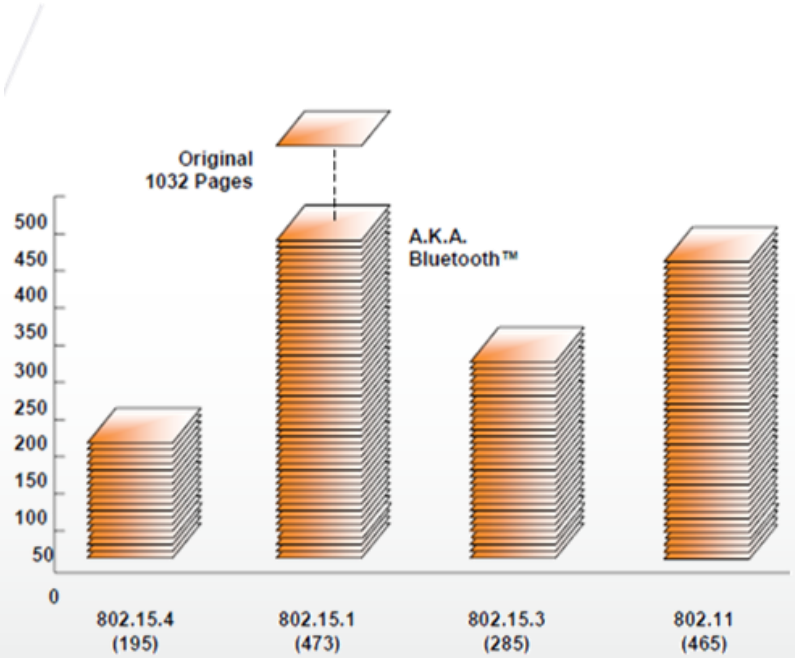
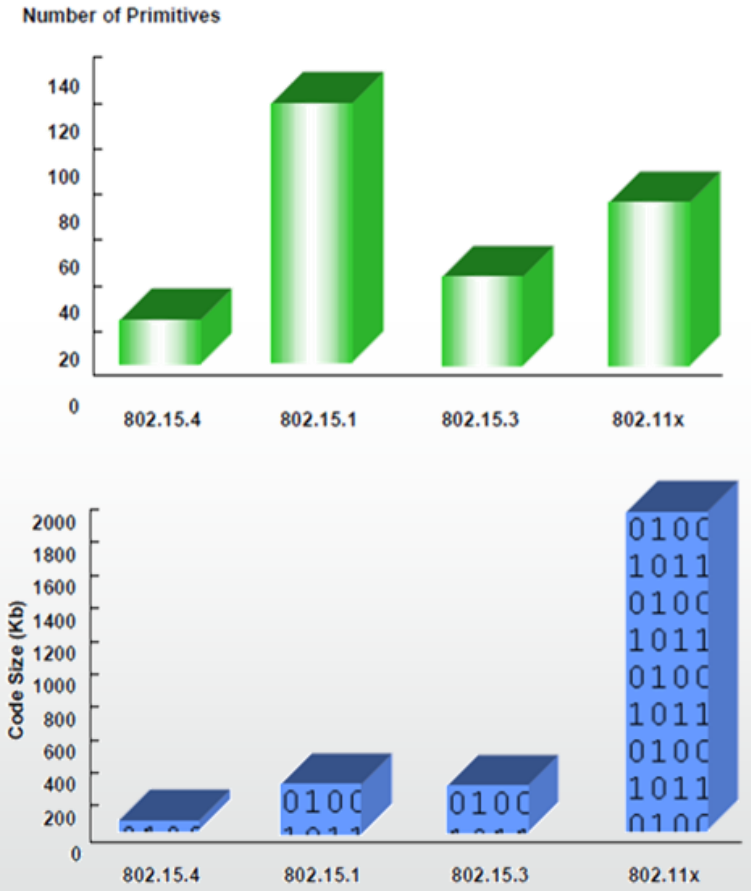
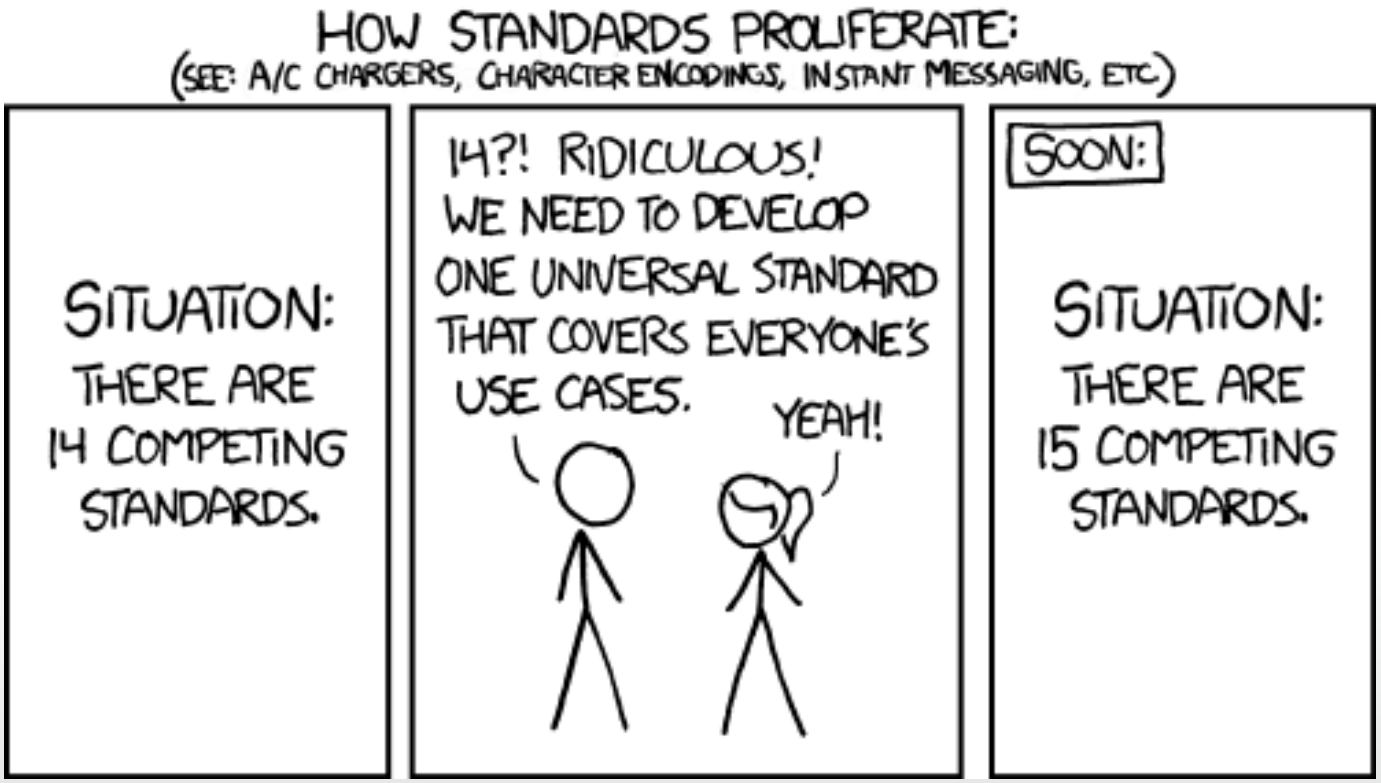
Complexity of Standards





Credit: Eaton

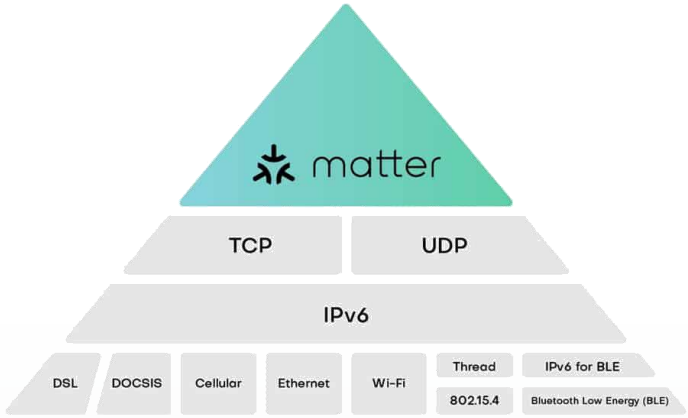
Options for Low-Power Wireless



Credit: https://xkcd.com/927/

Matter

- Built upon IP. Uses existing networking technologies – Wi-Fi, Thread, Bluetooth LE*…
- Initially targeted at smart home applications.
- Cross-compatibility between various devices.
- Ensures devices are supported by multiple ecosystems.
  - Compatibility with Apple HomeKit, Amazon Alexa, Google Assistant, without need for multiple protocols.



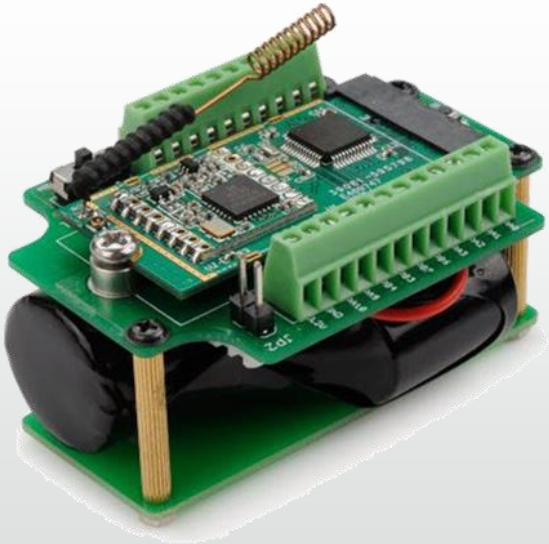
** For device commissioning*

matter

Images: https://nodon.fr/en/wireless-protocols/matter/

Why Low Power?

- End devices may be **battery-powered** or **self-powered** (energy harvesting).
- Batteries are costly to replace, harvesting gives very limited power levels.
- So must minimise communication costs.

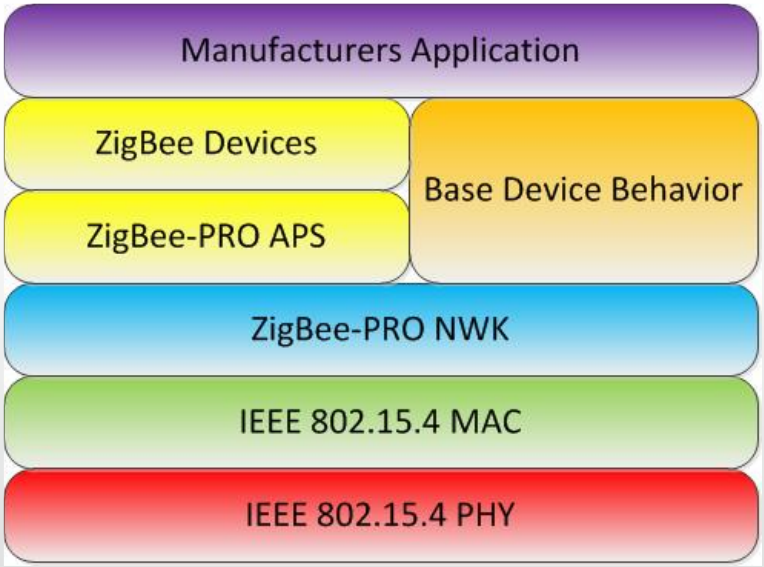


Credit: Tindie

Credit: Niko, Enocean

802.15.4 LP-WPAN Enables LP Wireless

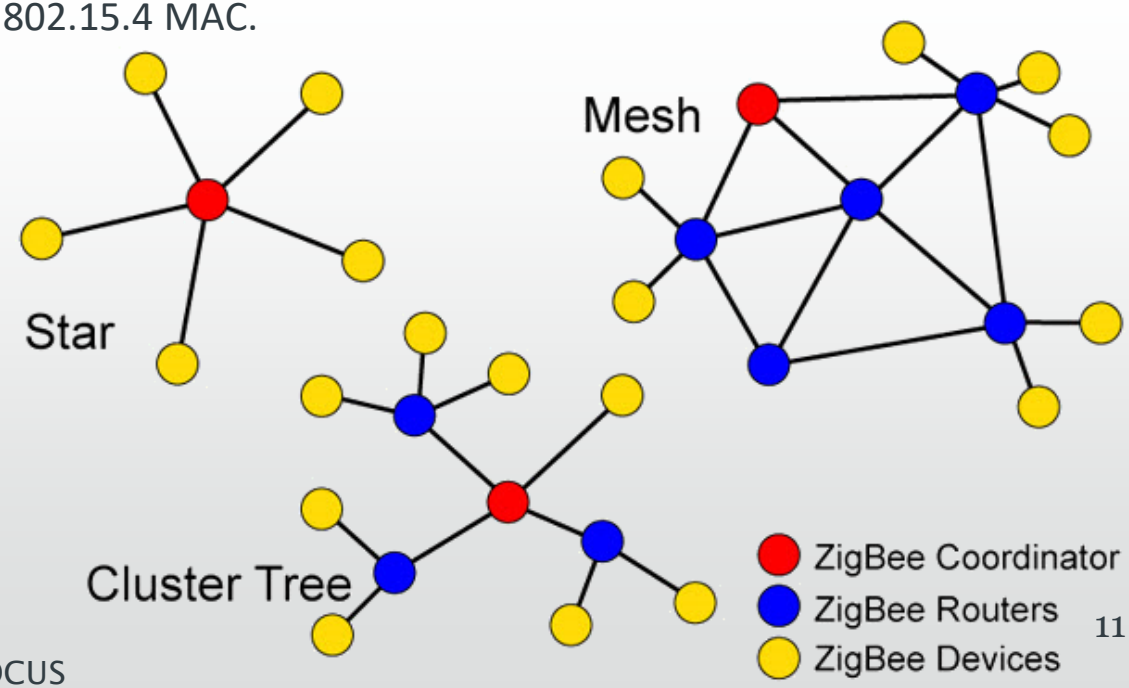
- A range of LP-WPAN protocols are based on IEEE 802.15.4 standard
- Protocols include Zigbee, ISA100.11a, WirelessHART, Thread/6LoWPAN…
- The 802.15.4 standard defines only the PHY and MAC layers
- Protocols build on this, adding their own layers, providing application, routing, etc.



Credit: Zigbee Alliance

Device Classes

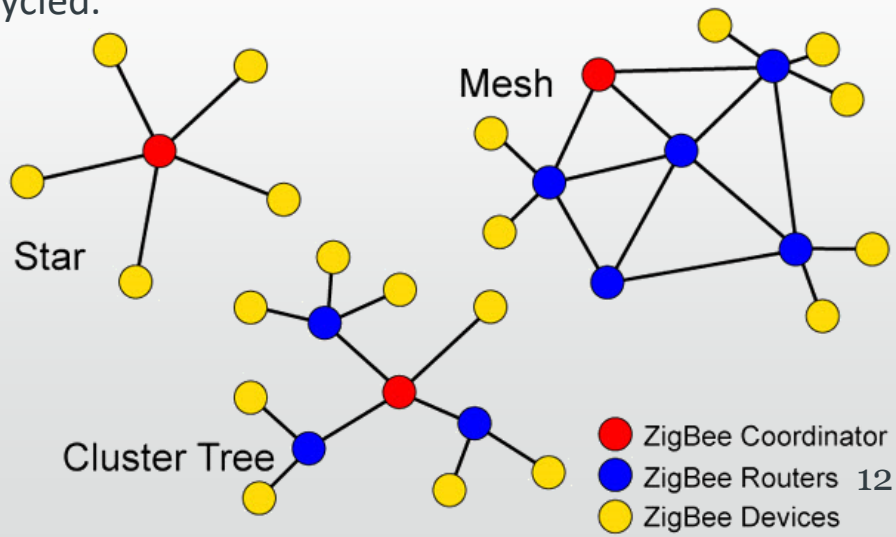
- Full Function Devices (FFDs)
  - Able to act as co-ordinators, routers, or (less commonly) as end devices.
  - Typically more capable and power-hungry platforms, often hard-wired.
- Reduced Function Devices (RFDs)
  - Able to act only as end devices.
  - Typically a cut-down, constrained platform – lower-power, often battery-powered.
  - Only implement part of the 802.15.4 MAC.



Credit: ELPROCUS

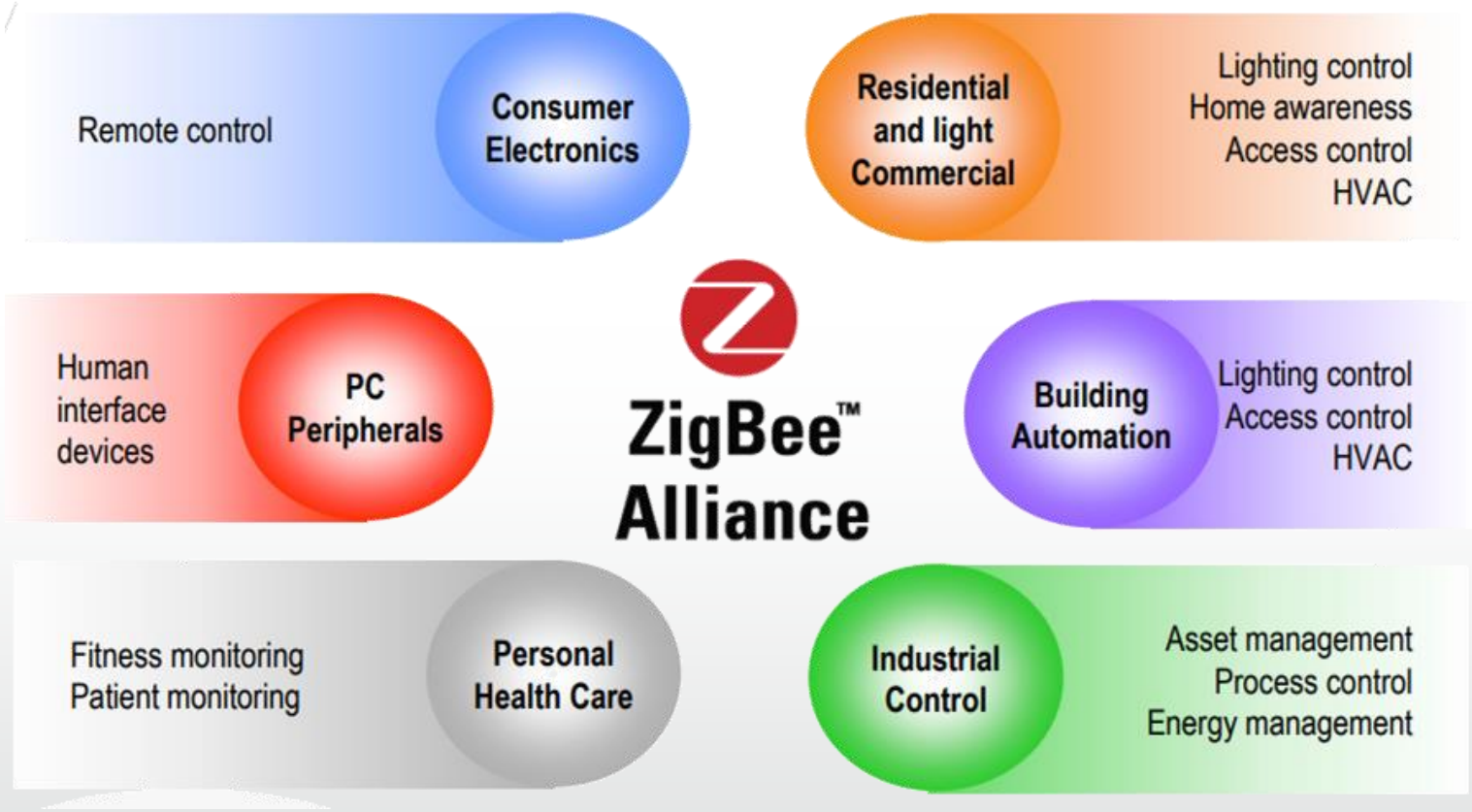
Device Classes

- Coordinator
  - **One** per network – coordinates the whole network. Channel, PAN ID, network address, security. Acting as "trust centre" – authenticating new nodes, distributing keys.
  - Also routes traffic.
- Router
  - Routes traffic between nodes.
  - Typically always-on.
- Device (or *End Device*)
  - Typically battery powered, heavily duty-cycled.
  - Only communicate with their router.



Credit: ELPROCUS

ZigBee Target Applications



ZigBee Networking in Smart Homes

- Typically operate with a **bridge/hub**.
- This acts as a controller – sets up devices and controls them, also allows configuration.
- Allows devices to be controlled by (and communicate with) the outside world, without the overheads of standard WiFi.

Credit: Philips Hue

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ZigBee in Smart Cities

- Dense networks of ZigBee-based sensors already deployed around cities – on streetlights.
- Current deployment programme 400,000+ nodes – 150,000 in Hampshire alone.
- Closed networks, protected by encryption – sharing access is not straightforward.

Credit: Mayflower Complete Lighting Control

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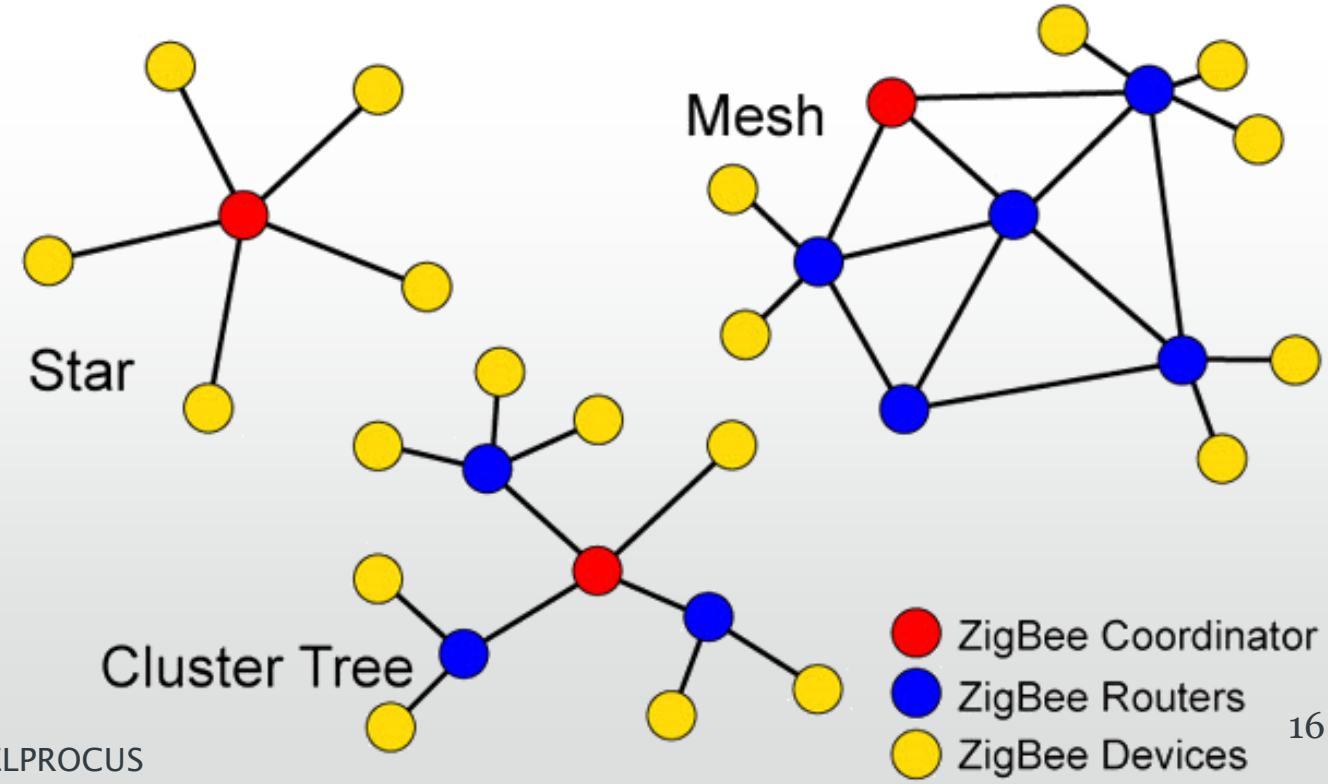
ZigBee Network Topologies

- Supports three main topologies:
  - Star: co-ordinator with direct path to end devices.
  - Cluster tree: tree topology – hierarchical path from co-ordinator to routers, end devices.
  - Mesh: multi-path topology, but end devices cannot participate in routing.



Credit: ELPROCUS

Self-Organising Networks

- Networks generally need to be self-organising
- Automatic routing: devices connect automatically with neighbours
- Topology adaptation: adapts as network layout changes.
- Ad-hoc On-demand Distance-Vector (AODV) routing.

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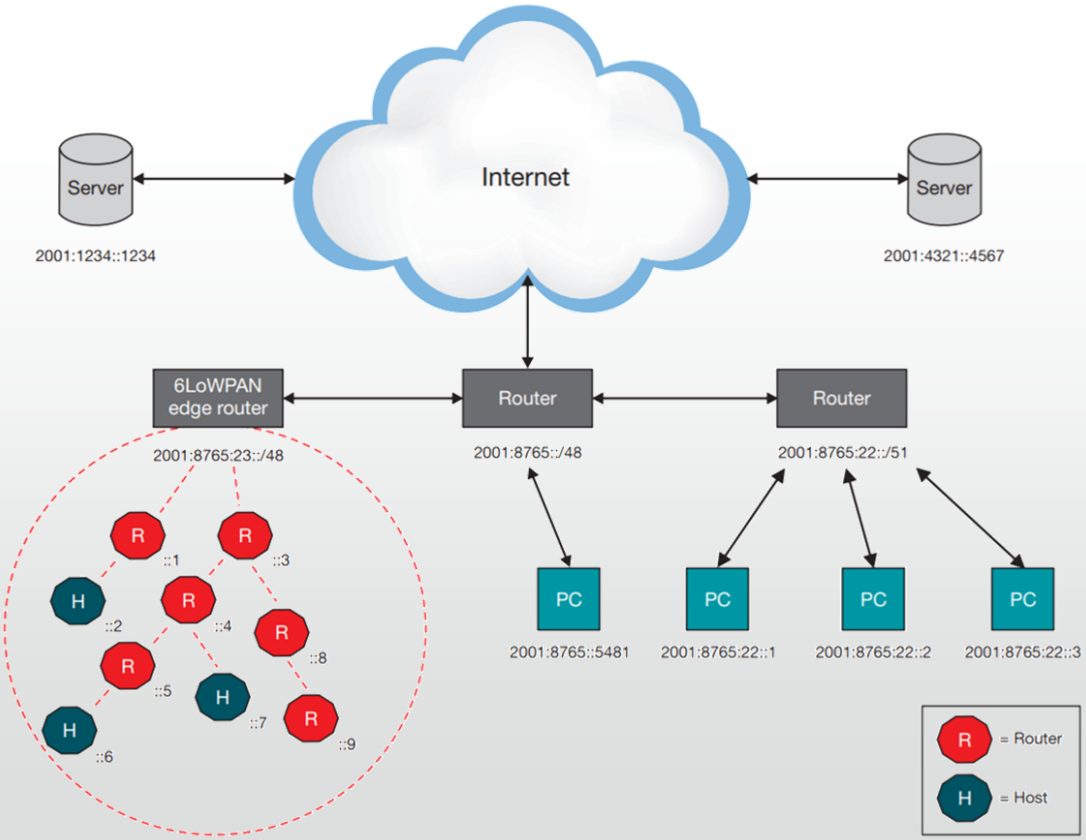
6LoWPAN

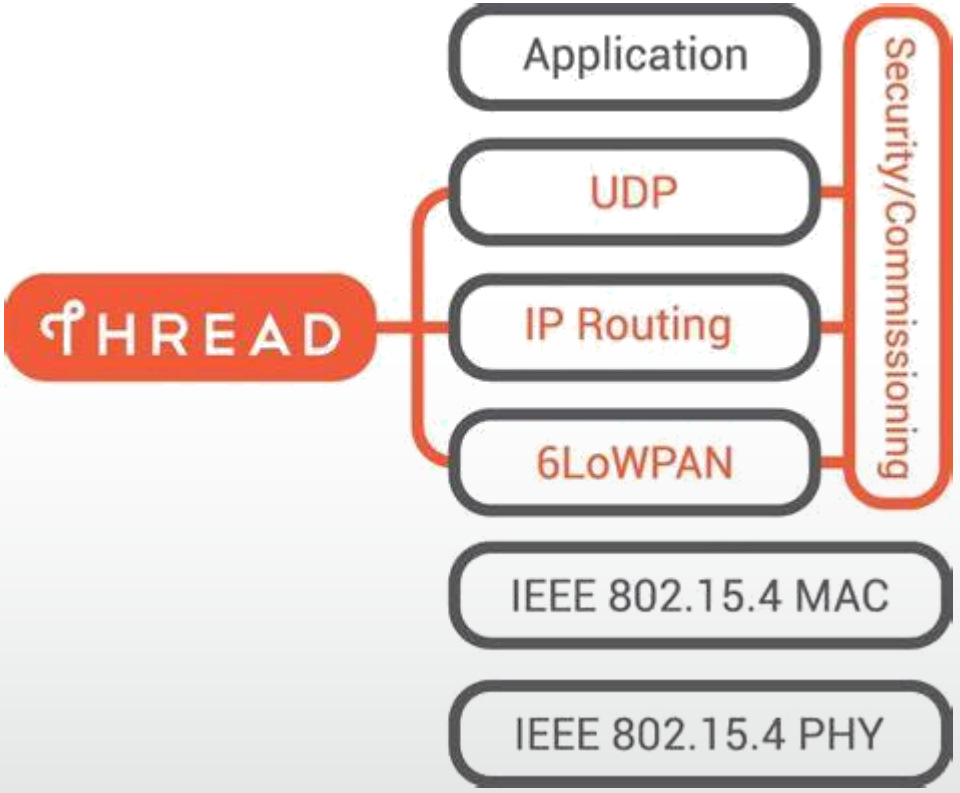
- IPv6 over LP-WPAN network
- Smallest possible header is two bytes
  - Compared against 40-bytes for full IPv6 header



Credit: Texas Instruments

Thread

- Low-power, low-latency mesh networking protocol.
- Built on top of IEEE 802.15.4 with 6LoWPAN.
- IP-addressable, with AES encryption.
- Offers UDP only.



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Bluetooth

- Bluetooth is built on IEEE 802.15.1 WPAN standard
- Built for audio streaming, control (e.g. computer mice, keyboards), file transfer, etc.
- Maximum 7 connections/device
- **Star** is the only topology supported

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Bluetooth Low Energy

- Targeted at M2M communication.
- Aims to run on a small battery for *up to 5 years*.
- Adds capability for **mesh** and **broadcast** networking, direction finding.
- Some benefits for locationing.
- Similar range, power consumption, data rates as 802.15.4-based systems…
- Ultimately it's a standards battle: Bluetooth Low Energy is already built into smartphones, tablets, etc. so no dedicated hub needed.
- *Has BLE come to market too late for industrial applications?*

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LoRaWAN and The Things Network

- Long-range: typically several kilometres, ~900MHz.
- Also low power! Heavily duty-cycled, and aimed at IoT applications.
- However, a ‘free’ service run by hobbyists: need to think about reliability.
- Nodes communicate with base station, base station uses IP to talk to cloud service.
- ‘Fair use’ limit of 30s uplink airtime per 24 hours per node (equates to 0.03% duty-cycle!).

THE THINGS NETWORK

Credit: Things Network

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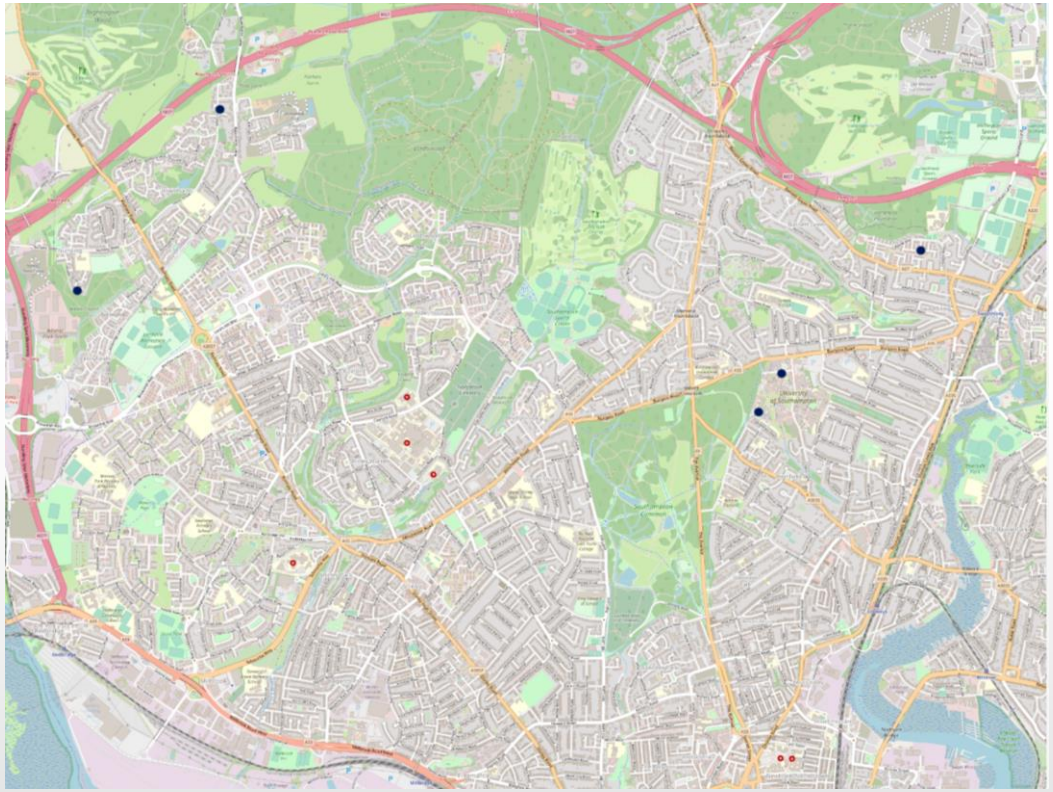
LoRaWAN – The Things Network

- >100k gateways worldwide
- Around 5 gateways in Southampton, another 5 in the surrounding area



Credit: Things Network

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LoRAWAN Coverage

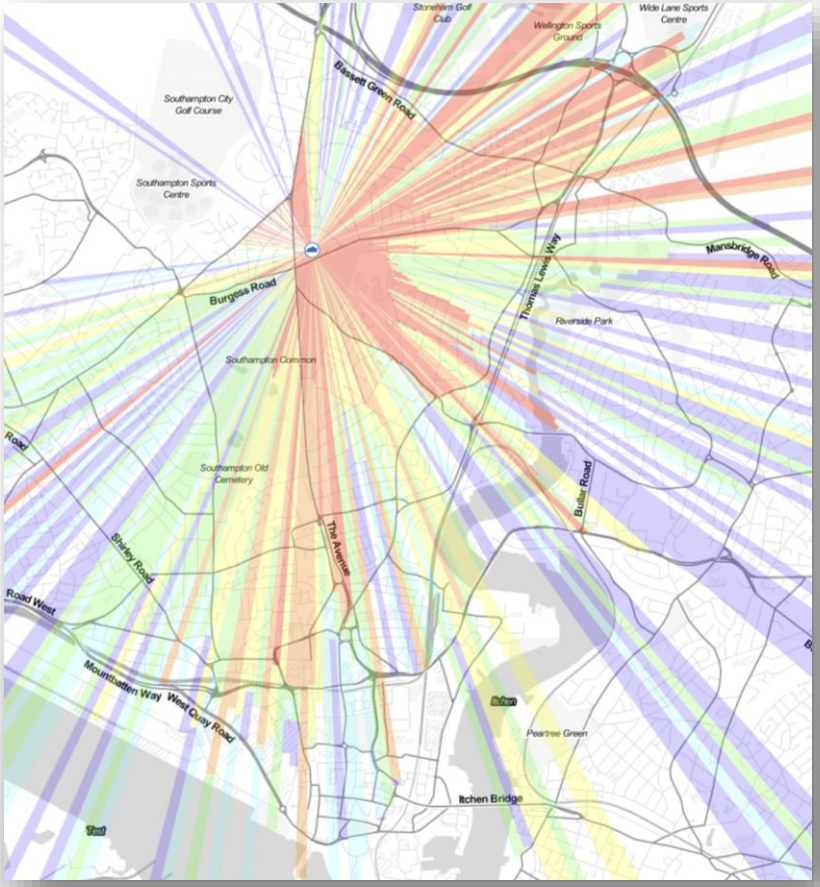

Fig. 11 Tests at short range about point X

https://ttnmapper.org/
https://eprints.soton.ac.uk/420163/1/10008429.pdf

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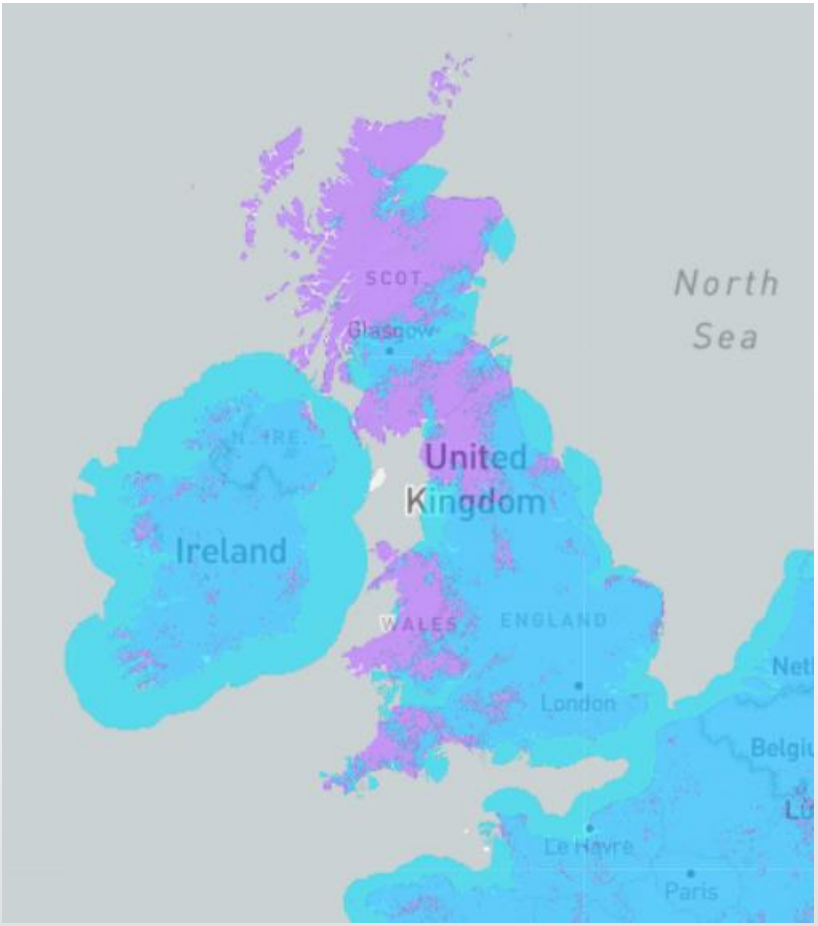
Alternatives to LoRA

- SigFox
  - Dedicated commercial IoT network.
  - Good international coverage.
  - Relatively cheap (around £10 for a device. to connect for a year, sending 2 messages/day).



Credit: SigFox

Alternatives to LoRA

- NB-IoT and LTE-M
  - New standards developed by 3GPP.
    - LTE-M – up to 4Mbps, better indoor coverage than 4G. Supports roaming.
    - NB-IoT – up to 127kbps, best indoor coverage, designed for efficiency.
  - Cellular – operated by mobile network operators.
  - Operates over 4G/5G network, so coverage should be good.
- Relatively limited adoption
  - O2 rolled-out LTE-M, rolling-out NB-IoT
  - Vodafone rolled-out NB-IoT (coverage: 98% UK land area)

Summary

- Requirements of low-power networks.
- Personal Area Networks… Including IP on small devices
  ZigBee, Bluetooth vs. Bluetooth Low Energy, Thread (6LoWPAN), Matter.
- Wide Area Networks: LoRA, SigFox and NB-IoT.