Internet of Things Systems, Security, and the Cloud (IoTSSC)

Paul Patras

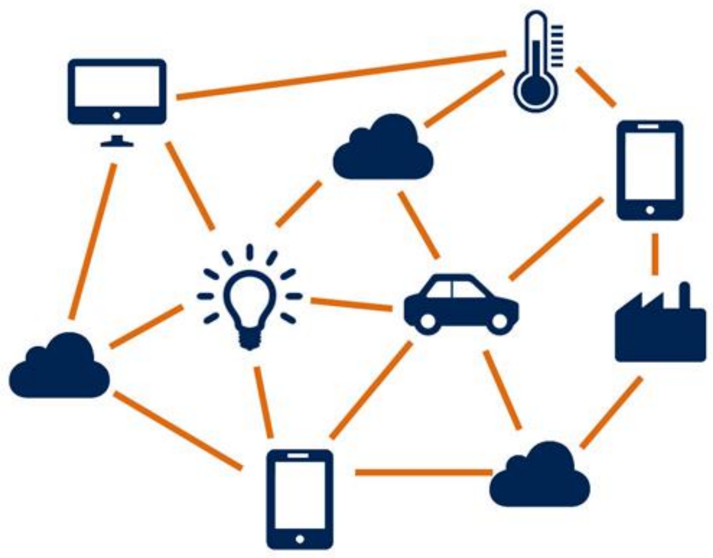


Image: sns-it.ca

Course Objectives

- Give you technical grounding in key aspects of Internet of Things (IoT), including
    - IoT systems architecture,
    - hardware platforms,
    - embedded programming and debugging,
    - networking paradigms for IoT,
    - secure operation,
    - cloud integration.

- You will also design, build, evaluate, document, and demonstrate an IoT prototype.

Learning Outcomes

On completion of this course, you should:

1. Have a good understanding of the Internet of Things concept and systems architecture;
2. Operate comfortably with wireless technologies and networking protocols specific to IoT systems;
3. Be familiar with standard security and privacy preserving mechanisms, and understand different cloud integration methods;
4. Be able to design, implement, and test a simple IoT system equipped with sensors and wireless transceivers;
5. Know how to write technical documentation of a project and present experimental results obtained, in a workshop style paper format.

Pre-/Co-requisites

IoTSSC is available to 4th year undergraduate students and MSc students, as long as:

- UG4: have passed Operating Systems (INFR09047)
- You are strongly advised to take Computer Communications and Networks (INFR10074)
- MSc: have completed introductory courses in OS or have done a project in a relevant area/must have passed Informatics Research Review (INFR11136) or Research Methods in Security, Privacy, and Trust (INFR11188)
- All: have reasonable computer programming skills, and interest in systems, security, and networking.

If you do not meet these requirements and you do not have a concession agreed, then this course is not for you.

Housekeeping (I)

- Two-hour lectures every week
  - When: Thursdays, 13:10–15:00
  - We will take a 10 min break in the middle
  - Video playlist online a few days before - you **MUST** watch these videos
  - First hour: technical discussion
  - Second hour: formal teaching
  - Please ask questions at any time

- Office hours: by appointment (email at least 48h in advance at ppatras@inf.ed.ac.uk).

Housekeeping (II)

Labs

When: Mondays 10:00-13:00.

Where: Appleton Tower, Room 3.09.

Labs start on Monday (20 January).

You will use NXP FRDM-K64 development boards, a range of sensors, smartphones, and the Google Cloud Platform.

The same tools will be used for the coursework.

Assessment:

Coursework: 55%

Practical examination: 15%

Written examination: 30%

Reading material

Lectures only scratch the surface. You will need to read research papers and books.

Reading list at

https://eu01.alma.exlibrisgroup.com/leganto/public/44UOE_INST/lists/1493836449000246

Coursework

- Develop in pairs a full-stack IoT system that can be used to for geospatial air quality monitoring. Full-stack in this assignment refers to implementing:
- Firmware for an embedded system,
- A simple Android app that will enable forwarding measurements collected by the embedded system to the cloud,
- A cloud-based analytics pipeline including a visualisation dashboard; a subscriber notification system
- Teams: pairing should be complete by now; please get in touch with each other to start planning.
- Coursework handout available at http://tiny.cc/iotssc-cw

Dates/Deadlines

Part 1 (formative)	Proposal document outlining the planned IoT prototype	
	Deadline: Wednesday, 29 January 2020, 16:00	
Part 2 (55 marks)	Workshop style paper documenting projects and results	
	Deadline: Friday, 27 March 2020, 16:00	
Quick prototype demos	Date/time: Thursday, 26 March 2020, 15:10	
Presentations (15 marks)	Date/time: Monday, 23 March 2020, 10:00	
Written exam (30 marks)	Date/time: TBC	

Extensions

- Do not ask me for an extension;

  I cannot grant any.

- The correct place is the ITO who will pass this on to your year organiser

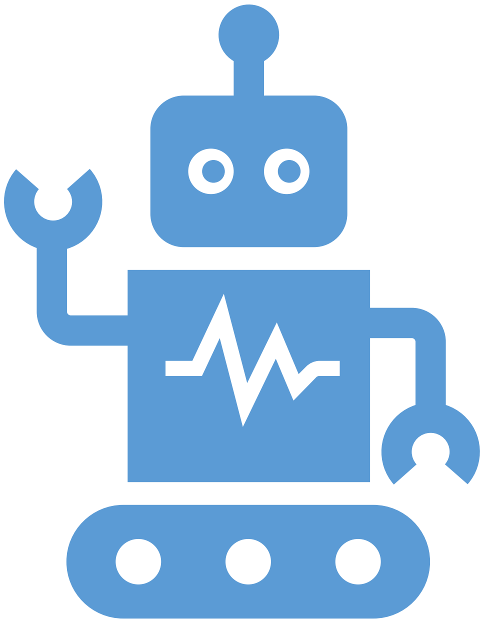
- See the policy on late coursework submission first.

How much time should you spend

IoTSSC is a 20 credit course – 200 hours over S2:

- 22 hours lectures
  - Dr Tom Spink will give: one on HW platforms, and one on device programming and optimisation
  - Two guest lectures: one given by Marc Cohen of Google, the other TBA.
- 21 hours labs
- **94 hours individual work**
- 20 hours program level activities (office hours, PT meetings, training, ILW, etc.)
- 7 hours demo preparation
- 32 hours exam preparation
- 4 hours examinations

IoTSSC
The Coursework



Project Overview

Develop a **full-stack IoT system** (FW, app, cloud logic) for geospatial air quality monitoring.

Experimental environment: 'In the wild' (Edinburgh).

At the end you must write a report as a workshop style paper, based on prototypes developed and results obtained.

The handout provides guidance on core functionality expected; Specific details and requirements are intentionally omitted → **be creative!**

Resources

- NXP Semiconductors FRDM-K64F Development Platform with the following specifications: ARM Cortex M4 CPU,1 MB flash memory, 256 KB RAM, Bluetooth support (add-on).
- Sensors (multichannel gas sensor, TVOC/eCO2 sensor, optical gas sensor).
- USB battery pack, base shield, cables.
- Mobile phones - Motorola Moto G7, Android 9 (please do not update SW or PIN lock them).

You will need to return all of the above at the end in working condition and with all the cables/packaging.

- Credits on the Google Cloud Platform (should have received instructions).

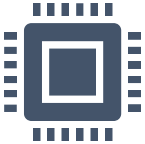
Requirements

Two phases advised:

- **Phase 1**: getting started with embedded systems development and communication with the cloud;
- **Phase 2**: practical implementation of the IoT system.

Complete Phase 1 first, otherwise you will not be able to make progress in Phase 2.

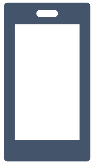
Project Phase 1



Develop embedded application that will read from different sensors attached to it:

E.g. NO2,eCO2, PM2.5, etc.

Record time of acquisition and the value.



Develop simple Android app that will query the embedded system for measurements, retrieve these from the device via BLE communication, and append geolocation.

Upload sensed information to the cloud. Communication with the cloud performed using the Android app that you will develop.

Project Phase 1 (cont'd)

For cloud integration, see Google Core IoT core tutorial on how to upload data using the HTTP bridge.

You may use BigQuery to store the data that you collect.

Alternatively, you can create a Google virtual machine (VM) and run an HTTP server to receive measurements; subsequently process these with whatever tool you find appropriate.

Important: you have limited budget

- Be careful about how often you upload readings;
- Compress payloads before making requests;
- Don't leave a VM running all the time.

Project Phase 2

Build an air quality monitoring system using the sensors provided

The sensors allow you to measure a number of pollutants considered dangerous to health and specific to outdoor/indoor environments. You may compute an AQI based on these.

Consider validating accuracy against publicly available data.

Can chose what sensors to use and which locations to monitor/for how long.

Perform analysis on spatio-temporal variation of pollutants.

More sophisticated analysis also encouraged (e.g. statistics about peak pollution times, ‘hotspot’ locations, forecasts, correlation analyses, etc.)

Project Phase 2 (cont’d)

- Develop cloud functionality that notifies list of subscribers to the monitoring service when the air quality exceeds certain limits.
- Different sensors affected by distortions in different ways – be creative; make use of resources available in the cloud.
- Ground-truth collection is also highly important for evaluation (don’t forget!)
- Visualise data you collect in a creative manner; think about what insights you want to offer to a user.

Deliverables

Part 1 (formative) – Document proposal

- outlining planned prototype (firmware, app, comms, cloud integration, analytics),
- discussing envisioned building blocks,
- arguing for/against algorithm(s) for air quality monitoring,
- briefly explaining planned evaluation methodology.

Max 2 pages, one proposal per team.

Deadline: Wed, 29 January 2020, 16:00.

Deliverables (cont’d)

Part 2 (55 marks) – Submit:

- Device firmware for implementing the functionality developed during both phases.
- Mobile app implementing comms with the embedded devices and respectively with cloud.
- Any appropriate cloud code used for data processing and notification system.
- **Individual** reports that give a complete summary of your work.

Deadline: Friday, 29 March 2020, 16:00.

Deliverables (cont'd)

Report:

- Workshop style paper, formatted using ACM LaTeX template;
- Max 7-pages + any number of pages for references;
- Introduce problem domain, challenges specific to air quality monitoring task & IoT prototyping;
- Description of end-to-end prototype, key design choices, solution approach;
- Evidence of the prototype's performance, including graphs obtained with your visualisation tool(s). Again be creative and think what matters beyond accuracy.

Good academic practice

Code sharing among teams not permitted

Reusing code snippets you find online OK, as long as (1) you clearly explain in report why you used some publicly available functionality; (2) appropriately comment source code, acknowledging original.

Prototypes are team work, reports are individual – I want to see that each of you is able to articulate in your own terms and explain the challenges faced, solution(s) developed, and results obtained.

Marking

Evaluation according to the quality of your implementation, air quality estimation accuracy achieved by your solution and features, and quality of the report.

Accuracy demonstration

Will choose several testing locations around George Square

Presentation of actual project not need – this is separate and carries other 15 marks (date/time: Mon, 23 March 10:00 –)

5 minutes per team

Marking criteria

Basic Criteria

1. Understanding of the problem
2. Completion of the project
3. Quality of the work
4. Quality of the report

Additional Criteria

1. Knowledge of existing solutions
2. Justification of design decisions
3. Solutions to any conceptual problems
4. Evaluation of solution
5. Amount of work

Exceptional Criteria

1. Evidence of originality
2. Publishable research

Notes on marking

Evidence of excellent quality of the work may include code optimisation for embedded devices.

Must demonstrate rigorous efforts were made to verify air quality monitoring functionality is accurate.

Report must be well written and organised, provide clear summary of system design, algorithms implemented, and insights gained (backed by appropriate graphs).

Amount of work measurable through the number of approaches explored to implement the core functionality, including fusing data from different types of sensors to improve accuracy.

An Introduction to Internet of Things

Image: sns-it.ca

How did we arrive here?

1988

Mark Weiss (Xerox PARC) – **Ubiquitous Computing**

“…hundreds of wireless computing devices per person per office, of all scales […] This is different from PDA's, dynabooks, or information at your fingertips. It is invisible, everywhere computing that does not live on a personal device of any sort, but is in the woodwork everywhere. […] its highest ideal is to make a computer so imbedded, so fitting, so natural, that we use it without even thinking about it.”

How did we arrive here?

1988 1999 - 2002

Neil Gershenfeld (MIT Media Lab)
"in retrospect it looks like the rapid growth of the World Wide Web may have been just the trigger charge that is now setting off the real explosion, as things start to use the Net."

Kevin Ashton (Auto-ID @ MIT) – **Internet of Things**

"We need an internet for things, a standardized way for computers to understand the real world"

How did we arrive here?

1988 | 1999 - 2002 | 2005

ITU Internet Report: The Internet of Things

"always on communications, in which new ubiquitous technologies (such as radio-frequency identification and sensors) promise a world of networked and interconnected devices (e.g. fridge, television, vehicle, garage door, etc.) that provide relevant content and information whatever the location of the user – heralding the dawn of a new era, one in which the internet (of data and people) acquires a new dimension to become an Internet of Things."

How did we arrive here?

1988 | 1999 - 2002 | 2005 | 2009

EC, IoT — An action plan for Europe

“network of interconnected objects, from books to cars, from electrical appliances to food […]. These objects will sometimes have their own Internet Protocol addresses, be embedded in complex systems and use sensors to obtain information from their environment […] and/or use actuators to interact with it”.

How did we arrive here?

1988 | 1999 - 2002 | 2005 | 2009 | 2013

Cisco – coins **Internet of Everything**

“The Internet of Everything (IoE) brings together people, processes, data, and things to make networked connections more relevant and valuable than ever before – turning information into actions that create new capabilities, richer experiences, and unprecedented economic opportunity for businesses, individuals, and countries.”

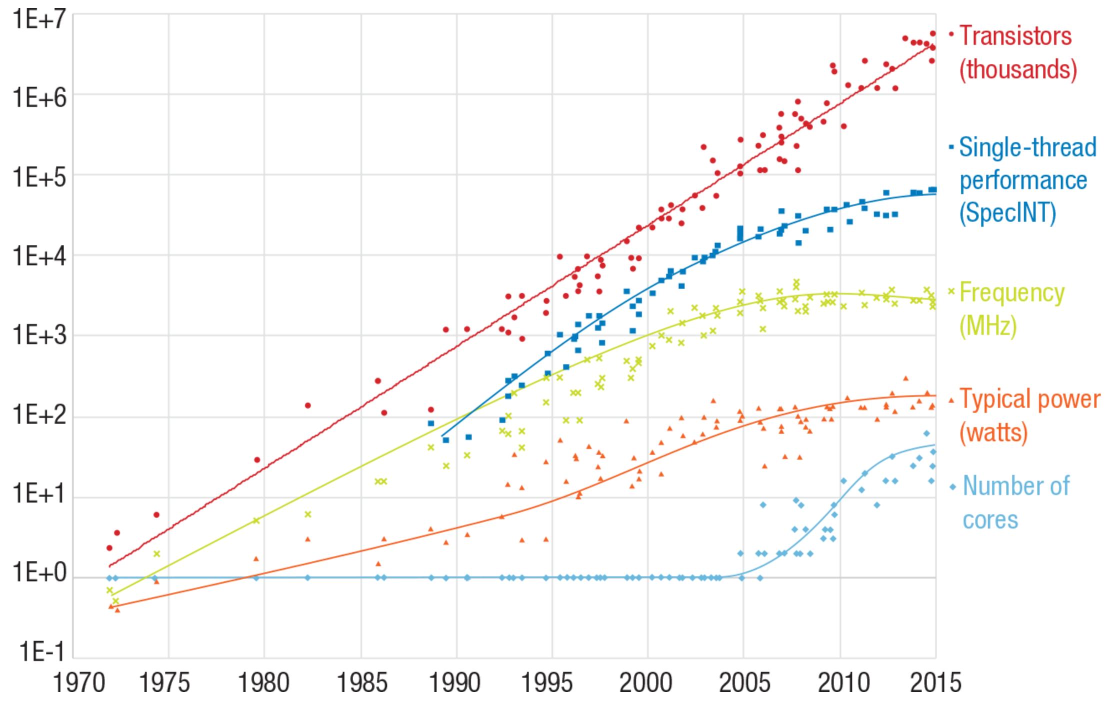
Key ingredients

- Small form factor
- Low power, low cost
- Sensors and actuators
- Wireless communication
- Connected to the Internet
- Programmable
- Some level of autonomy

Beyond the buzzword

- Much like wireless sensor networks, BUT not dedicated to a single application. Instead providing a **platform** that can accommodate heterogeneous applications.
- Pervasive operation like ubiquitous computing, BUT connected the Internet.
- Encompassing extremely large numbers of devices, e.g. Arm envision 1 trillion Internet connected devices by 2030.

Enablers:
1. Computing power

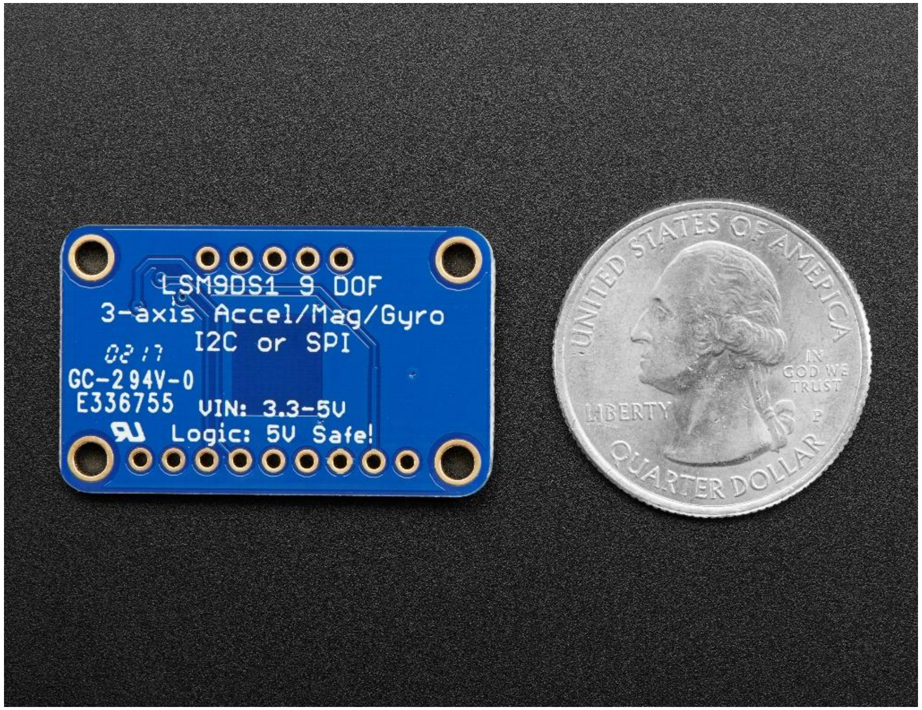


K. M. Bresniker, S. Singhal, R. S. Williams, "Adapting to Thrive in a New Economy of Memory Abundance", Computer vol. 48 no. 12, p. 44-53, 2015

Enablers:
2. Miniaturisation, more sensors, decreasing cost

LSM9DS1:
accelerometer + gyroscope + magnetometer

Cost: ~£10

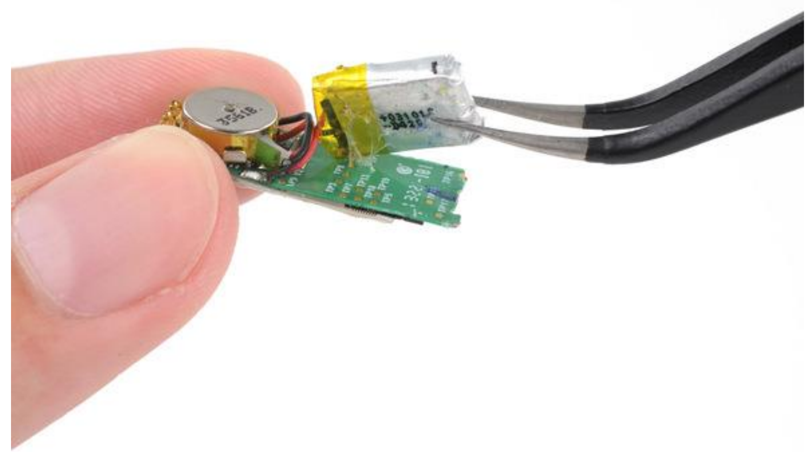


Source: adafruit.com

Enablers:
3. Batteries

Fitbit Flex

Li-Polymer, Single Cell, 5-day supply



Source: ifixit.com

Enablers:
4. Communications

Short range:

Bluetooth, Zigbee, ANT, RFID

Medium range:

Wi-Fi, cellular

Long-range:

LoRa, NB-IoT, SigFox

Enablers:
5. Development Resources

- **Simple programming languages**
  Arduino C, (Micro)Python
- **Cloud communication protocols**
  (HTTP, MQTT, CoAP)
- **A range of powerful APIs/frameworks**
  (REST, IFTTT)
- **Language independent data formats**
  (JSON, YAML)
- **Cloud platforms**
  (AWS, GCP, Microsoft Azure, Arm Pelion)
- **Visualisation tools**
  (Chart.JS, dygraphs, Kibana)

Application domains

Industry (manufacturing, transportation, agriculture)

Consumer (smart homes, appliances, assisted living)

Wearables (healthcare, fitness, productivity)

Images adapted from dattus.com, makeuseof.com, technologyadvice.com

Interconnecting many devices that exchange (big) data is challenging

Developing code that runs on embedded devices and ensure energy efficient operation.

Ensuring reliable connectivity, optimal infrastructure sharing, scalability.

Guaranteeing secure operation, ease of use, and not compromising user privacy for some utility.

Aggregating large data sets and exploiting only context specific information in real-time.

Modelling and predicting the behaviour of complex systems.

Multiple approaches required

UK researchers wrote Ubicomp manifesto in 2006[*] – some challenges facing ubiquitous system design still hold

Theoretical perspective: rigorous models that capture system behaviour at different levels of abstraction.

Engineering perspective: architectural and network challenges posed by large scale, heterogeneous, and dynamic nature.

Experience perspective: understand what principles underpin human-machine interaction and how a ubiquitous computing society might be shaped from a socio-technical perspective.

[*]D. Chalmers, M. Chalmers, J. Crowcroft, M. Kwiatkowska, R. Milner, E. O'Neill, T. Rodden, V. Sassone, M. Sloman, "Ubiquitous Computing: Experience, Design and Science", A Grand Challenge in Computing Research sponsored by the UK Computing Research Committee, 2006.

Application-specific challenges

Computationally/energy constrained vs unconstrained devices

Communication type (decentralised vs scheduled) and range (long vs short)

User interface (display, keys, touch, voice, gestures)

Example: Wristband fitness trackers (activity, sleep, heart rate monitoring)

Wearables specific constraints

- Limited memory
- Battery powered
- Minimal user interface
- Short range communication
  - typically Bluetooth low Energy (BLE)
- Wireless communication
  - prone to eavesdropping, surveillance, etc.

Example: Smart homes

A range of appliances controllable via a mobile app

Source: eurocomms.com

Benefits vs Risks

- Lower home carbon footprint (thermostats)
- Personalisation (access control)
- Increased comfort (appliances automation)
- Safety (IP cameras, smart locks)

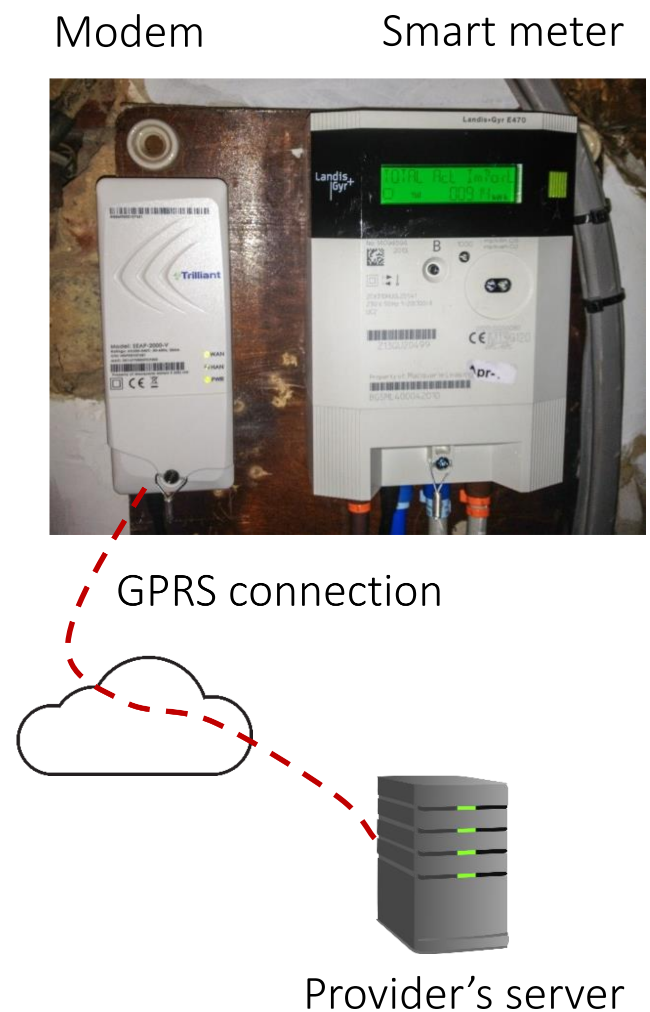
- Communication again wireless and therefore subject to abuse
- Control via software running on phone (app) – risk of malware and privileges abuse
- Hijacking and weaponisation (remember Mirai)

What about scalability?

- Mobile phone numbers likely to run out as more devices deployed

  → alternative technologies?

- Decentralised, IP based, perhaps better. But what about medium access?



What about robustness and service assurance?

Questions