IoT Engineering
3: Sending Sensor Data to IoT Platforms

Slides: tmb.gr/iot-3

Overview

These slides introduce *Wi-Fi connectivity*.

How to connect to a Wi-Fi network.

How to send data to a server.

Prerequisites

Install the Arduino IDE, set up ESP8266, get Wi-Fi:

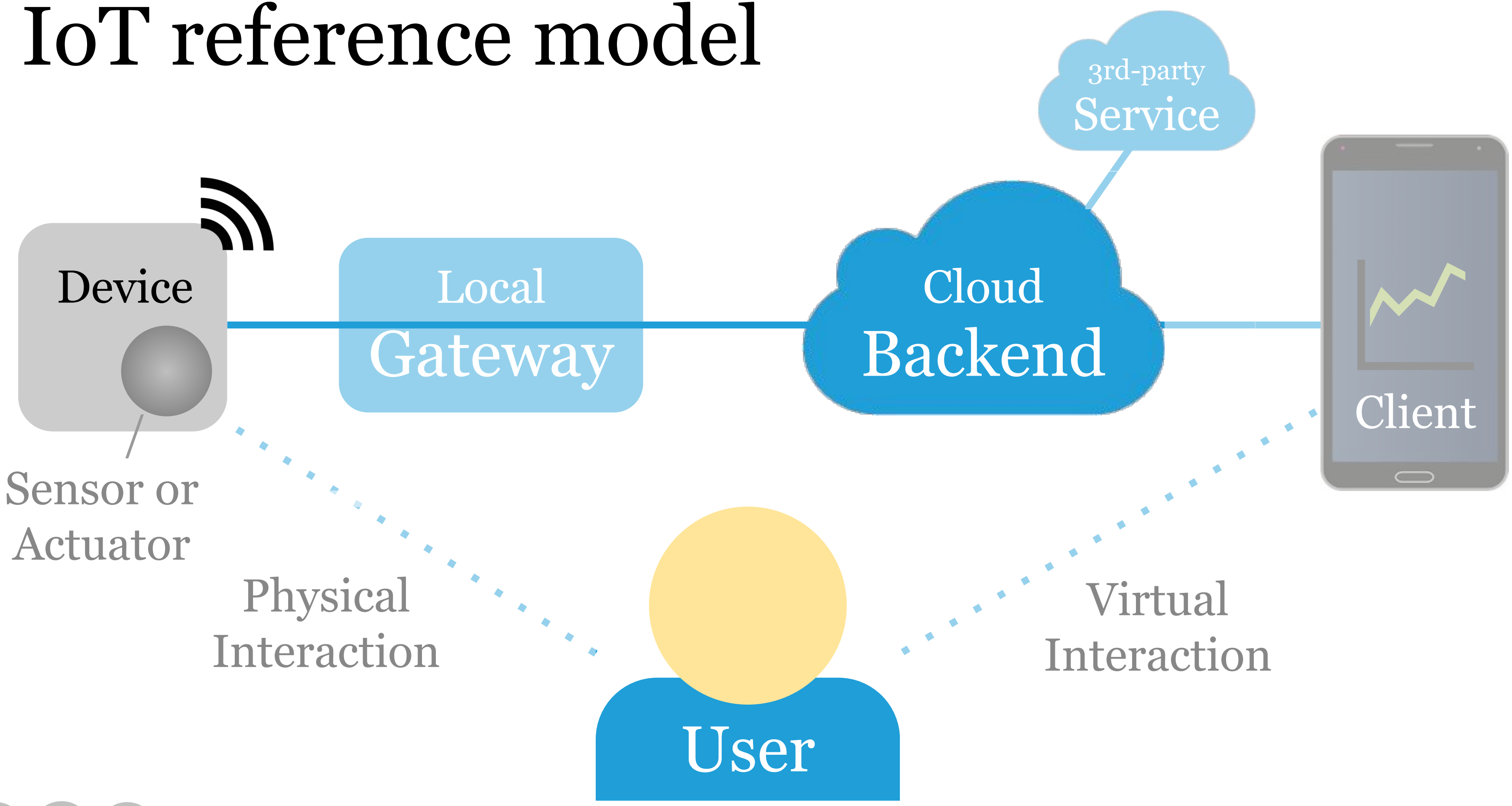
Check the Wiki entry on Installing the Arduino IDE.

Set up the Feather Huzzah ESP8266 for Arduino.

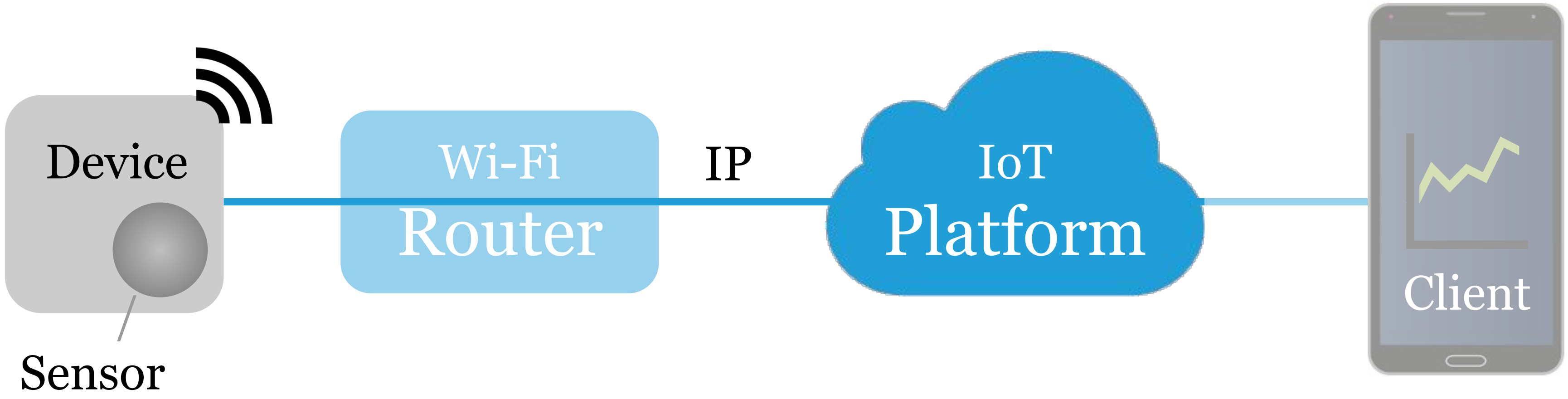
Get access to a Wi-Fi network* without a portal.

*In class, try MY_SSID with MY_PASSWORD.

IoT reference model



Wi-Fi connectivity



The device first connects to the local Wi-Fi network, then it uses an IP-based protocol to transport data to a backend server, e.g. an existing IoT platform.

Wi-Fi

Wi-Fi is based on IEEE 802.11/a/b/g/n/… standards.

Uses 2.4 GHz, 5 GHz & 6 GHz radio frequency bands.

100 m line-of-sight, many materials absorb/reflect it.

Throughput depends on version, 11 Mbps up to Gbps.

Uses more energy than Bluetooth LE, less than 4/5G.

ESP8266 Wi-Fi setup .ino

```
#include <ESP8266WiFi.h>

void setup() {
  Serial.begin(115200); // for debug output
  WiFi.mode(WIFI_STA); // _AP|_AP_STA|_OFF
  WiFi.begin("MY_SSID", "MY_PASSWORD"); // TODO
  while (WiFi.status() != WL_CONNECTED) {
    delay(500);
  }
  Serial.println(WiFi.localIP());
}
```

MAC address

The MAC address, e.g. 80:7d:3a:58:8a:ef, is a unique identifier assigned to the network interface controller (NIC) for data link layer communications.

Used as a network address for IEEE 802 technology including Ethernet, Wi-Fi and Bluetooth.

The first six digits identify the vendor, e.g. 80:7d:3a.

ESP8266 Wi-Fi MAC address .ino

This code reads the ESP8266 Wi-Fi MAC address:

```
#include <ESP8266WiFi.h>

void setup() {
  Serial.begin(115200);
  Serial.print(WiFi.macAddress());
}
```

Some networks grant access based on MAC address.

HTTP Web request

HTTP is a TCP/IP-based protocol to transport data.

To test* HTTP (Web) requests, we use the cURL tool.

```
$ curl -v tmb.gr/hello.json
```

```
> GET /hello.json HTTP/1.1\r\n
> Host: tmb.gr\r\n
> \r\n
```

*On your computer, before writing any code.

HTTP Web response

```
< HTTP/1.1 200 OK\r\n
< Content-Type: application/json\r\n
< Content-Length: 32\r\n
< \r\n
{\n
  "message": "Hello, World!"\n
}
```

ESP8266 Wi-Fi client .ino

```
WiFiClient client;
client.connect(host, port));
client.print(
  "GET /hello.json HTTP/1.1\r\n" \
  "Host: tmb.gr\r\n" \
  "\r\n");
while (client.connected() ||
  client.available()) {
  int ch = client.read(); … }
```

Hands-on, 15': Wi-Fi

Build and run the previous Wi-Fi related examples.

Use the *.ino* link on each page to find the source.

The examples are in the course repository.

Make sure to use the ESP8266 board.

Sending sensor data

Here is a simple recipe for "remote sensing".

Repeat the following steps in a loop:

- Ensure WiFi is connected
- Read values from sensors
- Add a timestamp (UTC)
- Send data to backend

Transport Layer Security

Transport Layer Security (TLS) allows a device to:

- Encrypt a communication channel, for privacy.
- Verify that it talks to the right backend server.

Trust is based on certificates issued by authorities.

HTTPS relies on TLS to secure HTTP connections.

See this video by @spiessa for an introduction.

ESP8266 secure Wi-Fi client .ino

```
#include <ESP8266WiFi.h>

const char *host = "www.howsmyssl.com";
const char *path = "/a/check";
const int port = 443;

BearSSL::WiFiClientSecure client;
client.setInsecure(); // no cert validation
if (client.connect(host, port)) {
  // the connection is encrypted
```

ESP8266 verify host fingerprint .ino

```
// Browser > 🔒 > Certificate > Fingerprint
const char *fingerprint = "CB 4D 0A 4F E5
0A DA 76 68 A4 33 37 BC 9A F9 C5 47 DD 5D
F6"; // SHA-1, not really secure anymore

BearSSL::WiFiClientSecure client;
client.setFingerprint(fingerprint);
if (client.connect(host, port)) {
  // certificate fingerprint matched
  …
```

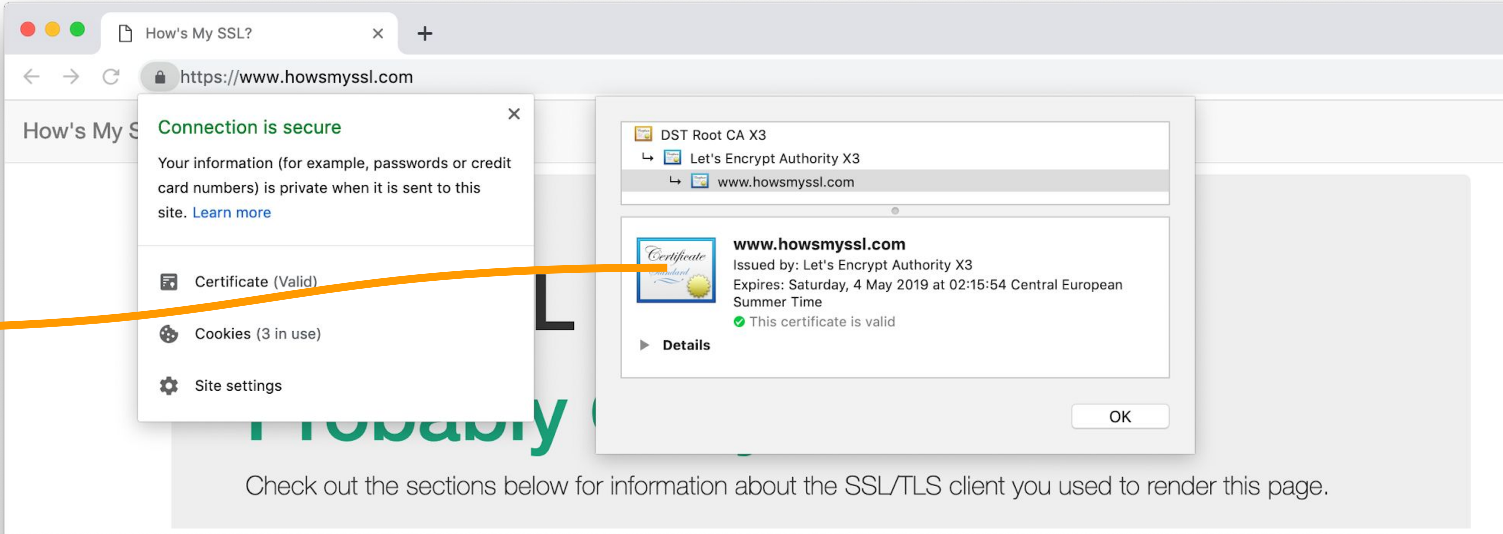
ESP8266 check certificate .ino

```
char cert_pem [] PROGMEM = R"CERT(…)CERT";
X509List cert(cert_pem); // CA or server cert

// make sure time() is set, see NTP client
BearSSL::WiFiClientSecure client;
client.setTrustAnchors(&cert);
if (client.connect(host, port)) {
  // certificate chain verified
  …
```

Getting a server's certificate in Chrome

Drag & drop...



Convert:

Desktop — -zsh — 89×7

~/Desktop — -zsh

```
tamberg@mac Desktop % openssl x509 -inform der -in www.howsmyssl.com.cer -out cert.pem
tamberg@mac Desktop % cat cert.pem
-----BEGIN CERTIFICATE-----
MIIEjzCCA3egAwIBAgISBJ1bFpXEv5L7HobG8ytsWpA1MA0GCSqGSIb3DQEBCwUA
MDIxCzAJBgNVBAYTAlVTMRYwFAYDVQQKEw1MZXQncyBFbmNyeXB0MQswCQYDVQQD
EwJSMzAeFw0yMTA4MjIwMTA5MThaFw0yMTExMjAwMTA5MTdaMBwxGjAYBgNVBAMT
```

Hands-on, 15': ESP8266 TLS clients

Build, run and compare the following TLS clients:

Secure Wi-Fi client, with fingerprint, with CA check.

Locate/download the CA certificate in your browser.

Locate the SHA-1 fingerprint of the host certificate.

Bonus: Try to change the host to another Website.

IoT platforms

IoT platforms enable storing/displaying sensor data.

There are many examples, we start with these two:

Dweet.io stores name/value pairs in JSON format.

ThingSpeak stores sensor data and displays graphs.

Both receive data through HTTP POST requests.

Dweet.io

Dweet.io stores name/value pairs in JSON format.

```
Host: dweet.io
Port: 443
```

```
POST /dweet/for/THING_NAME?name=value
POST /dweet/for/THING_NAME?x=23&y=42&t=…
GET /get/dweets/for/THING_NAME
```

See Wiki for Dweet.io cURL examples.

Hands-on, 15': Dweet.io

Dweet.io works without an account, data is public.

Use your ESP8266 MAC address as THING_NAME.

On the ESP8266, read the analog pin A0, then POST its value to `/dweet/for/THING_NAME?a0=`*`value`*

Use cURL or your browser to read stored data from `https://dweet.io/get/dweets/for/THING_NAME`

ThingSpeak

ThingSpeak stores sensor data and displays graphs.

```
Host: api.thingspeak.com
Port: 80 or 443
```

```
POST /update?api_key=WRITE_API_KEY&field1=3
GET /channels/CHANNEL_ID/feed.json?
api_key=READ_API_KEY
```

See Wiki for ThingSpeak cURL examples.

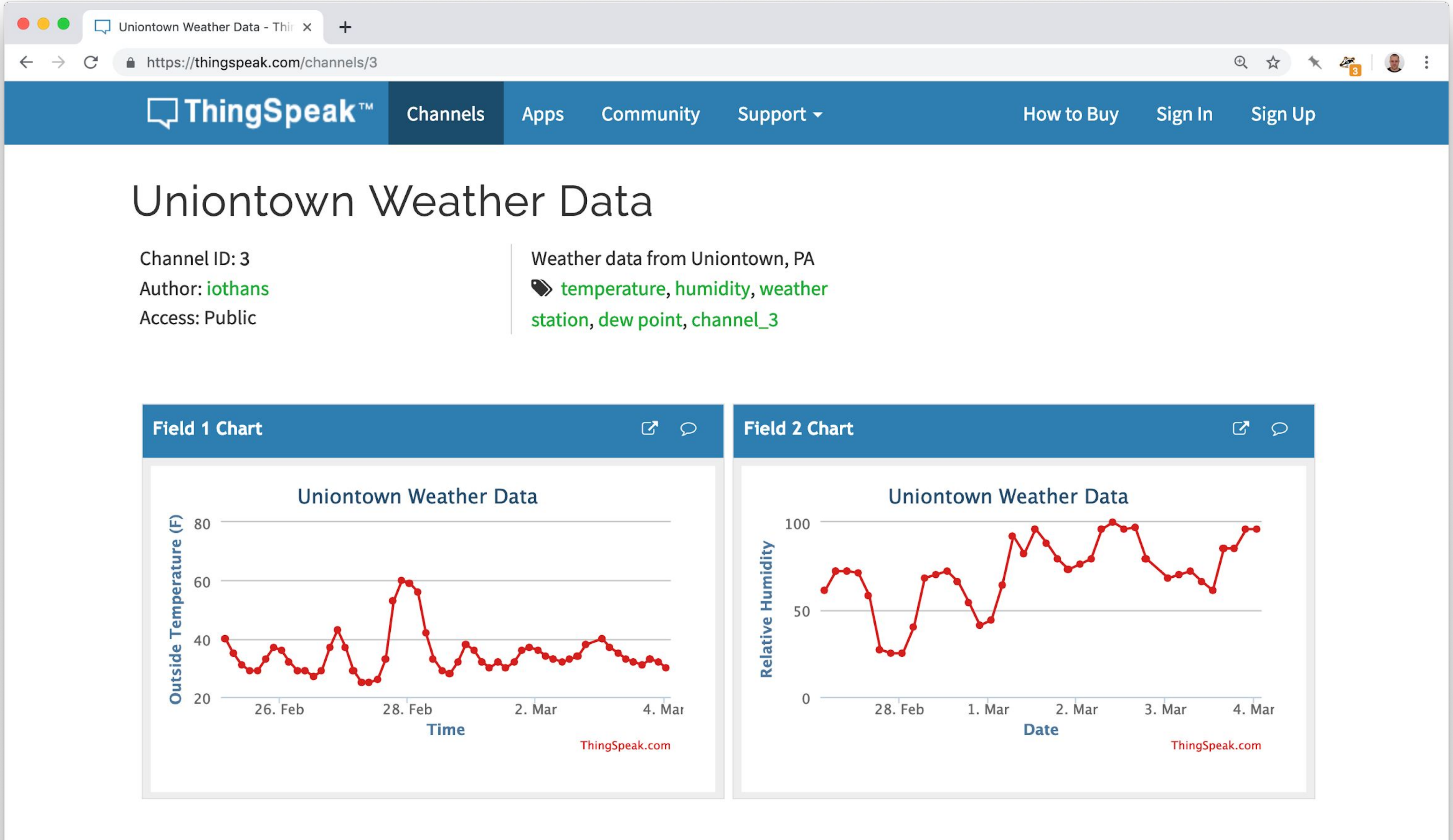
Hands-on, 15': ThingSpeak

Get an account to create channels and get API keys.

Add the Arduino library with *Sketch > Include Library > Manage Libraries… >ThingSpeak > Install*

Try the example code *File > Examples > ThingSpeak > ESP8266 > WriteMultipleFields.ino*

Make sure values arrive in your ThingSpeak channel.


Uniontown Weather Data - Thi
https://thingspeak.com/channels/3
ThingSpeak™
Channels
Apps
Community
Support
How to Buy
Sign In
Sign Up
Uniontown Weather Data
Channel ID: 3
Author: iothans
Access: Public
Weather data from Uniontown, PA
temperature, humidity, weather station, dew point, channel_3
Field 1 Chart
Uniontown Weather Data
Outside Temperature (F)
80
60
40
20
26. Feb
28. Feb
2. Mar
4. Mar
Time
ThingSpeak.com
Field 2 Chart
Uniontown Weather Data
Relative Humidity
100
50
0
28. Feb
1. Mar
2. Mar
3. Mar
4. Mar
Date
ThingSpeak.com

Timestamps

Adding a timestamp can happen in two places:

- In the backend, when a data packet just arrived.
- On the device, when a sensor value is measured.

The first requires sending immediately or discarding values, the second allows caching of measurements.

Trade-off: simplicity vs. accuracy & completeness.

Time

The time on a microcontroller is reset to 0 at startup.

Timestamps use Coordinated Universal Time (UTC).

There are different ways to get and keep UTC time:

- Get time from a standard Web server, using HTTP.
- Get time from a network time server, using NTP.
- Set and keep time with a real time clock (RTC).

ESP8266 Web-based time client .ino

```
> HEAD / HTTP/1.1\r\n
> Host: google.com\r\n
> \r\n
< HTTP/1.1 301 Moved Permanently\r\n
< Location: http://www.google.com/\r\n
< Content-Type: text/html\r\n
< Date: Sat, 02 Mar 2019 17:10:20 GMT\r\n
< \r\n
```

Network Time Protocol

Network Time Protocol (NTP) is a network protocol for clock synchronization between computer systems[1].

Synchronizes participating computers to within a few milliseconds of Coordinated Universal Time (UTC).

Implementations send and receive timestamps using the User Datagram Protocol (UDP) on port 123.

ESP8266 built-in NTP client .ino

```
configTime(timezone * 3600, dst_offset,
  "pool.ntp.org", "time.nist.gov");
// wait for time() being adjusted
while (time(NULL) < 28800 * 2) {
  delay(500);
}
// time() is set
time_t now = time(NULL);
```

Hands-on, 15': ESP8266 NTP clients

Build, run and compare the following NTP clients:

Web-based time client and built-in NTP client and

Arduino > Examples > ESP8266WiFi > NTPClient.

Bonus: Read the code of this low memory version.

Which one would you use, and why?

Hands-on, 15': Temperature sensor

Design a connected temperature sensor as specified:

Gets current time and date in ISO 8601 UTC format.

Gets temperature & humidity from a DHT11 sensor.

Connects* to api.thingspeak.com port 443 with TLS.

Posts sensor values, timestamp every 30 seconds.

*And robustly reconnects, if disconnected.

Summary

We learned to connect a device to a Wi-Fi network.

We sent sensor measurements to an IoT platform.

We looked at ways to get UTC time on a controller.

These are the basics of remote sensing.

Next: Internet Protocols, HTTP and CoAP.

Challenge

Implement or finish the temp. sensor you designed.

Post your IoT platform data feed URL* to Teams.

Commit the Arduino code to the hands-on repo.

Measure the temperature for at least 24 hours.

*Ideally public, we'll take a look together.

Feedback or questions?

Write me on Teams or email

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Thanks for your time.