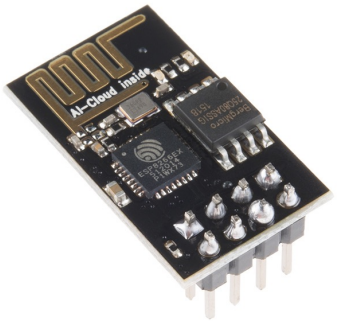
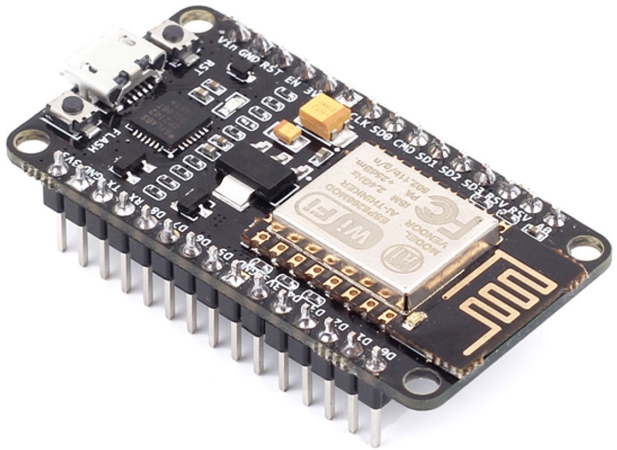
Embedded Systems

Master 's Degree in Informatics Engineering

ESP-01 & NodeMCU Platform



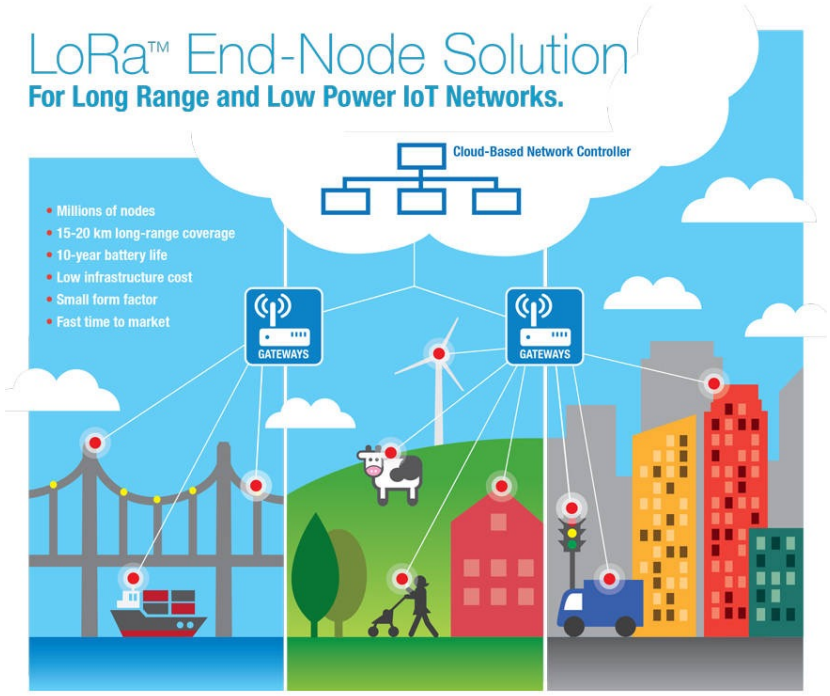


LoRa – Long Range Radio

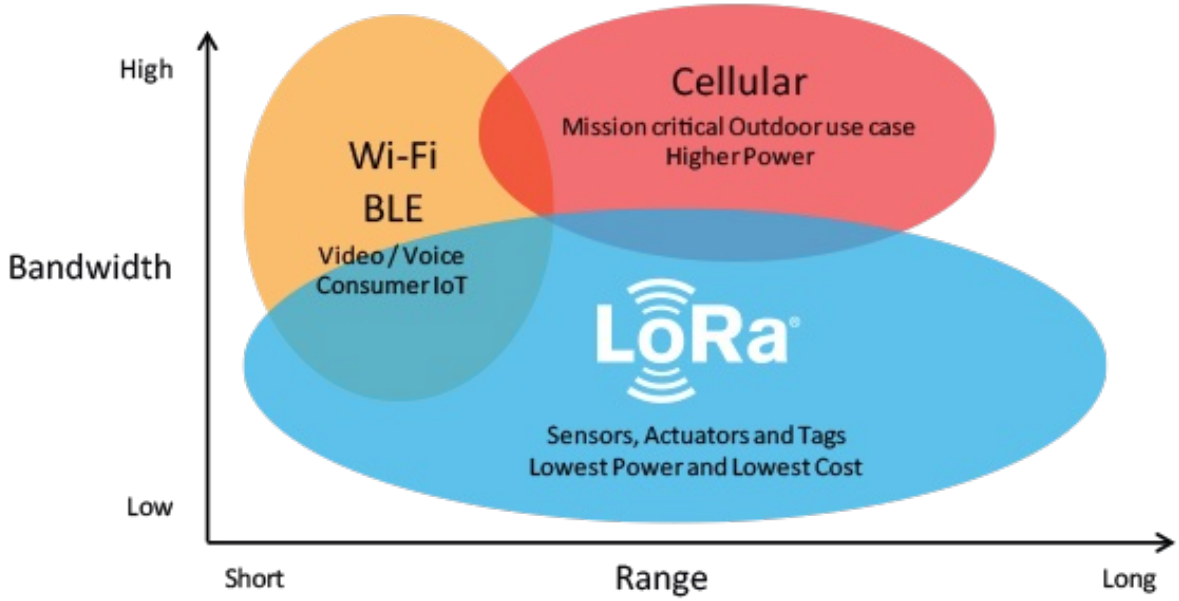
- LoRa (Long Range) is a low-power wide-area network (LPWAN) technology (more than 10 km in rural areas)

- The LoRa Alliance is an association created in 2015 to support LoRaWAN (~ 500 members)

- The LoRa physical layer protocol is proprietary



LoRa – Long Range Radio



LoRa uses unlicensed frequencies that are available worldwide. These are the most widely used frequencies:

- 868 MHz for Europe
- 915 MHz for North America
- 433 MHz band for Asia

https://www.semtech.com/lora/what-is-lora

Key Feature of LoRa

Long Range
Connects devices up to 30 miles apart in rural areas and penetrates dense urban or deep indoor environments

Low Power
Requires minimal energy, with prolonged battery lifetime of up to 10 years, minimizing battery replacement costs

Secure
Features end-to-end AES128 encryption, mutual authentication, integrity protection, and confidentiality

Standardized
Offers device interoperability and global availability of LoRaWAN networks for speedy deployment of IoT applications anywhere

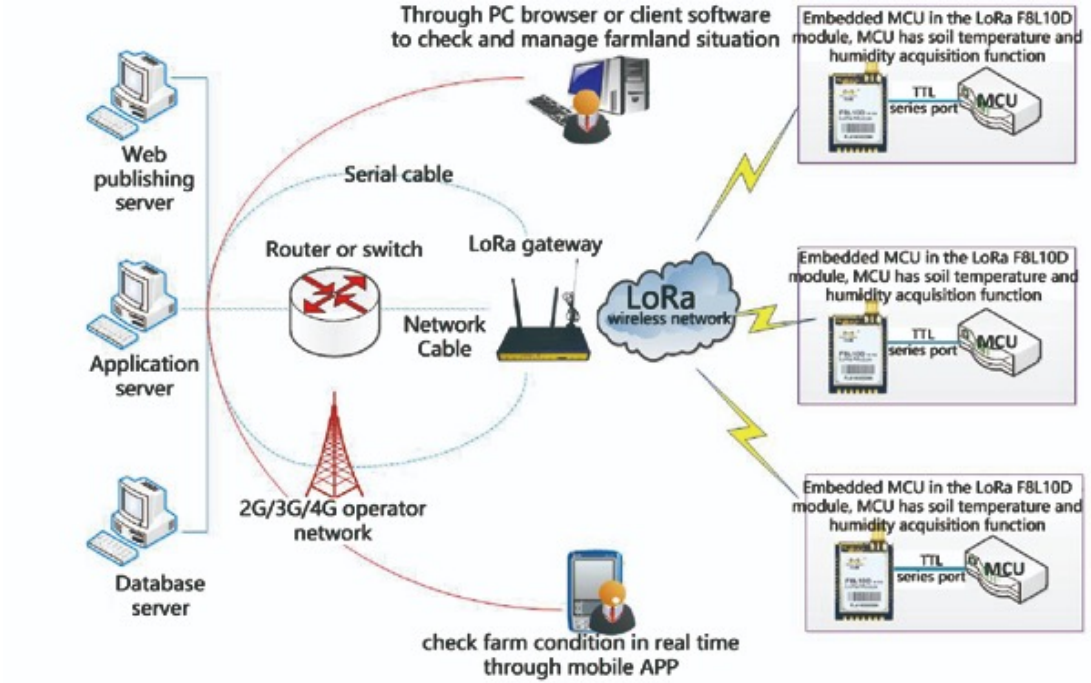
Geolocation
Enables GPS-free tracking applications, offering unique low power benefits untouched by other technologies

Mobile
Maintains communication with devices in motion without strain on power consumption

High Capacity
Supports millions of messages per base station, meeting the needs of public network operators serving large markets

Low Cost
Reduces infrastructure investment, battery replacement expense, and ultimately operating expenses

LoRa – Applications

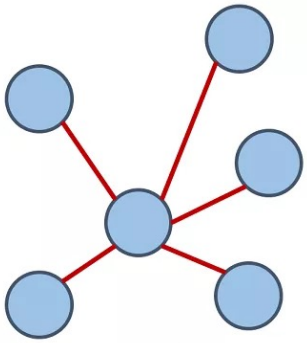


LoRa long range and low power features, makes it perfect for battery-operated sensors and low-power applications in:

- Internet of Things (IoT)
- Smart home
- Machine-to-machine communication
- Etc.

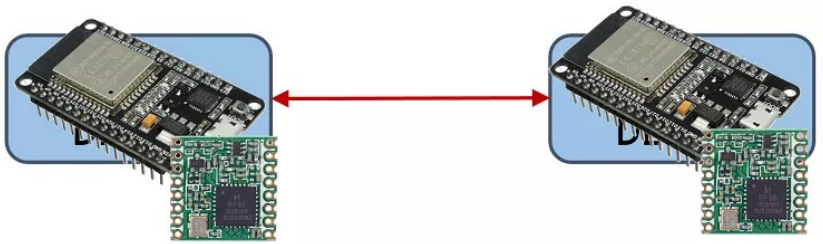
LoRa - Topologies

Point to point communication

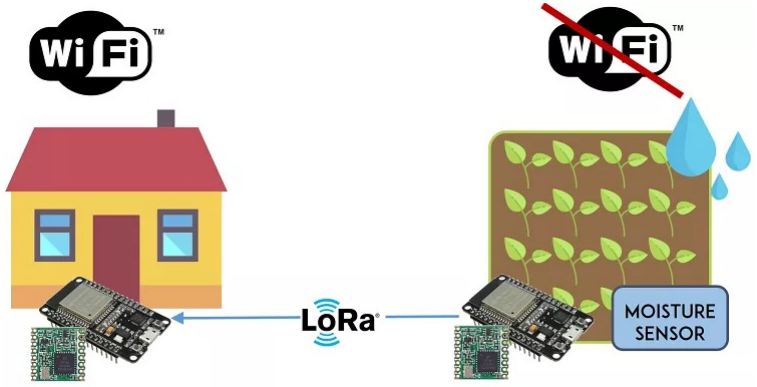


Network

Point to Point Communication: two LoRa enabled devices talk with each other using RF signals.

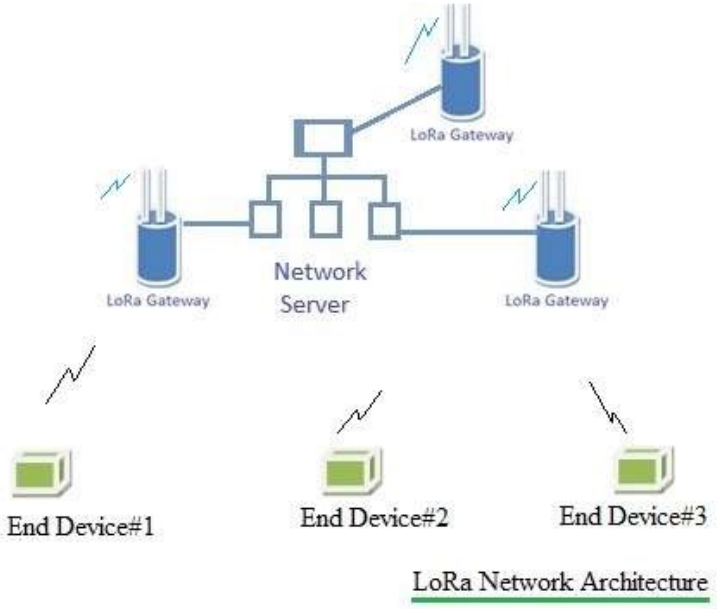


Network or LoRa WAN: It allows accessing to gateways

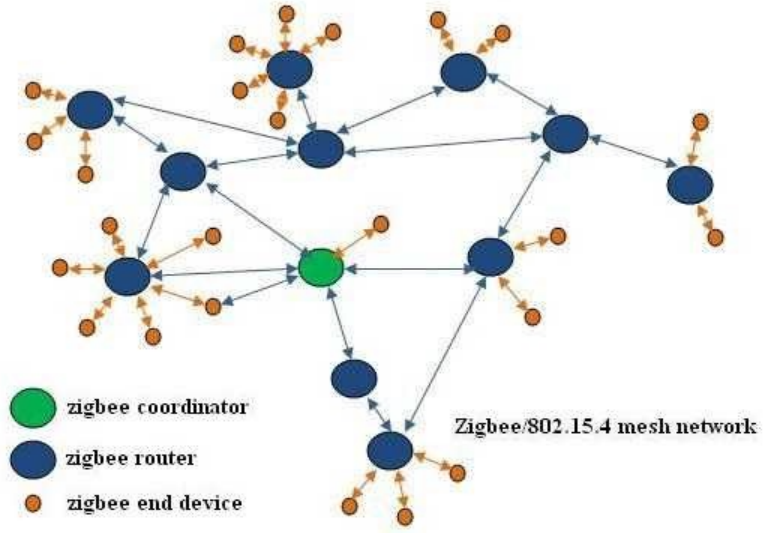


LoRa vs ZigBee

Network Architecture



LoRa Network Architecture



Gateway, servers and end devices.
Wide Area Network

- 2-5 Km (urban areas)
- 15 Km (suburban areas)

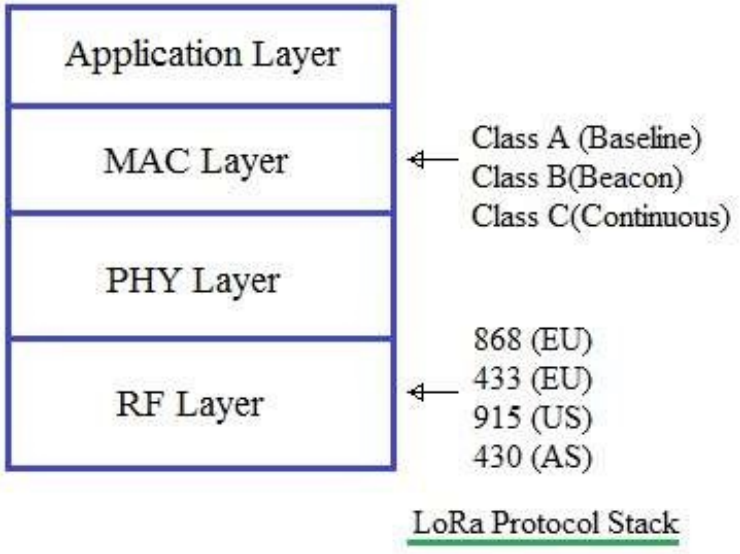
Coordinator, routers and end devices.
Low rate wireless personal area network

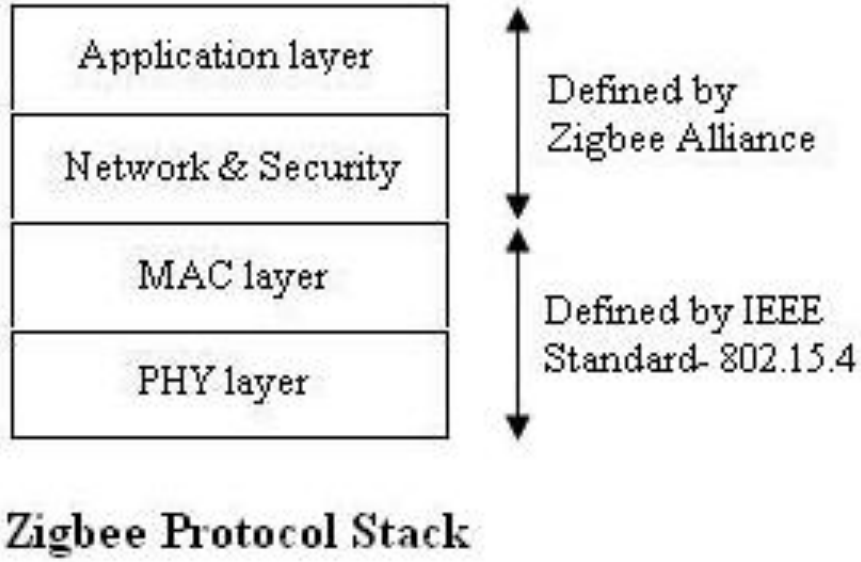
- 10 to 100 meters

https://www.rfwireless-world.com/Terminology/LoRa-vs-Zigbee.html

LoRa vs ZigBee

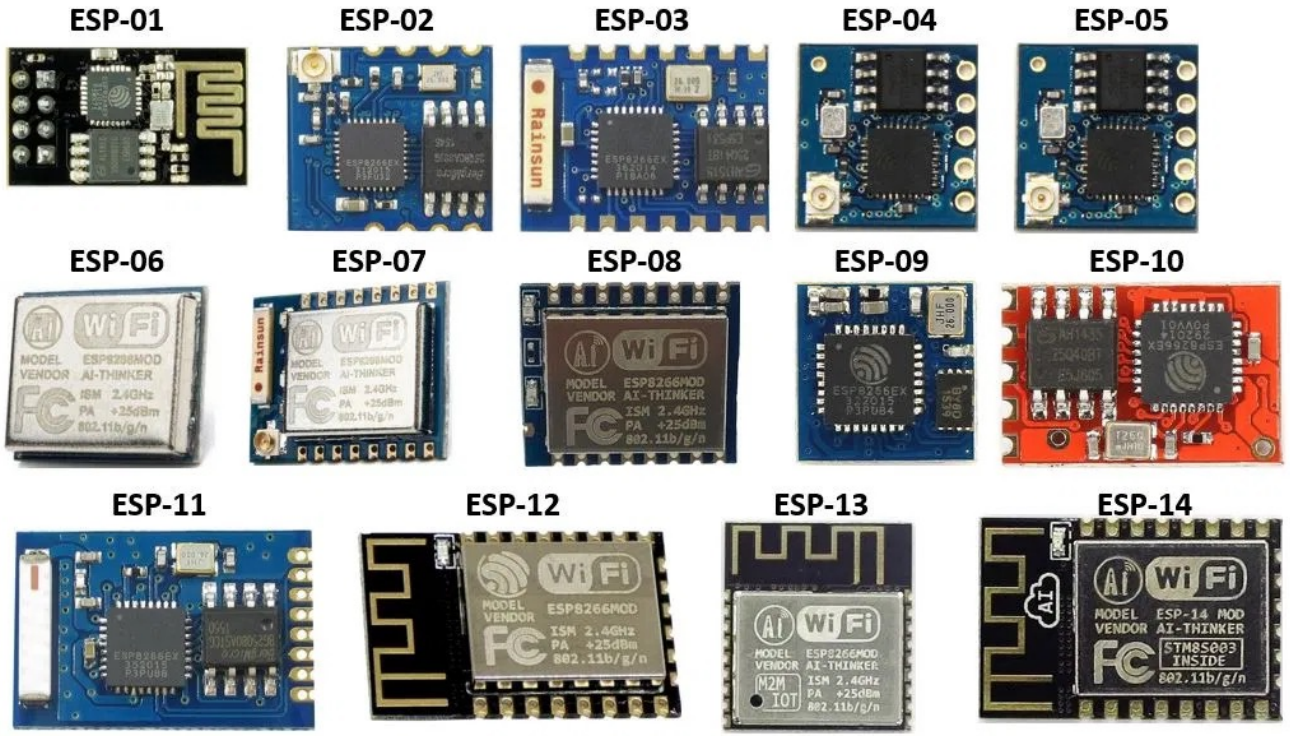
Protocol Stack





https://www.rfwireless-world.com/Terminology/LoRa-vs-Zigbee.html

ESP family



Ai-Thinker series based around ESP8266 and , referred as ESP-xx modules ranges from 01 to 14.

Wemos D1 mini -- 2017 versions

US / UK Prices -- includes shipping to US / UK

MicroPython based boards

mini V3.0.0
ESP8266 4MB
$4.21 / £3.23

mini Lite V1.0.0
ESP8285 1MB
$3.71 / £2.84

mini Pro V1.1.0
ESP8266 16MB
ceramic antenna
$6.81 / £5.41

https://www.wemos.cc/en/latest/

NodeMCU family

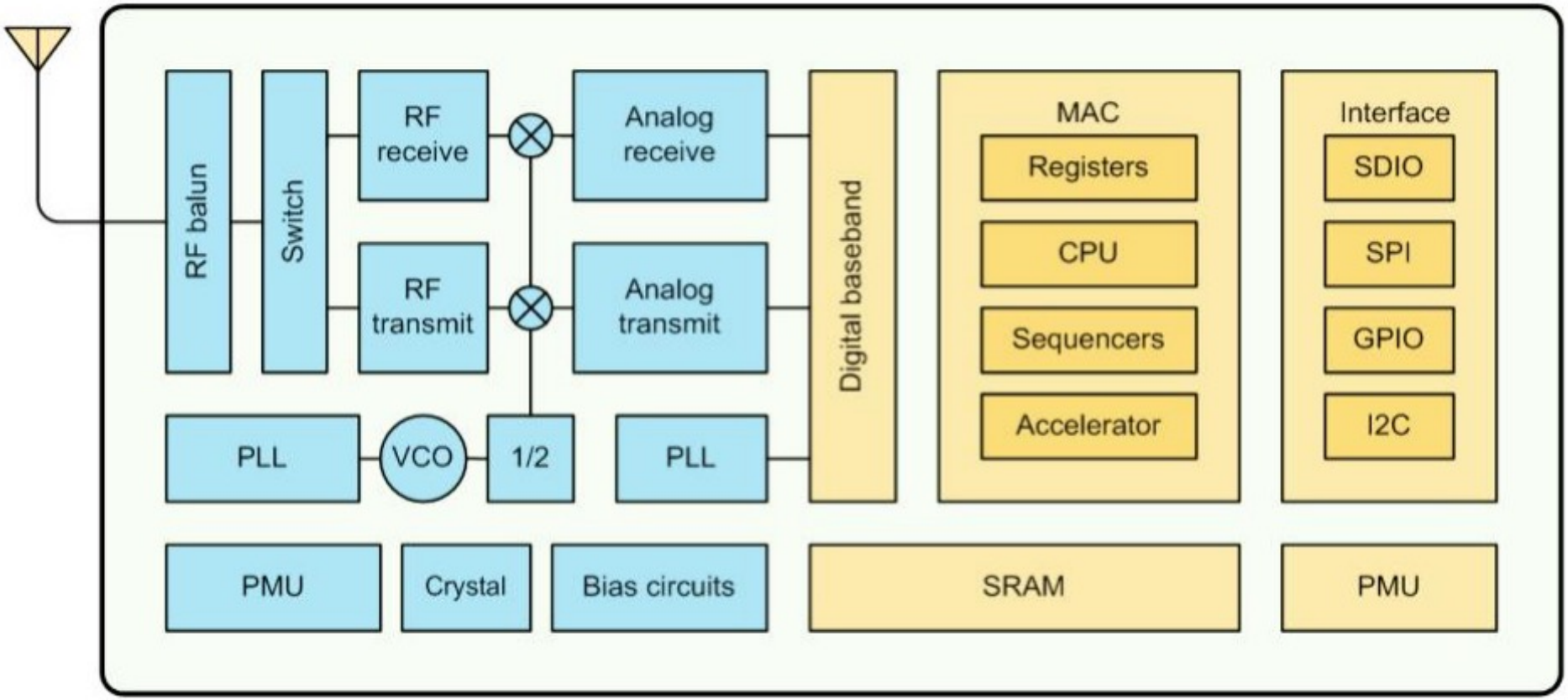
NodeMCU v0.9 / V1

NodeMCU v1.0/ V2

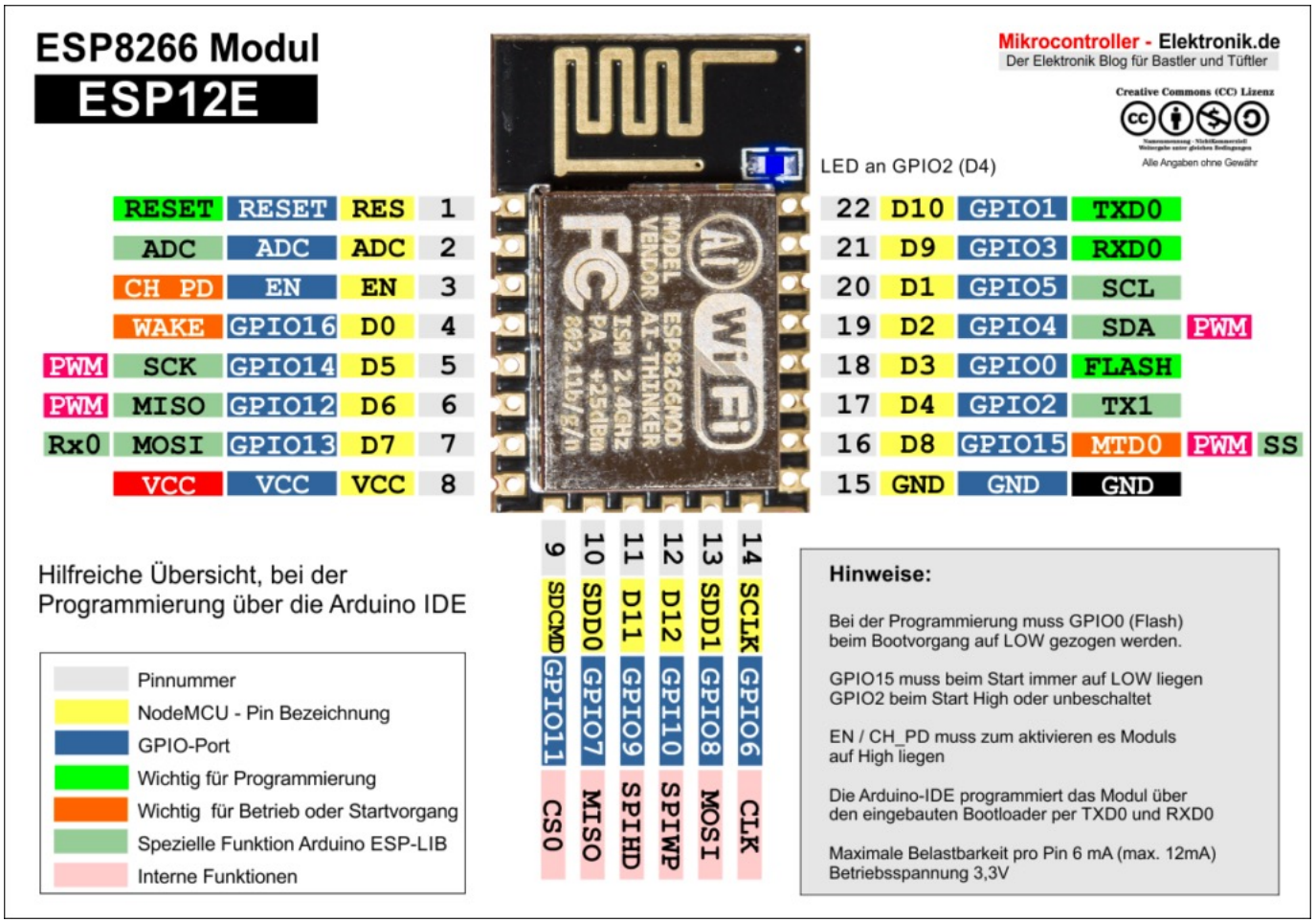
NodeMCU v1.0/ V3

NodeMCU development board has a total 30 pins in which 14 pins are active, uses ESP-12 module, onboard reset and flash button, 3.3 voltage regulator, Micro USB, USB to UART Bridge and some other components.

ESP8266-12E Block Diagram



ESP8266-12E pinout



ESP-01

- Low cost, compact and powerful Wi-Fi Module
- Power Supply: +3.3V only
- Built-in low power 32-bit MCU @ 80MHz
- 512kB Flash Memory
- Can be used as Station or Access Point or both combined
- Supports Deep sleep (<10uA)
- Supports serial communication hence compatible with many development platform like Arduino
- Can be programmed using Arduino IDE or AT-commands or Lua Script

What is NodeMCU?

- Open-source
- WI-FI enabled
- Based on the ESP8266-12
- Arduino-like hardware IO (3.3V)
- Nodejs style network API
- MicroPython/LUA programming*

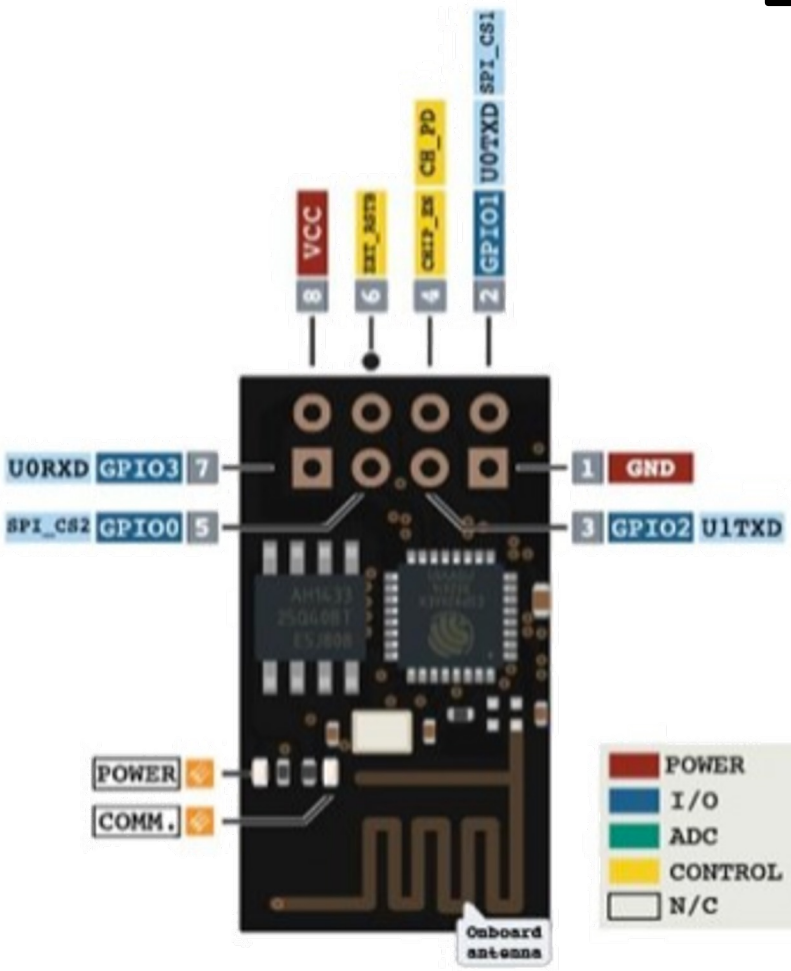
- Extremelly low cost <5€ !!

* https://nodemcu.readthedocs.io/en/master/ > LUA
** https://www.nodemcu.com/index_en.html

ESP-01 vs NodeMCU?

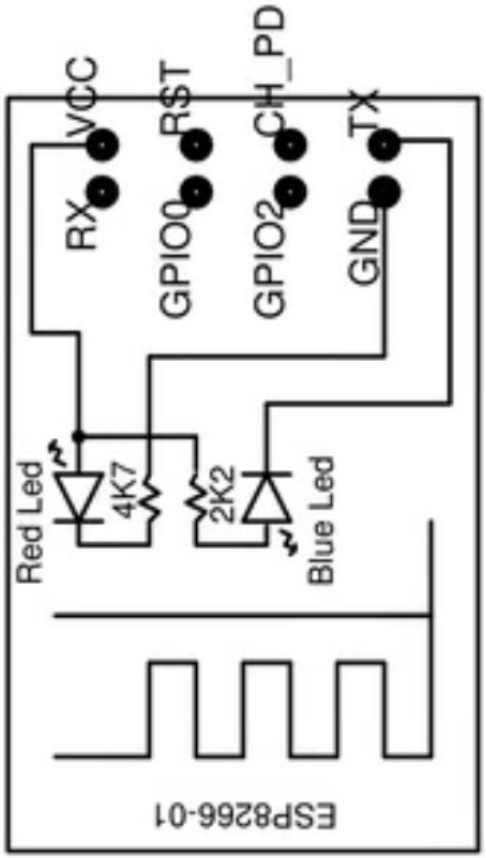
	ESP-01	NodeMCU v1.0
CPU	32-bit Tenselica Xtensa LX106	
CPU Clock	80MHz/160MHz	
Instruction SRAM	64KBytes (<36KB Station Mode)	
Data SRAM	96KBytes	
Flash Memory	1MByte	4MBytes
GPIO Pins	2	11
ADC	-	1
USB-to-Serial	-	CH340G
UART/SPI/I2C	1/1/1	
WiFI Built-In	802.11 b/g/n	

ESP-01

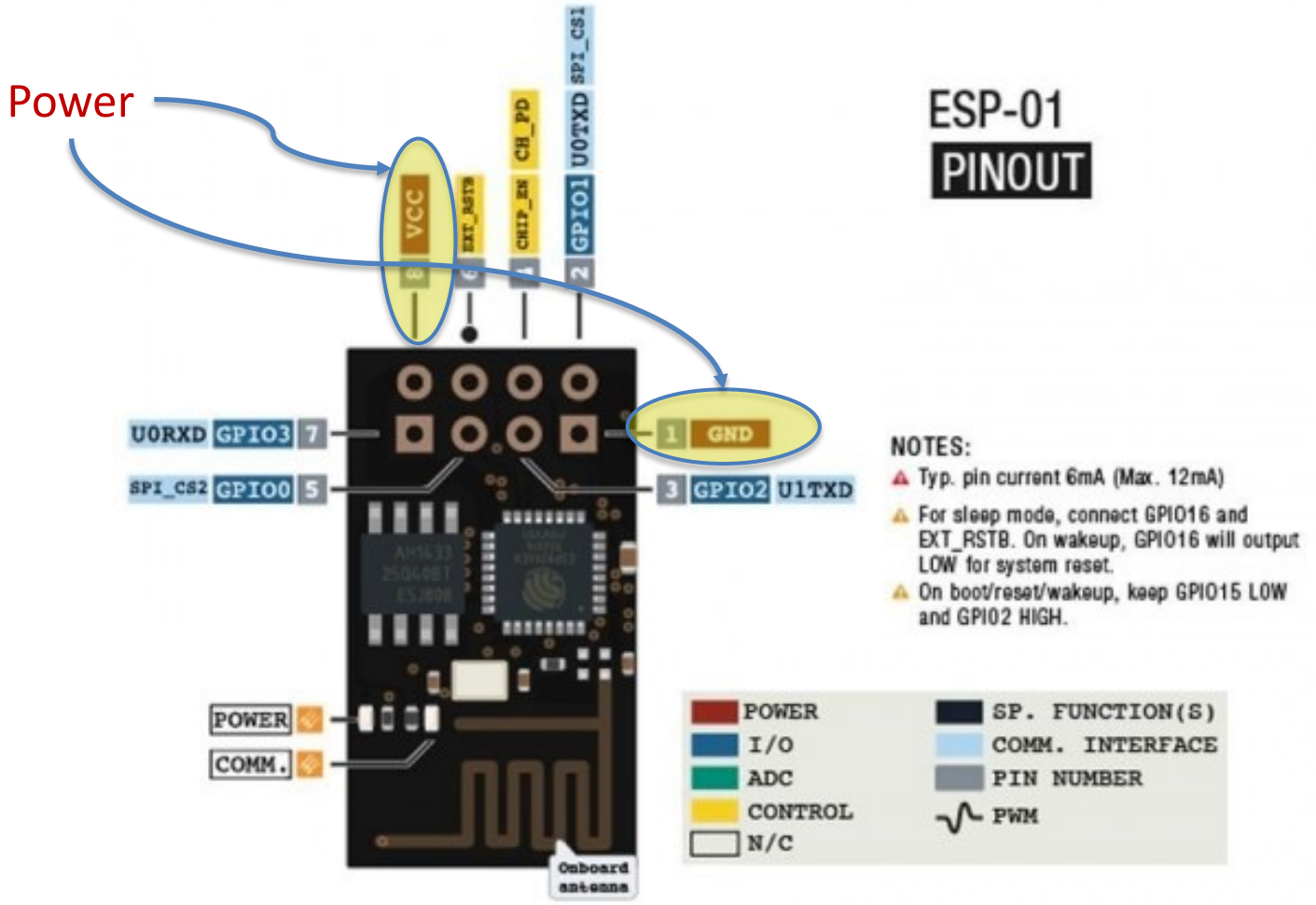


NOTES:

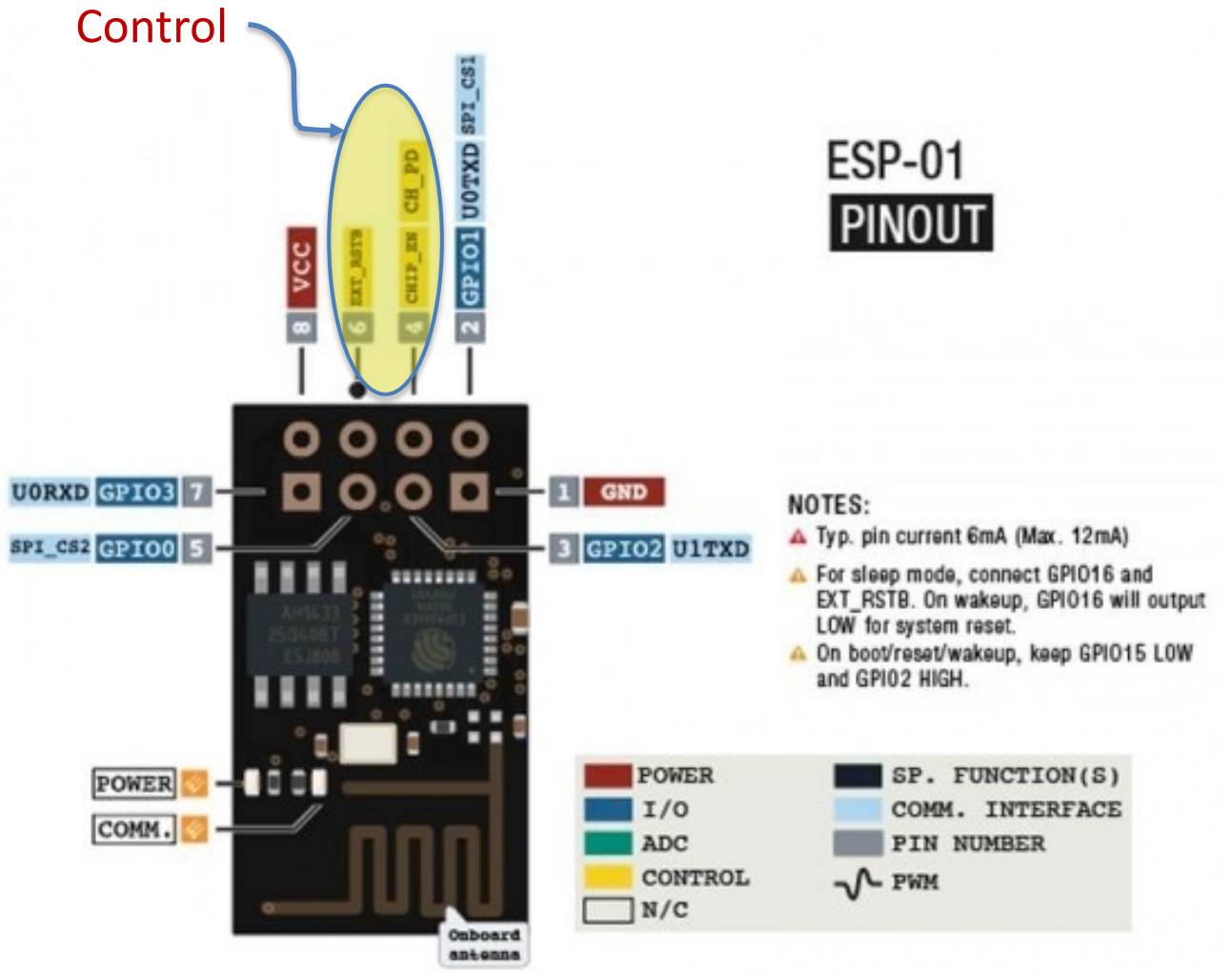
- Typ. pin current 6mA (Max. 12mA)
- For sleep mode, connect GPIO16 and EXT_RSTB. On wakeup, GPIO16 will output LOW for system reset.
- On boot/reset/wakeup, keep GPIO15 LOW and GPIO2 HIGH.



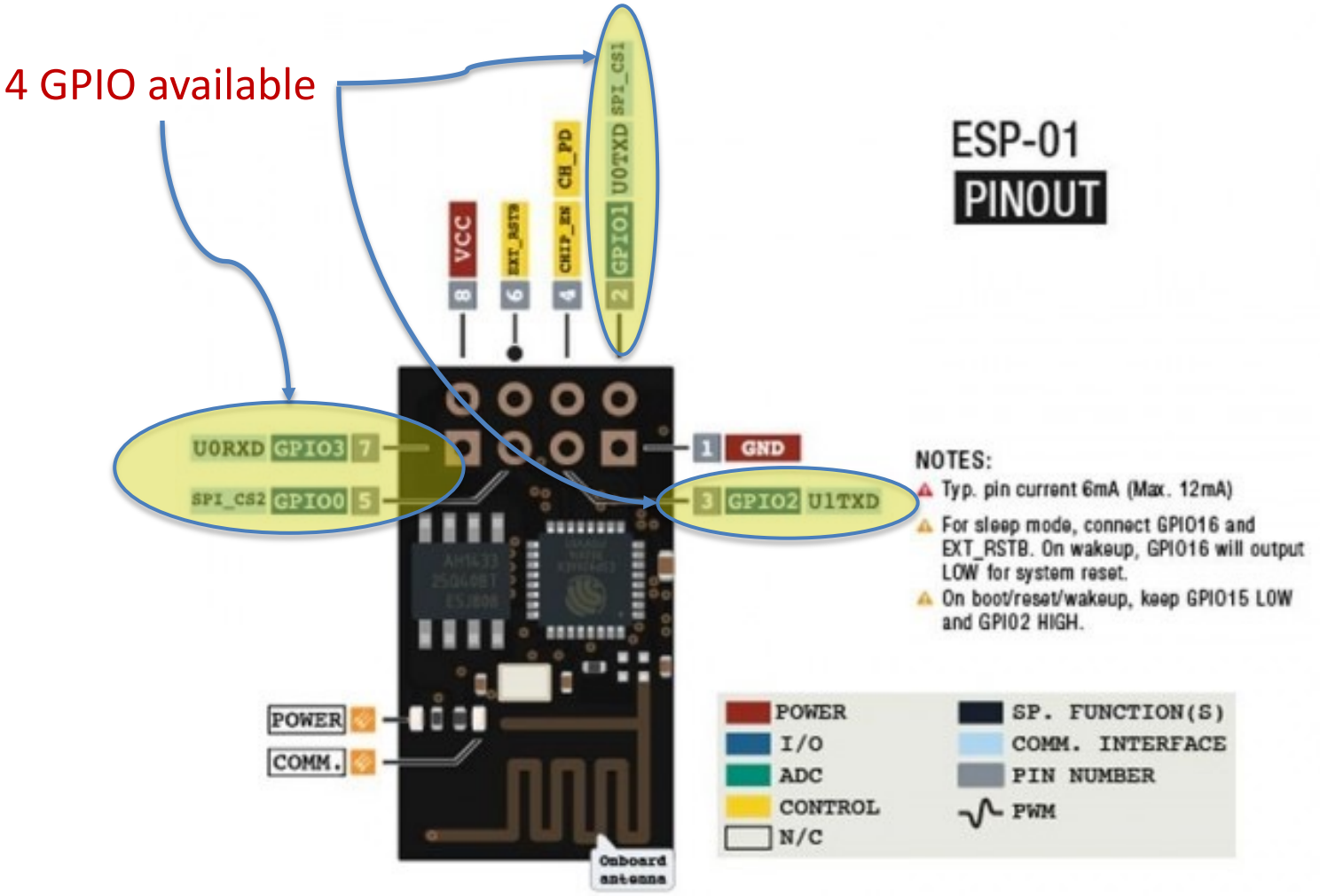
ESP-01


Power
VCC
EXT_RSTB
CHIP_EN
GPIO1
U0TXD
SPI_CS1
CH_PD
8
6
4
2
U0RXD GPIO3 7
SPI_CS2 GPIO0 5
1 GND
3 GPIO2 U1TXD
POWER
COMM.
Onboard antenna
ESP-01
PINOUT
NOTES:
Typ. pin current 6mA (Max. 12mA)
For sleep mode, connect GPIO16 and EXT_RSTB. On wakeup, GPIO16 will output LOW for system reset.
On boot/reset/wakeup, keep GPIO15 LOW and GPIO2 HIGH.
POWER
I/O
ADC
CONTROL
N/C
SP. FUNCTION(S)
COMM. INTERFACE
PIN NUMBER
PWM

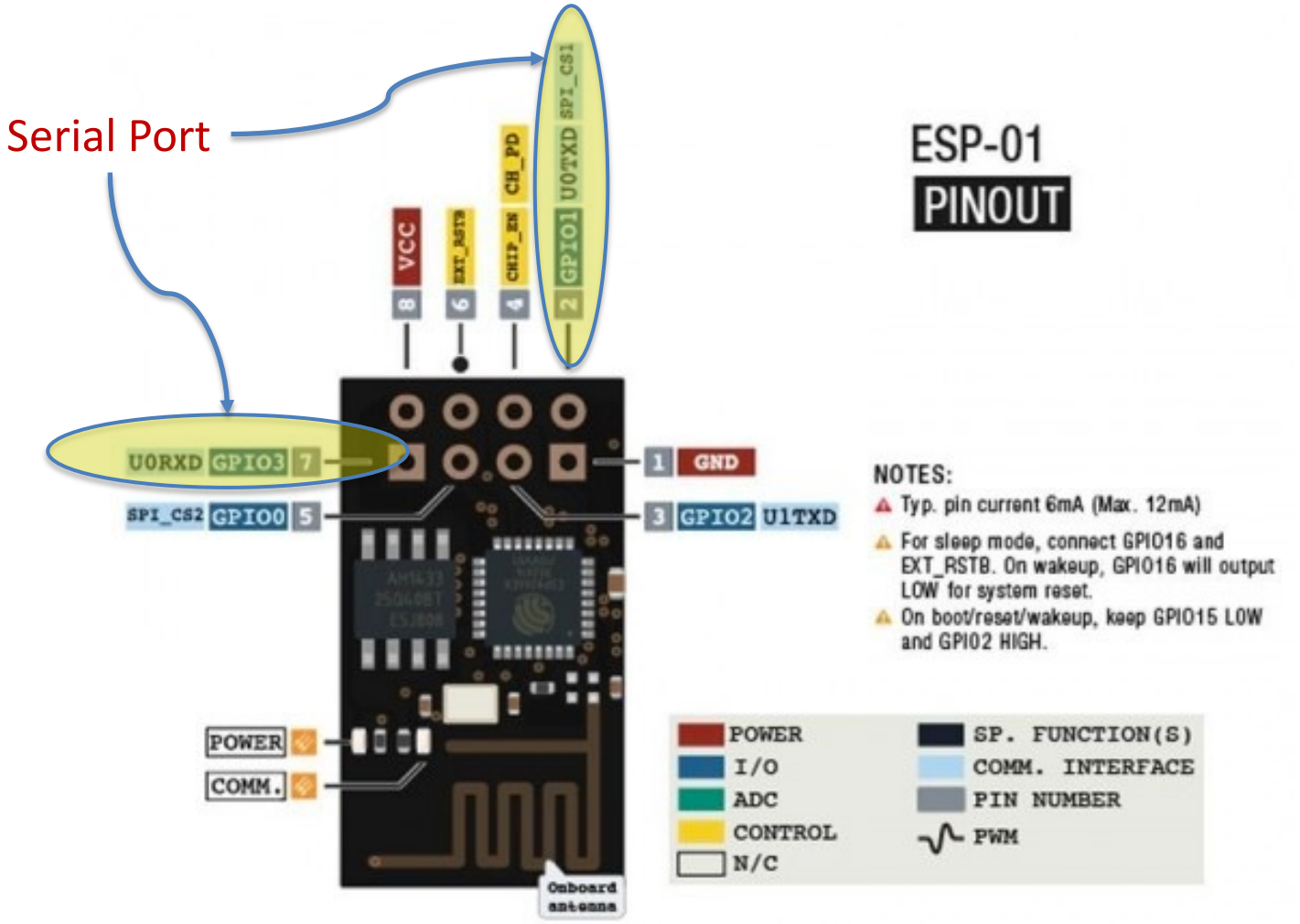
ESP-01


Control
VCC
EXT_RSTB
CHIP_EN
CH_PD
GPIO1
U0TXD
SPI_CS1
8
6
4
2
U0RXD GPIO3 7
SPI_CS2 GPIO0 5
1 GND
3 GPIO2 U1TXD
POWER
COMM.
Onboard antenna
ESP-01
PINOUT
NOTES:
Typ. pin current 6mA (Max. 12mA)
For sleep mode, connect GPIO16 and EXT_RSTB. On wakeup, GPIO16 will output LOW for system reset.
On boot/reset/wakeup, keep GPIO15 LOW and GPIO2 HIGH.
POWER
I/O
ADC
CONTROL
N/C
SP. FUNCTION(S)
COMM. INTERFACE
PIN NUMBER
PWM

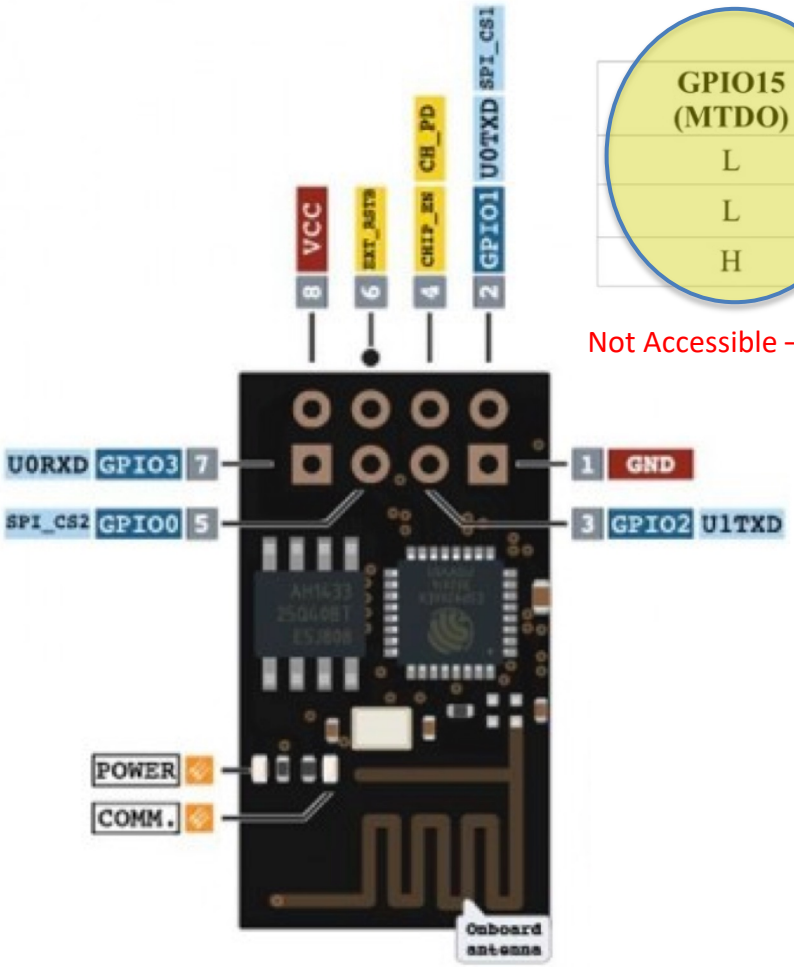
ESP-01


4 GPIO available
ESP-01
PINOUT
VCC
EXT_RSTB
CHIP_EN
CH_PD
GPIO1
U0TXD
SPI_CS1
8
6
4
2
U0RXD GPIO3 7
SPI_CS2 GPIO0 5
1 GND
3 GPIO2 U1TXD
POWER
COMM.
Onboard antenna
NOTES:
Typ. pin current 6mA (Max. 12mA)
For sleep mode, connect GPIO16 and EXT_RSTB. On wakeup, GPIO16 will output LOW for system reset.
On boot/reset/wakeup, keep GPIO15 LOW and GPIO2 HIGH.
POWER
I/O
ADC
CONTROL
N/C
SP. FUNCTION(S)
COMM. INTERFACE
PIN NUMBER
PWM

ESP-01


Serial Port
VCC 8
EXT_RSTB 6
CHIP_EN 4
GPIO1 U0TXD SPI_CS1 2
U0RXD GPIO3 7
SPI_CS2 GPIO0 5
1 GND
3 GPIO2 U1TXD
POWER
COMM.
Onboard antenna
ESP-01
PINOUT
NOTES:
Typ. pin current 6mA (Max. 12mA)
For sleep mode, connect GPIO16 and EXT_RSTB. On wakeup, GPIO16 will output LOW for system reset.
On boot/reset/wakeup, keep GPIO15 LOW and GPIO2 HIGH.
POWER
I/O
ADC
CONTROL
N/C
SP. FUNCTION(S)
COMM. INTERFACE
PIN NUMBER
PWM

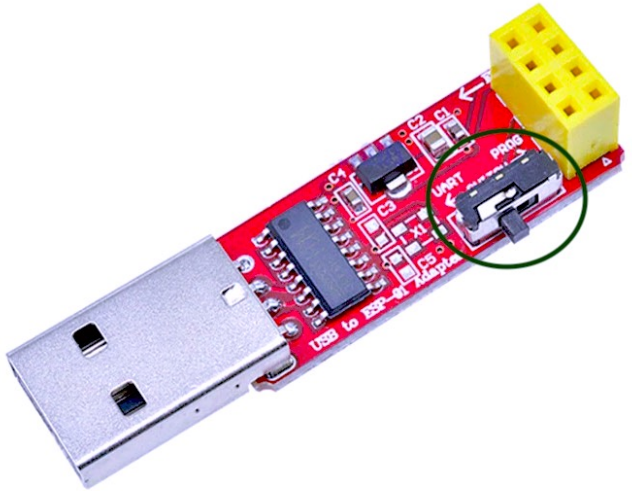
ESP-01 – Programming module



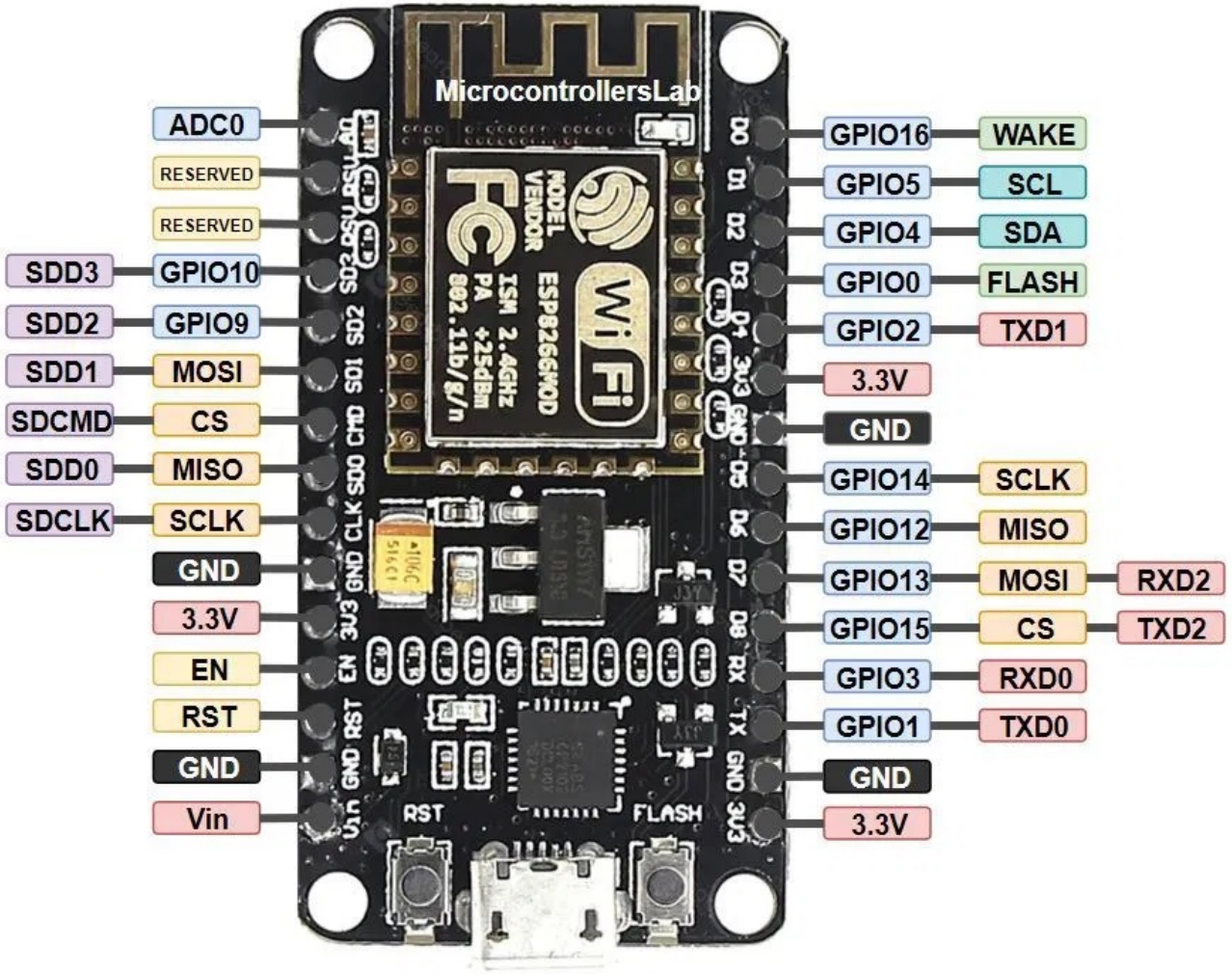
ESP8266 Boot Options

GPIO15 (MTDO)	GPIO0	GPIO2	Mode	Comments
L	H	H	Flash	Boot from SPI Flash (Normal running)
L	L	H	UART	Program via UART (TX/RX)
H	x (not care)	x (not care)	SDIO	Boot from SD-card

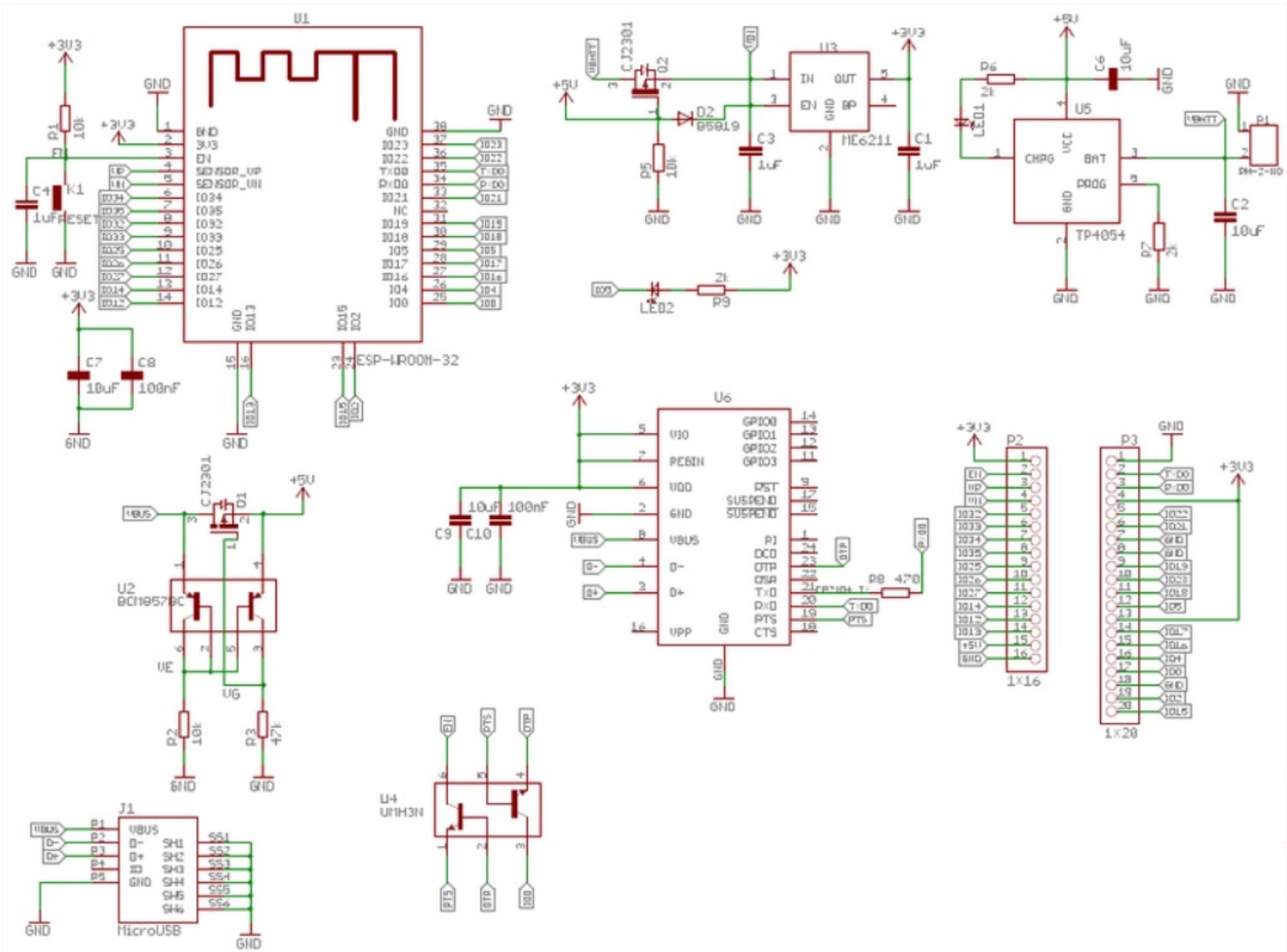
Not Accessible – ESP-01



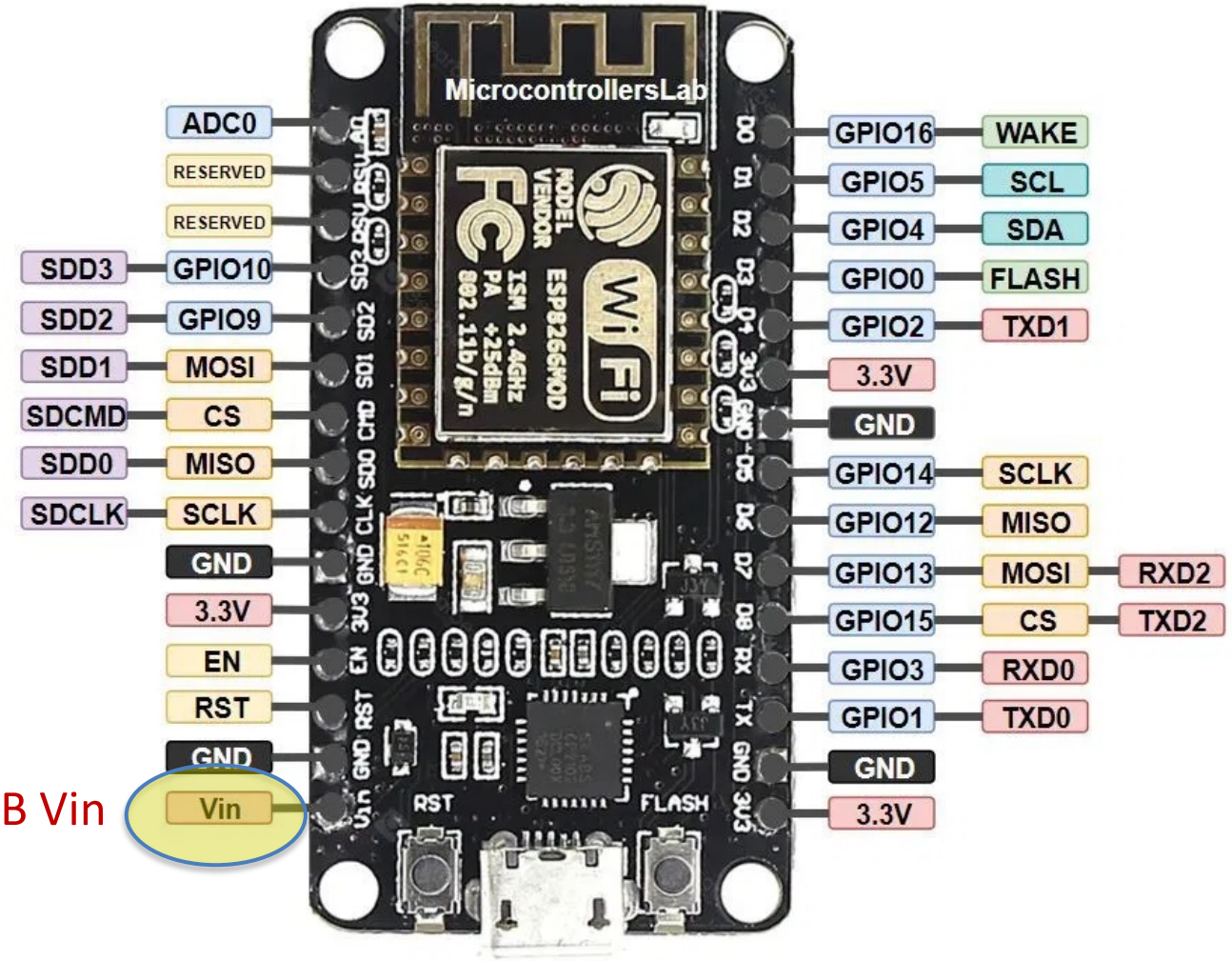
NodeMCU 12E


MicrocontrollersLab
ADC0
RESERVED
RESERVED
SDD3
GPIO10
SDD2
GPIO9
SDD1
MOSI
SDCMD
CS
SDD0
MISO
SDCLK
SCLK
GND
3.3V
EN
RST
GND
Vin
GPIO16
WAKE
GPIO5
SCL
GPIO4
SDA
GPIO0
FLASH
GPIO2
TXD1
3.3V
GND
GPIO14
SCLK
GPIO12
MISO
GPIO13
MOSI
RXD2
GPIO15
CS
TXD2
GPIO3
RXD0
GPIO1
TXD0
GND
3.3V
RST
FLASH

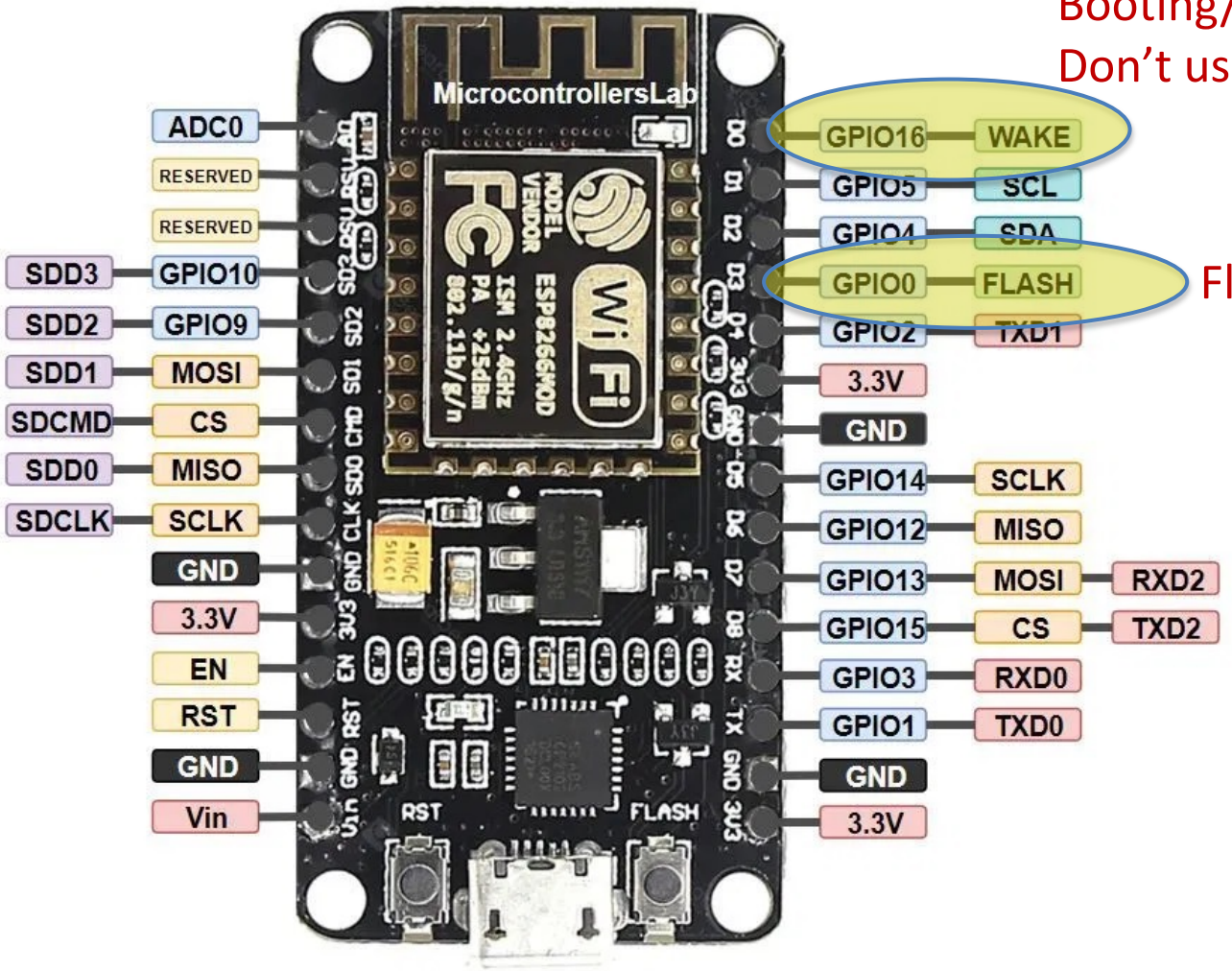
NodeMCU 12E


U1
ESP-WROOM-32
U3
ME6211
U5
TP4054
U6
U2
U4
UMH3N
J1
MicroUSB
P2
1x16
P3
1x20
CJ2301
B5819
+3V3
+5V
GND

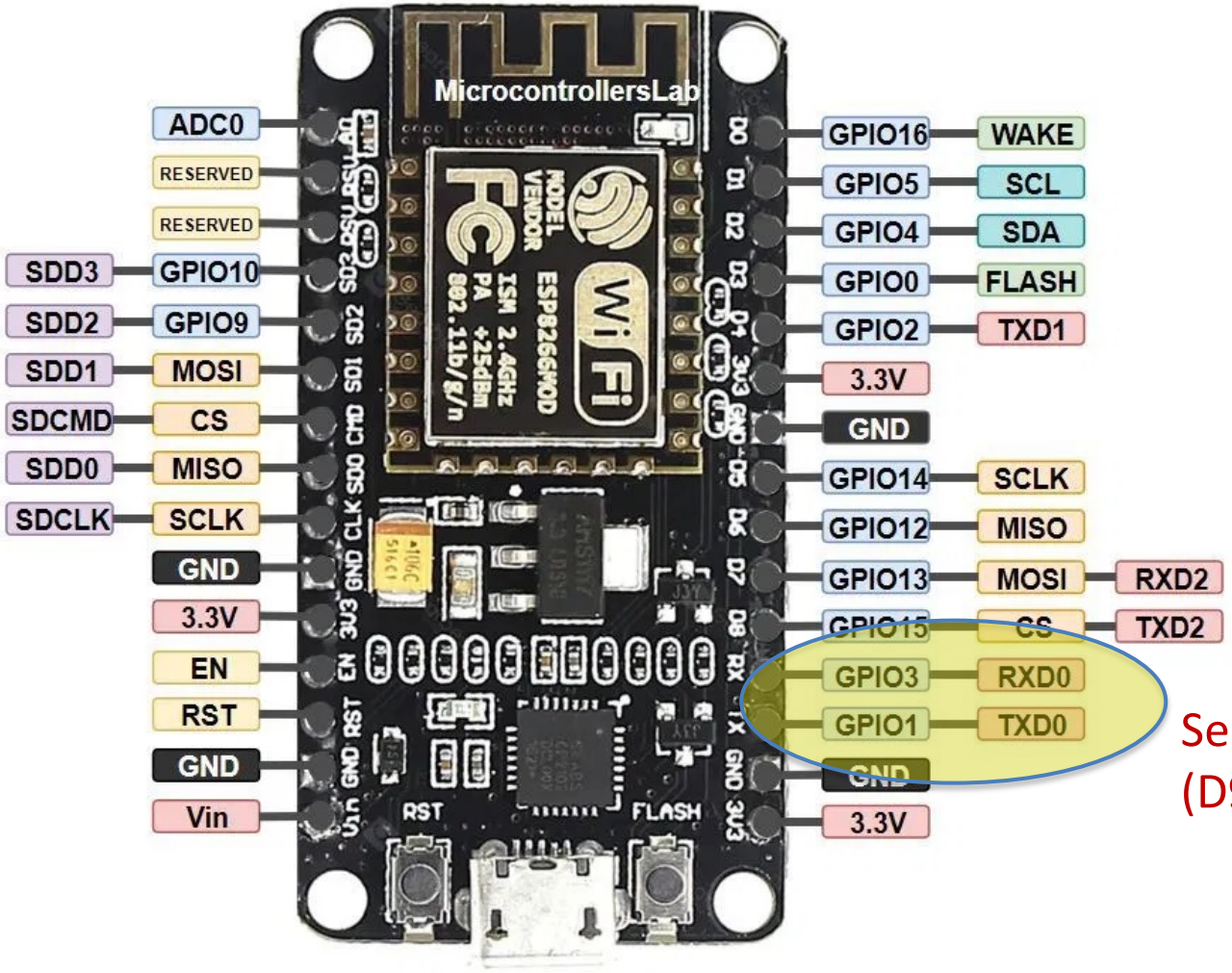
NodeMCU 12E


MicrocontrollersLab
ADC0
RESERVED
RESERVED
SDD3
GPIO10
SDD2
GPIO9
SDD1
MOSI
SDCMD
CS
SDD0
MISO
SDCLK
SCLK
GND
3.3V
EN
RST
GND
Vin
Direct USB Vin
GPIO16
WAKE
GPIO5
SCL
GPIO4
SDA
GPIO0
FLASH
GPIO2
TXD1
3.3V
GND
GPIO14
SCLK
GPIO12
MISO
GPIO13
MOSI
RXD2
GPIO15
CS
TXD2
GPIO3
RXD0
GPIO1
TXD0
GND
3.3V
RST
FLASH

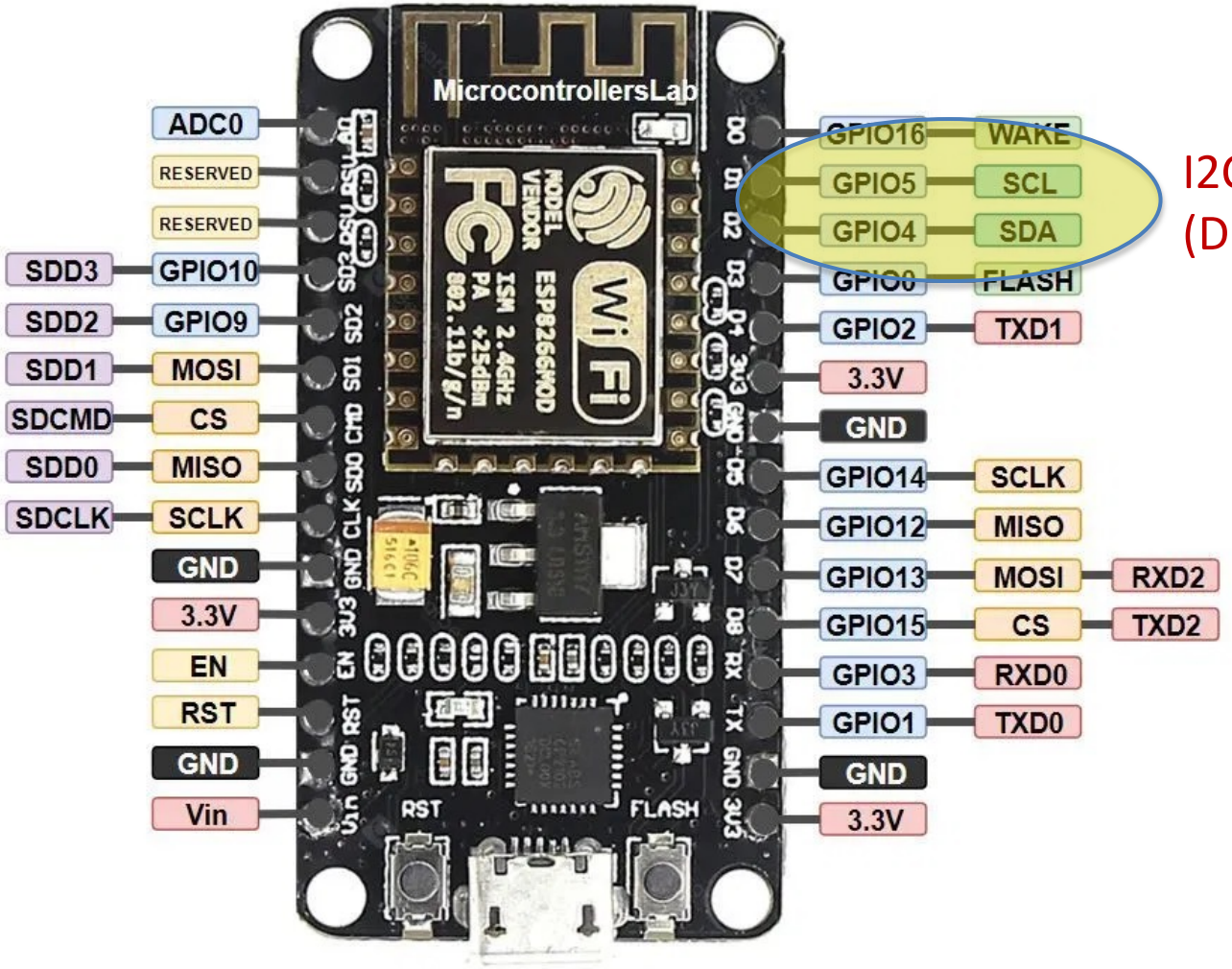
NodeMCU 12E


Booting/Flash ping
Don't use it
Flash pin
MicrocontrollersLab
ADC0
RESERVED
RESERVED
SDD3
GPIO10
SDD2
GPIO9
SDD1
MOSI
SDCMD
CS
SDD0
MISO
SDCLK
SCLK
GND
3.3V
EN
RST
GND
Vin
GPIO16
WAKE
GPIO5
SCL
GPIO4
SDA
GPIO0
FLASH
GPIO2
TXD1
3.3V
GND
GPIO14
SCLK
GPIO12
MISO
GPIO13
MOSI
RXD2
GPIO15
CS
TXD2
GPIO3
RXD0
GPIO1
TXD0
GND
3.3V
RST
FLASH

NodeMCU 12E


MicrocontrollersLab
ADC0
RESERVED
RESERVED
SDD3
GPIO10
SDD2
GPIO9
SDD1
MOSI
SDCMD
CS
SDD0
MISO
SDCLK
SCLK
GND
3.3V
EN
RST
GND
Vin
GPIO16
WAKE
GPIO5
SCL
GPIO4
SDA
GPIO0
FLASH
GPIO2
TXD1
3.3V
GND
GPIO14
SCLK
GPIO12
MISO
GPIO13
MOSI
RXD2
GPIO15
CS
TXD2
GPIO3
RXD0
GPIO1
TXD0
GND
3.3V
RST
FLASH
Serial Port
(D9/D10)

NodeMCU 12E


MicrocontrollersLab
ADC0
RESERVED
RESERVED
SDD3
GPIO10
SDD2
GPIO9
SDD1
MOSI
SDCMD
CS
SDD0
MISO
SDCLK
SCLK
GND
3.3V
EN
RST
GND
Vin
GPIO16
WAKE
GPIO5
SCL
GPIO4
SDA
GPIO0
FLASH
GPIO2
TXD1
3.3V
GND
GPIO14
SCLK
GPIO12
MISO
GPIO13
MOSI
RXD2
GPIO15
CS
TXD2
GPIO3
RXD0
GPIO1
TXD0
GND
3.3V
RST
FLASH
I2C Bus
(D1,D2)

Programming ESP8266

Native Expressig SDK

ESP8266 - SDK-Getting_started_guide_en.pdf

1.5. ESP8266 Toolkit

1.5.1. Compiler

Linux OS is required to compile the ESP8266 SDK. When using Windows OS, we recommend VirtualBox as the virtual machine for ESP8266. In order to simplify the compilation procedure, we have installed the compiling tools on the virtual machine. Users can directly compile the ESP8266 SDK by importing the ESP8266 compiler (OVA image) into the virtual machine. http://downloads.espressif.com/FB/ESP8266_GCC.zip

1.5.2. Firmware Download Tool

The ESP8266 DOWNLOAD TOOL is the official firmware download tool developed by Espressif. Users can download multiple binaries to the SPI Flash of the ESP8266 mother board (ESP-LAUNCHER or ESP-WROOM-02) at the same time according to the actual compilation mode and flash size.

1.5.3. Serial Port Debug Tool

The serial port debug tool can be used to directly communicate with the ESP8266 module over a standard RS-232 port. For PCs that do not have a physical serial port, a virtual com port (USB-to-serial converter) can be used.

Programming ESP8266

Native Expressig SDK

ESP8266 - SDK-Getting_started_guide_en.pdf

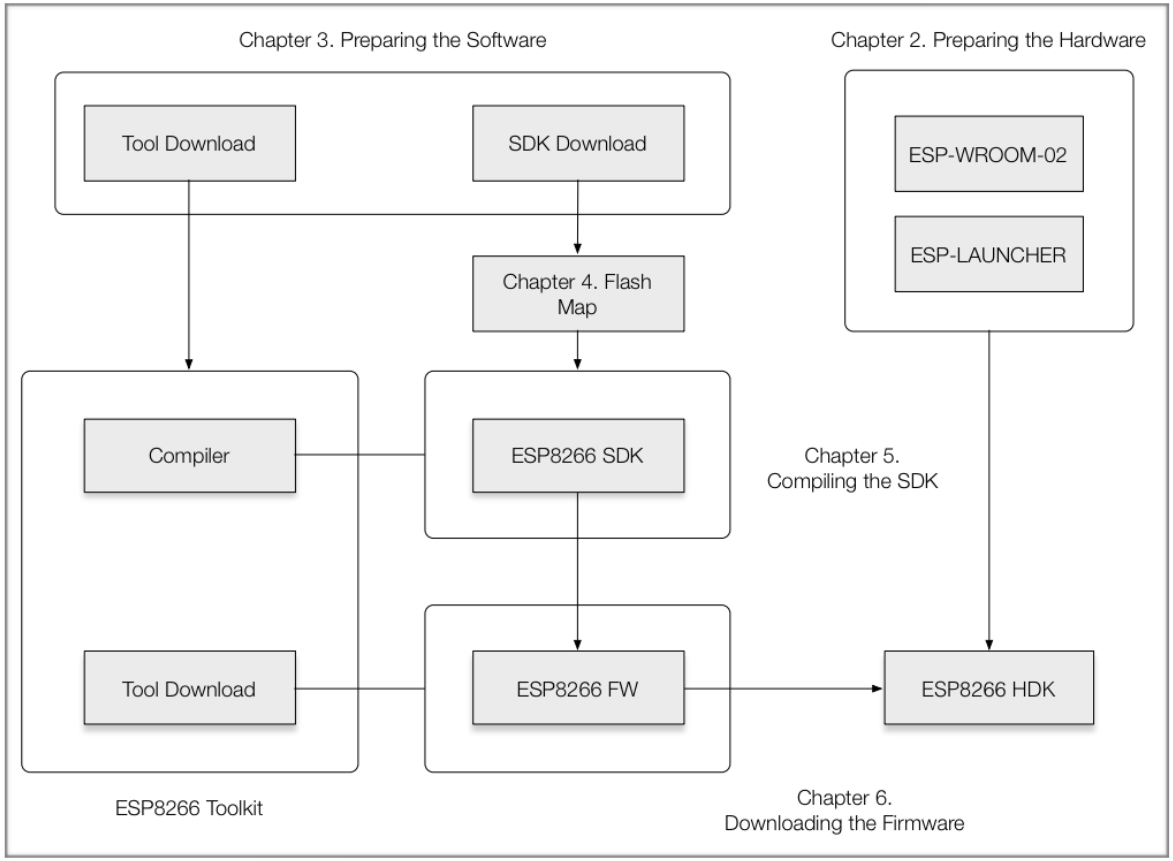
Xtensa-lx106-elf Toolchain

+

ESP8266 IoT SDK Espressif Systems

+

Standard GNU development tools



Programming ESP8266

Native Expressig SDK
https://github.com/pfalcon/esp-open-sdk

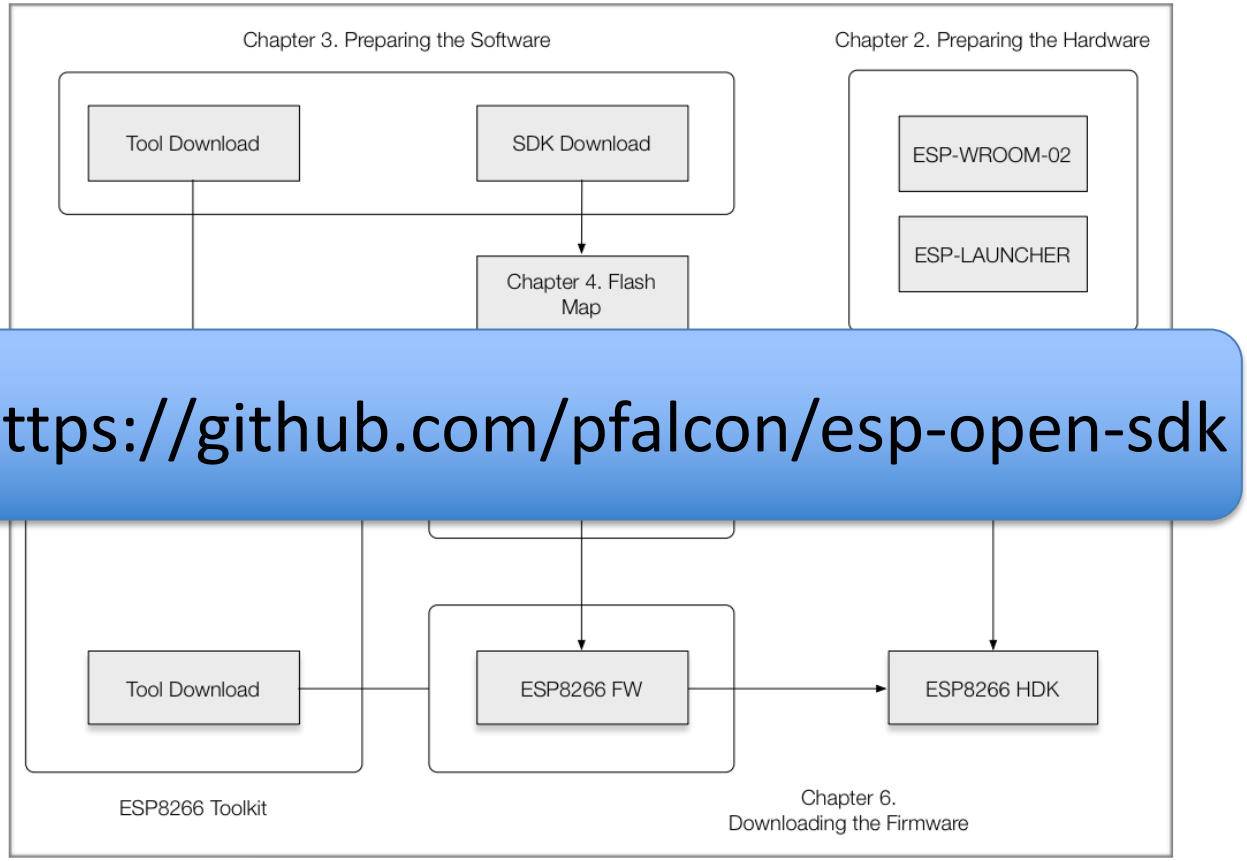
Xtensa-lx106-elf Toolchain

+

ESP8266 IoT SDK Espressif Systems

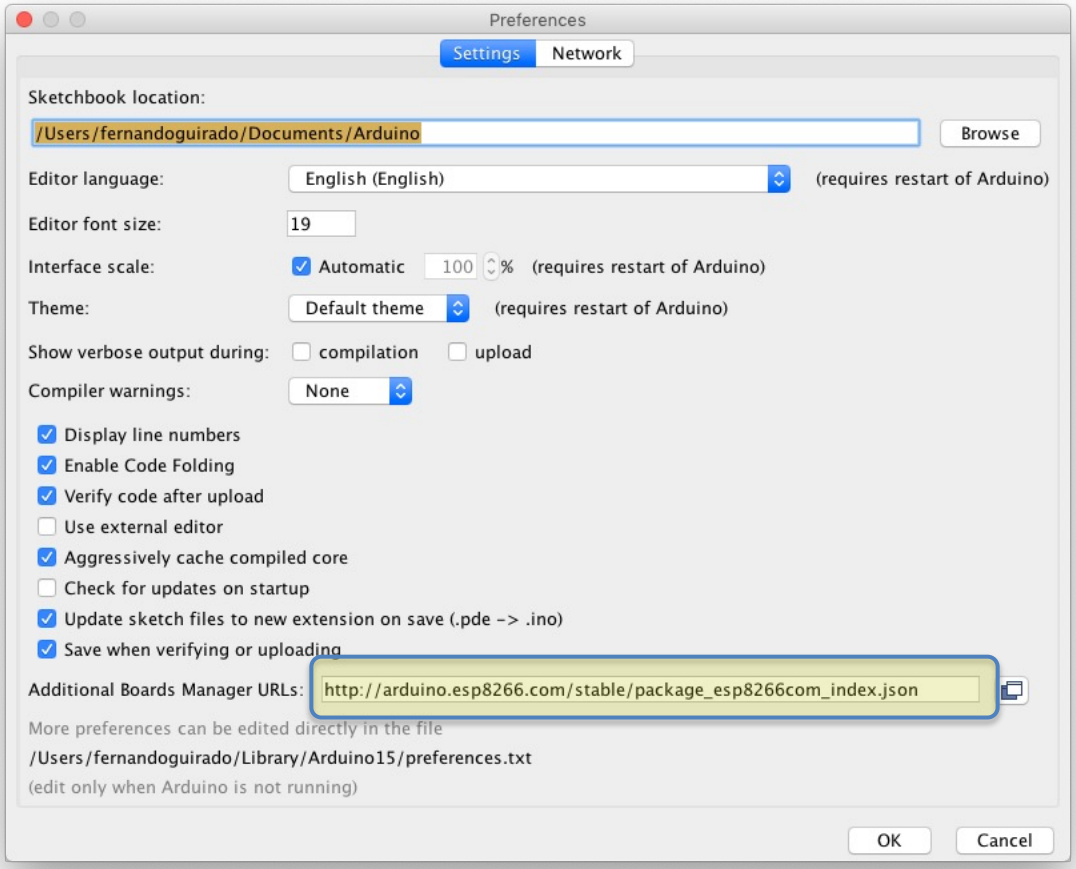
+

Standard GNU development tools



Arduino IDE – ESP8266

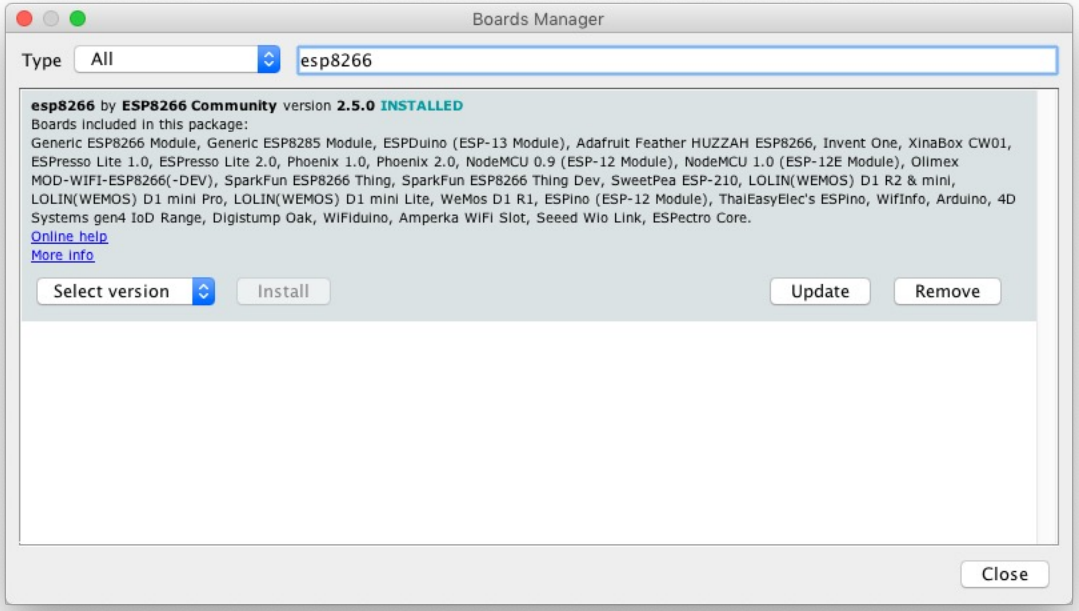
Arduino - Preferences



http://arduino.esp8266.com/stable/package_esp8266com_index.json

Arduino IDE - NodeMCU

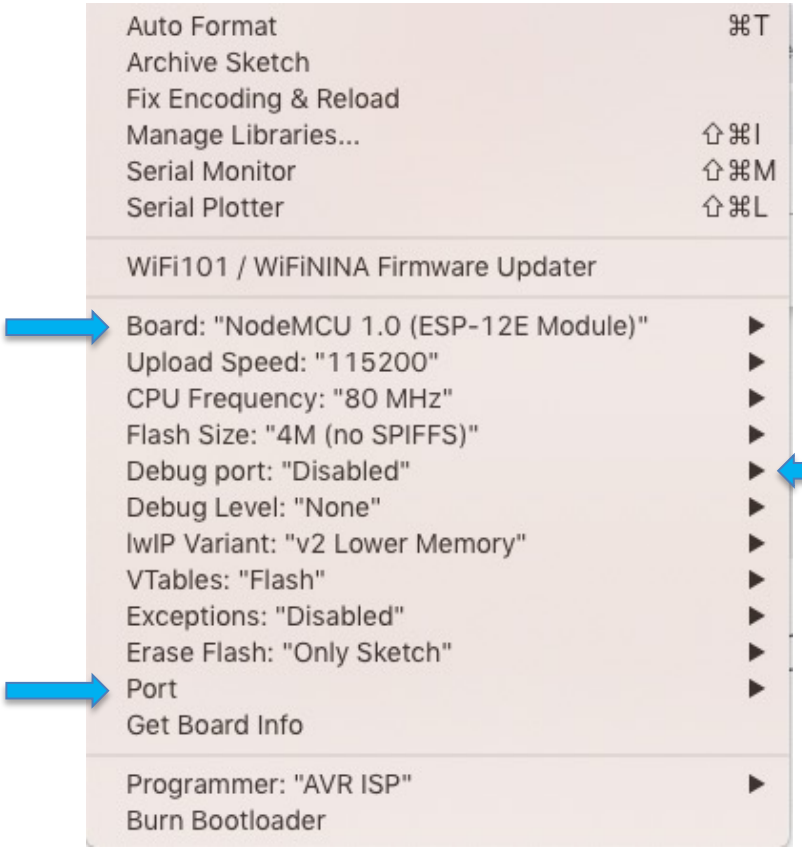
Arduino – Tools > Boards > Boards Manager



In some cases latest version has problems with older boards!

Arduino IDE - NodeMCU

Arduino – Select Board and Serial Port



Debugging feature is controllable over the IDE menu. The new menu points manage the real-time Debug messages.

The Serial port must be initialized by the user at the highest baudrate > Serial.begin(115200) and selected in the Debug Port menu

Debugging level is user selected

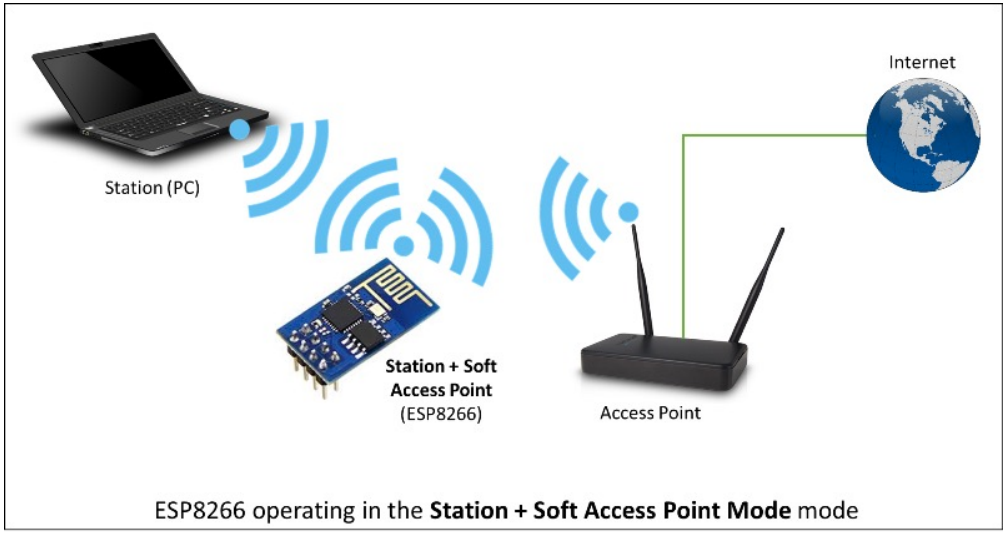
https://arduino-esp8266.readthedocs.io/en/latest/

ESP8266 - WiFi

Station Mode (WIFI_STA) → It can connect to the Wi-Fi network as any other device

Access Point (WIFI_AP) → It establishes its own Wi-Fi network, then any other device can connect to the ESP8266

Both Station and Access Point (WIFI_AP_STA) → It operates as both a station and a soft access point mode. This provides the possibility of building e.g. mesh networks.



ESP8266 operating in the **Station + Soft Access Point Mode** mode

ESP8266 – WiFi Station

WiFi.begin(ssid, password, channel, bssid, connect) / WiFi.begin(ssid, password) / WiFi.begin()

- ssid - a character string containing the SSID of Access Point we would like to connect to, may have up to 32 characters
- password to the access point, a character string that should be minimum 8 characters long and not longer than 64 characters
- channel of AP, if we like to operate using specific channel, otherwise this parameter may be omitted
- bssid - mac address of AP, this parameter is also optional
- connect - a boolean parameter that if set to false, will instruct module just to save the other parameters without actually establishing connection to the access point

WiFi.config(local_ip, gateway, subnet, [dns1], [dns2])
> Disable DHCP client and set the IP configuration of station interface to user defined arbitrary values.

- local_ip - enter here IP address you would like to assign the ESP station's interface
- gateway - should contain IP address of gateway (a router) to access external networks
- subnet - this is a mask that defines the range of IP addresses of the local network
- dns1, dns2 - optional parameters that define IP addresses of Domain Name Servers (DNS) that maintain a directory of domain names (like e.g. www.google.co.uk) and translate them for us to IP addresses

> It is possible to configure multiple Access Points using the *ESP8266WiFiMulti* library.

https://arduino-esp8266.readthedocs.io/en/latest/esp8266wifi/station-class.html

ESP8266 – WiFi Station

```
#include <ESP8266WiFi.h>

const char* ssid = "********";
const char* password = "********";

IPAddress staticIP(192,168,1,22);
IPAddress gateway(192,168,1,9);
IPAddress subnet(255,255,255,0);

void setup(void)
{
  Serial.begin(115200);
  Serial.println();

  Serial.printf("Connecting to %s\n", ssid);
  WiFi.config(staticIP, gateway, subnet);
  WiFi.begin(ssid, password);
  while (WiFi.status() != WL_CONNECTED)
  {
    delay(500);
    Serial.print(".");
  }
  Serial.println();
  Serial.print("Connected, IP address: ");
  Serial.println(WiFi.localIP());
}
```

https://arduino-esp8266.readthedocs.io/en/latest/esp8266wifi/station-class.html

ESP8266 – WiFi Access Point

WiFi.softAP(ssid) / WiFi.softAP(ssid, psk, channel, hidden, [max_connection])

- ssid - character string containing network SSID (max. 32 characters)
- psk - optional character string with a pre-shared key. For WPA2-PSK network it should be minimum 8 characters long and not longer than 64 characters. If not specified, the access point will be open for anybody to connect.
- channel - optional parameter to set Wi-Fi channel, from 1 to 13. Default channel = 1.
- hidden - optional parameter, if set to true will hide SSID.
- max_connection - optional parameter to set max simultaneous connected stations, from 0 to 8. Defaults to 4. Once the max number has been reached, any other station that wants to connect will be forced to wait until an already connected station disconnects.

*There are other overloaded methods

WiFi. softAPConfig (local_ip, gateway, subnet)

- local_ip - enter here IP address you would like to assign the ESP station's interface
- gateway - should contain IP address of gateway (a router) to access external networks
- subnet - this is a mask that defines the range of IP addresses of the local network

>Not using this method the network established by softAP will have default IP address of 192.168.4.1

https://arduino-esp8266.readthedocs.io/en/latest/esp8266wifi/soft-access-point-class.html

ESP8266 – WiFi Access Point

```
#include <ESP8266WiFi.h>
#include <Ticker.h>

Ticker tickerFunction;

void clientsConnected() {
  Serial.printf("Stations connected = %d\n", WiFi.softAPgetStationNum());
}

IPAddress local_IP(192,168,100,1);
IPAddress gateway(192,168,100,255);
IPAddress subnet(255,255,255,0);

void setup()
{
  Serial.begin(115200);
  Serial.println();

  Serial.print("Setting soft-AP configuration ... ");
  Serial.println(WiFi.softAPConfig(local_IP, gateway, subnet) ? "Ready" : "Failed!");

  Serial.print("Setting soft-AP ... ");
  Serial.println(WiFi.softAP("ESPsoftAP_01") ? "Ready" : "Failed!");

  Serial.print("Soft-AP IP address = ");
  Serial.println(WiFi.softAPIP());

  tickerFunction.attach(3, clientsConnected); // 3 seconds
}

void loop()
{
}
```

ESP8266 – WiFi Server & Client

It provides functionality to other programs or devices, called clients
Methods come directly from the Arduino library

WiFiServer server(port) → Creates a new server port

- port - the port to listen on (int)

WiFiClient client → Creates a client able to be connected to any server

https://arduino-esp8266.readthedocs.io/en/latest/esp8266wifi/server-class.html
https://arduino-esp8266.readthedocs.io/en/latest/esp8266wifi/client-class.html