MODULE 5
INTRODUCTION TO ARDUINO PROGRAMMING

Arduino:

- Arduino is an open-source prototyping platform which depend on simple to utilize equipment and programming.
- It is easy- to-use hardware and software.
- Arduino boards are able to read inputs – such as detecting power of light, events triggered by a button or a twitter message and can respond into a yield.
- Instructions to the microcontroller are given by the use of the Arduino programming dialect which depend on writing and handled through the utilization of Arduino Software.

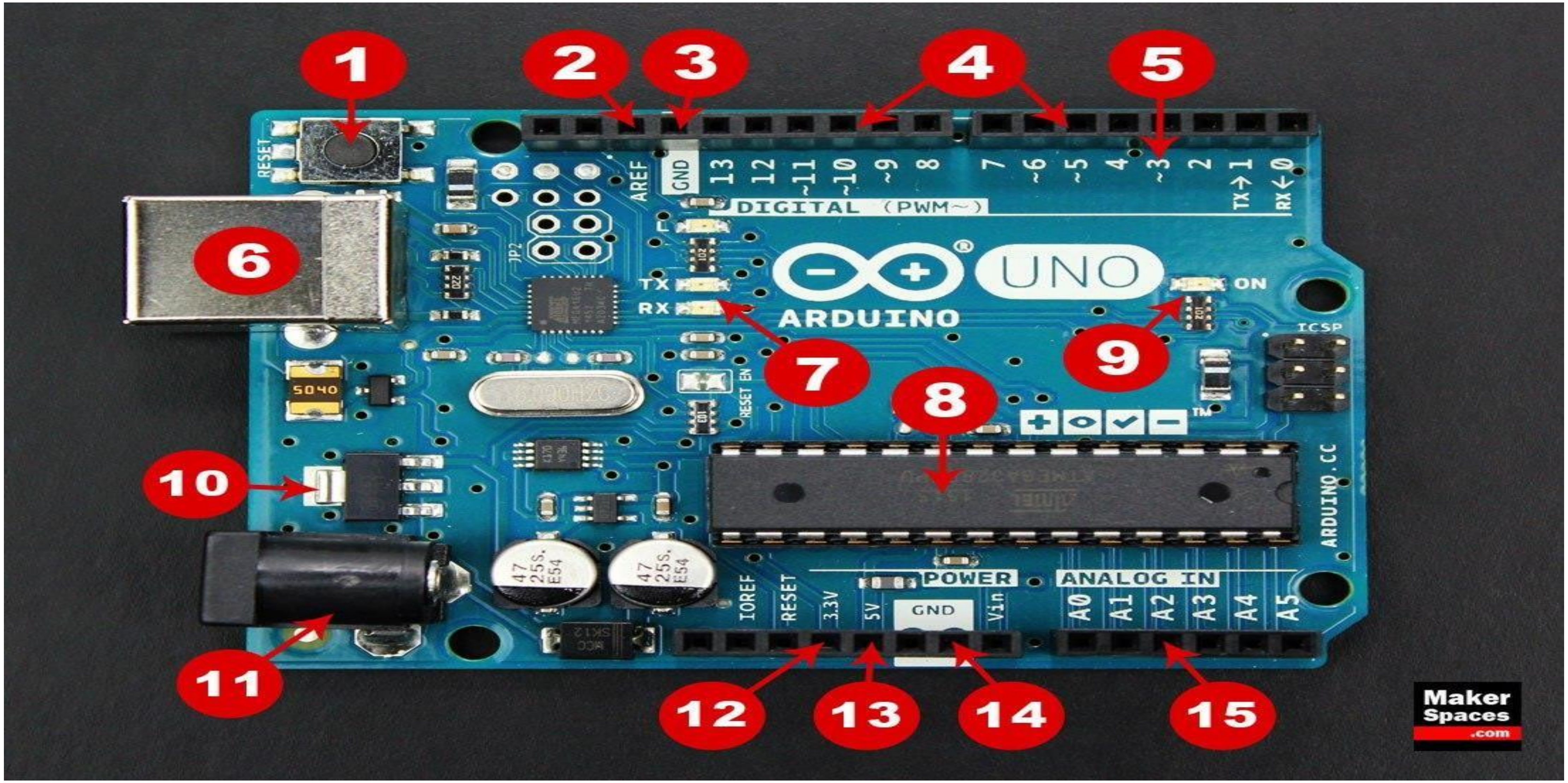
Why Arduino

- Arduino is an open source product, software/hardware which is accessible and flexible to customers.
- Flexible because of offering variety of digital and analog pins.
- It is easy to use, connected to a computer via a USB and communicates using serial protocol.
- Inexpensive with free authoring software.
- It is Cross-platform
- Arduino follows simple, clear programming.

Arduino UNO:

- Arduino Uno is a microcontroller board based on the ATmega328P.
- It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button.
- "Uno" means one in Italian and was chosen to mark the release of Arduino Software (IDE) 1.0. The Uno board and version 1.0 of Arduino Software (IDE) were the reference versions of Arduino, now evolved to newer releases.

Arduino UNO Learning Board:



Arduino UNO Learning Board: Pins

1. Reset button: when u press this button, the program that is currently being run in your Arduino will start from the beginning. There is a Reset pin next to the power pins that acts as reset button. When we apply a small voltage to that pin, it will reset the Arduino.
2. AREF : Stands for "Analog Reference" and is used to set an external reference voltage.
3. Ground Pin – There are a few ground pins on the Arduino and they all work the same.
4. Digital Input/Output – Pins 0-13 can be used for digital input or output. When set as inputs, these pins can read voltage. They can read two different states high and low. When set as outputs, these pins apply voltage. They can apply 5V(high) or 0V(low).
5. PWM – The pins marked with the (~) symbol can simulate analog output.
6. USB Connection – Used for powering up your Arduino and uploading sketches.

Arduino UNO Learning Board: Pins

7. TX and RX pins: These pins blink when there are information being sent between the computer and the Arduino. Transmit and receive data indication LEDs.
8. ATmega328p Microcontroller – This is the brains and is where the programs are stored. Everything on the Arduino board is meant to support this microcontroller.
9. Power LED Indicator – This LED lights up anytime the board is plugged in a power source.
10. Voltage Regulator – This controls the amount of voltage going into the Arduino board.
11. DC Power Barrel Jack – This is used for powering your Arduino with a power supply.
12. 3.3V Pin – This pin supplies 3.3 volts of power to your projects output
13. 5V Pin – This pin supplies 5 volts of power to your projects

15. Analog Pins – These pins can read the signal from an analog sensor and convert it to digital.

Fundamentals of Arduino Programming:

- **Two required functions / methods / routines:**

```
void setup()
{
        // runs once
}

void loop()
{
        // repeats
}
```

Concepts of Programming

- DigitalWrite( )
- AnalogWrite( )
- DigitalRead( )
- AnalogRead( )
- If( ) statements
- Delay( )

COMMENTS

- // this is for single line comments
- /* this is for multi-line comments */

Commands to know

- pinMode(pin, INPUT/OUTPUT);
- ex: pinMode(13, OUTPUT);
- digitalWrite(pin, HIGH/LOW);
- ex: digitalWrite(13, HIGH);
- delay(time_ms);
- ex: delay(2500); // delay of 2.5 sec.
- Commands are case-sensitive

Arduino code basics

Arduino programs run on two basic sections:

```
void setup()
{

        //setup motors, sensors etc

}
void loop()
{

        // get information from sensors
        // send commands to motors

}
```

SETUP

- The setup section is used for assigning input and outputs (Examples: motors, LED’s, sensors etc) to ports on the Arduino.
- It also specifies whether the device is OUTPUT or INPUT. To do this we use the command “pinMode”.

SETUP

```
void setup() {

    pinMode(9, OUTPUT);

}
```

port #

Input or Output

LOOP

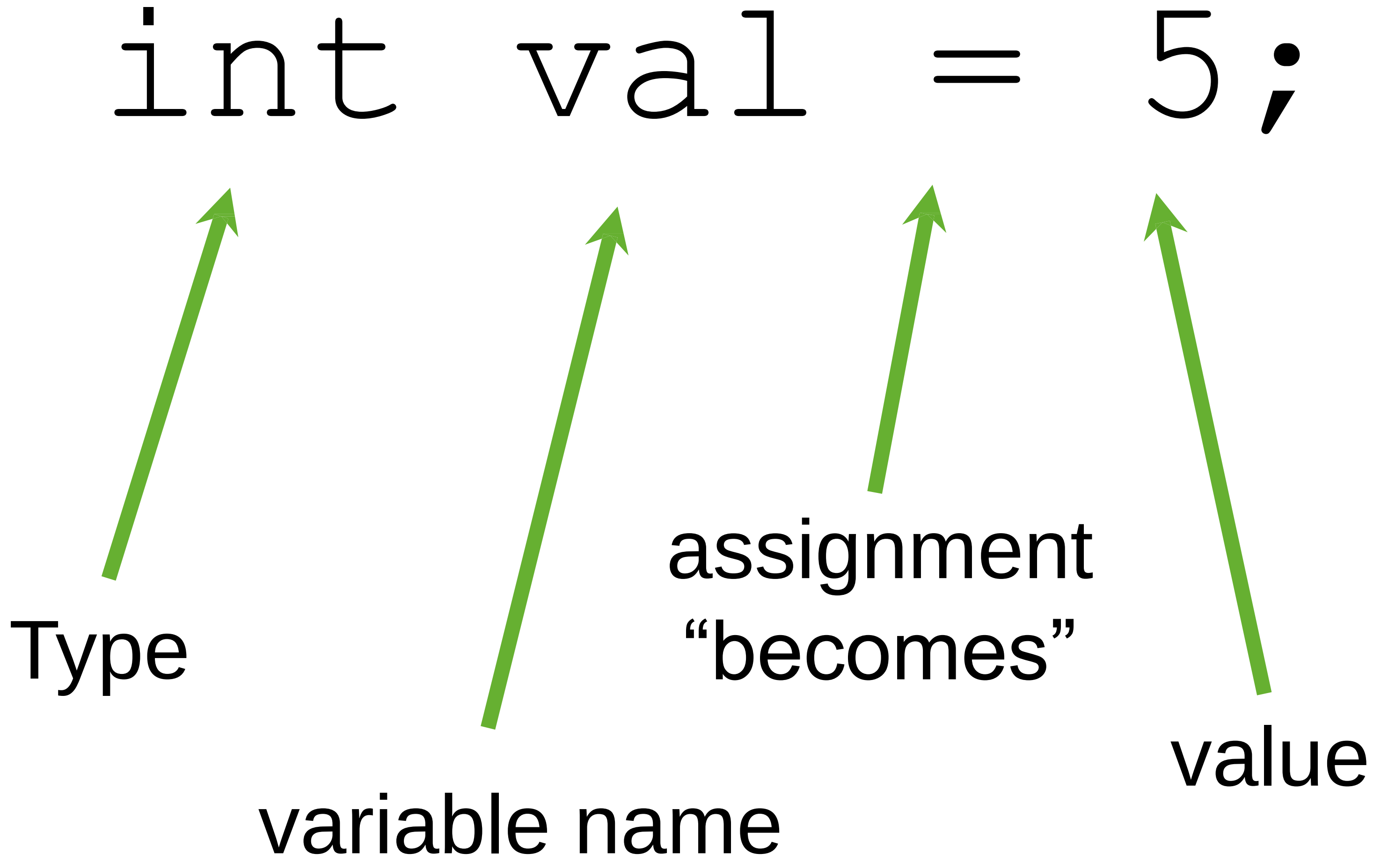
```
void loop() {

    digitalWrite(9, HIGH);
    delay(1000);
    digitalWrite(9, LOW);
    delay(1000);

}
```

Port # from setup

Turn the LED on
or off

Wait for 1 second
or 1000 milliseconds

DECLARING A VARIABLE



```
int val = 5;
```

USING VARIABLES

```
int delayTime = 2000;
int greenLED = 9;
void setup() {

     pinMode(greenLED, OUTPUT);


}

void loop() {

      digitalWrite(greenLED, HIGH);
      delay(delayTime);
    digitalWrite(greenLED, LOW)
     delay(delayTime);

}
```

Declare delayTime
Variable

Use
delayTime

Using Variables

```
int delayTime = 2000;
int greenLED = 9;

void setup() {
      pinMode(greenLED, OUTPUT);
}
void loop() {
      digitalWrite(greenLED, HIGH);
      delay(delayTime);
      digitalWrite(greenLED, LOW);
 delayTime = delayTime - 100;
}
      delay(delayTime);
```

delayTime to gradually increase LED's blinking
subtract 100 from speed

Conditions

- To make decisions in Arduino code we use an ‘if’ statement
- ‘If’ statements are based on a TRUE or FALSE question

VALUE COMPARISONS

GREATER THAN

a > b

GREATER THAN OR EQUAL

a >= b

LESS

a < b

LESS THAN OR EQUAL

a <= b

EQUAL

a == b

NOT EQUAL

a != b

IF Condition

```
if(true)
{
        "perform some action"
}
```

IF Example

```
int counter = 0;

void setup() {
    Serial.begin(9600);
}
void loop() {

    if(counter < 10)
    {
        Serial.println(counter);
    }
    counter = counter + 1;

}
```

Input & Output

- Transferring data from the computer to an Arduino is done using Serial Transmission
- To setup Serial communication we use the following

```
void setup() {

        Serial.begin(9600);

}
```

Writing to the Console

```
void setup() {
        Serial.begin(9600);
        Serial.println(“Hello World!”);
}

void loop() {}
```

IF-ELSE Condition

```
if( “answer        is true”)
{
        “perform some action”
}
else
{
        “perform some other action”
}
```

IF-ELSE Example

```
int counter = 0;
void setup() {
        Serial.begin(9600);
}
void loop() {
if(counter < 10)
        {
                Serial.println(“less than 10”);
        }
        else
        {
                Serial.println(“greater than or equal to 10”);
                Serial.end();
        }
        counter = counter + 1;
        }
```

IF-ELSE IF Condition

```
if( “answer is true”)
{
        “perform some action”
}
else if( “answer is true”)
{
        “perform some other action”
}
Else
{
}
```

IF-ELSE IF Example

```
int counter = 0;
void setup() {
        Serial.begin(9600);
}
void loop() {

        if(counter < 10)
        {
                Serial.println(“less than 10”);
        }
        else if (counter == 10)
        {
                Serial.println(“equal to 10”);
        }
        else
        {
                Serial.println(“greater than 10”);
                Serial.end();
        }
        counter = counter + 1;
}
```

BOOLEAN operators AND

- If we want all of the conditions to be true we need to use ‘AND’ logic (AND gate)
- We use the symbols &&
- Example: if (val > 10 && val < 20)

BOOLEAN operators OR

- If we want either of the conditions to be true we need to use ‘OR’ logic (OR gate)
- We use the symbols ||
- Example: `if ( val < 10 || val > 20)`

Important functions

- Serial.println(value);
  - Prints the value to the Serial Monitor on your computer
- pinMode(pin, mode);
  - Configures a digital pin to read (input) or write (output) a digital value
- digitalRead(pin);
  - Reads a digital value (HIGH or LOW) on a pin set for input
- digitalWrite(pin, value);
  - Writes the digital value (HIGH or LOW) to a pin set for output

OUTLINE

- Essential Programming Concepts
  - Delay
  - Infinite Loop
- General Input/Output
  - Polling or Busy/Wait I/O
  - Interrupt Processing
- Timers and Internal Interrupts
- High-Level Language Extensions
- Code Transformations for Embedded Computing
  - Loop Unrolling
  - Loop Merging
  - Loop Peeling
  - Loop Tiling

DELAY

- Delays are essential in embedded systems, unlike high-performance systems where we want the program to execute as fast as possible
- Delays are used to synchronize events, or read inputs with a specific sampling frequency (more on Bus/Wait I/O)

Infinite Loop

- Embedded Systems are mostly single-functioned
- Their core application never terminates
- Infinite loops are not forbidden as long as they are done correctly.

Infinite Loop

```
void main()
{
  light enum {RED, ORANGE, GREEN};
  loop: light = RED;    //no exit from
     loop!  delay(20000); //20-sec red
     light = ORANGE;
     delay(2000);   //2-sed orange
     light = GREEN;
     delay(20000); //20-sec green
     goto loop;     //just repeat sequence
}
```

Introduction to Raspberry Pi

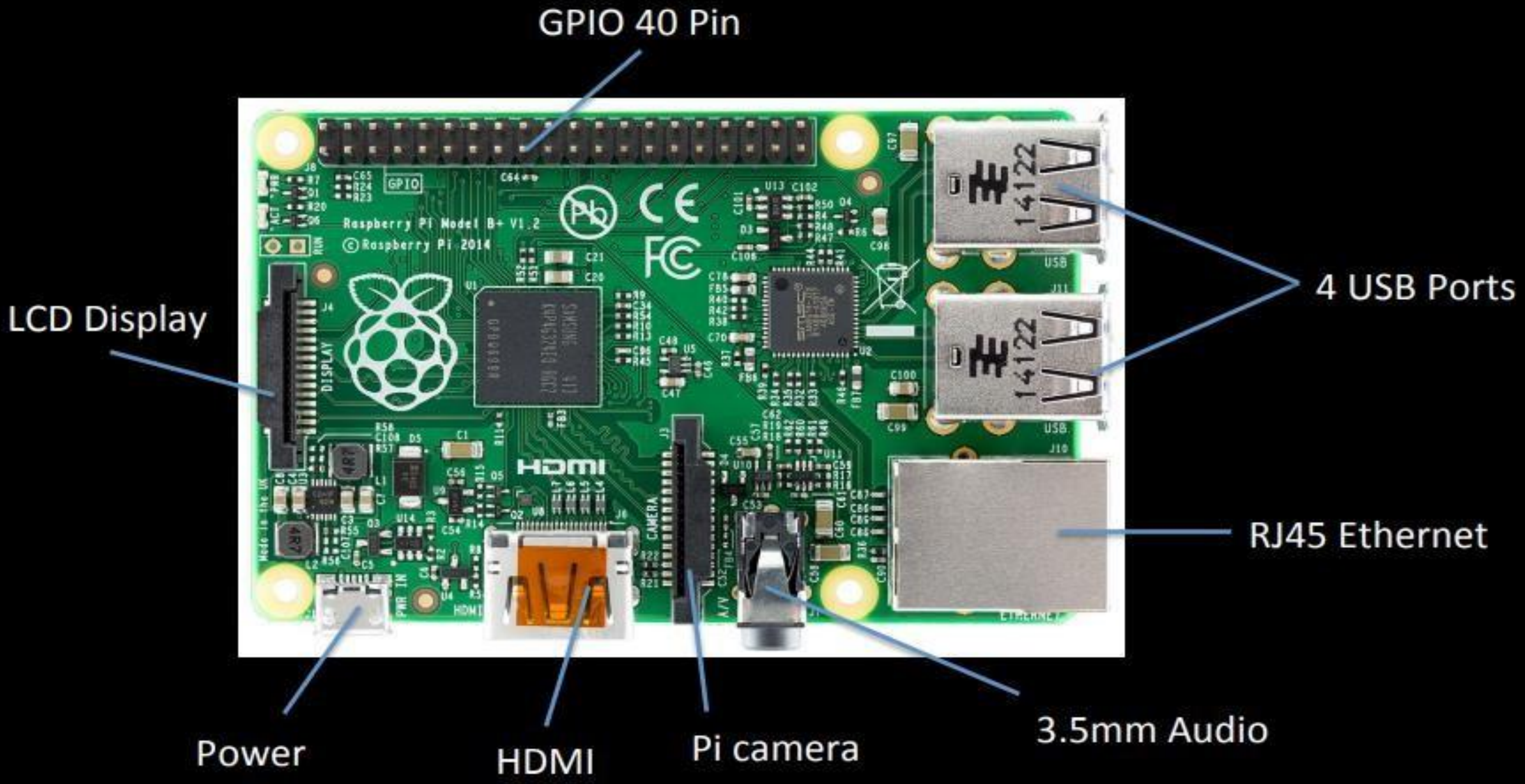
Raspberry Pi

- Raspberry Pi is the name of a series of single-board computers made by the Raspberry Pi Foundation, a UK charity that aims to educate people in computing and create easier access to computing education.

- The Raspberry Pi launched in 2012, and there have been several iterations and variations released since then. The original Pi had a single-core 700MHz CPU and just 256MB RAM, and the latest model has a quad-core 1.4GHz CPU with 1GB RAM. The main price point for Raspberry Pi has always been $35 and all models have been $35 or less, including the Pi Zero, which costs just $5.

WHAT IS A RASPBERRY PI?

A low cost, **credit-card sized computer**



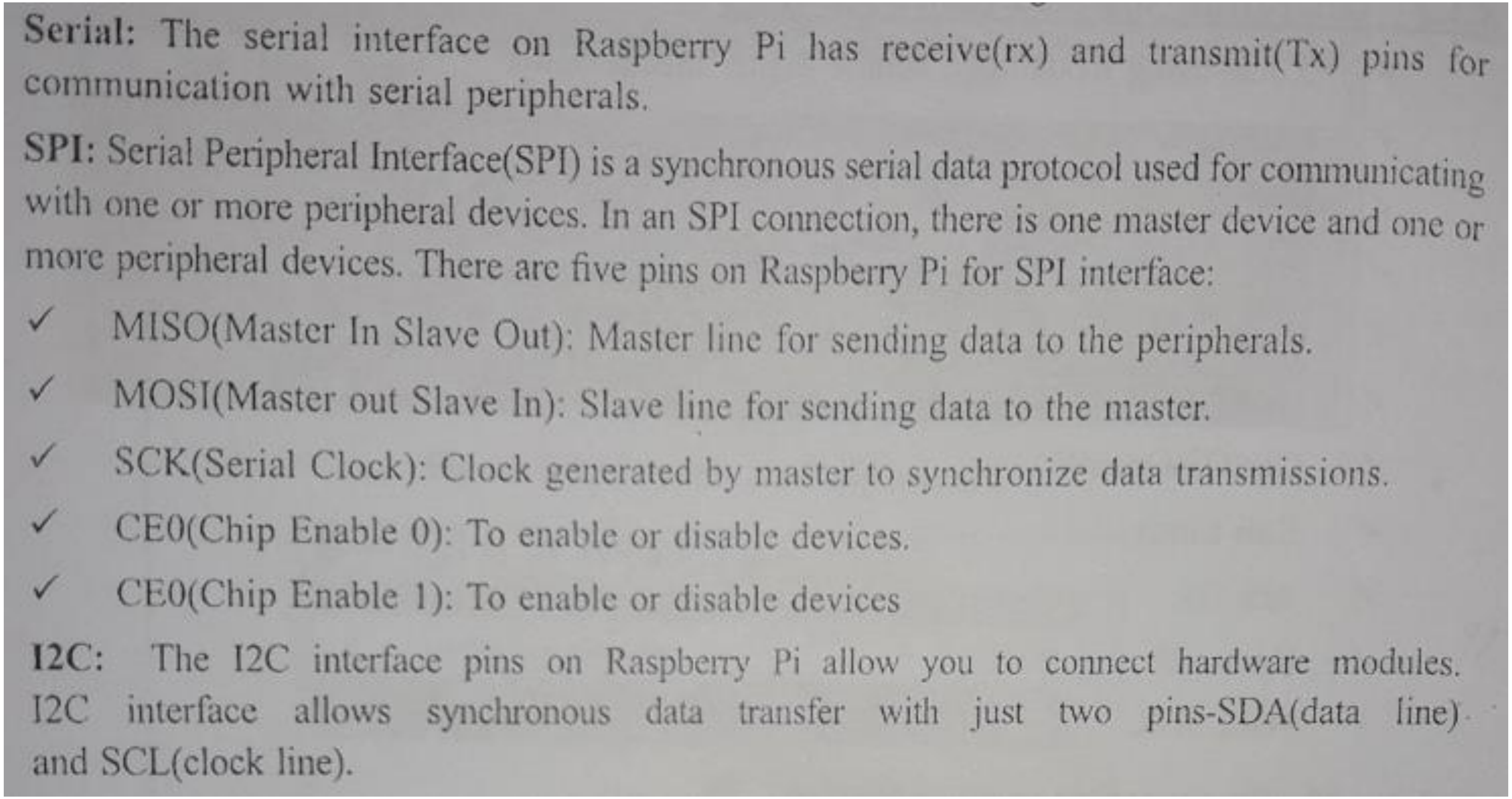
Raspberry Pi

- Processor: The Broadcom BCM2835 SOC is used in first generation. It included 700MHz ARM processor, Graphical Processing Unit and RAM. L1 cache is 16KB and L2 cache is 128KB. The Raspberry Pi 2 uses a Broadcom BCM2836 SoC with 900 MHz 32-bit quad-core ARM cotex A7 processor, which 256 KB shared L2 cache. The Raspberry Pi 3 uses a Broadcom BCM2837 SoC with a 1.2 GHz 64-bit quad core ARM Cortex A53 processor , with a 512KB shared L2 cache.
- Power source: Raspberry Pi is powered by using USB port on the side of the unit. Input voltage is 5V and input current is 2A.
- SD Card: The working framework is stacked on a SD card which is embedded on the SD card space on the Raspberry Pi.
- HDMI: High Definition Multimedia Interface to give both video and sound yield.

Raspberry Pi

- GPIO: General purpose input and output is a non specific pins on a coordinated circuit to know which is an input or output pin which can be controlled by the client at the run time. Capabilities of GPIO are:
  - GPIO pins can be designed to be input or output
  - GPIO pins can be empowered/crippled
  - Input values can be high or low
  - Yield values are writable/meaningful
- Display: The Raspberry Pi connector S2 is a DSI (Display Serial Interface) for connecting a LCD panel using a 15-pin ribbon cable.
- Audio Jack: A standard 3.5mm TRS connector is accessible on the RPi for stereo sound yield.
- Ethernet port: It is accessible on Model B and B+. It can be associated with a system or web utilizing a standard LAN link on the Ethernet port. This ports are controlled by Microchip LAN9512 LAN controller chip.

Raspberry Pi Interface



Serial: The serial interface on Raspberry Pi has receive(rx) and transmit(Tx) pins for communication with serial peripherals.

SPI: Serial Peripheral Interface(SPI) is a synchronous serial data protocol used for communicating with one or more peripheral devices. In an SPI connection, there is one master device and one or more peripheral devices. There are five pins on Raspberry Pi for SPI interface:

- ✓ MISO(Master In Slave Out): Master line for sending data to the peripherals.
- ✓ MOSI(Master out Slave In): Slave line for sending data to the master.
- ✓ SCK(Serial Clock): Clock generated by master to synchronize data transmissions.
- ✓ CE0(Chip Enable 0): To enable or disable devices.
- ✓ CE0(Chip Enable 1): To enable or disable devices

I2C: The I2C interface pins on Raspberry Pi allow you to connect hardware modules. I2C interface allows synchronous data transfer with just two pins-SDA(data line) and SCL(clock line).

BASIC PI COMMAND LINE - 1

Useful commands to run from a terminal or command line.

rasp-config
Change your pi configuration settings.

startx
Start the GUI (Graphical User Interface)

ifconfig
Get the details of your Ethernet or wireless network adapter.

rpi-update
Updates your Raspberry Pi firmware.

ssh
Connect your pi to other computers.

sudo
Run commands as super user.

shutdown
This will shutdown your pi.

nano
This is your text editor for changing or adding files. Save, edit, create.

BASIC PI COMMAND LINE - 2

Useful commands to run from a terminal or command line

ls
List out the current directory files.

cd
Go to directory or folder.

find
Searches whole system for files or directories.

clear
Clears the terminal screen.

mv
Move files or folders.

touch
Create a blank file.

mkdir
Create a directory.

ping
Test connectivity between two devices.

df -h
Shows disk space.

iwconfig
Wireless configuration tool.

Hardware Layout of Raspberry Pi

raspi-config

- **The Raspberry Pi configuration tool in Raspbian, allowing you to easily enable features such as the camera, and to change your specific settings such as keyboard layout.**

config.txt

- **The Raspberry Pi configuration file.**

Wireless networking

- **Configuring your Pi to connect to a wireless network using the Raspberry Pi 3's or Pi Zero W's inbuilt wireless connectivity, or a USB wireless dongle.**

Wireless access point

- **Configuring your Pi as a wireless access point using the Raspberry Pi 3 and Pi Zero W's inbuilt wireless connectivity, or a USB wireless dongle.**

Hardware Layout of Raspberry Pi

Using a proxy

- Setting up your Pi to access the internet via a proxy server

HDMI Config

- Guide to setting up your HDMI device, including custom settings

Audio config

- Switch your audio output between HDMI and the 3.5mm jack

Camera config

- Installing and setting up the Raspberry Pi camera board

External storage config

- Mounting and setting up external storage on a Raspberry Pi

Hardware Layout of Raspberry Pi

Localisation

- Setting up your Pi to work in your local language/time zone Default pin configuration
- Changing the default pin states. Device Trees config
- Device Trees, overlays, and parameters Kernel command line
- How to set options in the kernel command line UART configuration
    - How to set up the on-board UARTS.

Firmware warning icons

- Description of warning icons displayed if the firmware detects issues

Hardware Layout of Raspberry Pi

[LED warning flash codes]

- Description of the meaning of LED warning flashes that are shown if a Pi fails to boot or has to shut down

[Securing your Raspberry Pi]

- Some basic advice for making your Raspberry Pi more secure

[Screensaver]

- How to configure screen blanking/screen saver

[The boot folder]

- What it's for and what's in it

Programming RaspberryPi with Python:

- The Raspberry Pi is an amazing single board computer (SBC) capable of running Linux and a whole host of applications. Python is a beginner-friendly programming language that is used in schools, web development, scientific research, and in many other industries.

Operating System on Raspberry Pi

- OS (not Linux based)
  - RISC OS Pi
  - FreeBSD
  - NetBSD
  - PLAN 9 from Bell Labs and Inferno
  - Windows 10 IOT core
  - Xv6(unix os)

Operating System on Raspberry Pi

- OS (linux based)
    - Xbian
    - Raspberry Pi fedora remix
    - Pidora
    - Diet Pi
    - Kano OS
- Media center OS
    - OSMC
    - OpenElec
    - Xbian
    - Rasplex
- Audio OS
- Recalbox

Operating System on Raspberry Pi

- Audio OS
    - Volumnio
    - Pimusicbox
    - Runeaudio
    - moOdeaudio
- Recalbox
    - Happy Game Center
    - Lakka
    - ChameleonPi
    - Piplay

Wireless Temperature Monitoring System Using Pi:

- Raspberry Pi which having inbuilt wi-fi, which makes Raspberry Pi to suitable for IoT applications, so that by using IoT technology this monitoring system works by uploading the temperature value to the Thingspeak cloud by this project you can able to learn to how to handle cloud-based application using API keys.
- In this monitoring system, we used Thingspeak cloud, the cloud which is suitable to view the sensor logs in the form of graph plots.
- Here we created one field to monitor the temperature value, that can be reconfigurable to monitor a number of sensor values in various fields. This basic will teach you to how to work with a cloud by using LM35 as a temperature sensor, to detect the temperature and to upload those values into the cloud.

Wireless Temperature Monitoring System Using Pi:

▣HARDWARE REQUIRED

- Raspberry Pi
- SD card
- Power supply
- VGA to HDMI converter (Optional)
- MCP3008 (ADC IC)
- A temperature sensor(LM35)

▣SOFTWARE REQUIRED

- Raspbian Stretch OS
- SD card Formatter
- Win32DiskImager (or) Etcher

PYTHON LIBRARIES USED

- **RPi.GPIO as GPIO (To access the GPIO Pins of Raspberry Pi)**
- **Time library (For Time delay)**
- **Urllib2 to handle URL using Python programming**

DS18B20 Temperature Sensor

- The DS18B20 is a 1-wire programmable Temperature sensor from maxim integrated. It is widely used to measure temperature in hard environments like in chemical solutions, mines or soil etc.
- The construction of the sensor is rugged and also can be purchased with a waterproof option making the mounting process easy. It can measure a wide range of temperature from -55°C to +125° with a decent accuracy of ±5°C.
- Each sensor has a unique address and requires only one pin of the MCU to transfer data so it a very good choice for measuring temperature at multiple points without compromising much of your digital pins on the microcontroller.

DS18B20 Temperature Sensor

Applications:

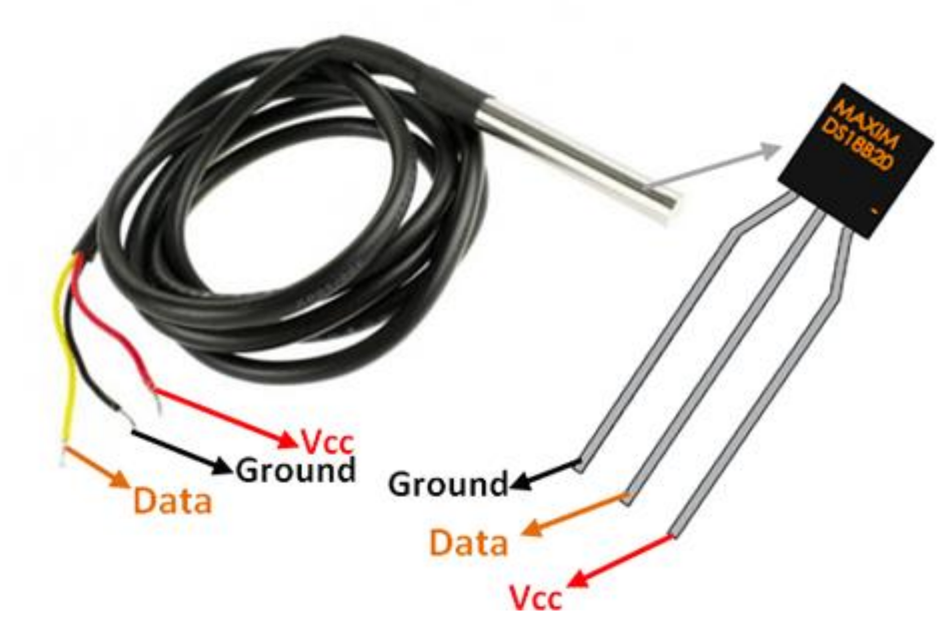
- **Measuring temperature at hard environments**
- **Liquid temperature measurement**
- **Applications where temperature has to be measured at multiple points**

Pin Configuration:

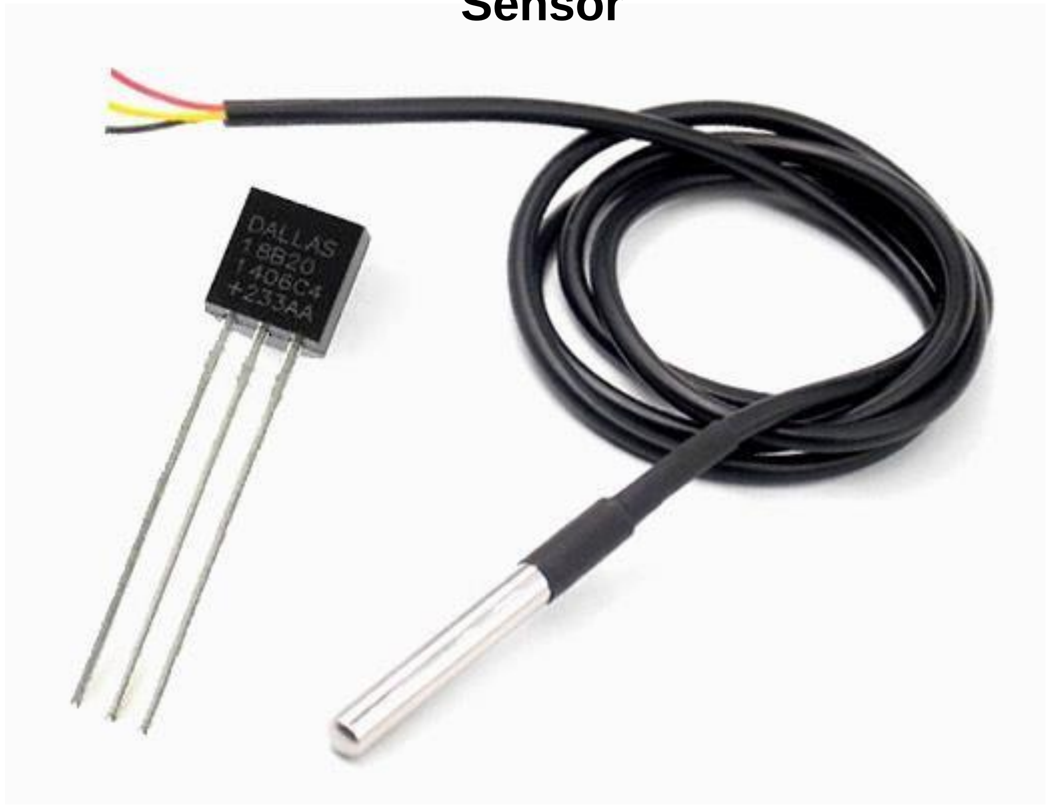
No	Pin Name	Description
1	**Ground**	**Connect to the ground of the circuit**
2	**Vcc**	**Powers the Sensor, can be 3.3V or 5V**
3	**Data**	**This pin gives output the temperature value which can be read using 1-wire method**

DS18B20 Temperature Sensor

DS18B20 Temperature Sensor Pinout



DS18B20 Temperature Sensor



Connecting Raspberry Pi via SSH:

You can access the command line of a Raspberry Pi remotely from another computer or device on the same network using SSH. The Raspberry Pi will act as a remote device: you can connect to it using a client on another machine.

1. **Set up your local network and wireless connectivity**
2. **Enable SSH**
3. **Enable SSH on a headless Raspberry Pi (add file to SD card on another machine)**
4. **Set up your client**

Accessing Temperature from DS18B20 sensors:

- The DS18B20 is a digital thermometer that allows to get 9-bit to 12-bit Celsius temperature measurements (programmable resolution). The temperature conversion time depends on the resolution used. For a 9-bit resolution it takes at most 93.75 ms and for a 12-bit resolution it takes at most 750 ms. The device is able to measure temperatures from -55°C to +125°C and has a ±0.5°C accuracy in the range from -10°C to +85°C.

- Additionally, it has an alarm functionality with programmable upper and lower temperature trigger points. These thresholds are stored internally in non-volatile memory, which means they are kept even if the device is powered off.

- The sensor communicates using the OneWire protocol, which means it only requires a pin from a microcontroller to be connected to it. Furthermore, each sensor has a unique 64-bit serial code, allowing multiple DS18B20 devices to function on the same OneWire bus. In terms of power supply, the device can operate with a voltage between 3.0 V and 5.5 V, which means it can operate with the same voltage of the ESP32 without the need for level conversion.

Remote access to RaspberryPi:

- To access a Raspberry Pi (or any home computer for that matter) from outside your home network, you'd usually need to jump through a lot of hoops, get an IP address, and tweak a few settings on your home router. If you just need to control a few simple things on your Raspberry Pi, that's overkill. We're going to outline two methods that skip all of that.

- The first thing you need to do is get your Raspberry Pi set up and connected to your home network. Since you're exposing your Raspberry Pi to the internet, be sure you change your default password during the set up process. Once that's done, come back here to set up everything else.

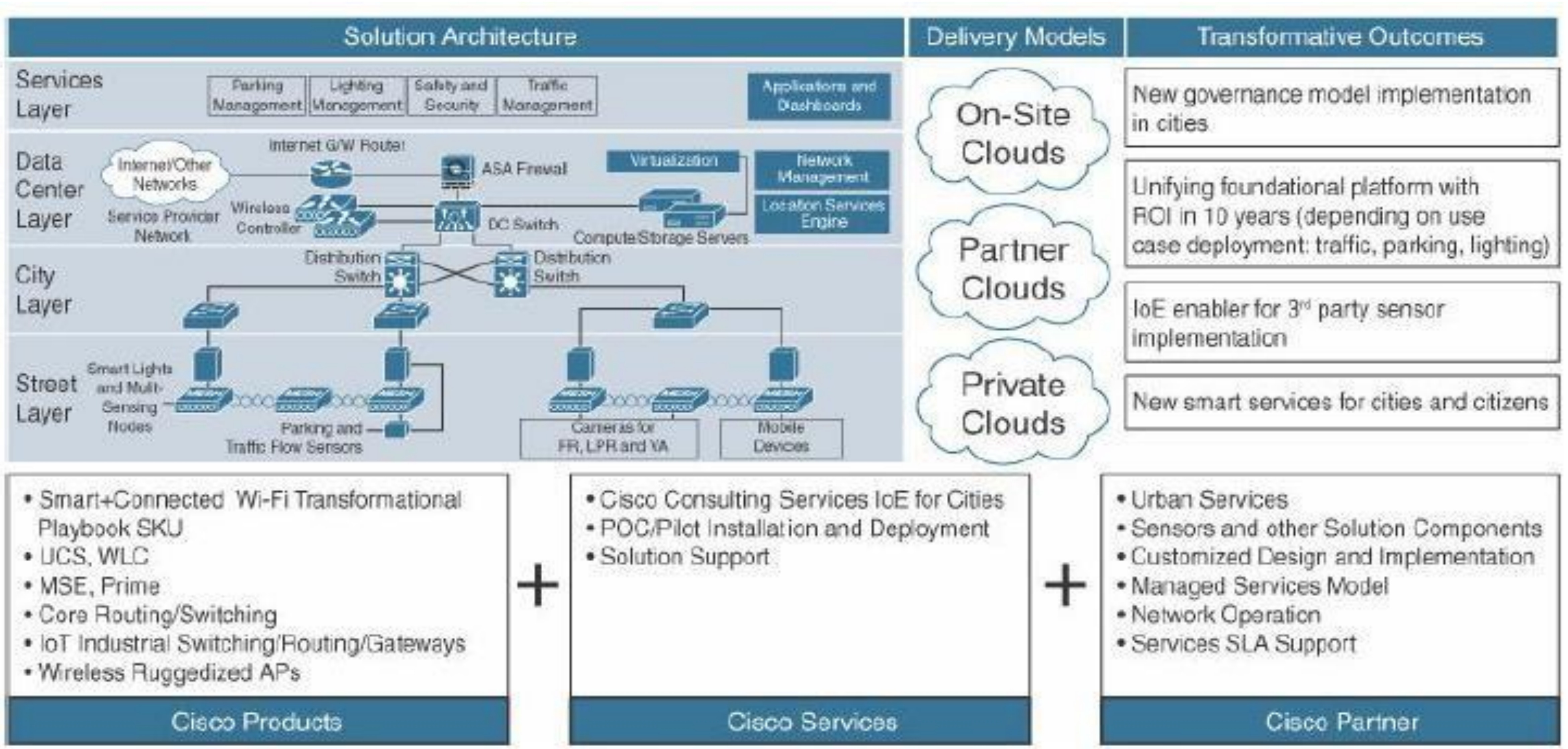
Remote Log Into Your Raspberry Pi's Full Operating System Using VNC Connect:

- VNC has long been the best way to access any computer remotely on the same network. Recently, VNC Connect came out to make it easy to access your Raspberry Pi from anywhere using a cloud connection. Once it's set up, you can access your Raspberry Pi's graphic interface from any other computer or smartphone using the VNC Viewer app.

Smart City IoT Architecture:

- A smart city IoT infrastructure is a four-layered architecture, as shown in Figure Data flows from devices at the street layer to the city network layer and connect to the data center layer, where the data is aggregated, normalized, and virtualized.
- The data center layer provides information to the services layer, which consists of the applications that provide services to the city.
- In smart cities, multiple services may use IoT solutions for many different purposes. These services may use different IoT solutions, with different protocols and different application languages.

Smart City IoT Architecture:



New governance model implementation in cities

Unifying foundational platform with ROI in 10 years (depending on use case deployment: traffic, parking, lighting)

IoE enabler for 3rd party sensor implementation

New smart services for cities and citizens

Cisco Products

- Smart+Connected Wi-Fi Transformational Playbook SKU
- UCS, WLC
- MSE, Prime
- Core Routing/Switching
- IoT Industrial Switching/Routing/Gateways
- Wireless Ruggedized APs

Cisco Services

- Cisco Consulting Services IoE for Cities
- POC/Pilot Installation and Deployment
- Solution Support

Cisco Partner

- Urban Services
- Sensors and other Solution Components
- Customized Design and Implementation
- Managed Services Model
- Network Operation
- Services SLA Support

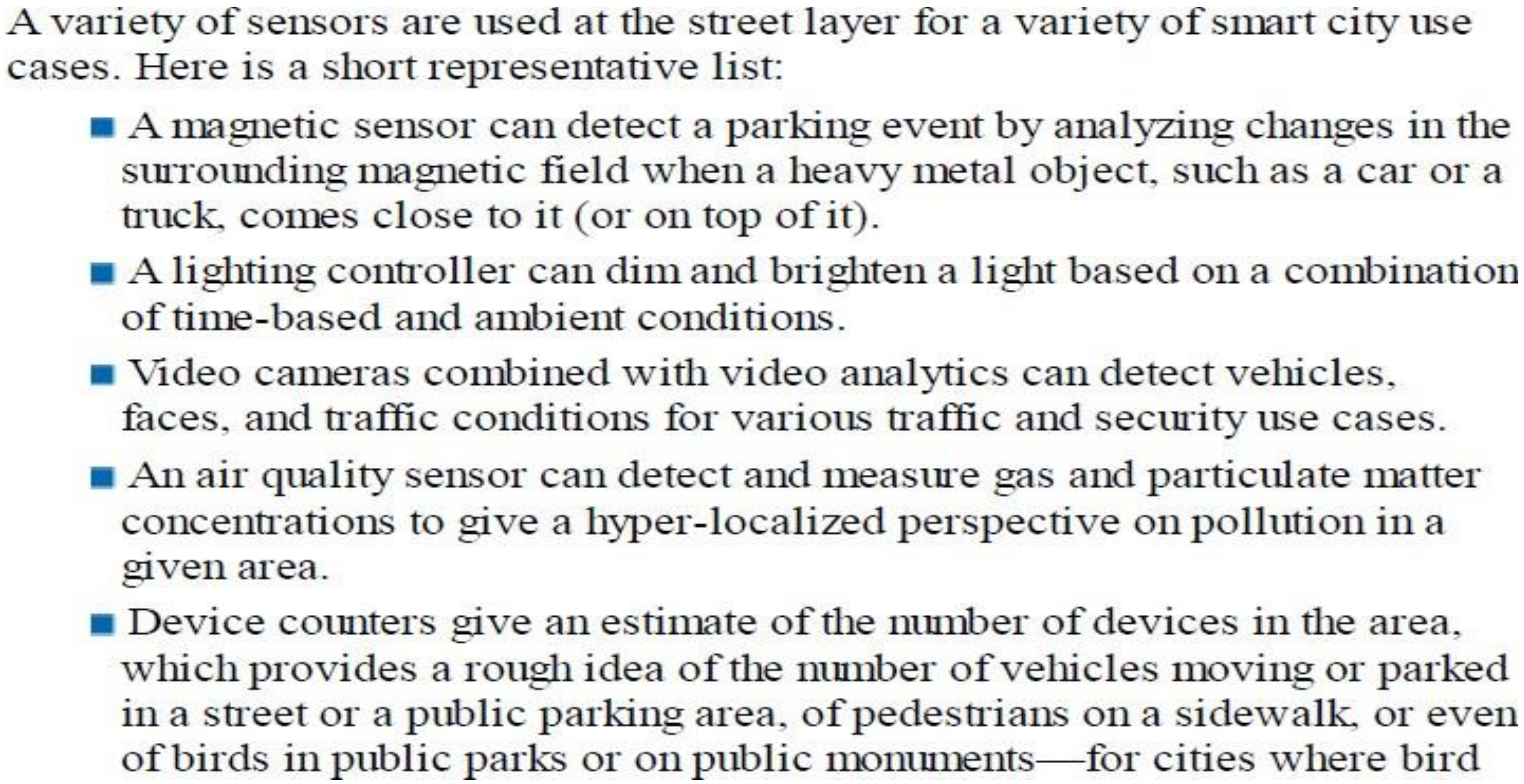
Smart Cities Layered Architecture

Smart City IoT Architecture:

Street Layer:

- The street layer is composed of devices and sensors that collect data and take action based on instructions from the overall solution, as well as the networking components needed to aggregate and collect data.
- A sensor is a data source that generates data required to understand the physical world. Sensor devices are able to detect and measure events in the physical world.
- ICT connectivity solutions rely on sensors to collect the data from the world around them so that it can be analyzed and used to operationalize use cases for cities.

Smart City IoT Architecture



A variety of sensors are used at the street layer for a variety of smart city use cases. Here is a short representative list:

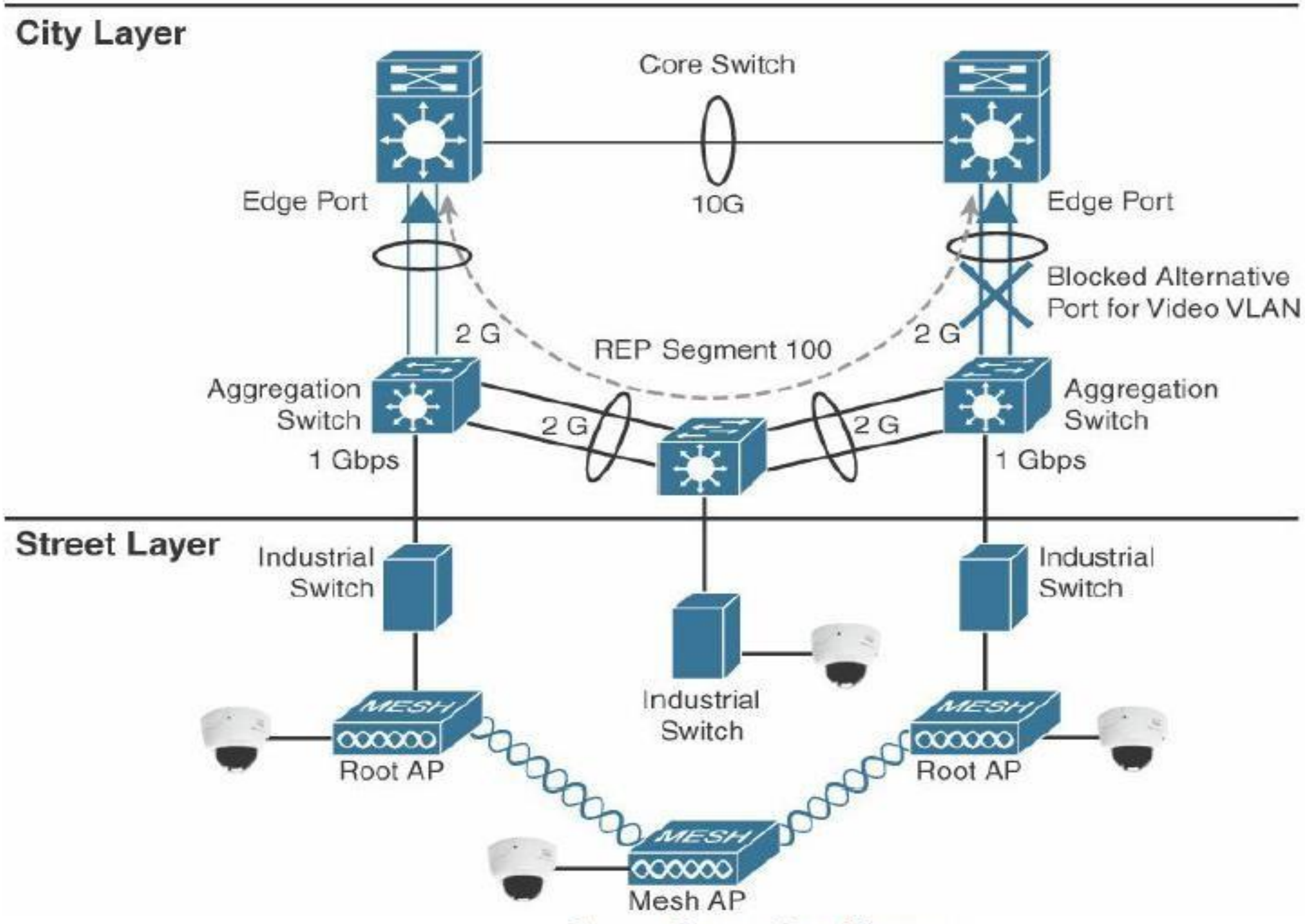
- A magnetic sensor can detect a parking event by analyzing changes in the surrounding magnetic field when a heavy metal object, such as a car or a truck, comes close to it (or on top of it).
- A lighting controller can dim and brighten a light based on a combination of time-based and ambient conditions.
- Video cameras combined with video analytics can detect vehicles, faces, and traffic conditions for various traffic and security use cases.
- An air quality sensor can detect and measure gas and particulate matter concentrations to give a hyper-localized perspective on pollution in a given area.
- Device counters give an estimate of the number of devices in the area, which provides a rough idea of the number of vehicles moving or parked in a street or a public parking area, of pedestrians on a sidewalk, or even of birds in public parks or on public monuments—for cities where bird

Smart City IoT Architecture

City Layer:

- At the city layer, which is above the street layer, network routers and switches must be deployed to match the size of city data that needs to be transported.
- This layer aggregates all data collected by sensors and the end-node network into a single transport network.
- The city layer may appear to be a simple transport layer between the edge devices and the data center or the Internet.
- However, one key consideration of the city layer is that it needs to transport multiple types of protocols, for multiple types of IoT applications. Some applications are delay- and jitter sensitive, and some other applications require a deterministic approach to frame delivery.
- A missed packet may generate an alarm or result in an invalid status report. As a result, the city layer must be built around resiliency, to ensure that a packet coming from a sensor or a gateway will always be forwarded successfully to the headend station.

Smart City IoT Architecture:



Street Layer Resiliency

Smart City IoT Architecture:

City Layer:

- In this model, at least two paths exist from any aggregation switch to the data center layer. A common protocol used to ensure this resiliency is Resilient Ethernet Protocol (REP).

Smart City IoT Architecture:

Data Center Layer:

- Ultimately, data collected from the sensors is sent to a data center, where it can be processed and correlated.
- Based on this processing of data, meaningful information and trends can be derived, and information can be provided back.
- For example, an application in a data center can provide a global view of the city traffic and help authorities decide on the need for more or less common transport vehicles. At the same time, an automated response can be generated.

Smart City IoT Architecture:

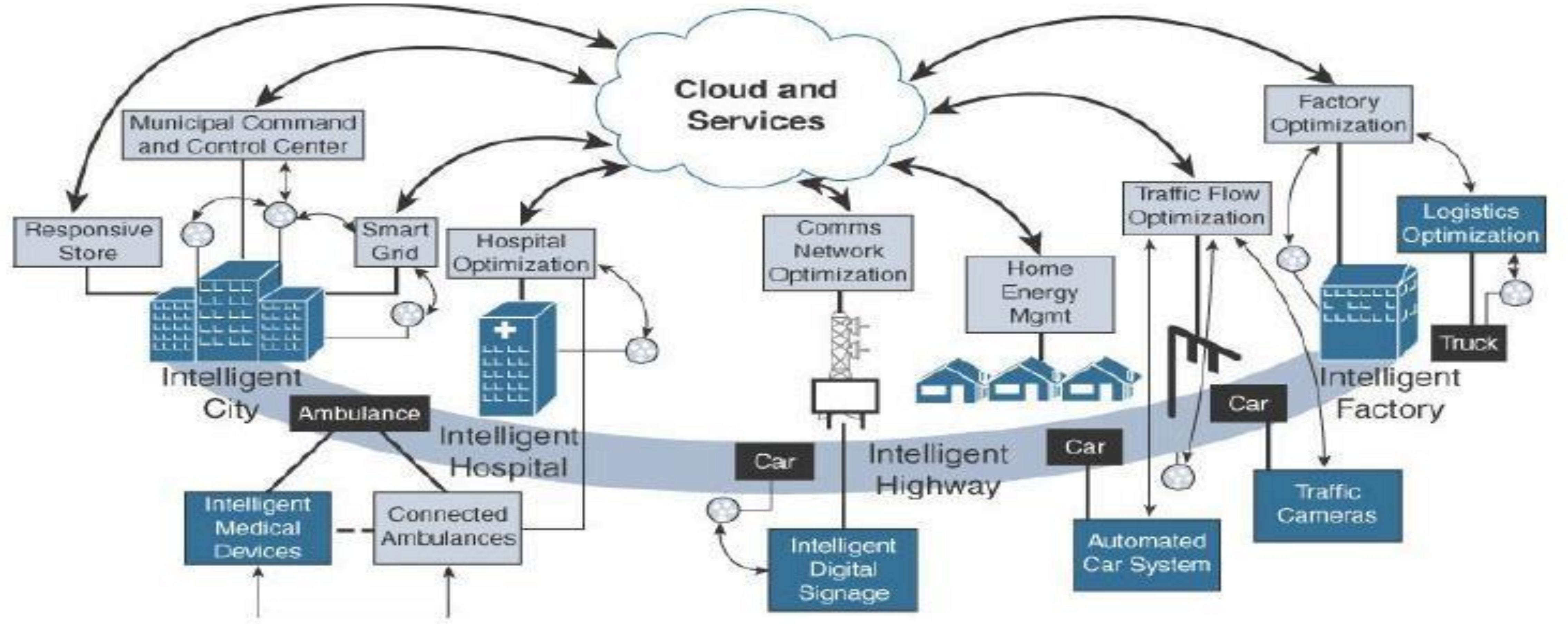
Data Center Layer:

- The cloud model is the chief means of delivering storage, virtualization, adaptability, and the analytics know-how that city governments require for the technological mashup and synergy of information embodied in a smart city.
- Traditional city networks simply cannot keep up with the real-time data needs of smart cities, they are encumbered by their physical limitations.
- The cloud enables data analytics to be taken to server farms with large and extensible processing capabilities.

Smart City IoT Architecture:

Data Center Layer:

Figure shows the vision of utilizing the cloud in smart solutions for cities. The cloud provides a scalable, secure, and reliable data processing engine that can handle the immense amount of data passing through it.



Smart City IoT Architecture:

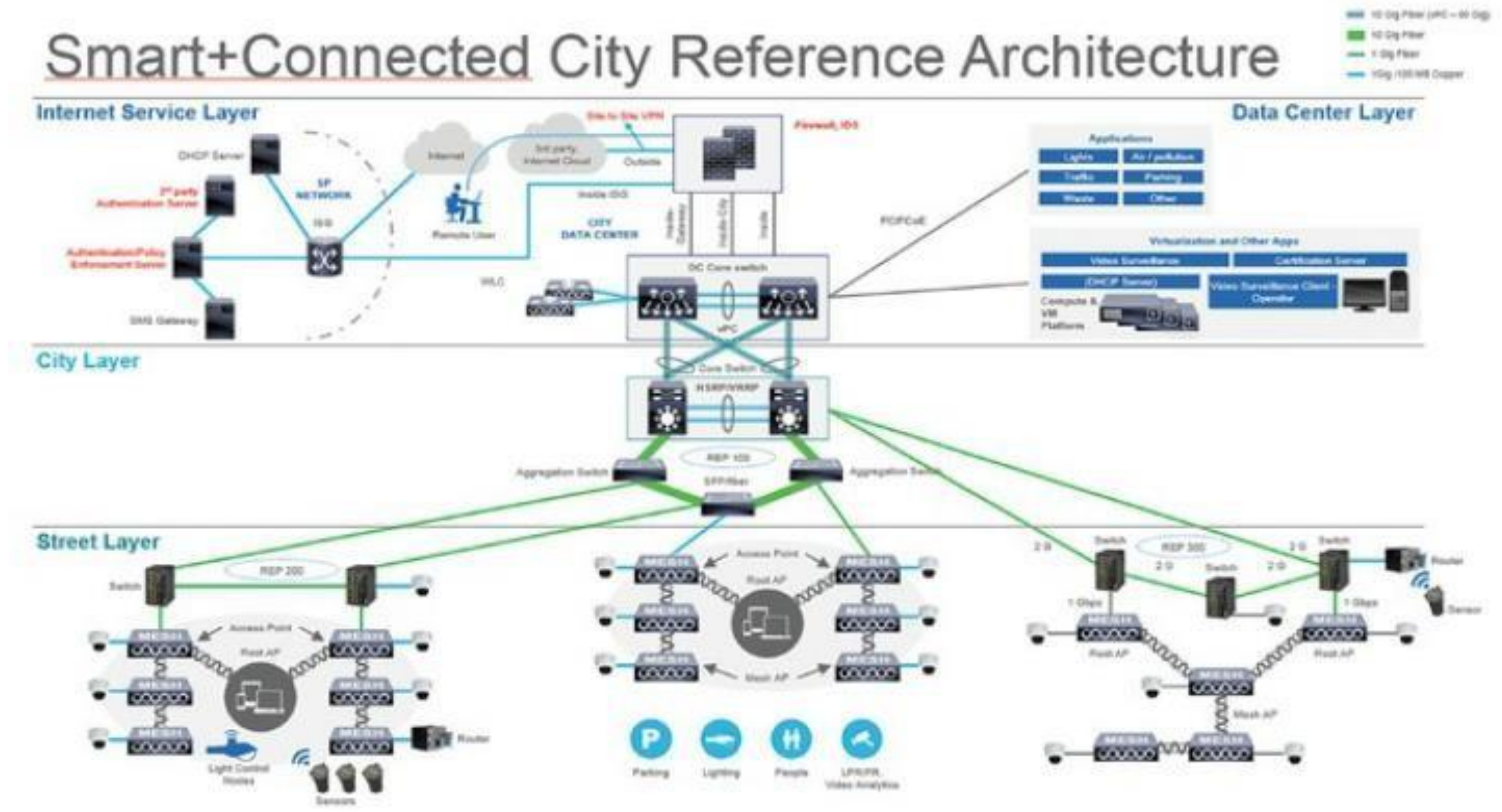
Service Layer:

- Ultimately, the true value of ICT connectivity comes from the services that the measured data can provide to different users operating within a city.
- Smart city applications can provide value to and visibility for a variety of user types, including city operators, citizens, and law enforcement.
- The collected data should be visualized according to the specific needs of each consumer of that data and the particular user experience requirements and individual use cases.

Smart City Security Architecture

- A serious concern of most smart cities and their citizens is data security.
- Vast quantities of sensitive information are being shared at all times in a layered, real- time architecture, and cities have a duty to protect their citizens' data from unauthorized access, collection, and tampering.
- In general, citizens feel better about data security when the city itself, and not a private entity, owns public or city-relevant data.
- It is up to the city and the officials who run it to determine how to utilize this data.
- A security architecture for smart cities must utilize security protocols to fortify each layer of the architecture and protect city data.
- Figure shows a reference architecture, with specific security elements highlighted.
- Security protocols should authenticate the various components and protect data transport throughout.

Smart City Security Architecture:



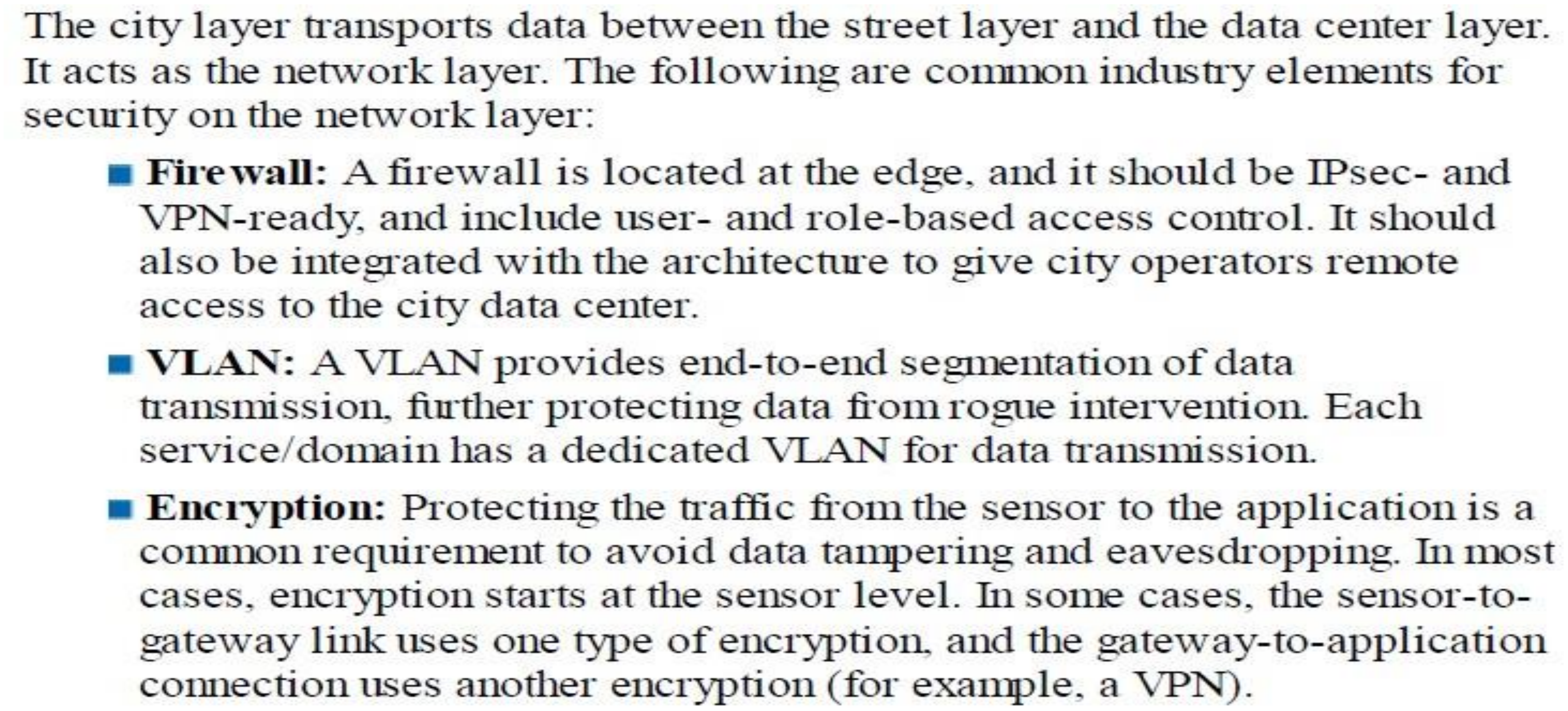
Key Smart and Connected Cities Reference Architecture

Smart City Security Architecture

- Starting from the street level, sensors should have their own security protocols.
- Some industry-standard security features include device/sensor identification and authorization; device/sensor data encryption; Trusted Platform Module, which enables self-destruction when the sensor is physically handled; and user ID authentication and authorization.
- Sensor identification and authorization typically requires a pre-installed factory X.509 certificate and public key infrastructure (PKI) at the organization level, where a new certificate is installed through a zero-touch deployment process.
- This additional processing may slow the deployment but ensures the security of the exchanges.
- Another consideration may be the type of data that the sensor is able to collect and process. For example, a roadside car counter may include a Bluetooth sensor that uniquely identifies each driver or pedestrian.

Smart City Security Architecture

Smart City Security Architecture:



The city layer transports data between the street layer and the data center layer. It acts as the network layer. The following are common industry elements for security on the network layer:

- **Firewall:** A firewall is located at the edge, and it should be IPsec- and VPN-ready, and include user- and role-based access control. It should also be integrated with the architecture to give city operators remote access to the city data center.
- **VLAN:** A VLAN provides end-to-end segmentation of data transmission, further protecting data from rogue intervention. Each service/domain has a dedicated VLAN for data transmission.
- **Encryption:** Protecting the traffic from the sensor to the application is a common requirement to avoid data tampering and eavesdropping. In most cases, encryption starts at the sensor level. In some cases, the sensor-to-gateway link uses one type of encryption, and the gateway-to-application connection uses another encryption (for example, a VPN).