Unit-III TOPICS PART-2

Bluetooth Smart Connectivity Bluetooth overview, Bluetooth Key Versions, Bluetooth Low Energy (BLE) Protocol, Bluetooth, Low Energy Architecture, PSoC4 BLE architecture and Component Overview.

Bluetooth is universal for short-range wireless voice and data communication. It is a Wireless Personal Area Network (WPAN) technology and is used for exchanging data over smaller distances. This technology was invented by Ericson in 1994. It operates in the unlicensed, industrial, scientific, and medical (ISM) band from 2.4 GHz to 2.485 GHz. Maximum devices that can be connected at the same time are 7. Bluetooth ranges up to 10 meters. It provides data rates up to 1 Mbps or 3 Mbps depending upon the version. The spreading technique that it uses is FHSS (Frequency-hopping spread spectrum). A Bluetooth network is called a **piconet** and a collection of interconnected piconets is called **scatternet**.

What is Bluetooth?

Bluetooth simply follows the principle of transmitting and receiving data using radio waves. It can be paired with the other device which has also Bluetooth but it should be within the estimated communication range to connect. When two devices start to share data, they form a network called piconet which can further accommodate more than five devices.

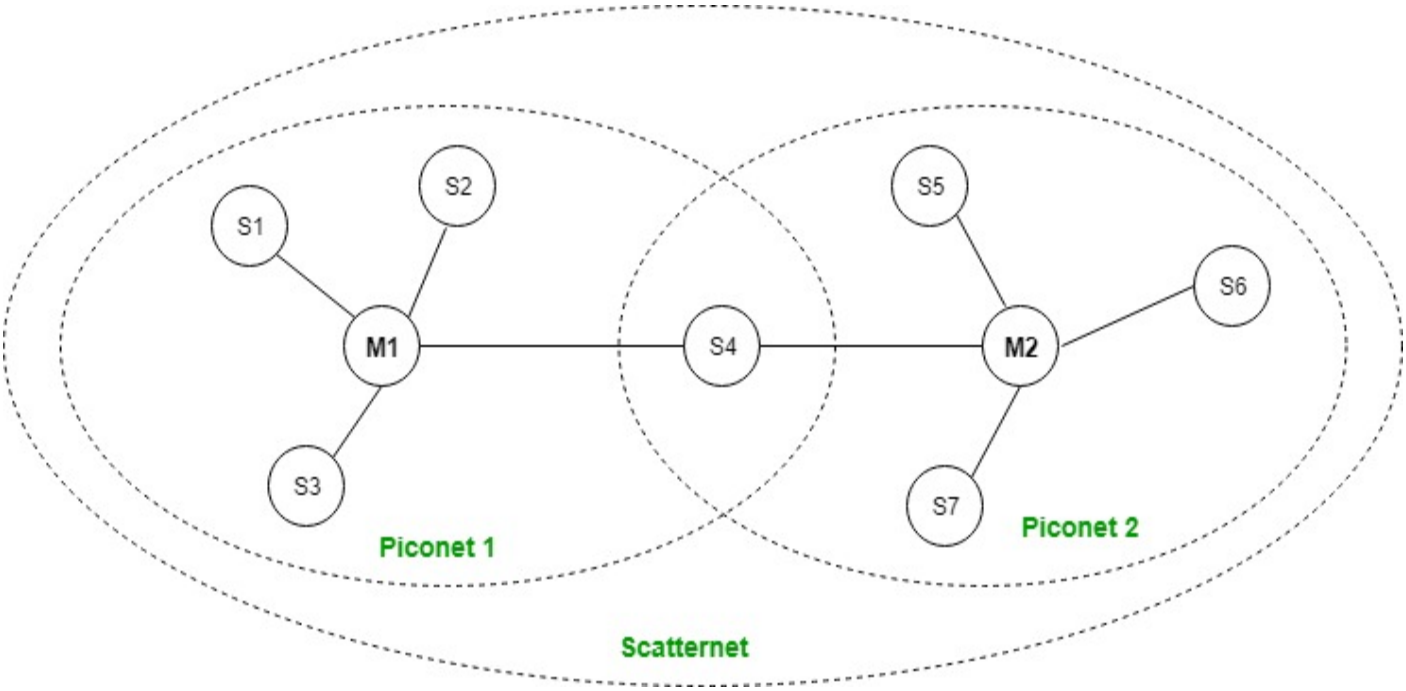
Points to remember for Bluetooth:

- Bluetooth Transmission capacity 720 kbps.
- Bluetooth is Wireless.
- Bluetooth is a Low-cost short-distance radio communications standard.
- Bluetooth is robust and flexible.
- Bluetooth is cable replacement technology that can be used to connect almost any device to any other device.
- The basic architecture unit of Bluetooth is a piconet.

Bluetooth Architecture:

The architecture of Bluetooth defines two types of networks:

1. Piconet
2. Scatternet



Piconet:

Piconet is a type of Bluetooth network that contains **one primary node** called the master node and **seven active secondary nodes** called slave nodes. Thus, we can say that there is a total of 8 active nodes which are present at a distance of 10 meters. The communication between the primary and secondary nodes can be one-to-one or one-to-many. Possible communication is only between the master and slave; Slave-slave communication is not possible. It also has **255 parked nodes**, these are secondary nodes and cannot take participation in communication unless it gets converted to the active state.

Scatternet:

It is formed by using **various piconets**. A slave that is present in one piconet can act as master or we can say primary in another piconet. This kind of node can receive a message from a master in one piconet and deliver the message to its slave in the other piconet where it is acting as a master. This type of node is referred to as a bridge node. A station cannot be mastered in two piconets.

Differentiate between piconet and scatternet

Let us understand the concept of piconet and scatternet before learning the differences between them.

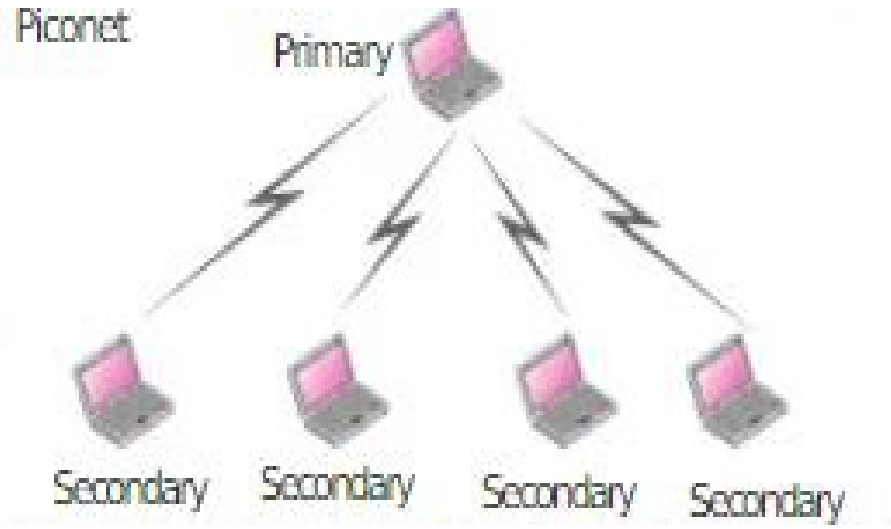
Piconet

A piconet is a network created by connecting multiple wireless devices using Bluetooth technology. In a piconet network a master device exists, this master device cm gets connected to 7 more slave devices.

It includes the master the number of devices that can be connected is limited to 8. Due to less number of devices active at a time the usage of channel band width is not more.

Number of devices that can be connected is limited to 8. It is applicable for devices belonging to small areas.

Given below is the diagram of piconet –



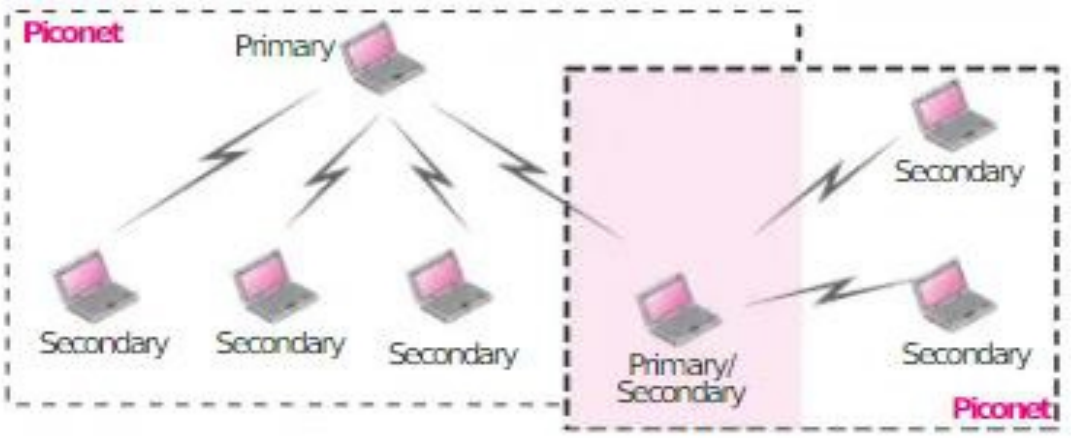
Scatternet

It is a network which connects multiple piconets using Bluetooth and it acts as a master and another type of piconet acts as a slave. It has more than 6 devices that can be connected.

Multiple devices are active, so there is an effective use of channel bandwidth.

It is a connection of multiple piconets therefore it is applicable for devices belonging to large areas.

Given below is the diagram of scatternet –



Differences

The major differences between piconet and scatternet are as follows –

Piconet	Scatternet
Piconet is the type of connection formed between 2 or more Bluetooth enabled devices.	between 2 or more Bluetooth enabled devices. It is a type of ad-hoc computer network consisting of 2 or more piconets.
It supports maximum 8 nodes i.e,1 master & 7 slaves	It supports more than 8 nodes.
It Allows less efficient use of Bluetooth channel bandwidth. It is usually applied to Bluetooth devices. It is a smaller coverage area	It Allows more efficient use of Bluetooth channel bandwidth. It is applied to Bluetooth devices too. It is a larger coverage area.

The figure given below depicts the piconet and scatternet together –

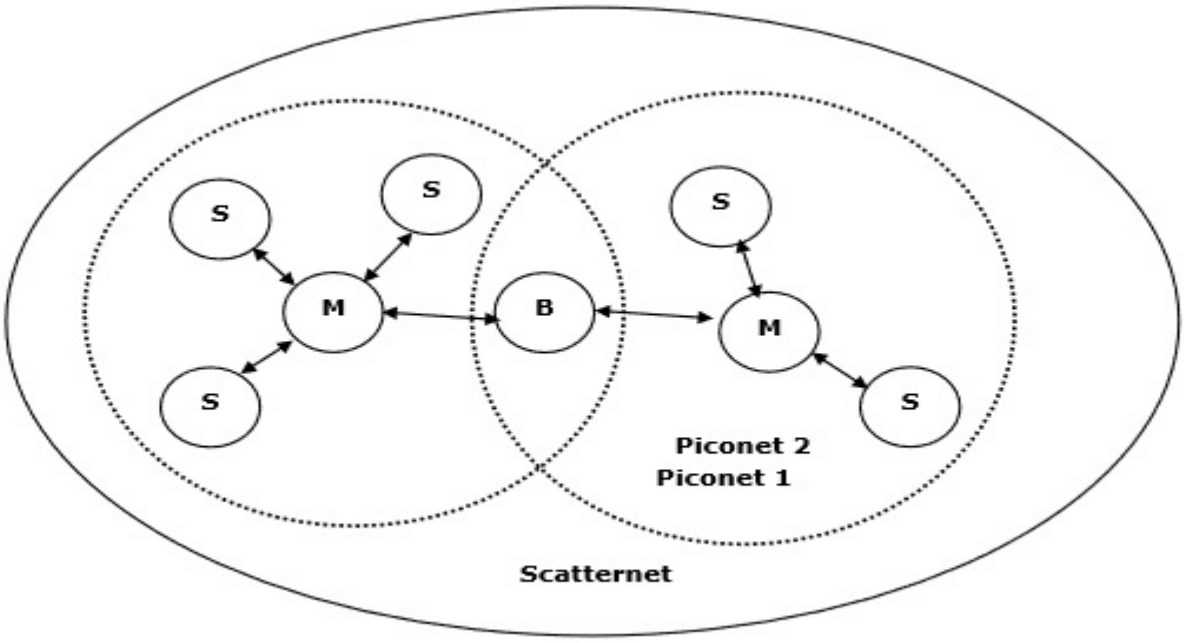


Figure: Piconets and Scatternets

Bluetooth Smart Connectivity

Bluetooth Smart, also known as Bluetooth Low Energy (BLE), is a wireless communication technology designed for short-range communication between devices. It was introduced as part of the Bluetooth 4.0 specification.

Bluetooth Smart Connectivity offers several advantages:

Low Power Consumption: BLE is optimized for low power consumption, making it ideal for devices that need to operate on battery power for extended periods without frequent recharging.

Short Range: BLE typically has a range of up to 100 meters, although this can vary depending on environmental factors and the specific implementation.

Low Cost: BLE technology is relatively inexpensive to implement, making it suitable for a wide range of applications, including consumer electronics, healthcare, fitness, smart home devices, and more.

Compatibility: BLE is backward compatible with previous versions of Bluetooth, allowing devices to support both traditional Bluetooth and BLE communication protocols.

Interoperability: Bluetooth Smart Connectivity is standardized, ensuring interoperability between devices from different manufacturers.

Security: BLE includes built-in security features to protect data transmitted between devices, including encryption and authentication mechanisms.

Applications of Bluetooth Smart Connectivity include:

Wearable Devices: Fitness trackers, smartwatches, and other wearable devices often utilize BLE for communication with smartphones and other peripherals.

Smart Home Devices: BLE is used in various smart home devices such as smart locks, thermostats, light bulbs, and sensors to enable wireless connectivity and communication with smartphones or other control devices.

Healthcare Devices: Many healthcare devices, such as blood glucose monitors, heart rate monitors, and medical sensors, leverage BLE for wireless data transmission to smartphones or other monitoring systems.

Beacon Technology: BLE beacons are used for location-based services, indoor navigation, proximity marketing, and asset tracking applications.

Overall, Bluetooth Smart Connectivity plays a significant role in enabling the Internet of Things (IoT) by providing a low-power, cost-effective, and reliable wireless communication solution for a wide range of devices and applications.

Bluetooth overview

Bluetooth is a wireless technology standard that facilitates communication between devices over short distances, typically within a range of up to 10 meters (30 feet). It operates in the 2.4 GHz frequency band and is globally available, making it widely adopted for various applications.

Here's an overview of Bluetooth:

History: Bluetooth technology was developed in the 1990s by Ericsson, and the first Bluetooth specification, Bluetooth 1.0, was released in 1999. Since then, there have been several iterations, each offering improvements in terms of data rate, range, power consumption, and functionality.

Versions and Profiles:

Bluetooth Classic: This refers to the traditional Bluetooth technology used for data exchange between devices like smartphones, computers, and peripherals such as keyboards, mice, and speakers.

Bluetooth Low Energy (BLE): Also known as Bluetooth Smart, BLE is optimized for low-power communication, making it suitable for applications like wearable devices, IoT sensors, and other battery-powered gadgets.

Core Features:

Pairing: The process of establishing a connection between two Bluetooth-enabled devices.

Discoverability: Devices can be set to "discoverable" mode to allow other devices to find and connect to them.

Security: Bluetooth supports various security measures, including authentication, encryption, and authorization protocols, to protect data transmission between devices.

Profiles: Bluetooth profiles define how different types of devices communicate with each other. Examples include the Hands-Free Profile (HFP), Advanced Audio Distribution Profile (A2DP), and Human Interface Device (HID) profile.

Applications:

Audio Streaming: Bluetooth is widely used for wireless audio streaming between devices such as smartphones, speakers, headphones, and car stereos.

Data Transfer: It facilitates data exchange between devices like smartphones, tablets, computers, printers, and peripherals.

Wearable Technology: Many wearable devices, including smartwatches, fitness trackers, and health monitors, utilize Bluetooth for communication with smartphones and other devices.

IoT and Smart Home: Bluetooth enables connectivity in smart home devices such as smart locks, thermostats, light bulbs, and sensors.

Automotive: Bluetooth is commonly integrated into car infotainment systems for hands-free calling, audio streaming, and vehicle diagnostics.

Advantages:

Universal Compatibility: Bluetooth is widely supported across various devices and platforms.

Ease of Use: Pairing and connecting Bluetooth devices is typically straightforward.

Wireless Convenience: Bluetooth eliminates the need for cables, providing greater flexibility and mobility.

Low Power Options: With the introduction of BLE, Bluetooth technology became more suitable for low-power devices, extending battery life.

Limitations:

Limited Range: Bluetooth's range is typically limited to around 10 meters, although advancements in technology have extended this in some cases.

Interference: The 2.4 GHz frequency band used by Bluetooth is shared with other wireless technologies, which can lead to interference in crowded environments.

Bandwidth: While Bluetooth is sufficient for many applications, it may not offer the same data transfer speeds as some other wireless technologies like Wi-Fi.

Compatibility Issues: Despite being widely adopted, compatibility issues can arise between devices from different manufacturers or using different versions of Bluetooth.

Overall, Bluetooth technology continues to evolve, offering enhanced capabilities and expanding its reach into various domains, including consumer electronics, healthcare, automotive, and IoT.

Bluetooth Key Versions

Bluetooth technology has evolved over the years, with each new version introducing enhancements in terms of features, performance, and security. Here's an overview of the key versions of Bluetooth:

Bluetooth 1.x: The initial release of Bluetooth technology, offering basic wireless connectivity for data transfer and audio streaming. Versions 1.0 and 1.0B had limited data rates and were prone to compatibility issues.`

Bluetooth 2.0 + EDR (Enhanced Data Rate): Introduced in 2004, this version brought significant improvements in data transfer speeds and reduced power consumption compared to the previous version. EDR increased the maximum data rate up to 3 Mbps, enhancing the performance of applications like audio streaming.

Bluetooth 3.0 + HS (High-Speed): Released in 2009, Bluetooth 3.0 introduced the High-Speed feature, which allowed for faster data transfer rates by leveraging Wi-Fi technology for data-intensive tasks. This version primarily targeted applications requiring high-speed data transfer, such as large file sharing.

Bluetooth 4.0: This version, introduced in 2010, brought significant improvements, including the introduction of Bluetooth Low Energy (BLE) technology. BLE is optimized for low-power applications, making it ideal for devices like wearables, sensors, and other IoT devices. Bluetooth 4.0 also introduced features like improved pairing mechanisms and enhanced security.

Bluetooth 4.1, 4.2: These incremental updates to Bluetooth 4.0 introduced enhancements such as improved coexistence with LTE (Long-Term Evolution) radios, more efficient data exchange, and enhanced privacy features.

Bluetooth 5.0: Released in 2016, Bluetooth 5.0 introduced several significant improvements, including higher data transfer speeds, longer range, and enhanced broadcasting capabilities. It doubled the data transfer rate to 2 Mbps and quadrupled the range compared to Bluetooth 4.x. Bluetooth 5.0 also introduced the ability to transmit data to multiple devices simultaneously.

Bluetooth 5.1: Introduced in 2019, Bluetooth 5.1 introduced the direction finding feature, enabling devices to determine the direction of a Bluetooth signal with greater precision. This feature enhances location-based services and indoor positioning systems.

Bluetooth 5.2: Released in 2020, Bluetooth 5.2 introduced several enhancements, including improvements to the Low Energy feature, enhanced audio quality with the LC3 codec, and support for audio sharing with multiple Bluetooth devices.

Each new version of Bluetooth builds upon the previous ones, offering improved performance, security, and features, and expanding the possibilities for wireless connectivity across various devices and applications.

Bluetooth Low Energy(BLE) Protocol

Bluetooth Low Energy (BLE), also known as Bluetooth Smart, is a wireless communication protocol designed for low-power, short-range communication between devices. It was introduced as part of the Bluetooth 4.0 specification and is optimized for applications requiring low energy consumption, such as wearables, IoT devices, and sensors. Here's an overview of the BLE protocol:

GATT (Generic Attribute Profile): BLE communication revolves around the concept of attribute-based data exchange using the Generic Attribute Profile (GATT). GATT defines a hierarchical data structure known as the Attribute Protocol (ATT), which consists of attributes organized into services and characteristics. Services represent a collection of related data or functions, while characteristics represent a single piece of data or a function within a service.

Advertising and Scanning: BLE devices can operate in two primary modes: advertising and scanning. Advertising involves broadcasting packets of data containing information about the device and its capabilities. Scanning involves listening for these advertising packets. Devices can initiate connections based on the information obtained during scanning.

Connections: BLE devices can establish connections in a master-slave architecture. The device initiating the connection acts as the master, while the device responding to the connection request acts as the slave. Once a connection is established, data exchange occurs using the GATT protocol.

Attributes and Services: BLE devices communicate by exchanging data through attributes. Attributes are organized into services, which represent a collection of related functionality or data. Services and characteristics are identified by unique UUIDs (Universally Unique Identifiers).

Low Power Operation: BLE is designed for low-power operation, allowing devices to conserve battery life. It achieves this through mechanisms such as short data packets, low duty cycles, and efficient connection establishment and termination procedures.

Security: BLE includes security features to protect data exchanged between devices. This includes encryption, authentication, and authorization mechanisms to ensure secure communication.

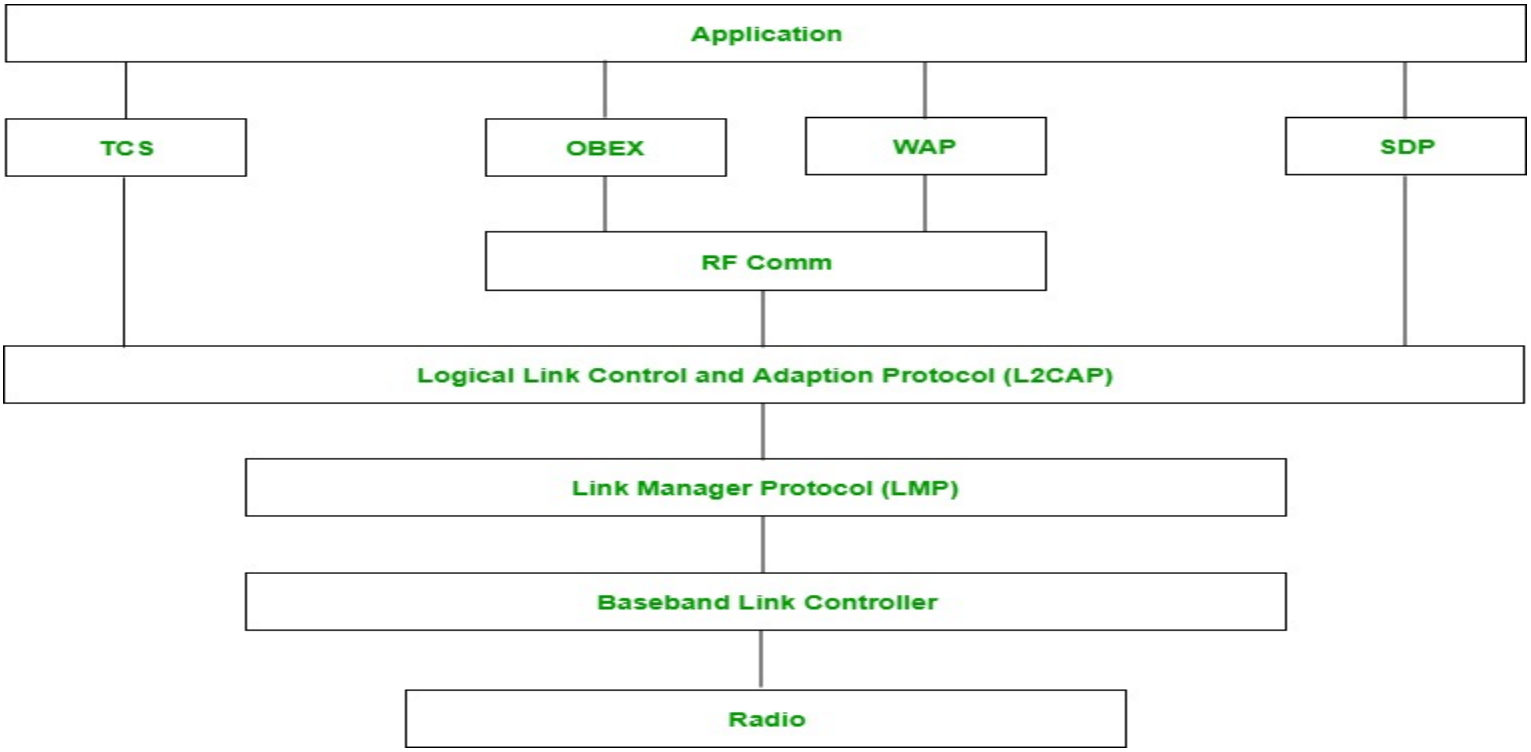
Profiles and Services: BLE profiles define specific use cases and functionality built on top of the GATT protocol. Examples include the Heart Rate Profile for heart rate monitors, the Health Thermometer Profile for temperature sensors, and the HID (Human Interface Device) Profile for keyboards and mice.

Long Range: While BLE was initially designed for short-range communication, newer versions of the specification, such as Bluetooth 5.0 and later, have introduced features for longer-range communication, extending the reach of BLE applications.

Overall, Bluetooth Low Energy is a versatile protocol that enables efficient, low-power communication between devices, making it well-suited for a wide range of applications in the IoT, wearable technology, healthcare, and smart home domains.

Bluetooth protocol stack:

1. **Radio (RF) layer:** It specifies the details of the air interface, including frequency, the use of frequency hopping and transmit power. It performs modulation/demodulation of the data into RF signals. It defines the physical characteristics of Bluetooth transceivers. It defines two types of physical links: connection-less and connection-oriented.



2. **Baseband Link layer:** The baseband is the digital engine of a Bluetooth system and is equivalent to the MAC sublayer in LANs. It performs the connection

establishment within a piconet, addressing, packet format, timing and power control.
3. **Link Manager protocol layer:** It performs the management of the already established links which includes authentication and encryption processes. It is responsible for creating the links, monitoring their health, and terminating them gracefully upon command or failure.
4. **Logical Link Control and Adaption (L2CAP) Protocol layer:** It is also known as the heart of the Bluetooth protocol stack. It allows the communication between upper and lower layers of the Bluetooth protocol stack. It packages the data packets received from upper layers into the form expected by lower layers. It also performs segmentation and multiplexing.
5. **Service Discovery Protocol (SDP) layer:** It is short for Service Discovery Protocol. It allows discovering the services available on another Bluetooth-enabled device.
6. **RF comm layer:** It is a cabal replacement protocol. It is short for Radio Frontend Component. It provides a serial interface with WAP and OBEX. It also provides emulation of serial ports over the logical link control and adaption protocol(L2CAP). The protocol is based on the ETSI standard TS 07.10.
7. **OBEX:** It is short for Object Exchange. It is a communication protocol to exchange objects between 2 devices.
8. **WAP:** It is short for Wireless Access Protocol. It is used for internet access.
9. **TCS:** It is short for Telephony Control Protocol. It provides telephony service. The basic function of this layer is call control (setup & release) and group management for the gateway serving multiple devices.

10. **Application layer:** It enables the user to interact with the application.

Types of Bluetooth

Various types of Bluetooth are available in the market nowadays. Let us look at them.

- In-Car Headset: One can make calls from the car speaker system without the use of mobile phones.
- Stereo Headset: To listen to music in car or in music players at home.
- Webcam: One can link the camera with the help of Bluetooth with their laptop or phone.
- Bluetooth-equipped Printer: The printer can be used when connected via Bluetooth with mobile phone or laptop.
- Bluetooth Global Positioning System (GPS): To use GPS in cars, one can connect their phone with car system via Bluetooth to fetch the directions of the address.

Advantage:

- It is a low-cost and easy-to-use device.
- It can also penetrate through walls.
- It creates an Ad-hoc connection immediately without any wires.

- It is used for voice and data transfer.

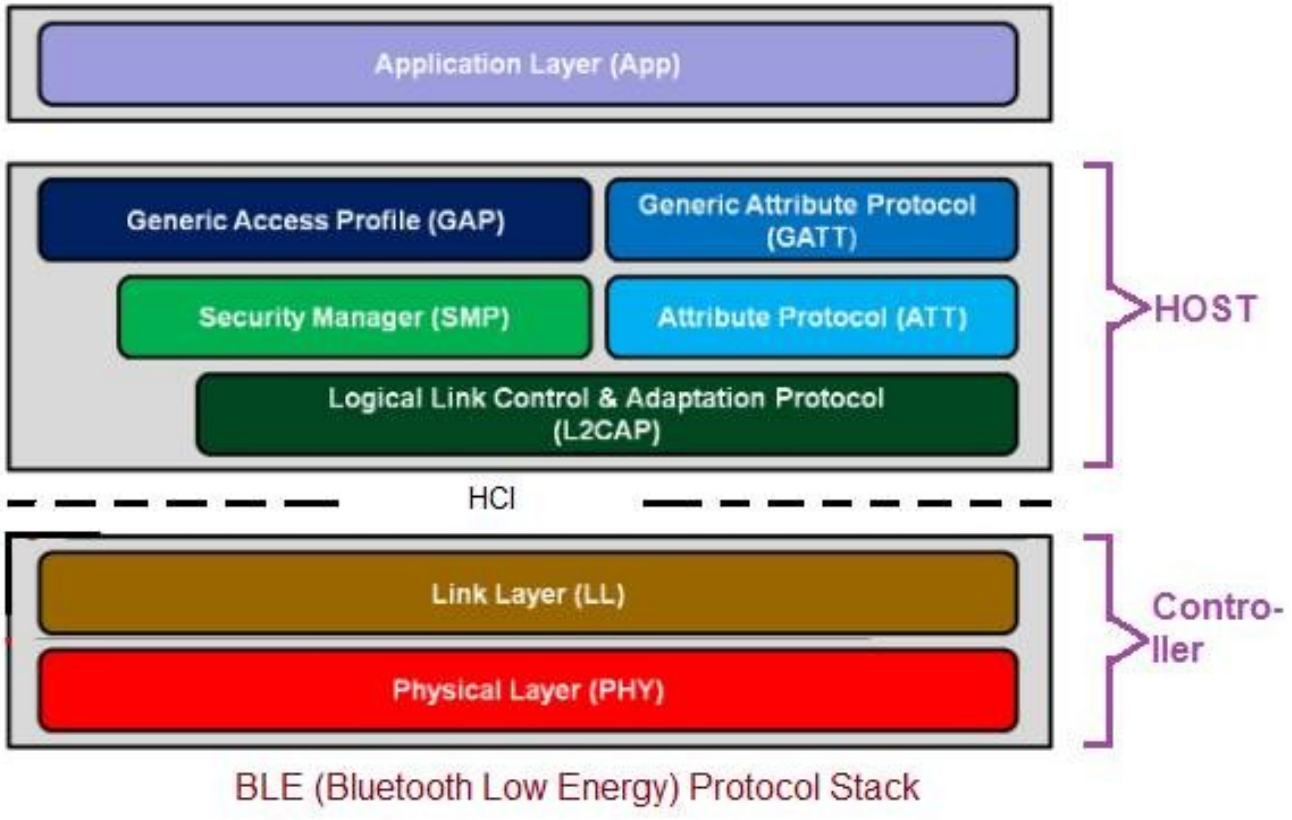
Disadvantages:

- It can be hacked and hence, less secure.
- It has a slow data transfer rate: of 3 Mbps.
- It has a small range: 10 meters.
- Bluetooth communication does not support routing.
- The issues of handoffs have not been addressed.

Applications:

- It can be used in laptops, and in wireless PCs, printers.
- It can be used in wireless headsets, wireless PANs, and LANs.
- It can connect a digital camera wirelessly to a mobile phone.
- It can transfer data in terms of videos, songs, photographs, or files from one cell phone to another cell phone or computer.
- It is used in the sectors of Medical health care, sports and fitness, Military.

Bluetooth, Low Energy Architecture



BLE (Bluetooth Low Energy) Protocol Stack

The architecture of Bluetooth Low Energy (BLE) encompasses various layers and components that work together to facilitate efficient, low-power communication between devices. Here's an overview of the typical BLE architecture:

Application Layer: This layer contains the application-specific logic and user interface elements of the BLE device. It interacts with the higher layers of the BLE stack to implement specific functionalities and services required by the application. For example, in a fitness tracker, the application layer would handle tasks such as sensor data processing, user interface interactions, and communication with other devices.

Generic Attribute Profile (GATT): GATT is a protocol used in BLE for organizing and exchanging data between devices. It defines a hierarchical structure of attributes, including services, characteristics, and descriptors. Services represent a collection of related data or functionality, while characteristics represent specific data points or features within a service. Descriptors provide additional information about characteristics. GATT is typically implemented within the Attribute Protocol (ATT) layer.

Attribute Protocol (ATT): ATT is a lightweight protocol that defines how data is organized and exchanged between BLE devices. It is responsible for reading, writing, and updating attributes defined by the GATT. ATT operates on top of the BLE Link Layer and is optimized for low-power communication.

BLE Link Layer: The Link Layer is responsible for managing the physical and logical links between BLE devices. It handles tasks such as advertising, scanning, connection establishment, packet transmission, and error handling. The Link Layer operates at the lowest level of the BLE protocol stack and interfaces directly with the hardware.

Controller and Host: In BLE devices, the Bluetooth functionality is typically divided between the Controller and Host layers. The Controller manages the physical layer functions, such as radio frequency (RF) communication, modulation, and error correction. The Host layer, running on the device's main processor, handles higher-level protocol operations, including GATT, ATT, and application logic. This separation allows for flexibility in system design and implementation.

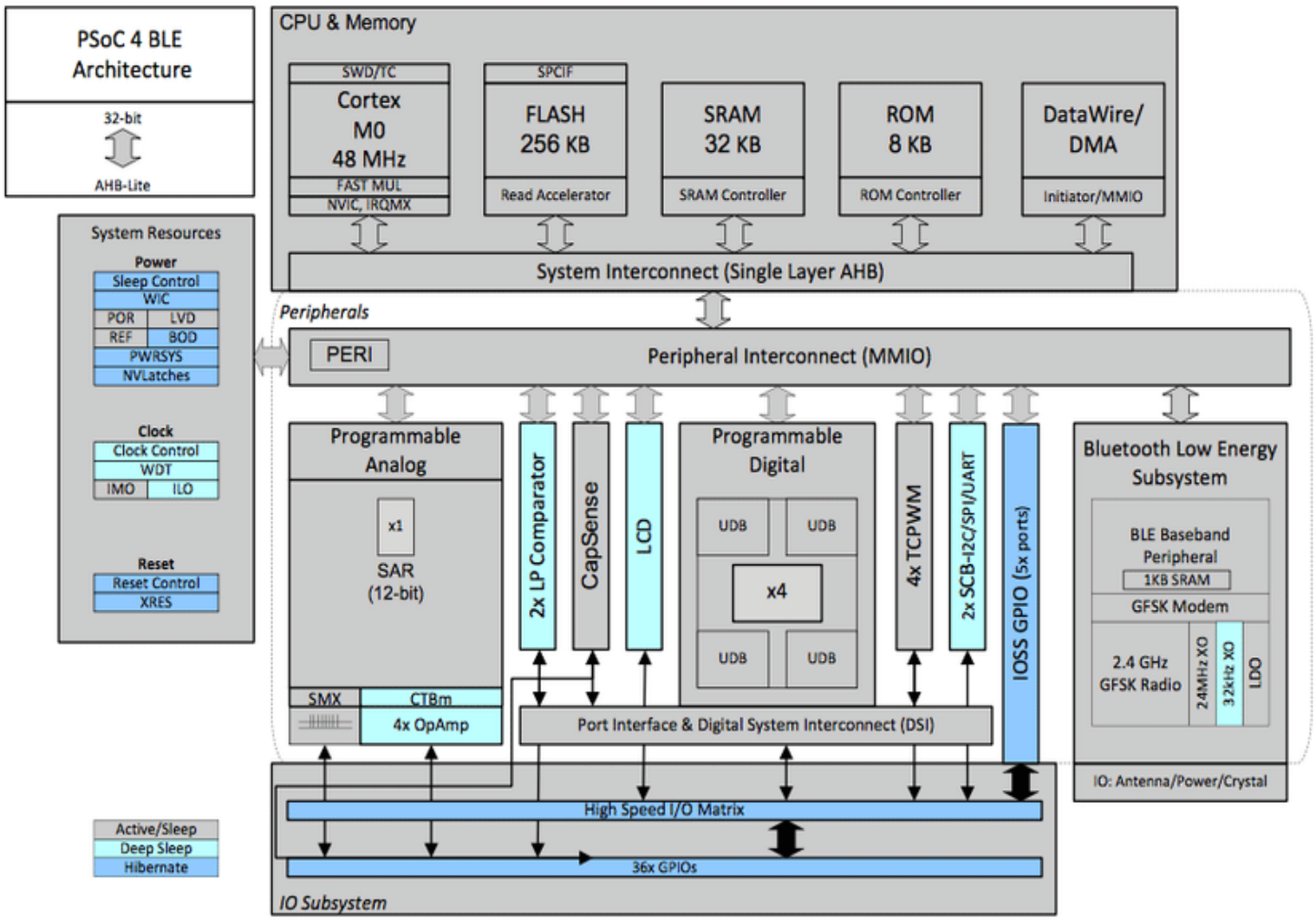
Security Manager (SM): The Security Manager is responsible for managing security aspects of BLE communication, including encryption, authentication, and key exchange. It ensures that data exchanged between devices is secure and protected from unauthorized access or tampering.

Profiles and Services: BLE profiles define specific use cases and functionalities built on top of the GATT protocol. Profiles define standardized sets of services, characteristics, and behaviors tailored to specific application requirements. Examples include the Heart Rate Profile, Battery Service, and HID (Human Interface Device) Profile.

Overall, the architecture of Bluetooth Low Energy is designed to provide a flexible and efficient framework for building low-power wireless communication solutions across a wide range of applications, including IoT, wearables, healthcare, and smart home devices.

PSoC4 BLE architecture and Component Overview.

PSoC 4 BLE (Bluetooth Low Energy) is a system-on-chip (SoC) solution developed by Cypress Semiconductor, now part of Infineon Technologies. It combines a microcontroller unit (MCU) with a Bluetooth Low Energy radio, enabling developers to create low-power wireless applications with integrated BLE connectivity. Here's an overview of the architecture and key components of PSoC 4 BLE:



What is a PSoC Mixed Signal Device?

Programmable
System
on
Chip

PSoC combines:

- the familiarity of a microcontroller
- the configurability of a CPLD
- the capabilities of an ASSP

CYPRESS

Microcontroller Unit (MCU):
PSoC 4 BLE integrates a 32-bit ARM Cortex-M0 CPU, providing processing power for executing application code, handling BLE protocol stack operations, and interfacing with peripherals and external devices.
The MCU also includes on-chip memory (flash and SRAM) for storing program code, data, and variables.

Bluetooth Low Energy Radio:
PSoC 4 BLE features a dedicated BLE radio subsystem, which includes a transceiver, baseband controller, and RF front-end.
The BLE radio enables wireless communication between PSoC 4 BLE devices and other BLE-enabled devices, such as smartphones, tablets, and IoT sensors.

BLE Protocol Stack:
PSoC 4 BLE includes a BLE protocol stack that implements the Bluetooth Low Energy standard. The protocol stack consists of layers such as the Controller, Host, and Profiles, which handle tasks such as advertising, scanning, connection management, and data exchange.
Cypress provides a software stack called "BLE Component" that runs on top of the MCU firmware and abstracts the complexities of the BLE protocol stack, making it easier for developers to integrate BLE functionality into their applications.

Peripheral Components:
PSoC 4 BLE integrates a wide range of configurable analog and digital peripherals, including ADCs, DACs, timers, PWMs, UARTs, SPI, I2C, GPIOs, and more.
These peripherals can be configured and customized using Cypress's PSoC Creator Integrated Development Environment (IDE) to meet the specific requirements of the application.

CapSense Capacitive Sensing:
Many PSoC 4 BLE devices include Cypress's CapSense technology, which enables touch and gesture sensing capabilities without requiring external components.
CapSense allows developers to create user interfaces with touch-sensitive buttons, sliders, and proximity sensors, enhancing the user experience of their applications.

PSoC Creator IDE:
PSoC 4 BLE development is supported by Cypress's PSoC Creator IDE, which provides a graphical user interface for configuring and designing PSoC-based applications.
PSoC Creator allows developers to visually design their applications by dragging and dropping components, configuring parameters, and writing firmware code using C or C++.
Overall, PSoC 4 BLE offers a highly integrated solution for building low-power wireless applications with BLE connectivity. Its configurable architecture, comprehensive set of peripherals, and easy-to-use development tools make it well-suited for a wide range of IoT, wearable, and smart device applications.