EXPERIMENT NO.1

AIM : To Study different Wireless Technologies and their parameters.

Theory :

Wireless technology enables communication and data transfer between devices without physical connections, using electromagnetic waves. It is widely used in various applications, including mobile networks, IoT, home automation, healthcare, and industrial automation.

1. Wi-Fi (Wireless Fidelity)

- **Range of Communication**:
  Wi-Fi is designed for local area networks (LANs). The range can vary based on the Wi-Fi standard used and the environment. In general:
  - **Wi-Fi 4 (802.11n)**: Up to 100 meters indoors, 300 meters outdoors.
  - **Wi-Fi 5 (802.11ac)**: Similar to Wi-Fi 4 indoors, but with better performance at higher speeds.
  - **Wi-Fi 6 (802.11ax)**: Indoor range is similar, but with better efficiency, especially in dense environments.
- **Cost**:
  Wi-Fi routers and adapters are affordable for most users, with home routers costing anywhere from $20 to $300 depending on speed and features.
- **Propagation Delay**:
  Propagation delay is the time it takes for a signal to travel from the sender to the receiver. In Wi-Fi networks, delays are typically in the **10–50 milliseconds** range. Wi-Fi 6 optimizes latency for real-time applications like gaming or video conferencing.
- **Power Consumption**:
  Modern Wi-Fi chips are optimized for power efficiency, but still require moderate power consumption. **Wi-Fi 6** introduces features that improve battery life for devices, especially when idle.
- **Throughput**:
  Throughput varies greatly depending on the Wi-Fi standard:
  - **Wi-Fi 4 (802.11n)**: Up to **150 Mbps**.
  - **Wi-Fi 5 (802.11ac)**: Up to **1 Gbps**.
  - **Wi-Fi 6 (802.11ax)**: Can exceed **10 Gbps** with the right equipment.
- **Fan-out**:
  Wi-Fi supports many devices (up to hundreds) simultaneously, especially with routers using **MU-MIMO** (multi-user, multiple input, multiple output) technology, allowing efficient communication with multiple devices.
- Range: **30-100m**, Speed: **Up to 9.6 Gbps (Wi-Fi 6)**, Frequency: **2.4 GHz, 5 GHz, 6 GHz**
- **Applications**:
  Wi-Fi is widely used for home and office internet access, enabling online streaming, gaming, video conferencing, and IoT connectivity. Public Wi-Fi hotspots provide internet in cafes,

airports, and hotels, while smart homes use Wi-Fi for controlling appliances, security cameras, and voice assistants.

2. Bluetooth

- **Range of Communication**:
  Bluetooth is generally used for short-range communication, and its range can vary based on the version:
  - **Classic Bluetooth**: Typically up to **10 meters** (with a maximum of **100 meters** in some high-power devices).
  - **Bluetooth 5.0**: The range can extend to **100 meters** under optimal conditions.
- **Cost**:
  Bluetooth is cost-effective, with inexpensive chips and modules. Bluetooth technology is embedded in most consumer electronics, including smartphones, headphones, and home automation devices.
- **Propagation Delay**:
  The latency in Bluetooth communications is typically low, in the range of **1–5 milliseconds**, suitable for voice communication or device synchronization.
- **Power Consumption**:
  One of Bluetooth's most significant advantages is low power consumption, especially with **Bluetooth Low Energy (BLE)**, which is designed for devices like fitness trackers, smartwatches, and IoT devices. BLE can last for months or years on a small battery.
- **Throughput**:
  - **Bluetooth Classic**: The maximum throughput is **3 Mbps**.
  - **Bluetooth 5.0**: Can achieve up to **2 Mbps** (BLE) and can handle larger data transfers.
- **Fan-out**:
  Bluetooth supports **point-to-point communication** (1-to-1) in its classic form. However, with **Bluetooth mesh**, many-to-many communication is possible, supporting **hundreds to thousands** of devices, which is ideal for IoT applications.
- Range: **1-100m**, Speed: **Up to 3 Mbps (Bluetooth 5.0)**, Frequency: **2.4 GHz**
- **Applications**:
  Bluetooth is used for wireless communication in devices like headphones, smartwatches, fitness trackers, and car infotainment systems. It also enables file transfer between devices, remote control of smart home gadgets, and medical applications like wireless glucose monitors and heart rate sensors.

3. Infrared (IR)

- **Range of Communication**:
  Infrared communication is short-range and typically limited to **5 meters**. It requires a direct line of sight between the transmitter and receiver, as infrared light cannot pass through obstacles.
- **Cost**:
  IR components (LEDs, photodiodes, and sensors) are very cheap, making it a low-cost option for short-range communications.

- **Propagation Delay**:
  The delay is very low, typically in the **microseconds** range, making it suitable for quick signaling.
- **Power Consumption**:
  IR devices are low-power, requiring only a small amount of energy for transmission, making them ideal for remote controls and other small devices.
- **Throughput**:
  IR communication has a very low throughput, typically up to **4 Mbps** in systems like **IrDA** (Infrared Data Association), though most common uses (like TV remotes) operate at much lower data rates.
- **Fan-out**:
  IR is primarily designed for **point-to-point** communication, so it doesn't support fan-out like other technologies.
- Range: **<5m**, Speed: **Up to 16 Mbps**, Frequency: **300 GHz - 400 THz**
- **Applications**:
  Infrared technology is commonly used in remote controls for TVs, air conditioners, and home appliances. It is also utilized in thermal imaging cameras, night vision equipment, and short-range data transfer between mobile devices. Medical devices like pulse oximeters and temperature sensors also use IR communication.

4. 5G (Fifth Generation)

- **Range of Communication**:
  5G networks use a variety of frequency bands, which influence range. **Sub-6 GHz 5G** offers a range of about **2–5 kilometers** in urban areas. **mmWave (24 GHz and higher)** offers faster speeds but has a very limited range, often only **100–200 meters** in optimal conditions.
- **Cost**:
  The deployment of 5G infrastructure is expensive, including base stations, antennas, and the necessary upgrades to telecom networks. However, 5G-enabled devices such as smartphones can range from $300 to $1000.
- **Propagation Delay**:
  5G has low latency, typically **1–10 milliseconds**, making it ideal for applications requiring real-time feedback, such as augmented reality, autonomous driving, and high-speed gaming.
- **Power Consumption**:
  While 5G offers high-speed communication, it also has high power consumption. However, **5G NR (New Radio)** technology incorporates optimizations for better energy efficiency than previous generations like 4G.
- **Throughput**:
  5G offers ultra-high throughput, with speeds potentially exceeding **10 Gbps**, depending on the frequency band and the technology in use (e.g., **mmWave** or **Sub-6 GHz**).
- **Fan-out**:
  5G is designed to handle **massive device connectivity**, with the ability to support up to **1 million devices per square kilometer**, which is crucial for the growing number of IoT devices.
- **Up to 10 km**, Speed: **Up to 10 Gbps**, Frequency: **450 MHz - 52 GHz**

- **Applications**:
  5G is used in high-speed mobile networks, enabling ultra-fast internet access, cloud gaming, and real-time video streaming. It supports applications in autonomous vehicles, smart cities, industrial automation, and remote healthcare, including robotic surgeries and telemedicine.

5. Zigbee

- **Range of Communication**:
  Zigbee has a typical range of **10–100 meters**, but it can vary based on environmental conditions. In mesh network configurations, it can extend further.
- **Cost**:
  Zigbee is cost-effective, with modules priced similarly to Bluetooth, making it suitable for low-cost IoT applications.
- **Propagation Delay**:
  Zigbee is optimized for low-latency communication with a typical delay of **10–50 milliseconds**, but it's not as fast as Wi-Fi or 5G.
- **Power Consumption**:
  Zigbee is designed for **low-power consumption**, ideal for battery-powered IoT devices. Devices can last for **years** on small coin-cell batteries.
- **Throughput**:
  Zigbee supports lower data rates, up to **250 kbps**. It's optimized for small data transmissions and infrequent communication rather than high-speed data transfer.
- **Fan-out**:
  Zigbee's **mesh networking** allows for **large-scale networks**. Zigbee networks can support **thousands of devices** in a single system.
- Range: **10-100m**, Speed: **250 kbps**, Frequency: **2.4 GHz, 915 MHz, 868 MHz**
- **Applications**:
  Zigbee is widely used in smart home automation for controlling lights, thermostats, and security systems. It is also applied in industrial automation, agricultural monitoring, and healthcare applications, including wireless patient monitoring systems.

6. LoRa (Long Range)

- **Range of Communication**:
  LoRa has a long communication range, with typical ranges of **2–5 kilometers** in urban areas and **up to 15 km** in rural areas. It uses low-power, wide-area networking (LPWAN).
- **Cost**:
  LoRa modules are low-cost, making it affordable for IoT applications, particularly in agriculture, smart cities, and environmental monitoring.
- **Propagation Delay**:
  LoRa is designed for relatively low-latency communication, with delays ranging from **100 to 500 milliseconds**.

- **Power Consumption**:
  LoRa is designed for **low-power operation**, and devices can run for **years** on small batteries, ideal for remote IoT devices like environmental sensors or agricultural monitoring.
- **Throughput**:
  LoRa has a very low throughput, usually in the range of **0.3–27 kbps**. It is optimized for small, infrequent data packets rather than large data transfers.
- **Fan-out**:
  LoRa networks can support a large number of devices, making it ideal for wide-area IoT applications, with a **high number of devices** connected in a single system.
- Range: **Up to 15 km**, Speed: **0.3-50 kbps**, Frequency: **868 MHz (EU), 915 MHz (US)**
- **Applications**:
  LoRa is ideal for long-range IoT applications such as smart agriculture, where it helps in monitoring soil moisture and weather conditions. It is used in smart cities for street lighting, parking management, and air quality monitoring. LoRa also supports logistics and supply chain tracking.

7. NFC (Near Field Communication)

- **Range of Communication**:
  NFC operates within a very short range of **typically 10 cm**. This range is necessary for security and convenience in use cases like contactless payments or secure access.
- **Cost**:
  NFC technology is low-cost, with modules priced similarly to Bluetooth.
- **Propagation Delay**:
  NFC communication is near-instantaneous, with propagation delays in the **nanoseconds to microseconds** range.
- **Power Consumption**:
  NFC has very low power consumption. The energy required to read or write NFC tags is minimal, which is why it's widely used for passive tags.
- **Throughput**:
  NFC supports low throughput, up to **424 kbps**, which is enough for short data exchanges like card payments or linking devices.
- **Fan-out**:
  NFC supports **point-to-point communication** only, so it doesn't have a fan-out capability like other technologies.
- Range: **<10 cm**, Speed: **424 kbps**, Frequency: **13.56 MHz**
- **Applications**:
  NFC is commonly used in contactless payments, enabling transactions through smartphones and credit cards. It is also used for secure access control in offices and transportation systems. NFC tags enable quick pairing of Bluetooth devices, smart advertising, and digital identity verificatio

8. Satellite Communication

- **Range of Communication**:
  Satellites provide **global coverage**, enabling communication over vast distances, such as between continents.
- **Cost**:
  Satellite communication is expensive due to the high cost of launching and maintaining satellites. Prices have decreased with newer low-earth orbit (LEO) systems, but it's still a costly technology.
- **Propagation Delay**:
  Because of the long distance signals travel between Earth and satellites, propagation delay is high, around **250 milliseconds** for geostationary satellites. LEO satellites have lower latency, typically under **100 milliseconds**.
- **Power Consumption**:
  The power consumption for satellite communication is moderate, considering the use of powerful ground stations and the need for satellite systems to communicate over long distances.
- **Throughput**:
  Satellite systems can offer throughput of up to **several Gbps**, especially with new systems like **SpaceX's Starlink**, providing broadband-like speeds.
- **Fan-out**:
  Satellite networks can support **global coverage** with millions of users connected, especially in remote areas where terrestrial networks are unavailable.
- Range: **Global**, Speed: **Up to 100 Mbps**, Frequency: **1 GHz - 40 GHz**
- **Applications**:
  Satellite communication provides global internet access, especially in remote areas where traditional networks are unavailable. It is used for GPS navigation, weather forecasting, military communication, and broadcasting services like television and radio transmission. Emergency disaster response teams also rely on satellite communication for connectivity.

9. Cellular (3G, 4G, LTE)

- **Range of Communication**:
  The range of cellular communication depends on the network infrastructure, with base stations covering a range of **up to 50 km** in rural areas and up to **5 km** in urban areas.
- **Cost**:
  The cost of cellular services is moderate to high, including infrastructure investments and service fees. However, devices like smartphones are relatively affordable.
- **Propagation Delay**:
  Cellular networks like **4G LTE** have relatively low latency, typically around **30–100 milliseconds**, suitable for most real-time applications.
- **Power Consumption**:
  Cellular communication requires moderate power, with devices consuming more power when transferring large amounts of data or using mobile networks.
- **Throughput**:
  - **3G**: Speeds up to **2 Mbps**.

    - **4G LTE**: Speeds can reach up to **1 Gbps**.
- **Fan-out**:
  Cellular networks can support **millions of users**, with **cell towers** handling multiple connections simultaneously.
- Range: **1-10 km**, Speed: **Up to 1 Gbps**, Frequency: **700 MHz - 2.7 GHz**
- **Applications**:
  Cellular networks support mobile internet, voice calls, and messaging. They enable applications like telemedicine, mobile banking, ride-sharing services, and smart transportation. 4G networks support high-speed video streaming, remote work, and real-time navigation systems.

Technology	Range	Cost	Propagation Delay	Power Consumption	Throughput	Fan-out
Wi-Fi	30-300m	Moderate	Low (ms)	Moderate	Up to 10 Gbps	High
Bluetooth	10-100m	Low	Low (ms)	Low	2-3 Mbps	Moderate
Infrared (IR)	5m	Very Low	Very Low (ms)	Low	Up to 4 Mbps	Point-to-point
5G	Several km	High	Very Low (ms)	High	10 Gbps+	Very High
Zigbee	100m	Low	Moderate	Very Low	Up to 250 kbps	High
LoRa	Several km	Low to Moderate	Low to Moderate	Very Low	Up to 27 kbps	High
NFC	10 cm	Low	Very Low (ms)	Very Low	Up to 424 kbps	Point-to-point
Satellite	Global	High	High (250 ms)	Moderate	Several Gbps	Global
Cellular (3G/4G)	50 km+	Moderate to High	Low (<100 ms)	Moderate	2 Mbps - 1 Gbps	Millions

Conclusion :

Wireless technologies have evolved significantly, offering various solutions based on range, speed, frequency, and application requirements. Short-range technologies like **Bluetooth, Zigbee, and NFC** are suitable for personal and IoT applications, while **Wi-Fi and Cellular networks (4G, 5G)** provide high-speed data transmission over medium to long distances. Technologies like **LoRa and Satellite communication** enable connectivity in remote areas where traditional networks are not feasible.