Department of Biomedical Engineering

VI Semester

CBM 370 - Wearable Devices

Unit- 3 WIRELESS HEALTH SYSTEMS

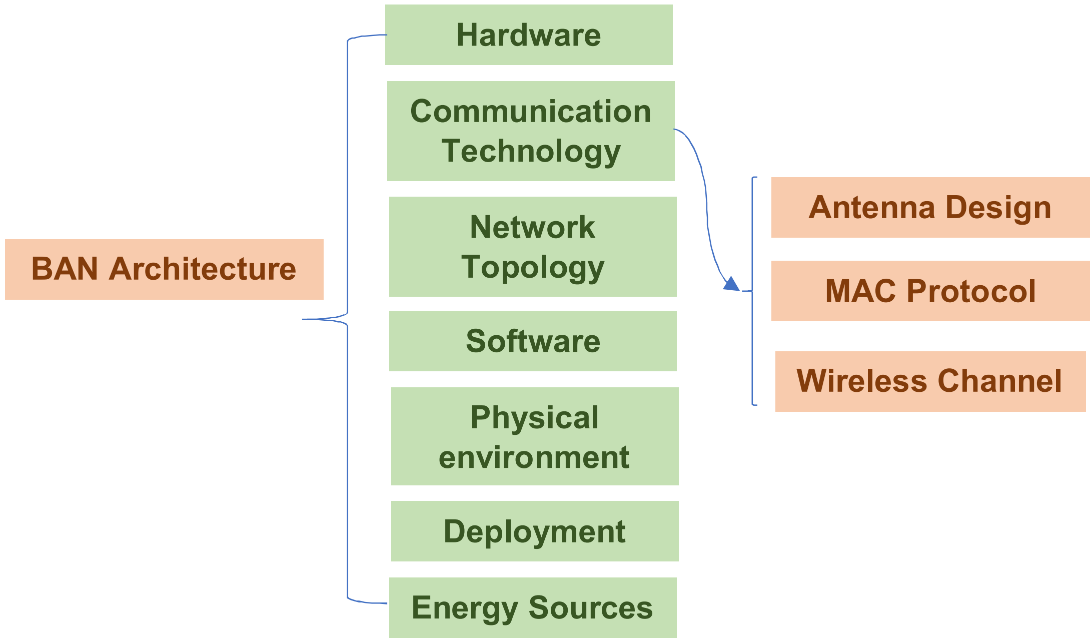
3.5 BAN Architecture

The nodes in a BAN are of varied capabilities; however, they can be broadly classified into two categories:

1. sensor nodes, which are implanted or wearable medical devices or simply low-capability wireless computing platforms interfaced with sensors and actuators (e.g., a PPG sensor interfaced with TelosB motes); and
2. base-station nodes, which have higher computational and communication capabilities (e.g., smart phones) than the worker nodes, and are used for disseminating information to and collecting information from the worker nodes.

- The base station controls the entire BAN and can reach every node in it in a single hop. It has significantly higher computational and communication capabilities than do the sensors, therefore all sensors send their data to it for processing.
- Note that, unlike in traditional wireless sensor network applications where there is limited control over the sensor networks after deployment, the BAN is a fairly controlled system, being under the supervision of the patient or medical personnel at all times.
- IEEE Task Group 6 (TG6) (http://ieee802.org/15/pub/TG6. html) has defined the standard architectures of a BAN.

❖ According to the standards the prominent characteristics of a BAN architecture can be summarized as follows.



3.7.1 Hardware:

❖ Sensors in a BAN are heterogeneous with respect to hardware configuration.

❖ With recent advances in embedded-systems research a plethora of small-scale computing units, radios, and storage devices can be implemented.

❖ Most of these are suitable candidates for BAN hardware.

❖ According to IEEE TG6, the hardware components of the BAN maybe

(1) **a general-purpose sensor** (e.g., TelosB motes, http://www.xbow. com/, in which a low-power micro-controller is interfaced with several sensors such as humidity, temperature, and light sensors),

(2) **a medical device** (e.g., a pulse-oximeter device for monitoring the pulse rate of an individual, which consists of an LED array, a photodetector, a micro-controller, and a radio for communication purposes),

(3) **data collectors or aggregators**, such as a bedside monitor or an image collector for a pill camera,

(4) **a controller or tuner**, such as an infusion-pump controller, or

(5) **a gateway or access point**, which can be a smart phone.

- ❖ With regard to general-purpose sensing, several commercial BAN platforms have been proposed to provide the computation, communication, and storage backbone for the sensors.
- ❖ The processors that are extensively used in such platforms are MSP430 from Texas Instruments, xScale or AtomTM from Intel, ATMEGA 128 from Atmel, and the ARM processor.
- ❖ Also, field-programmable-gate-array (FPGA)-based sensor nodes or application-specific-integrated-circuit (ASIC) components have been proposed for application-specific implementations.
- ❖ Further, hybrid platforms whereby different types of processors are integrated in the same board are being considered for better distribution of computation. In such cases, an FPGA might be interfaced with an Intel Atom processor such that the computationally intensive signal-processing task can be delegated to the fast-dedicated FPGA, while data-collection and-storage tasks can be performed by the Intel Atom.
- ❖ Apart from general-purpose sensing, platforms for sensing and processing specific signals such as electrocardiograms and photo plethysmograms have been developed.
- ❖ Special attention to their easy wearability, implantability, and unobtrusive ness has yielded a plethora of flexible sensing devices such as ECG patches (http:// www2.imec.be/), nano-sensors (http://www.nanosensors.com/),andsmart clothing (http://www.crunchwear.com/).
- ❖ Research in flexible electronics has further boosted wearable- or implanted-sensor design. In the base station, the smart phones use the ARM or the Intel Atom processor, and are more sophisticated than the sensors.

3.7.2 Network topology:

- ❖ BANs consist of two types of computing units:

(1) **sensor nodes**, which have a low processing capability; and

(2) **the base station**, which is a high-end computing device such as a cell-phone or a PDA

- In a BAN the computing units communicate with each other through a wireless channel, since wires running between sensors in a BAN would make it obtrusive.
- The sensor communication is assumed to be reliable, and each sensor is time synchronized, using several schemes that are based on packet-arrival time.
- Each node in a BAN has a set of neighboring nodes with which it can communicate through a one-hop wireless link (indicated by the communication range in Figure 3.5.1).
- Three network topologies have been recommended by IEEE TG6, as shown in Figure 3.5.2.
- Figure 3.5.2(a) shows the **star topology**, where each node has a one-hop wireless link to the base station. Multi-hop routing from the nodes to the base station is also recommended in the **mesh topology** shown in Figure 3.7.2(b)

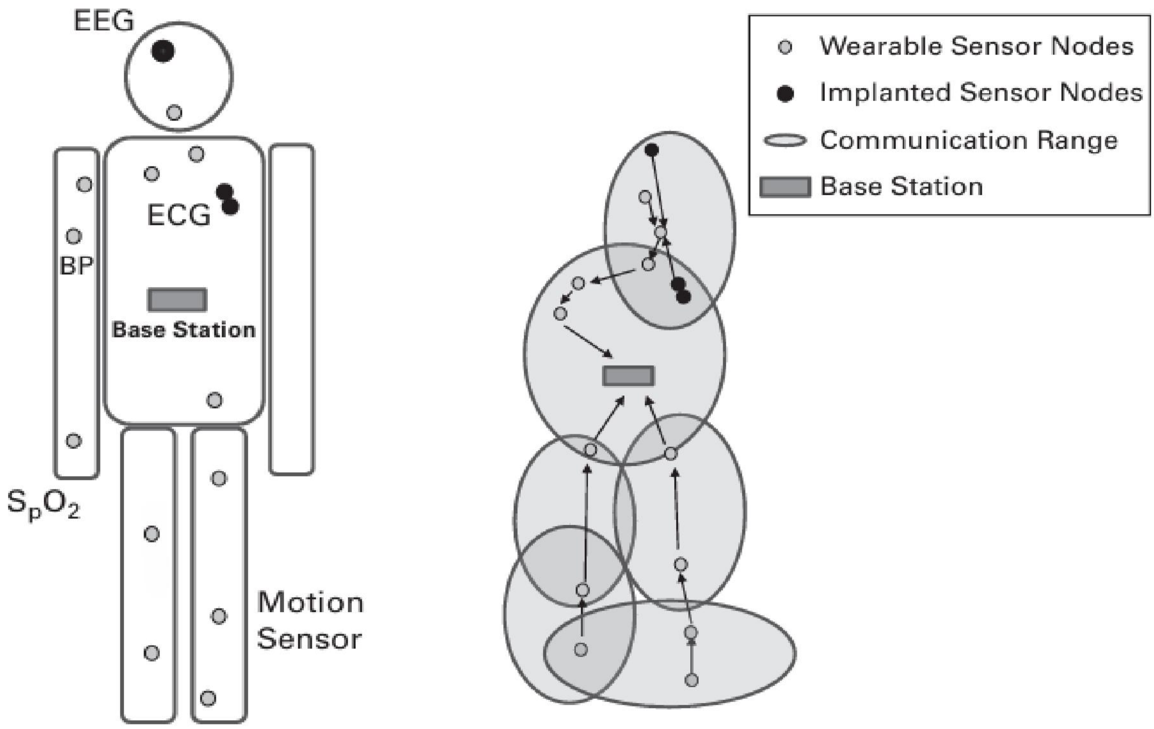


Figure 3.5.1 A body area network

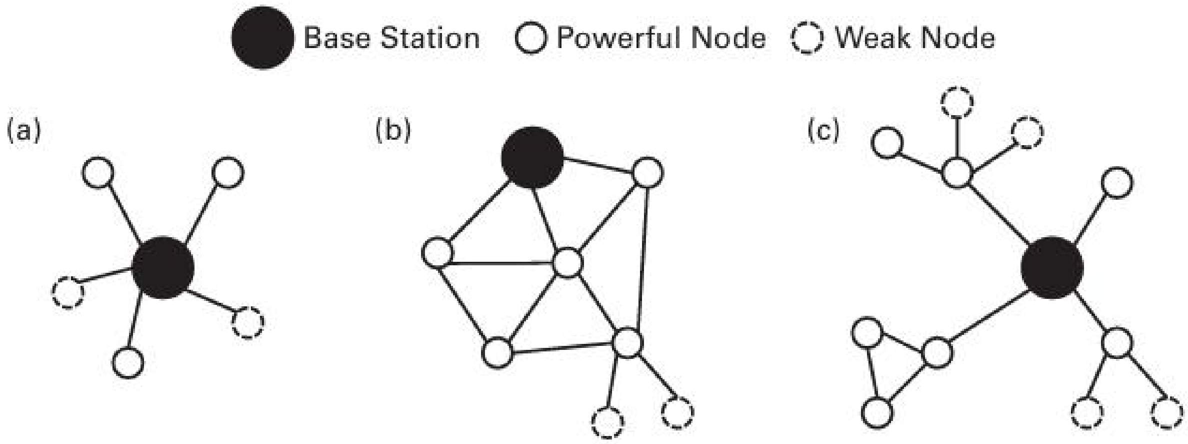


Figure 3.5.2 BAN network topologies recommended by IEEE TG6: (a) star topology, (b) mesh topology, and (c) hybrid topology

- A combination of single-hop access to the base station for powerful nodes and multi-hop access for weaker nodes is employed, with the base station at the root collecting the data from all the sensor nodes, in the **hybrid topology** shown in Figure 3.5.2(c).

3.7.3 Communication technology:

- Several communication technologies have been proposed for BANs, which vary in range, power consumption, frequency of transmission, and form factor. The communication infrastructures for BANs have a similar layered structure to the OSI stack. As shown in Figure 3.5.3, the BAN communication protocol stack has five layers:
  (1) **the physical layer**, which deals with the antenna and radio hardware;
  (2) **the medium-access control (MAC) layer**, which deals with channel access and contention management;
  (3) **the network layer**, which deals with routing management and reliable data transfer;
  (4) **the application-support sublayer**, which deals with applications such as securing the communication infrastructure; and
  (5) **the application framework**, which provides abstractions of the basic functionalities of the radio to any application.

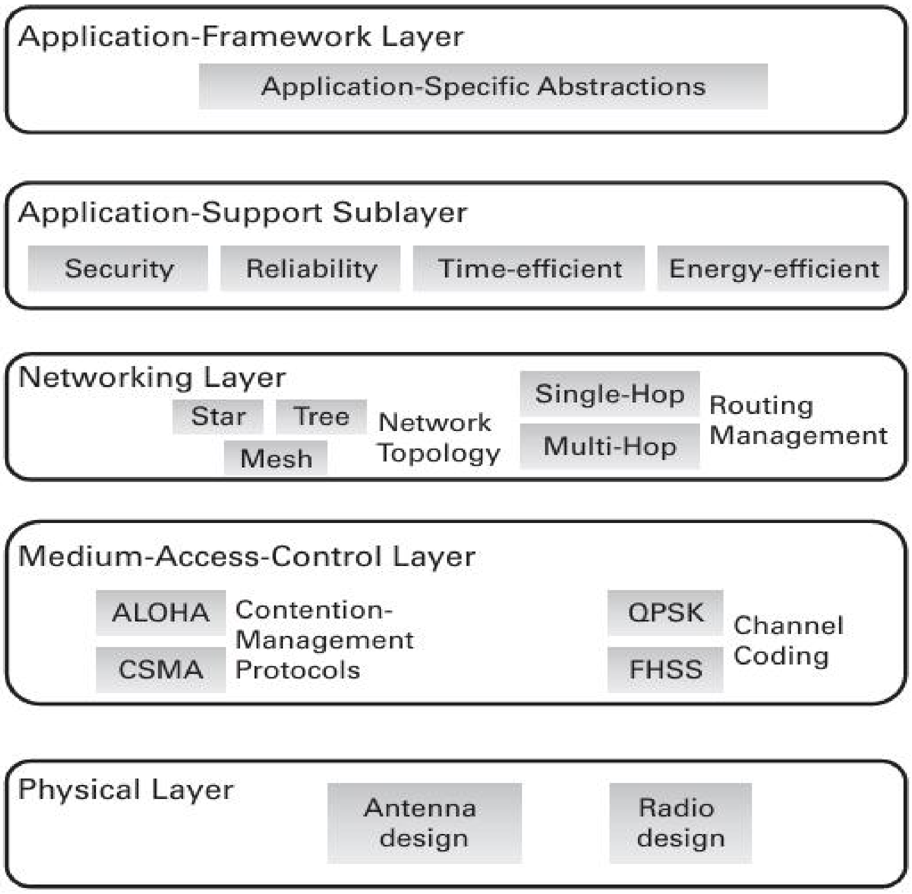


Figure 3.5.3 The protocol stack of a body area network.

(A). Antenna design:

- The quality of reception and transmission of data in the BAN depends largely on the design of the antenna.
- Since the form factor of sensor nodes in the BAN is constrained for easy wearability, the size of the antenna typically is very small.
- In some sensor nodes, such as Mica2 (http://xbow.com), the antenna is a quarter-wave dipole antenna that juts out from the PCB.
- However, in more current versions of the sensor nodes, such as in TelosB, BSN v3, Shimmer, and iMote2, the antenna is embedded in the PCB, where an inverted-F antenna, a miniaturized surface mount antenna, a chip antenna, and a full version of the surface mount antenna are used respectively.
- Owing to the antenna size the reception quality, measured using the packet-drop-ratio (PDR) metric, is affected.

- ❖ For example, at the same transmission power levels, the BSN v3 node has a very much lower PDR than that of the Imote2 node, which has the same antenna design.

(B). MAC protocol:

- ❖ The MAC protocol ensures that the wireless channel is accessed without contention and reliable data transfer is achieved.
- ❖ The principal types of radios used in BANs are listed in Table 3.7.1. The ZigBee radio is used for mesh networking and is particularly suitable for BAN multi-hop communication.

Table 3.5.1 Radio standards

	ZigBee	6lowPAN	Bluetooth low power	IEEE TG6 recommendation
Frequency	2.4 GHz	868/915 MHz	2.4 GHz	1 THz
Form factor	length 80 mm, width 26 mm, height 8.5 mm	12.7 mm × 25.4 mm × 3.5 mm	13.4 mm × 25.8 mm × 2 mm	No specific recommendation
Speed	250 kbps	250 kbps	3 Mbps	1 Gbps
Range	70 m	15 m	1–100 m	10 m
MAC protocol	CSMA-CA	QPSK	FHSS	
Power	2.5–100 mW	1 mW	75–90 mW	

- ❖ The channel-contention policy used by ZigBee is carrier-sense multiple-access-collision avoidance (CSMA CA), and is suitable for long-range communication with periodic data transfer.
- ❖ Often individual medical devices are interfaced to the smart phone through Bluetooth, which is suitable for short-range master–slave connection and intermittent transfer of data.
- ❖ Bluetooth uses the frequency-hopping spread-spectrum (FHSS) MAC protocol to resolve contention.
- ❖ However, such radio standards consume considerable amounts of power and are often not suitable for long-term or in-vivo operation. Hence, researchers have considered developing low-power radio standards such as 6lowPAN (http://6lowpan.net) and Bluetooth low power, which consume considerably less power.

(C). Wireless channel:

- The sensors in the BAN use the wireless channel to transfer data to the base station.
- The wireless channel is prone to errors such as random bit errors, burst errors, and fading errors.
- Several different channel models have been considered for BAN communication, where path loss is modelled as Ricean or Rayleigh.
- However, since the sensors are around the human body and are confined within a smaller area, it is near-field communication (NFC) and the fading is of small scale.
- Hence, a log-normal channel model fits better for BANs.
- Over the years, researchers have also considered using the human body as the communication channel.
- IEEE TG6 has also provided the standards for channel models of the human body, namely bio channels.
- Further, using the human body as a channel reduces overhearing and hence improves security. However, safety issues such as radiation safety and thermal safety pose an important challenge in using the human body as the communication channel.

3.5.4 Software:

- The BAN has two classes of software for programming the sensor and the base station.
- For the sensor, generally an event-driven programming paradigm is followed, whereby computation is scheduled on occurrence of an event.
- TinyOS is such an event-driven operating system, and is most commonly used for sensors.
- For the base station, there are three popular types of software used for smart phones: Android, which is open source, iOS, solely for programming iPhone by Apple, and Windows SilverLight.

3.5.5 Deployment:

- The sensors in the BAN are either worn on or implanted within the human body.
- The exact placement of sensors on or within the human body depends on the application. (e.g., fingertip pulse oximeters (www.smithsoem.com) are worn on the index finger).
- Further, recent research endeavors have networked the sensors in the BAN with car sensors to provide a car area network (CAN).
- Use of a BAN in automotive contexts has been shown to increase the safety of the driver by providing early feedback on fatigue.
- With the advent of social media such as Facebook, MySpace, and Google+, researchers have also investigated the combined usage of BAN and social media to facilitate easy sharing of health data and faster diagnosis

3.5.6 The physical environment:

- The physical environment is the BAN deployment environment (generally the human body).
- The operation of the sensor nodes in the BAN is inherently coupled with the environment through sensing or actuation or through side-effects of the computing on the environment (e.g., heat dissipation).

3.5.7 Energy source:

- The sensors and base station of the BAN have to be wireless devices in order to facilitate user mobility.
- Hence, the primary power sources for these devices are batteries. The lifetime of the BAN devices is thus limited by the battery capacity.
- For designing sustainable BANs it is important to use the battery in an efficient way. This requires a BAN designer to understand the load characteristics of the battery as it ages.
- A battery is primarily a means of storage of electrical energy. Batteries can be broadly classified into two groups:

    (1) re-chargeable, which can be re-charged upon full dis charge and reused; and

(2) un-chargeable, which can be used only once and cannot be recharged.

- ❖ Typically, for smart-phone devices, which serve as the base station for the BAN, the batteries are re-chargeable, while for sensor devices both types are used, e.g., TelosB (xbow.com) sensors need battery replacements, while the shimmer sensors (shimmer-research.info), use re-chargeable batteries. A re-chargeable battery is characterized by five key properties:

1.Cycle life: One cycle life of a battery is a discharge from full charge to full discharge and are turn to full charge again. The battery capacity is often measured by the number of cycle lives it can provide before the peak voltage drops.

2. Fast charging time: There are several methodologies to charge a battery. Typically a control circuitry is used to rapidly charge the batteries without damaging the cells' elements. Most such chargers have a cooling fan to help keep the temperature of the cells under control. Other existing types of charging are through USB and pulse chargers. The specification of a battery includes the fast charging time, which essentially lists the time taken to charge from zero to full charge using the control circuitry.

3. Overcharge tolerance. Batteries charged without using the control circuitry can be subject to overcharge. Poles can get reversed if batteries are overcharged. Typically, three levels of overcharge tolerance are reported– low, medium, and high.

4. **Self-discharge rate**. When not used, the battery slowly drains its charge due to inefficiencies in its design, which gives rise to internal resistance.

5. Gravimetric energy density. This is a term used for the amount of energy stored in a given system or region of space per unit volume

3.5.8 Three-tier communication model for a Body Area Network (BAN):

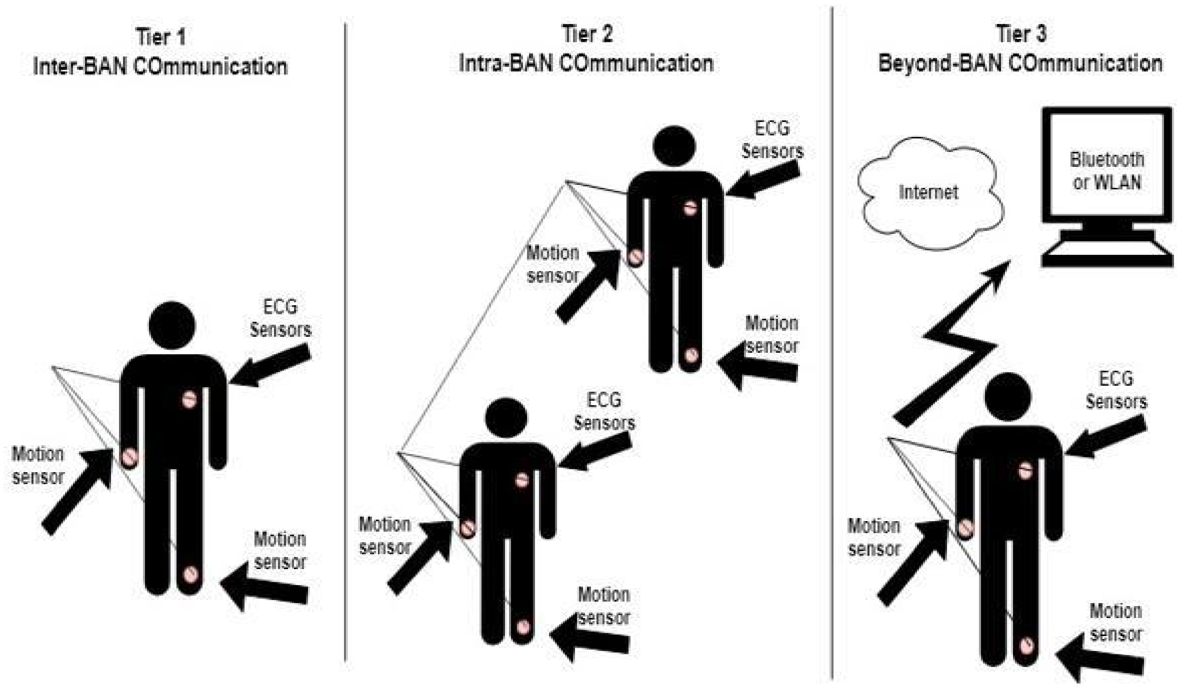


Fig. 2 Architecture of WBAN

❒ **Tier 1 - Inter-BAN Communication**

- ✓ Communication occurs between sensors on the same body.
- ✓ ECG sensors and motion sensors send data within the WBAN.
- ✓ Typically uses short-range communication like Bluetooth or Zigbee.

❒ **Tier 2 - Intra-BAN Communication**

- ✓ Communication occurs between multiple WBANs (e.g., between different individuals).
- ✓ Useful in scenarios like group health monitoring, collaborative healthcare, or team-based sports analytics.

❒ **Tier 3 - Beyond-BAN Communication**

- ✓ The collected sensor data is transmitted to an external network.
- ✓ Uses Bluetooth, WLAN, or the Internet to send information to remote servers or healthcare providers.
- ✓ Enables remote monitoring, telemedicine, and cloud-based health analytics.

Summary:

Components of BAN Architecture:

The **Body Area Network (BAN) Architecture** consists of several key components that enable efficient communication and data processing for health monitoring, fitness tracking, and other applications. These components can be categorized into the following:

1. Sensors (Wearable or Implantable)

- **Physiological Sensors**: Monitor vital signs such as ECG, heart rate, temperature, blood pressure, etc.
- **Motion Sensors**: Detect body movement, posture, or activity levels.
- **Environmental Sensors**: Monitor external conditions like air quality, temperature, or radiation exposure.
- **Implantable Sensors**: Placed inside the body for long-term health monitoring (e.g., glucose monitors, pacemakers).

2. WBAN Nodes

- Low-power devices that collect data from sensors.
- Act as communication hubs to transmit sensor data.

3. Communication Module

- **Intra-BAN Communication (Tier 1)**: Communication between sensors within the body.
- **Inter-BAN Communication (Tier 2)**: Data exchange between multiple BANs.
- **Beyond-BAN Communication (Tier 3)**: Transmitting data to external devices via Bluetooth, Wi-Fi, or cellular networks.

4. Personal Device/Gateway

- A smartphone, smartwatch, or custom device that acts as an intermediary between BAN sensors and the external network.
- Handles initial data processing and relays information to remote servers.

5. External Network & Cloud Storage

- Enables remote data storage and processing.
- Supports telemedicine, real-time monitoring, and AI-based analytics.

6. Security & Privacy Mechanisms

- Ensures data encryption, authentication, and secure access to prevent unauthorized use.
- Includes encryption protocols, anonymization techniques, and access control mechanisms.

7. Power Management System

- Energy-efficient solutions for extending sensor and device battery life.
- Includes energy harvesting techniques such as body heat, motion-based, or wireless charging solutions.

8. Data Processing & Analytics

- AI and machine learning models analyze sensor data.
- Detects abnormalities, generates health insights, and provides alerts.

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