

AL MUSTAQBAL UNIVERSITY

## **Hardware Architecture of Sensing**

## المادة : Wireless Body Sensor Networks

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# Hardware Architecture of Sensing Nodes and Communication Medium

Welcome to our comprehensive exploration of sensing node architecture and communication technologies. In this presentation, we'll break down the essential components that make up modern sensing systems and examine how they communicate with one another.

We'll start by looking at the basic building blocks of sensor nodes before diving into each component in detail. Finally, we'll discuss the various communication media that connect these nodes and explore future trends in this rapidly evolving field.

# Basic Components of a Sensor Node

## Sensing Unit

The sensing unit contains the actual sensors that detect physical phenomena and convert them into electrical signals. These may include temperature sensors, accelerometers, pressure sensors, or countless other specialized sensors depending on the application.

## **Processing Unit**

This is the brain of the node, typically a microcontroller or microprocessor that processes data from the sensors and executes the programmed logic. It manages memory, controls peripheral components, and makes decisions based on sensor inputs.

## Transceiver Unit

The transceiver handles communication, allowing the node to transmit collected data and receive instructions. It implements wireless protocols and manages the radio frequency operations essential for network connectivity.

## Power Unit

Providing energy to all components, the power unit typically consists of batteries and power management circuits. It may also include energy harvesting technology to extend operational life in the field.

# Sensing Unit

## Physical Sensors

Various types of sensors that detect environmental conditions like temperature, humidity, light, or pressure. Each sensor is designed to respond to a specific physical phenomenon by producing a corresponding electrical signal.

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## Signal Conditioning

Circuits that prepare the raw sensor signals for conversion by amplifying weak signals, filtering out noise, and compensating for sensor non-linearities to improve overall measurement accuracy.

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## Analog-Digital Conversion

ADCs transform the conditioned analog signals into digital data that can be processed by the microcontroller. The resolution and sampling rate of the ADC directly impact the precision of measurements.

Modern sensing units can incorporate multiple sensor types on a single node, creating multi-parameter measurement capabilities that provide a more comprehensive environmental picture while minimizing power consumption and physical footprint.



## **Processing Unit**

### Microcontroller/Microprocessor

The central computing element that executes instructions and processes sensor data.

8-bit to 32-bit architectures (e.g., ARM Cortex-M series)

Clock speeds typically 16MHz-180MHz •

Low-power sleep modes for energy conservation

### Peripherals

Additional hardware interfaces for expanded functionality.

- Digital I/O, PWM, and timer modules •
- Serial interfaces (I2C, SPI, UART) •
- External interrupt controllers •



Task scheduling and power management •

Storage components for program code and

- RAM: 2KB-512KB for runtime operations
- EEPROM/SD cards for extended data logging •

- Software platform managing hardware
- Real-time operating systems (e.g., FreeRTOS,
- Lightweight middleware for networking •

## Power Unit

Ē	<b>Power Sources</b> Primary and secondary batteries, capacitors, and energy harvesters that supply electricity		
B		<b>Power Management</b> Circuits that regulate voltage, control charging, and optimize power distribution	
Ð			<b>Energy Conservation</b> Software and hardware techniques to minimize end

Battery selection involves critical tradeoffs between capacity, size, cost, and environmental constraints. Common choices range from non-rechargeable lithium cells offering high energy density to rechargeable lithium-ion or lithium-polymer batteries that can be replenished through energy harvesting systems.

Energy harvesting technologies – including solar panels, piezoelectric generators, and thermoelectric converters – can significantly extend node lifetime by capturing energy from the environment. These systems require specialized power management circuits to handle the variable and intermittent nature of harvested energy.

Advanced power management techniques like dynamic voltage scaling, selective component shutdown, and adaptive duty cycling can extend battery life from months to years in low-power sensing applications.

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## **Communication Medium**



## Short-Range Technologies

Bluetooth Low Energy (BLE) excels in personal area networks with smartphones, offering simple pairing and low power consumption at ranges up to 100m. ZigBee creates reliable mesh networks ideal for home automation, supporting up to 65,000 nodes with very low power requirements. Thread provides IP-based connectivity specifically designed for smart home applications.

### Medium-Range Technologies

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Wi-Fi offers high bandwidth but at the cost of increased power consumption, making it suitable for data-intensive applications with access to continuous power. Z-Wave creates robust mesh networks specifically designed for home automation with excellent interoperability between different manufacturers' devices.



## Long-Range Technologies

LoRaWAN provides kilometers of range with minimal power, ideal for city-wide deployments. Cellular IoT technologies like NB-IoT and LTE-M leverage existing infrastructure for nationwide coverage with reasonable power consumption. Satellite communications offer truly global coverage but with higher cost and power requirements.

Network topology significantly impacts system resilience, power consumption, and scalability. Star topologies centralize control but create single points of failure. Mesh networks provide redundant paths but increase complexity. Tree topologies balance these factors for many applications.

## Challenges and Future Trends



As sensing technology advances, we're witnessing the integration of AI processing capabilities directly on sensor nodes. This edge computing approach reduces bandwidth requirements and enables real-time decision making without cloud connectivity, opening new applications in predictive maintenance, autonomous systems, and smart infrastructure.

The push toward extreme miniaturization continues to drive innovation in hardware design. Microscale sensing platforms no larger than a grain of sand are becoming technically feasible, enabling entirely new deployment scenarios like in-body medical monitoring or smart dust environmental sensing networks.

Security and privacy concerns remain significant challenges, particularly as sensing nodes collect increasingly sensitive data. Future architectures will need to incorporate hardware-level security features, secure boot processes, and efficient encryption even within severe power and processing constraints.