

Unit II: Wireless Health Monitoring Systems (WHMS)

8. Wireless Health Monitoring Systems (WHMS)

8.1 What Is a WHMS?

A Wireless Health Monitoring System (WHMS) is an integrated framework that uses wireless communication technologies to continuously collect, transmit and analyze physiological data from patients without restricting their mobility. Its core is the **Wireless Body Area Network (WBAN)** — miniature sensors placed on, around, or inside the body to monitor vital signs in real time.

- **Reduced caregiver workload** — continuous automated monitoring lightens clinical staff burden.
- **Improved patient mobility** — patients maintain quality of life while remotely monitored.
- **Lower healthcare costs** — early intervention and remote care reduce hospitalisation costs.

Overall shift: from hospital-centric, wired monitoring → location-independent, patient-centric care.

8.2 Historical Evolution

Period	Milestone
Early 2000s	Conceptualisation — initial research on wearable ECG/heart-rate sensors
2007–2010	Standardization begins — IEEE 802.15.6 (TG6) formed; early Bluetooth/ZigBee prototypes
2010–2015	Commercial adoption — fitness wearables go mainstream, smartphone & cloud integration
2016–2020	Medical-grade era — FDA approvals for Remote Patient Monitoring devices, IoT convergence
2020–present	AI & 5G acceleration — pandemic-driven growth, AI/ML analytics, 5G, advanced security

8.3 Three-Tier System Architecture

Tier	Function
Tier 1 — Intra-BAN (Body Area Network)	Sensor nodes (wearable/implantable/ingestible) collect ECG, EEG, EMG, temperature, SpO ₂ , glucose, BP; coordinator node (CCU) aggregates data with priority-based transmission.
Tier 2 — Inter-BAN (Personal Area Network)	Gateway devices (smartphone, PDA, dedicated hub) bridge the WBAN to external networks; edge computing enables local real-time preprocessing and alerts before any cloud round-trip.
Tier 3 — Extra-BAN (Wide Area Network)	Cloud/remote servers for long-term storage & advanced analytics; integration with Electronic Health Records (EHR); physician dashboards for remote multi-patient monitoring.

Three-Tier System Architecture

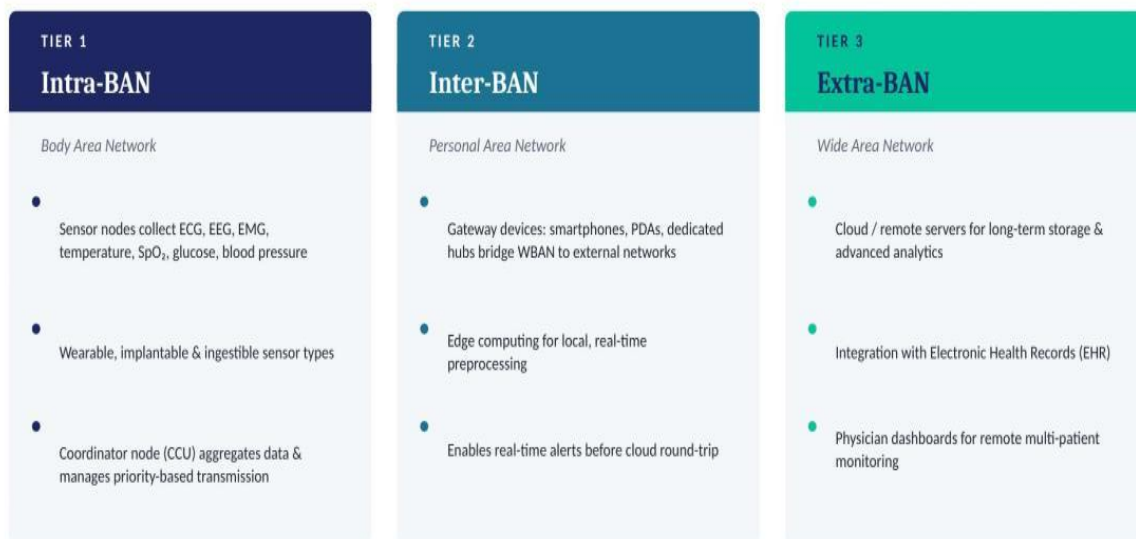


Fig 8.1 — Three-tier WHMS architecture: Intra-BAN → Inter-BAN → Extra-BAN

8.4 Wireless Communication Protocols

Technology	Standard	Key Characteristics	Medical Suitability
Bluetooth Low Energy	IEEE 802.15.1	Ultra-low power, ~10 m range, wide smartphone compatibility	Excellent for wearable sensors
ZigBee	IEEE 802.15.4	Low power, mesh networking, moderate data rate	Good for multi-sensor home monitoring
IEEE 802.15.6	Dedicated WBAN standard	Ultra-low power, high reliability, QoS support, security	Optimal for medical WBANs
Ultra-Wideband (UWB)	IEEE 802.15.6 (optional)	Very high data rate, low interference	High-bandwidth ECG/EEG streaming
MICS	402–405 MHz	Ultra-low power, propagates through body tissue	Essential for implantable devices
Wi-Fi / 5G	IEEE 802.11 / 3GPP	High bandwidth, long range, internet connectivity	Gateway-to-cloud transmission

8.5 MAC Protocols for Medical Data

Medical WBANs need specialised Medium Access Control (MAC) protocols that prioritise critical data (e.g., arrhythmia alerts) over routine measurements (e.g., temperature).

- **CSMA/CA** (Carrier Sense Multiple Access with Collision Avoidance) — used for critical, low-latency data such as emergency cardiac alerts requiring immediate transmission.
- **Polling / TDMA** (Time Division Multiple Access) — used for non-critical, power-efficient periodic data such as routine temperature readings.
- **Hybrid approach** — combines both to optimise reliability and battery life together.

8.6 Medical & Non-Medical Applications

Medical & Healthcare

- Continuous physiological monitoring: heart rate, BP, blood glucose, respiratory rate, body temperature.
- Chronic disease management: Parkinson's tremor tracking, epilepsy seizure detection, diabetes, cardiovascular disease.

- Post-operative & elderly care: fall detection, activity monitoring, medication-adherence tracking.
- In-hospital tracking: real-time location of patients & staff, drug-administration verification.

Beyond the Clinic

- **Sports & fitness** — athletic performance, gait analysis, calorie tracking.
- **Military** — soldier health and fatigue monitoring in the field.
- **Occupational safety** — continuous monitoring of workers in hazardous environments.
- **Gaming & AR/VR** — motion capture and body-as-input immersive interaction.

8.7 Challenges

Security & Privacy

- **Resource constraints** — limited computational power makes traditional encryption (e.g., RSA) impractical.
- **Physical accessibility** — wearable/implantable sensors are physically exposed and vulnerable to tampering.
- **Key management** — distributing/updating cryptographic keys across tiny, power-limited devices is complex.
- **Emerging solutions** — Elliptic Curve Cryptography (ECC), Attribute-Based Encryption (ABE), biometric key generation from ECG/PPG signals, blockchain for decentralised trust.

Power, Energy & Quality of Service (QoS)

QoS Parameter	Tolerance	Example
Latency	< 250 ms	Emergency cardiac alerts
Reliability	> 99.9%	Insulin pump control
Data rate	1–10 kbps to >1 Mbps	Temperature to ECG/EEG

- Sensor nodes must run for months to years on small batteries; higher data rate/transmission frequency increases power draw.
- **Solutions:** energy harvesting (thermal, kinetic, RF), ultra-low-power ASICs, dynamic duty cycling, sleep-wake scheduling.

Interoperability & Regulatory Hurdles

- Heterogeneous devices from different manufacturers often use incompatible protocols; lack of universal data formats hinders EHR integration.
- Seamless handover required: WBAN → Wi-Fi → 5G → Cloud.
- Medical devices require FDA/CE approval via extensive clinical trials; electrical isolation must ensure patient safety; implantable materials must be biocompatible.

8.8 Recent Advances (2024–2026)

- **AI & Deep Learning** — DNNs and ensemble classifiers for real-time activity recognition, epileptic seizure detection from imperfect EEG, predictive diagnostics.
- **5G & Tactile Internet** — ultra-reliable low-latency communication for remote surgery; massive machine-type communication for hospital-scale WBAN deployment.
- **Contactless Monitoring** — near-field coherent sensing (RFID-based) and bioimpedance analysis enable organ monitoring without skin contact.
- **Quantum-Enhanced Security** — quantum key distribution and quantum-resistant algorithms future-proof WBAN communication.
- **SDN & Blockchain** — software-defined networking for dynamic QoS allocation; blockchain for decentralised, tamper-proof health records.

8.9 Summary Table

Concept	Description
WBAN	Wireless Body Area Network — short-range network of physiological sensors on/inside the body
IEEE 802.15.6	Dedicated international standard for WBAN communications
MICS Band	402–405 MHz frequency band reserved for medical implant communications
CSMA/CA vs. TDMA	Contention-based vs. scheduled MAC protocols for medical data prioritisation
QoS	Quality of Service — ensures latency, reliability and bandwidth meet medical requirements
ECC / ABE	Lightweight cryptographic methods suitable for resource-constrained medical sensors
RPM	Remote Patient Monitoring — the clinical application layer built atop WBAN technology

Reference: R.S. Khandpur, Handbook of Biomedical Instrumentation, 3rd Edition (McGraw-Hill Professional, 2014). Lecture slide decks 2.1–2.5, Advanced Biomedical Instrumentation, prepared by Threase Sopra A., AP/DoBM.