Department of Electrical
and Computer Engineering

Body Area Networks: A Survey

ECE 720 – Cyber-Physical Systems
Course Presentation

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Publication of Interest

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Outline

- Introduction.
- BAN communication architecture.
- Hardware and devices.
- Physical layer.
- MAC layer.
- Radio technologies.
- Taxonomy of body sensor projects.
- Open research issues.
- Conclusion.

1. Introduction: A Basic Definition

Body Area Network is a class of networks deploying various sensors wirelessly connected , monitoring human physiological and vital signals for healthcare purposes.

Features of Body Area Network

- Mobility.
- Flexibility.
- Effectiveness and efficiency.
- Cost-effective.

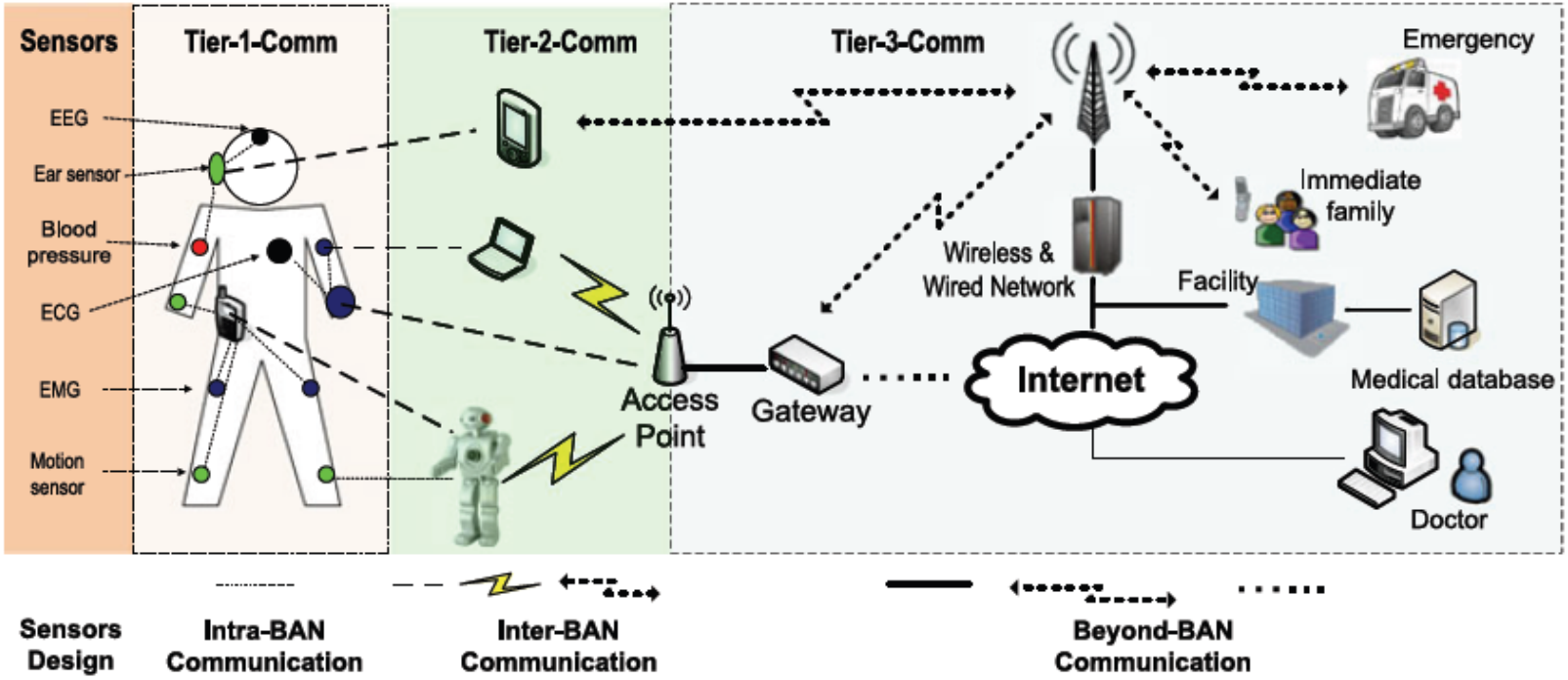
BAN Applications

- Remote health/fitness monitoring.
- Military and sports training.
- Interactive gaming.
- Personal information sharing.
- Secure authentication.

Design Constraints

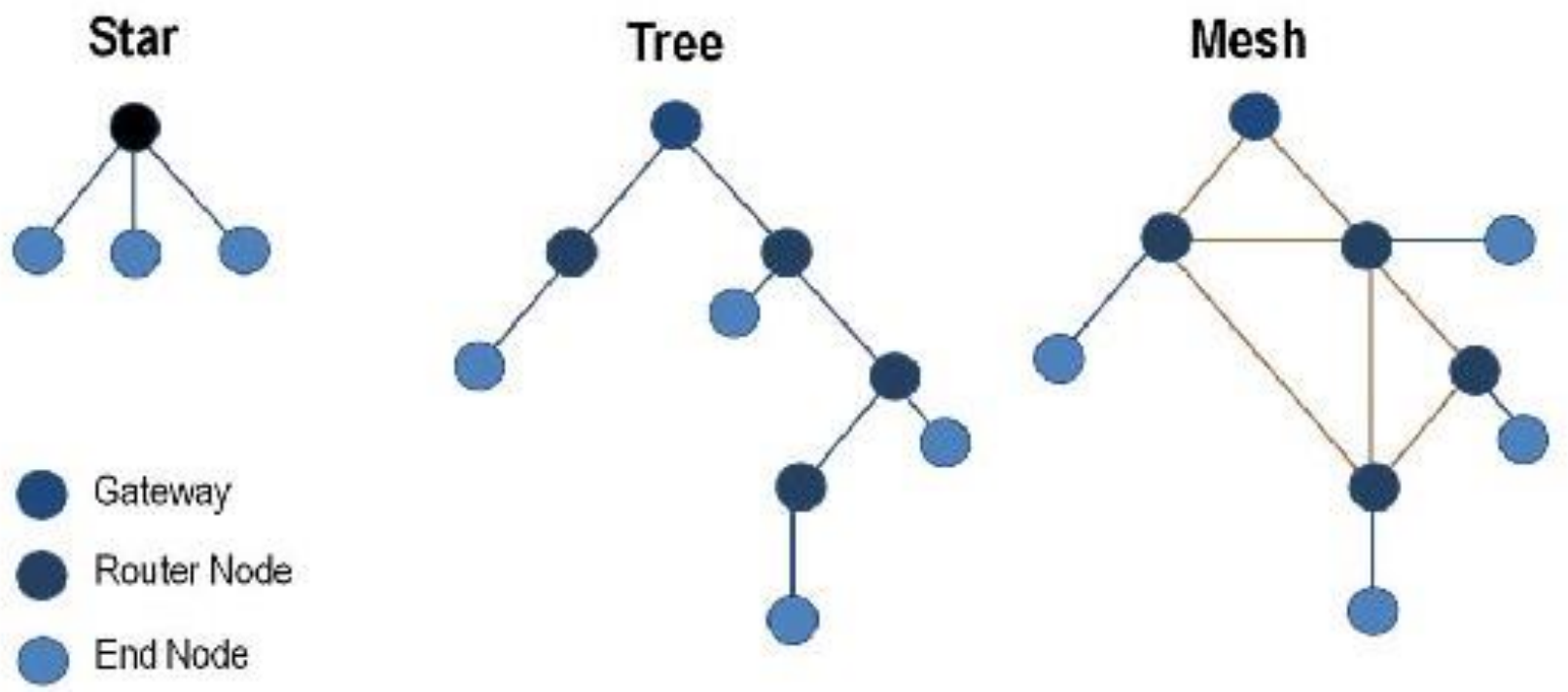
- **Sensor hardware:**
  - Thin.
  - Small.
  - Wirelessly enabled.
  - Non-invasive.
  - Very or Ultra low-power consumption.
- **Communication perspective:**
  - Higher network capacity.
  - Energy efficiency.
  - QoS.
- **Application level:**
  - Innovative architectures.

2. BAN Communication Architecture



A Three-tier architecture based on a BAN communications system

Different Network Topologies

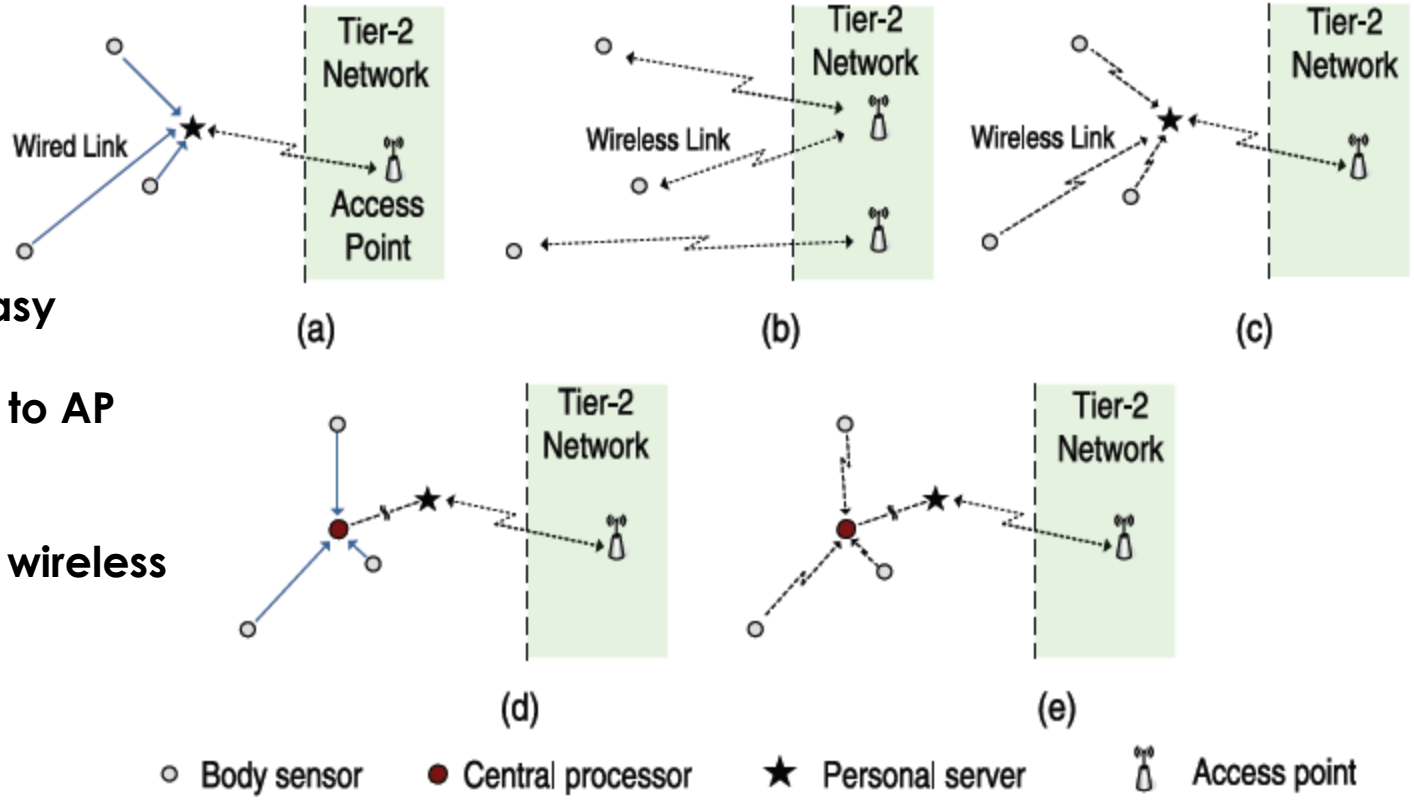


Source: National Instruments

Tier 1: Intra-BAN

- Intra-BAN is the radio communication in the range of **2 meters** around the body, which is subcategorized to:
  - Communication between body sensors.
  - Communication between body sensors and portable personal server.
- **Five** common architectures are used to connect body sensors to either personal servers or access points.

Intra-BAN Architectures



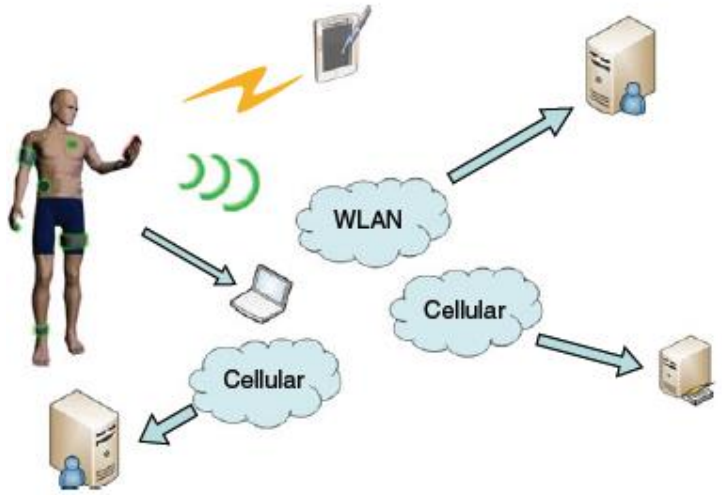
a. wired: easy
b. directly connected to AP
c. wireless
d. hybrid
e. cluster & wireless

Tier 2: Inter-BAN

- Inter-BAN is the communication between Personal Server (PS) and one or more Access Point (AP).
- Inter-BAN categories:
  - Infrastructure based architecture.
  - Ad-hoc based architecture.

Inter-BAN (cont.)

- **Infrastructure based architecture:**
  - sensor → PS → Network (3G, WLAN,…etc)
  - Larger bandwidth, centralized management and security control.



Inter-BAN (cont.)

- **Ad-hoc based architecture:**
  - Sensor → AP → Network.
  - Larger coverage.
  - Collision is high:

  CSMA/CA is required.
  - Types of nodes:
    - Sensor nodes.
    - Routing nodes.

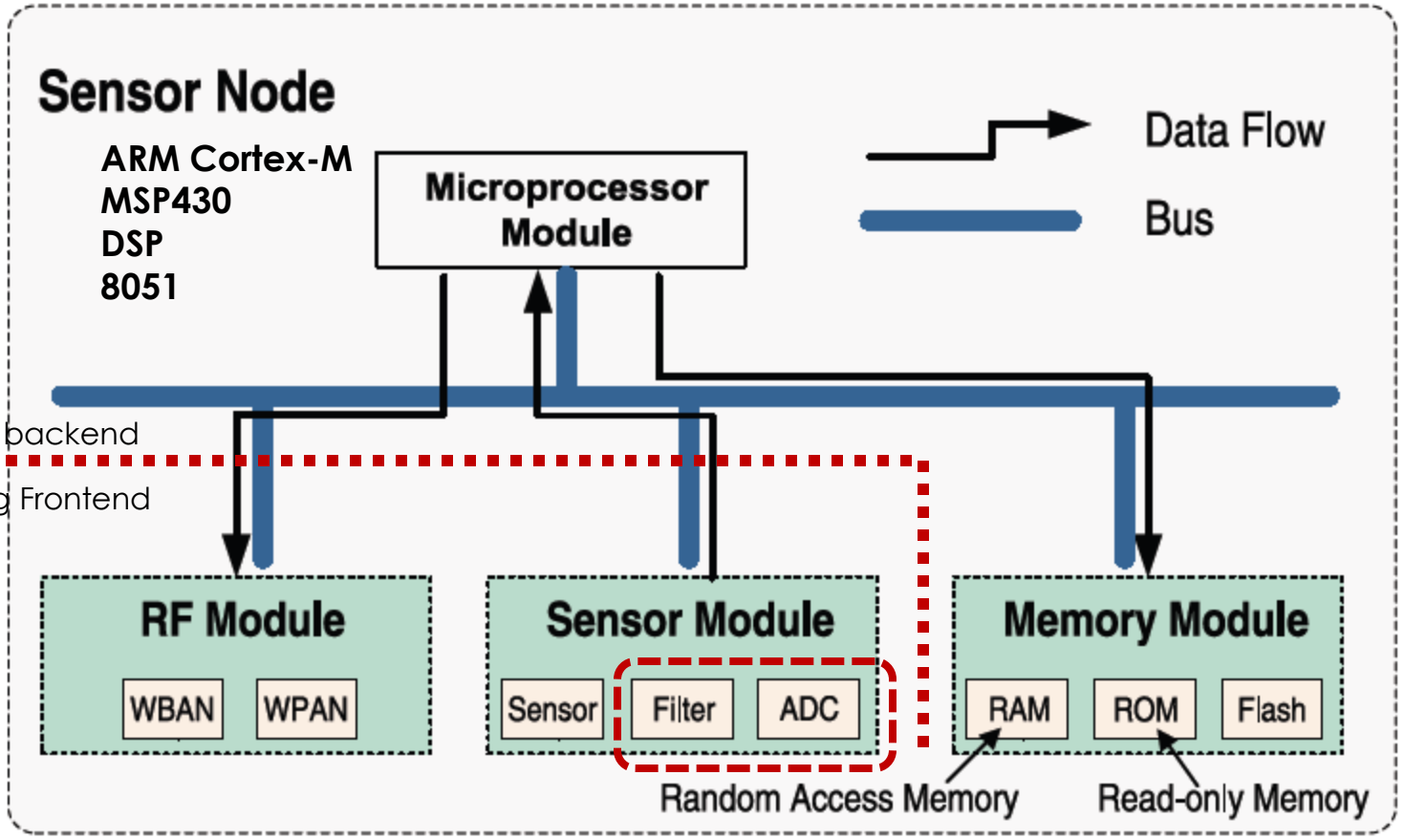
Wireless Technologies for Inter-BAN

- **Key factors** in choosing a wireless technology:
  - Low power consumption.
  - Low latency.
  - Low duty cycle (Idle, sleep – wake-up cycle).
- **Cellular**: GPRS, 3G, 4G (WiMax, LTE).
- **WLAN**.
- **Bluetooth**: EDR and Low-energy Bluetooth.
- **ZigBee** (IEEE 802.15.4/6).

Tier 3: Beyond-BAN

- For use in metropolitan areas.
- Connects to the inter-BAN through a **Gateway** (smartphone, PDA…etc).
- Key features:
  - Database and data storage.
  - Remote access for medical staff.
  - Increase and Maintain the coverage.

3. Sensor Hardware Design



Sensors used with BAN

Sensor	Topology	Data rate
Accelerometer/gyroscope	Star	High
Blood glucose	Star	High
Blood pressure	Star	Low
CO_2 gas sensor	Star	Very low
ECG sensor	Star	High
EEG sensor	Star	High
EMG sensor	Star	Very high
Pulse oximetry	Star	Low
Humidity	Star	Very low
Temperature	Star	Very low
Image/video sensor	P2P	Very high

Comparison of body sensor nodes

Name	OS support	Wireless standard	Data rate (kbps)	Outdoor range (m)	Power level
BAN node	TinyOS *	IEEE 802.15.4	250	50	Low
BTNode	TinyOS	Bluetooth	–	–	Low
eyesIFX	TinyOS	TDA5250	64	–	Low
iMote	TinyOS	Bluetooth	720	30	Low
iMote2	TinyOS or .NET	IEEE 802.15.4	250	30	Low
IRIS	TinyOS	IEEE 802.15.4	250	300	Low
Micaz	TinyOS	IEEE 802.15.4	250	75–100	Low
Mica2	TinyOS	IEEE 802.15.4	38.4	>100	Low
Mulle	TCP/IP or TinyOS	Bluetooth or IEEE 802.15.4	–	>10	Low
TelOS	TinyOS	IEEE 802.15.4	250	75–100	Low
ZigBit	ZDK	IEEE 802.15.4	250	3,700	Low

*** TinyOS** is a free and open source software component-based operating system and platform targeting wireless sensor networks (Wikipedia).

4. Physical Layer

- Frequency band: 402~405 Hz for **implanted sensors.**
- Frequency bands:13.5 MHz, 5~50 MHz, 400 MHz, 600 MHz, 900 MHz, 2.4 GHz and 3.1~10.6 GHz for **on-body sensors.**
- **Factors** contribute to **channel model**:
  - Environment: where the BAN user is located.
  - Link class: where sensor is located.
  - User's current activity: walking, running, jumping…etc.
- The complexity of human tissues' structure and body shape should be considered when characterizing the propagation of electromagnetic waves.

PHY: Antenna Design (cont.)

- Antenna gain must target lowest power consumption (maximum transmission/ reception with minimum power).
- The shape and size of an implant antenna depends on its location inside the body.
- Antenna design affected by:
  - User's posture.
  - Weight loss/gain.
  - Aging skin.

PHY: Protocol Design (cont.)

A protocol should support

- Seamless connectivity.
- In unlicensed bands robust protocol design is needed to mitigate interference.
- Power consumption

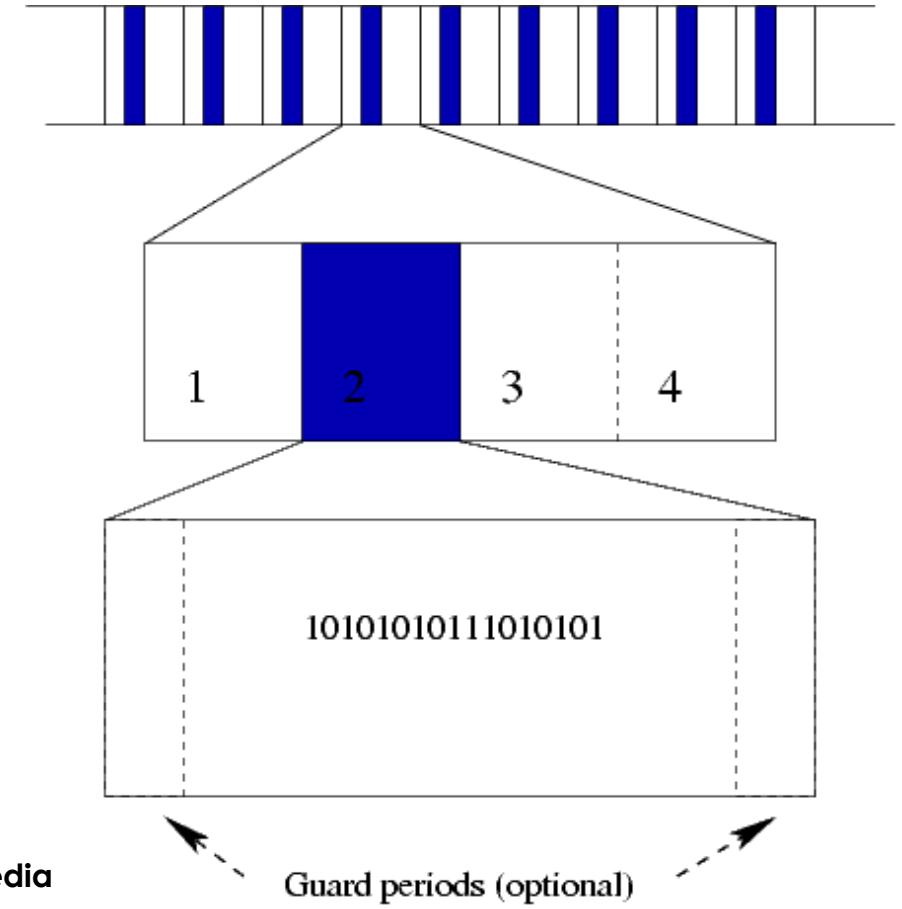
5. Media Access Control

- At the MAC layer, there is a **tradeoff** between **reliability**, **latency** and **energy consumption** that needs to be resolved.
- Energy efficient MAC protocols: several protocols propose to **synchronize** their transmission **schedule** and **listening** periods to maximize throughput, while **reducing energy** by **turning off radios** during much larger sleeping periods.

MAC Protocols

- **CICADA**: low-energy protocol design for multi-hop mobile high traffic BAN.
- **BAN-MAC**: ultra-low-power MAC protocol designed for star topology BANs.
- **H-MAC**: a novel TDMA-based MAC protocol, improve energy efficiency by **exploiting heartbeat rhythm** information to perform time **synchronization**.

Time Division Multiple Access (TDMA)



Data stream divided into frames

Frames divided into time slots. Each user is allocated one slot

Time slots contain data with a guard period if needed for syncronisation

Source: Wikipedia

QoS

- Handle real-time communications.
- optimization of
  - Latency.
  - Reliability.
  - Residual energy.
  - Transmission power

QoS Techniques in BAN

- **BodyQoS**: prioritize data stream service, asymmetric QoS framework, radio-agnostic QoS, and Adaptive Bandwidth Scheduling.
- **DQBAN**: uses a cross-layer fuzzy rulebased scheduling algorithm to optimize MAC layer performance in terms of QoS and energy efficiency, Less collisions and better transmission techniques

QoS Techniques in BAN (cont.)

- **IEEE 802.15.4 (ZigBee)** Beacon-enabled mode for QoS provisioning.
- **IEEE 802.15.6:** under development with open options to be used with ZigBee and UWB.

6. Radio Technologies

- Bluetooth.
- Bluetooth low-energy technology.
- ZigBee & IEEE 802.15.4
- Ultra-Wide Band (UWB).
- ANT.
- RuBee.
- Sensium.
- Zarlink.
- Insteon.

Bluetooth

- Master-slave architecture, star topology.
- Up to 8 devices in 10 meters range (piconet).
- Common clock and hopping sequence.
- Band: 2.4 GHZ ISM.
- Channels: 79
- Channel bandwidth: 1 MHz.
- Maximum data rate: 3 Mbps.

Bluetooth Low-energy Technology

- Provides ultra-low power consumption and cost using optimized hardware.
- Data rate: 1 Mbps.
- Topology: star.
- Uses fewer channels for less power consumption.

IEEE 802.15.4 – ZigBee

- Very low power consumption.
- Band: 2.4 GHz
- Data rate: 20 Kbps – 250 Kbps.
- MAC Support: CSMA/CA.
- Topology:
  - Star.
  - Cluster tree.
  - Mesh.

Ultra-Wide Band (UWB)

- Band: 3.1 GHz – 10.6 GHz.
- High data rates: e.g. wireless USB 480 Mbps.
- Ideal technology for precise localization and indoors BAN tracking.

Other Protocols

ANT and ANT+: light-weight protocol stack

- Ultra-low power consumption
- Data rate: 1 Mbps.
- Band: 2.4 GHz ISM.
- TDMA access method.

Other Protocols (cont.)

- **RuBee**: two way, active wireless protocol that uses Long Wave magnetic signals.
- Band: **131 KHz**, data rate: 1200 Baud (~ **15 Kbps**).
- **Sensium**: ultra-low-power platform for low data rate, topology: star.
- **Zarlink**: 2.45 GHz, used in **Implantable Medical Device**.
- **Insteon**: 900 MHz, targeting home automation.

7. Taxonomy of Body Sensor Projects

- **Remote health/fitness monitoring.**
- **Military and sport training.**
- **BAN based intelligent system:**
  - Intelligent biosensor system for vehicle-area-networks:
    - monitoring driver behavior information such as facial expression
  - Pervasive healthcare and affective computing: Monitoring emotion-related physiological signals.

BAN based intelligent system (cont.)

- **PEACH**: **detect** changes in patients' **physiological and emotional states**, and for **sharing** this information to interested **caregivers**, such as professional medical staff, relatives, and friends.
- **Digital-Being**: enables **dancers** to **express** their feelings and **moods** by dynamically and automatically **adjusting music and lighting** in a dance environment.

A comparison of existing BAN projects

Projects	Sensors	Intra-BSN communication	Inter-BSN communication	Beyond-BSN communication	Targeted Application
CodeBlue	Pulse oximeter EKG, motion	Wired	Mesh & Zigbee	N/A	Medical care
AID-N	Pulse, Blood, Temperature,ECG	Wired	Mesh & Zigbee	Internet/WiFi/ Cellular Networks	Mass casualty incident
SMART	ECG, SpO2 sensor	Wired	802.11b	N/A	Health monitoring In waiting room
CareNet	Tri-axial accelerometer/ gyroscope	N/A	Zigbee	Multi-hop 802.11/ Internet	Remote healthcare
ASNET	Blood pressure, temperature	Star topology	GPRS/GSM	N/A	Remote health monitoring
MITHril	ECG, EKG	Wired	WiFi	N/A	Healthcare
WHMS	ECG, EMG, EEG, SpO2 & motion sensor	Star topology	WLAN/Bluetooth/ GPRS	Internet	Telemedicine
WiMoCA	Tri-axial accelerometer	Star topology & Time table-based MAC protocol	Bluetooth	Internet/ Bluetooth/WiFi/ Cellular Networks	Gesture detection/sport
MIMOSA	Any sensors/ RFID sensor	Wibree/Bluetooth/ RFID	Cellular Networks	Internet	Ambient intelligence

8. Open Issues

- Integrating emerging wireless technologies in Inter-BAN communication.
- Enabling advanced E-healthcare services by using BANs.
- Physical layer.
- MAC layer: synchronization, capacity, power.
- Sensor devices:
  - Advanced sensor devices.
  - Physical characteristics of sensor/actuator materials and electronic circuits

9. Conclusion

- Motivation behind BAN.
- Radio technologies.
- Challenges for BAN design:
  - Comfortable, easy to use sensors.
  - Hardware (sensor, Antenna & RF and processing).
  - Network architecture.
  - Protocols and QoS (PHY & MAC)
  - Power consumption (battery life, energy harvesting).
- Most popular BAN projects in the field

Thanks for your time

Q/A

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