# Heartbeat-Driven Medium-Access Control for Body Sensor Networks

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## Objectives

- Novel medium-access (MAC) protocol designed for body sensors network → H-MAC
- Energy efficient
- Time-division multiple access (TDMA)
- Star-topology BSN's and powerful external network coordinator

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## Motivation

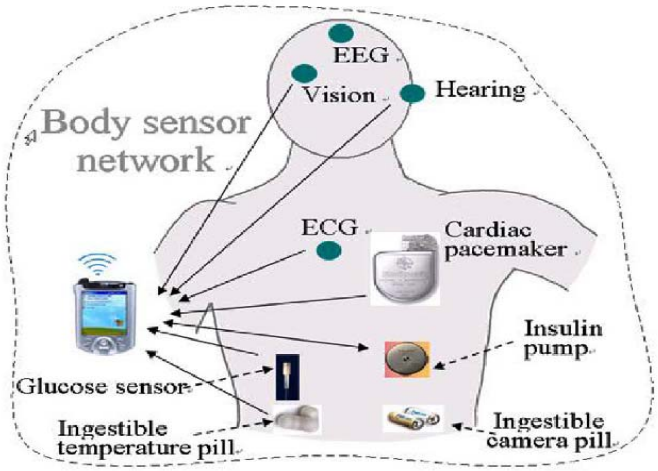
- A health monitoring system which is context-aware, noninvasive and ubiquitous is desirable.
- It helps: detect, evaluate and diagnose diseases
- Wearable/implantable biosensors + wireless communications= Body Sensor Networks



## Body Sensor Networks

- Energy efficiency is important
- MAC protocols are crucial for energy efficiency
- Traditional focus on fairness, latency, bandwidth utilization and throughput, lacks energy conserving mechanisms
- Major energy wastage sources: collisions, control packet overhead and idle listening.

# Body Sensor Networks

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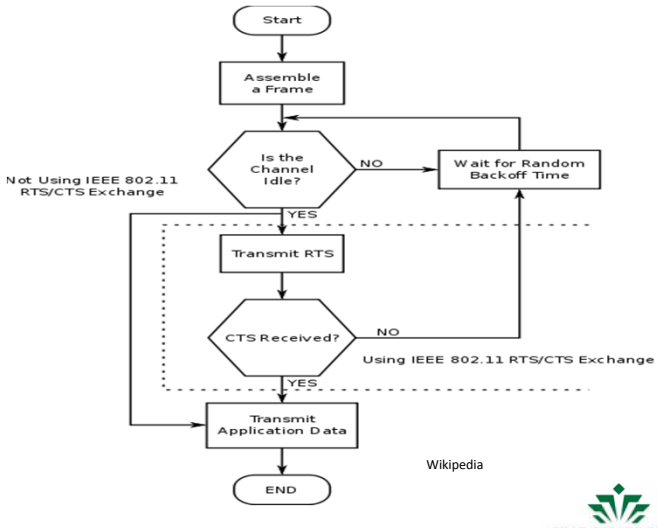
# Contention-based MAC protocols




Wikipedia

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## Contention-based MAC protocols

- Advantages: simplicity, infrastructure-free *ad-hoc* feature and good adaptability to traffic fluctuation.
- Energy costly: idle listening, overhearing and packet collisions
- BSN's: many physiological parameters dependent and coupled → potential collision avalanche.

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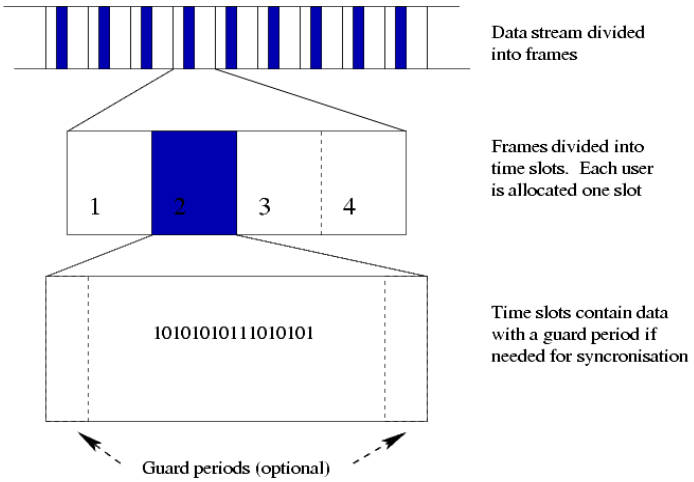
## Schedule-based MAC protocols: TDMA

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## Schedule-based MAC protocols: TDMA

- Collision-free and deterministic transmission features
- Synchronization requires extra energy cost

H-MAC: A TDMA-based MAC protocol designed for BSN's that uses heartbeat rhythm for synchronization


## Contention-based MAC's

S-MAC
- Introduces virtual cluster to enable communication according to schedule
- Trades-off energy by latency

T-MAC
- Introduces adaptive duty cycle
- Sacrifices throughput and introduces extra-delay

D-MAC
- Also has adaptive duty cycle
- Aims to support converge cast communication

Suffer from synchronization overhead and periodic exchange of sleeping schedules

# Schedule-based MAC's

L-MAC

- Time slots have traffic control section and fixed-length data section
- Has an overhearing problem

ER-MAC

- Introduces energy criticality concept
- Also has overhearing problem

Need time synchronization to guarantee collision-free transmission



# H-MAC overview

- It makes use of a powerful network coordinator
- Assigns dedicated time slots to each biosensor
- Achieves TDMA without distributing time synchronization information
- Biosensors extract the necessary synchronization from their own signals
- Exploits heartbeat rhythm information

# Biosignal Rhythm Information

- Many biosignals have similar rhythm
- Changes in physiological parameters are triggered by the heartbeat pulsation
- Explains the network traffic correlation phenomena
- Multipara meter Intelligent Monitoring for Intensive Care (MIMIC)

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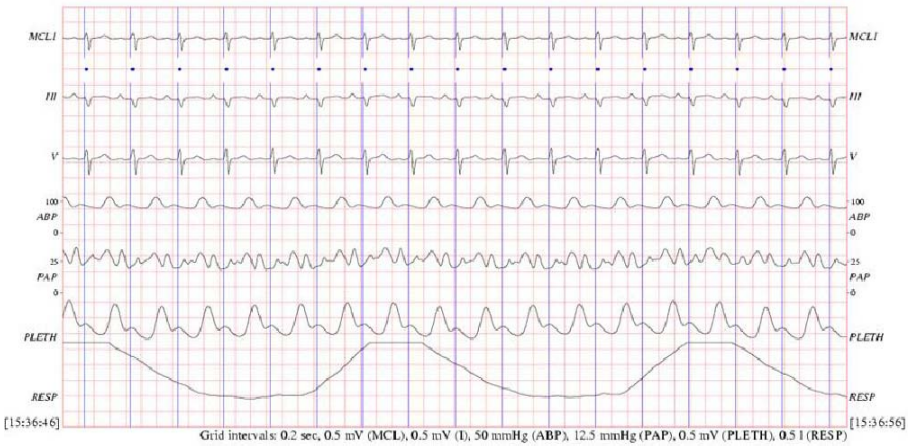
# Biosignal Rhythm Information




Simultaneously recorded biosignals from the MIT-BIH multiparameter database MIMIC.

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# Rhythm Representation

- Choose waveforms peaks to represent the biosignal rhythm information
- Peaks are the most significant characteristic of biosignal waveforms
- Many peak detection algorithms with good performance are already available
- The waveform peak detection is often already required

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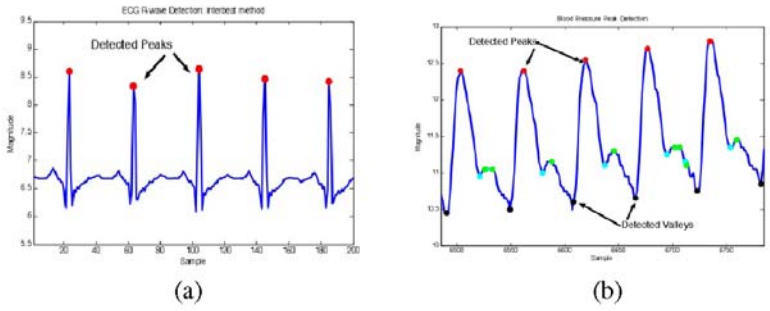
# Rhythm Representation




(a) (b)

Peak detection results (a) ECG. (b) Blood Pressure

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# Time Slot Scheduling

H-MAC considers time slot scheduling for one-hop star-topology

Uses peak intervals as time slots for data transmission

BSN coordinator broadcasts time slot scheduling messages and synchronization recovery beacons

Two kinds of control packets

- CS: peak count and bit indicating changes in time slot scheme
- CL: frame length, time slot scheme and mandatory radio wake up cycle

Uses guard-periods

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# Time Slot Scheduling

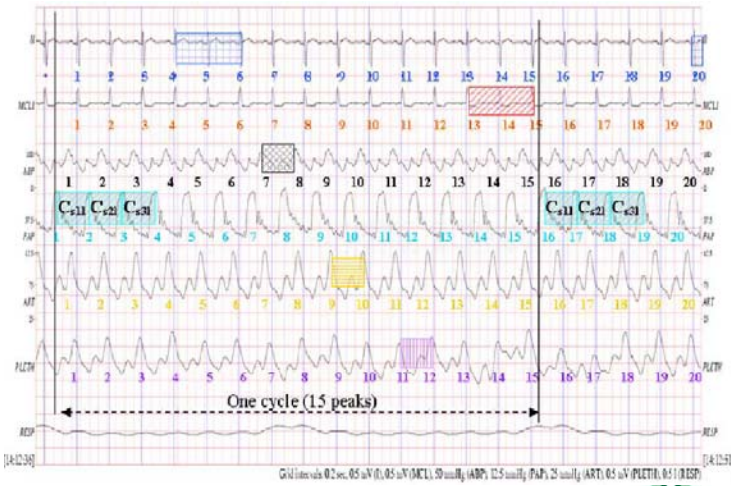


Illustration of H-MAC time slot scheduling

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# Time Slot Scheduling

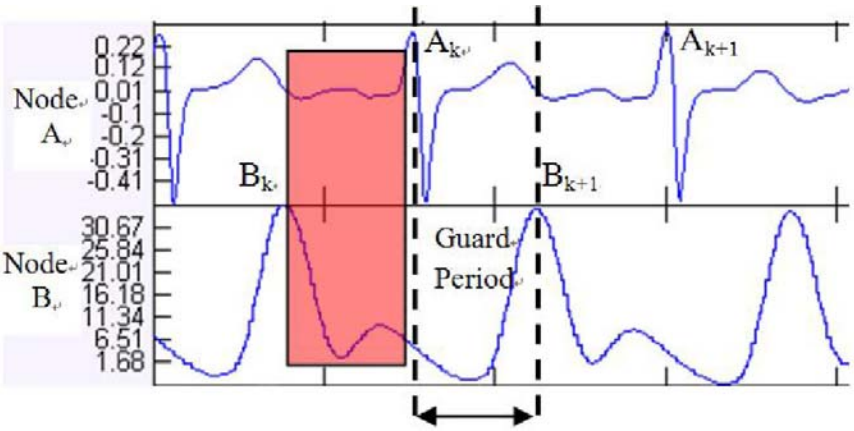


Illustration of the guard time period

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# Synchronization Recovery

- A sensor may lose synchronization when the peak detection algorithm fails and the heart rhythm information is lost.
- Sensors predict loss of synchronization by looking for abrupt changes of peak intervals
- Rate changes should be smooth and continuous
- Abrupt changes may indicate possible peak detection mistakes

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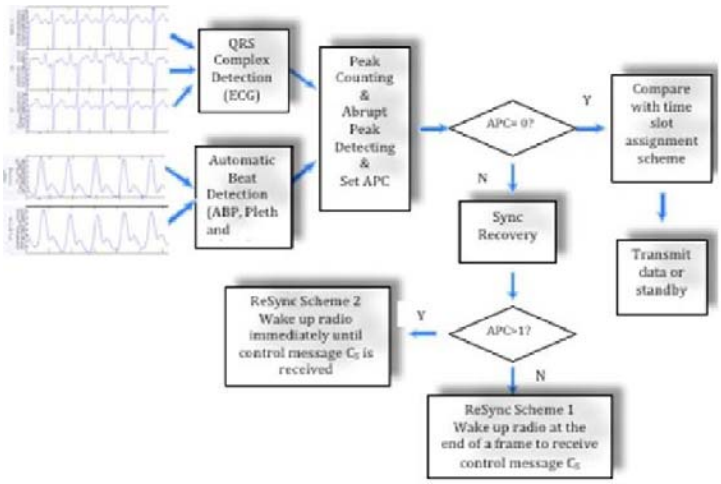
# Synchronization Recovery




Block diagram of H-MAC resynchronization scheme



# Synchronization Recovery

**SET** $APC \Leftarrow 0, PC \Leftarrow 0$
**While** no stop command **do**
Power off radio
**If** Peak is true**then**
**SET** $PC \Leftarrow PC + 1$
**End if**
**If** CPI−API $> T_1$ **then**
**SET** $APC \Leftarrow APC + 1$
**End if**
**If** $APC > T_2$ **then**
Wake up radio
**While** $CS$ not received **do**
Listen to the channel for $CS$
**If** get $CS$ **then**
Adjust PC according to $CS$
**SET** $APC \Leftarrow 0$
**End if**
**End While**
**End if**
**If** $T_2 \geq APC > 0$ and $PC = T$ **Then**
Wake up radio
**While** $CS$ not received **do**
Listen to the channel for $CS$
**If** get $CS$ **then**
Adjust PC according to $CS$
**SET** $APC \Leftarrow 0$
**End if**
**End While**
**End if**
**End While**

Synchronization recovery algorithm

# Experimental Results

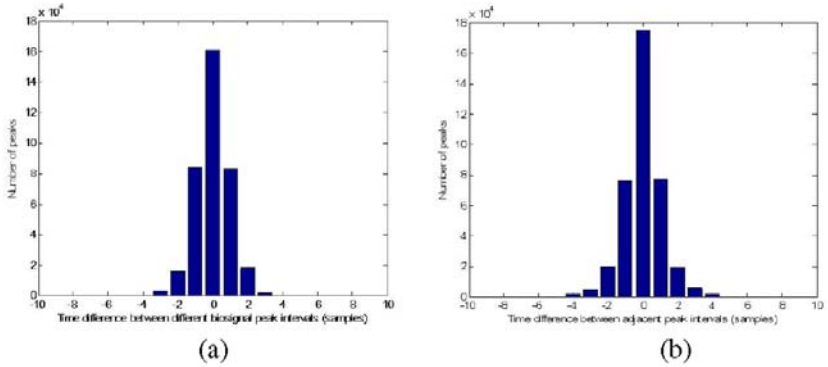
- MIMIC: includes 100 patient records containing between 24 and 48 hours of continuous data.
- Selected hemodynamically unstable patients

TABLE I
EXPERIMENT DATA RECORDS

| Record No. | Data duration (Seconds) | Sampling Rate (Hz) | Physiologic Parameters |
|---|---|---|---|
| 55 | 129600 | 750 | 3 leads ECG, ABP, PLETH |
| 216 | 90000 | 750 | 2 leads ECG, ABP, PAP, CVP, PAP, PLETH |
| 225 | 162000 | 750 | 3 leads ECG, ABP, PLETH |
| 230 | 61200 | 750 | 2 leads ECG, ABP, PAP, PLETH |
| 248 | 90000 | 750 | 3 leads ECG, ABP, PAP |



# Experimental Results




(a) (b)

Peak interval differences. (a) Between different biosignals. (b) Adjacent peak interval

# Experimental Results

- Uses OMNet++
- Compares with L-MAC and S-MAC
- Simulates star network with 10 m radius and 15 m transmission range
- Single channel transceiver and 3 operational states: transmitting, receiving and stand-by or sleep.

TABLE II
RADIO TRANSCEIVER DATA

| Parameter | Value |
|---|---|
| Energy consumption: Receiving (Rx) | 45 mW |
| Energy consumption: Transmitting (Tx) | 45 mW |
| Energy consumption: sleep | 2uW |
| Wakeup time from sleep | 6us |
| Data rate | 250kbps |

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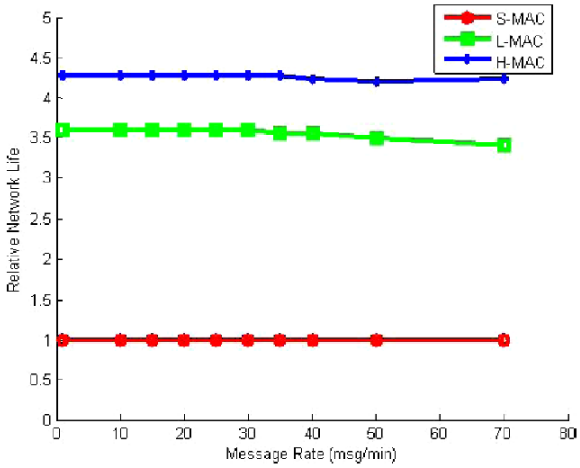
# Experimental Results




Relative network life time comparison for S-MAC, L-MAC, and H-MAC

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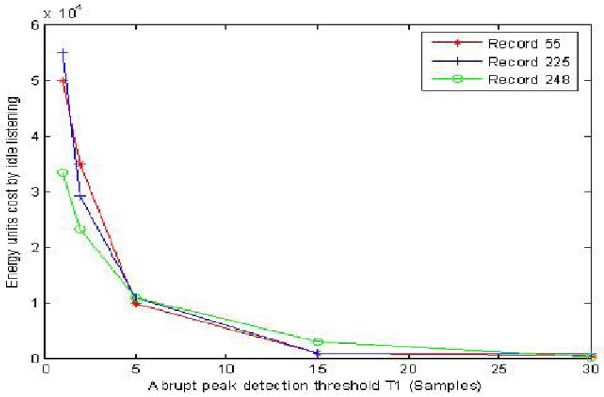
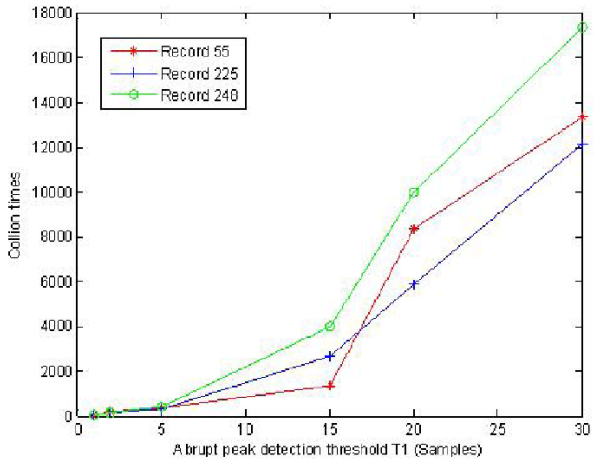
# Experimental Results




Relation between abrupt peak detection threshold T1 and idle listening cost



# Experimental Results




Relation between abrupt peak detection threshold T1 and collisions

# Experimental Results

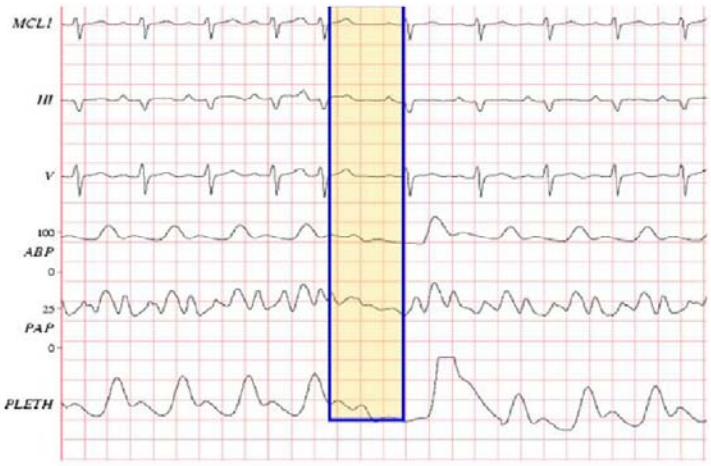



Illustration of a potential false alarm situation for resynchronization

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# Discussions and Future Work

- Time slot scheduling
- H-MAC is conservative
- Tradeoff between energy and bandwidth efficiency
- BSN coordinator can send resynchronization control packets during guarding time
- Bandwidth can improve assigning larger time slots to reduce the number or time intervals

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# Discussions and Future Work

- Sensors that can not use heartbeat rhythm
- Accelerometers: can be integrated with other biosensors
- Protocol integration: modified IEEE 802.15.4 (low-rate wireless personal area network)

- Single point of failure problem
- Integrate more reliable and multiple biosensors in the coordinator

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