



Wireless body area networks for ambulatory health monitoring

with prototype demonstration

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Outline



- Introduction
- Proposed Solution
- WBAN Prototype
- WBAN Wireless Communications
- Embedded Software
- Personal Server Application
- Demonstration
- Conclusions

Motivation

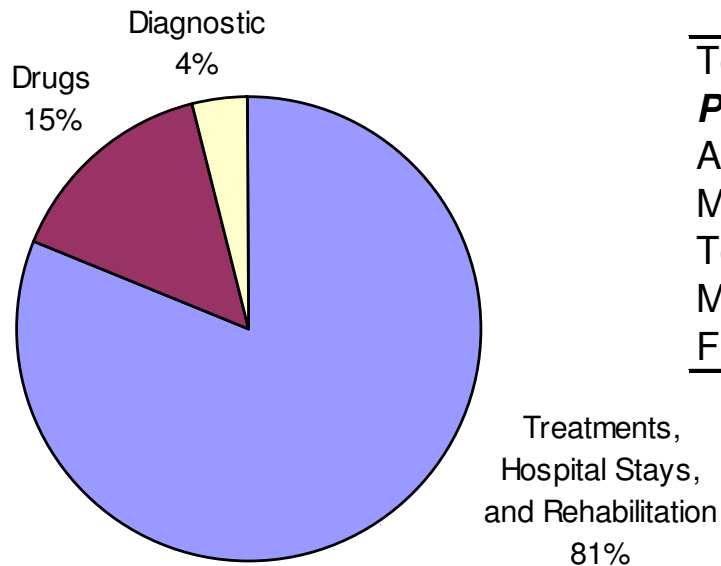


- Healthcare is the Largest Segment of US Economy
 - \$1.8 Trillion in 2004 (15% of GDP)
 - \$200 Million Informal Care Givers
 - \$4178 per capita (50% more than the next nearest nation)
 - US is less than 10th in life expectancy
 - US is 26th in infant mortality rates
- Pending Crisis
 - Retiring Baby Boomers
 - Elderly is the Largest Growing Age Group
 - 45 million Uninsured

Motivation

- Current Healthcare Systems are **Centralized**, Focused on *Reacting* to **Illness**
- We are in need of **Distributed** Systems, Focused on *Proactive* **Wellness Management**

Healthcare Spending by Category



Causes of Death in the US in 2000

Tobacco	18.1%
Poor diet and physical inactivity	16.0%
Alcohol consumption	3.5%
Microbial agents	3.1%
Toxic agents	2.3%
Motor vehicles	1.8%
Firearms	1.2%

Ambulatory Health Monitoring



- **Wearable Systems For Health Monitoring**
 - Close monitoring of Vital Signs
 - Quantitative Feedback
 - Computer Assisted Rehabilitation
- **Holter Monitors**
 - Data Recorders (< 24 hours)
 - Post-session Analysis
- **Telemedicine Systems**

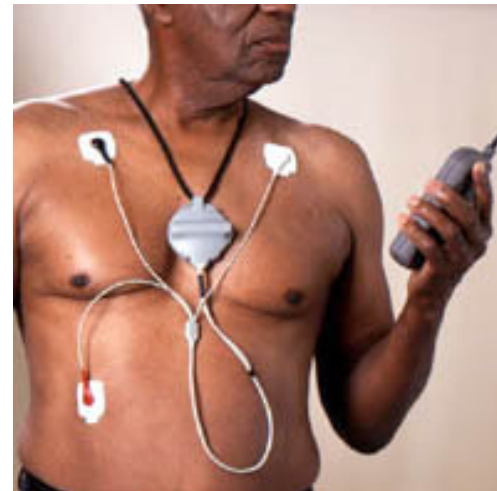
CardioLabs

- Ambulatory Heart Monitoring
- Event-based Recorders
 - Loop Recorders (32 min)
 - Patient Presses “event” button during episode
- Data Extracted for Post-Analysis



CardioNet

- Mobile Cardiac Outpatient Telemetry (MCOT)
- Wireless Sensor and Wireless Monitor
- Heartbeat by Heartbeat Monitoring
- Arrhythmia event detection



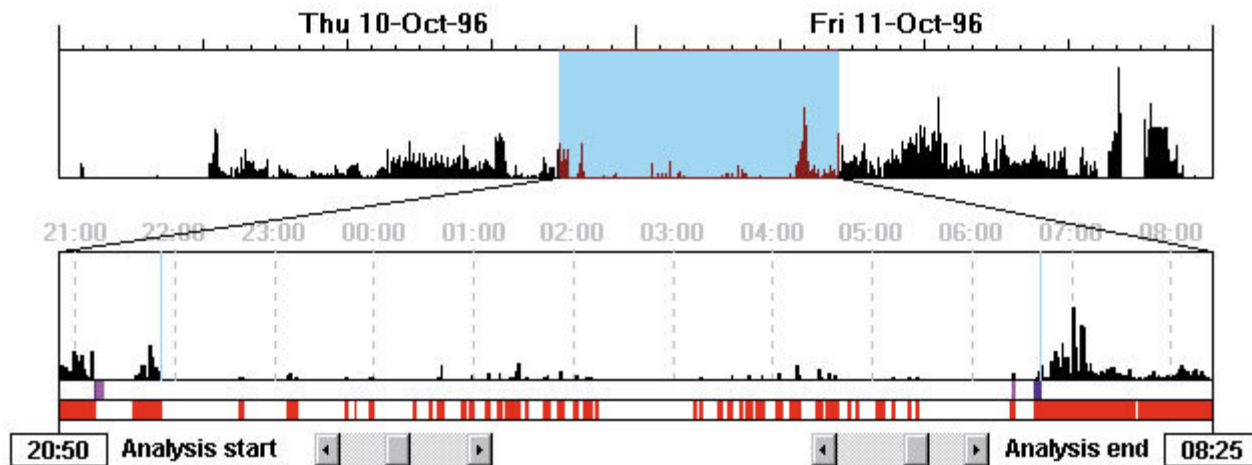
Heart Rate Monitors

- Polar Electro, Suunto, Timex, Reebok,...
- Integration into Fitness Equipment
- Real-time Heart rate
- Some “Journal” capabilities



ActiWatch

- Cambridge Neurotechnology
- Actigraphy
- Single Axis Accelerometer
- Clinical Research
 - Sleep / Wake Patterns
 - Sleep Disorders
 - Periodic Leg Movement (PLMS)
 - Infant Monitoring



Body Media (bodyBugg)

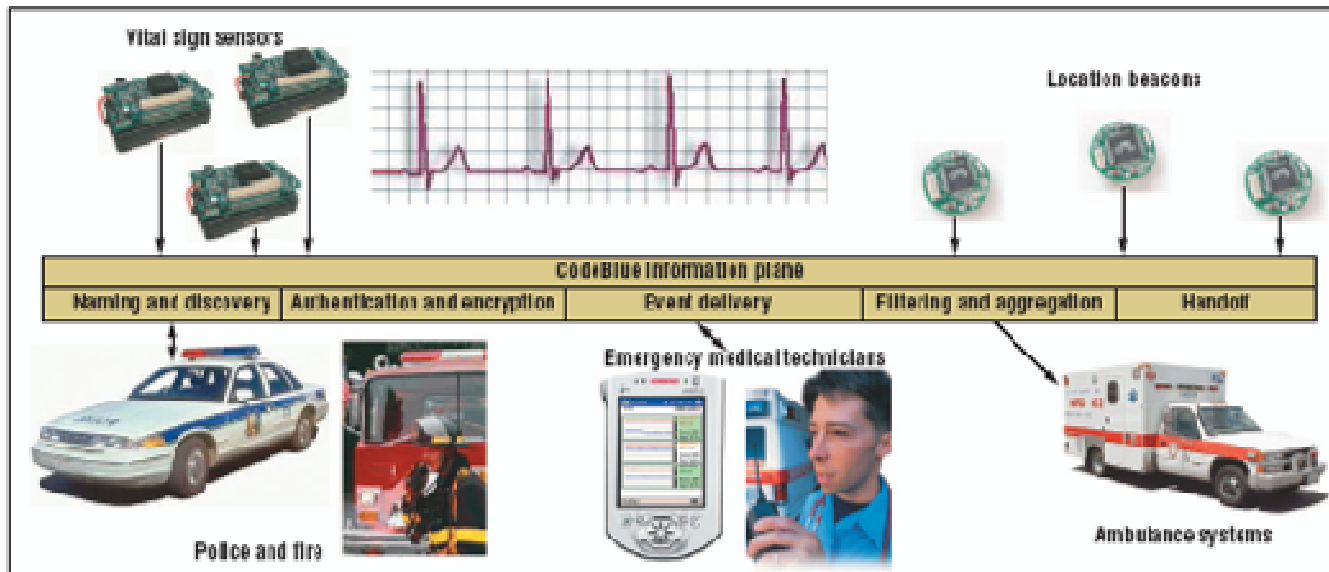
- Multi-modal sensing
 - Single axis-accelerometer (motion)
 - (2) Temperature Sensors (heat flux)
 - Galvanic Skin Response (GSR)
- Upload Data using USB
- Calorie Consumption Estimation
 - Proprietary Algorithms
 - Clinically tested

Body Media Monitor



CodeBlue

- Harvard University, Boston University School of Management, and Boston Medical Center, 10Blade (start-up)
- Real-time Triage, Disaster Relief
- Pulse Oximeters, ECG, accelerometers



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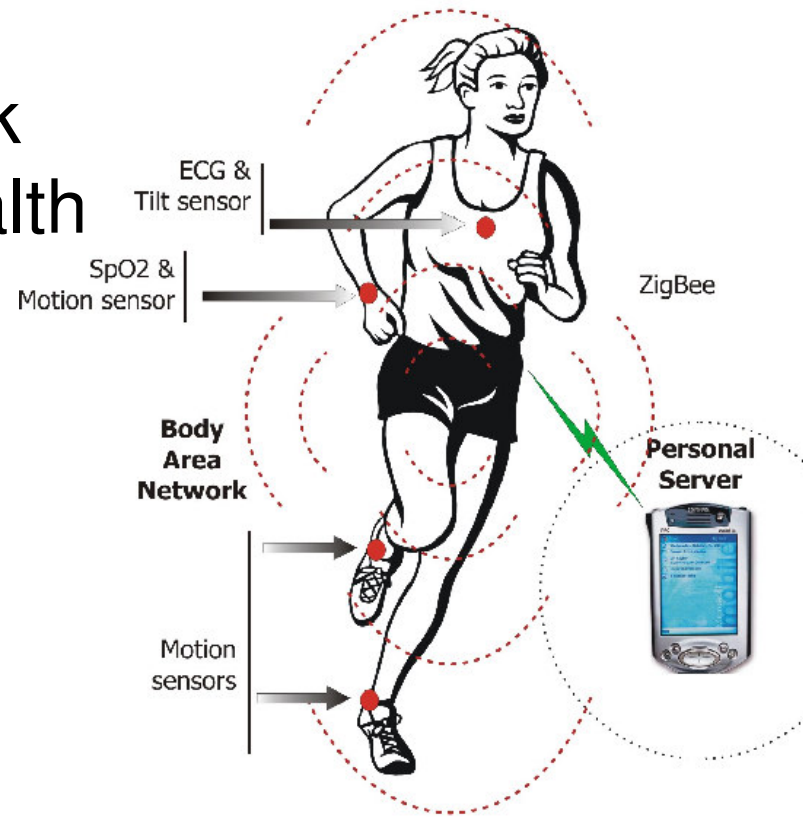
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Proposed Solution

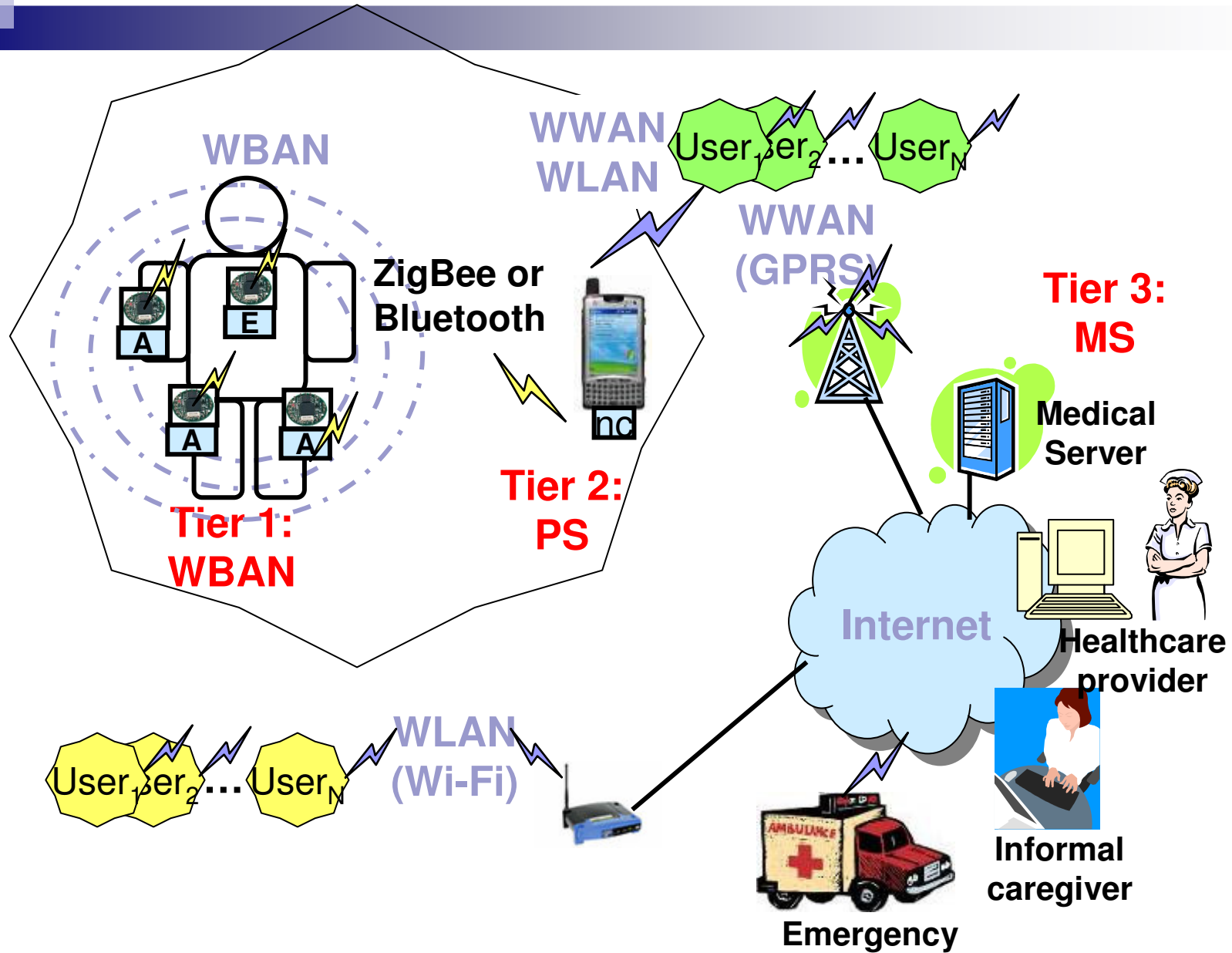
- **Wireless Body Area Network (WBAN) for Ambulatory Health Monitoring**

- Mobility
- Increased Quality of Life
- Multimodal Physiological Monitoring

- **Hierarchical Multi-tier Telemedicine System**



System Architecture



Outline



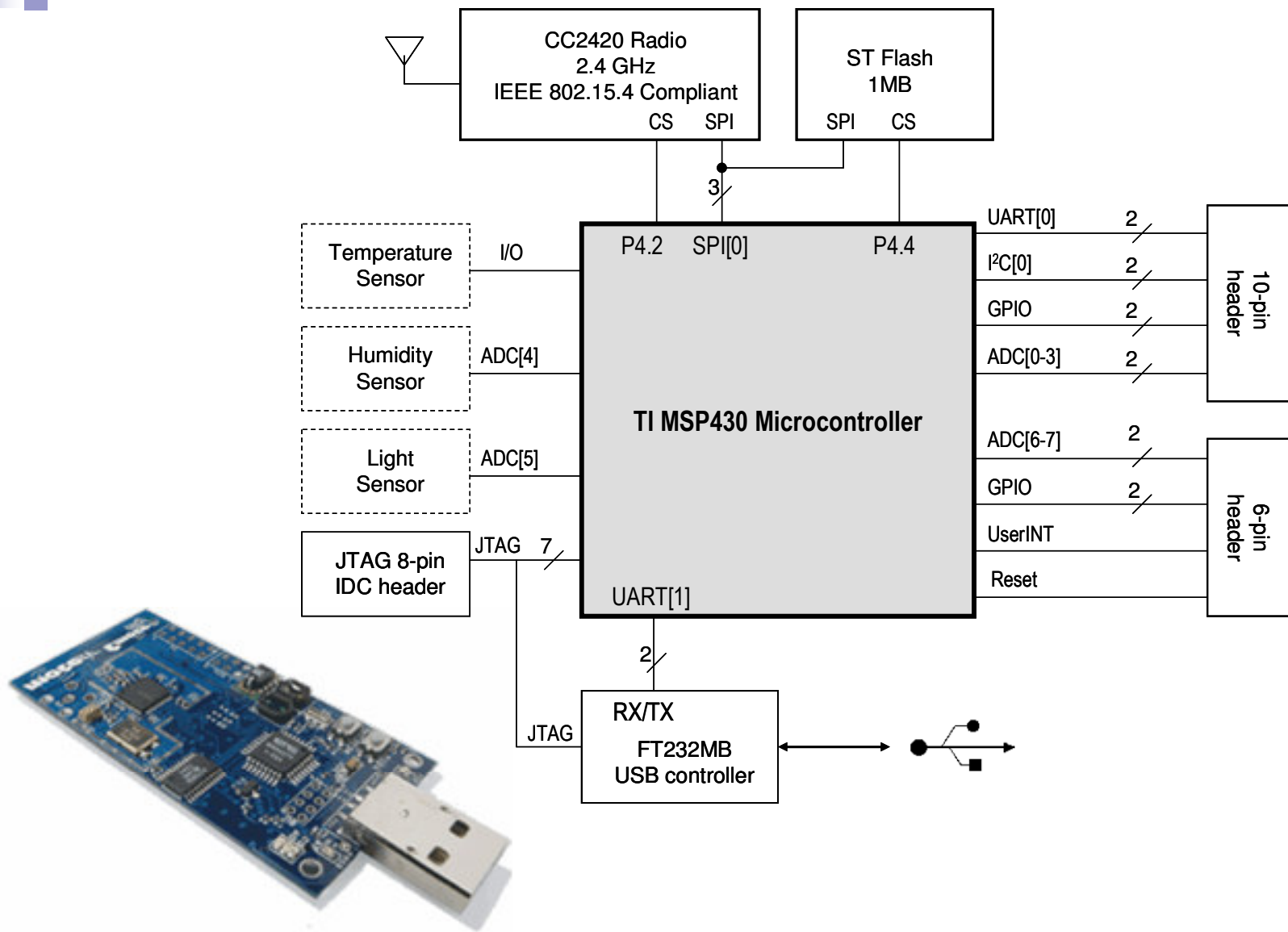
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WBAN Prototype - Goals



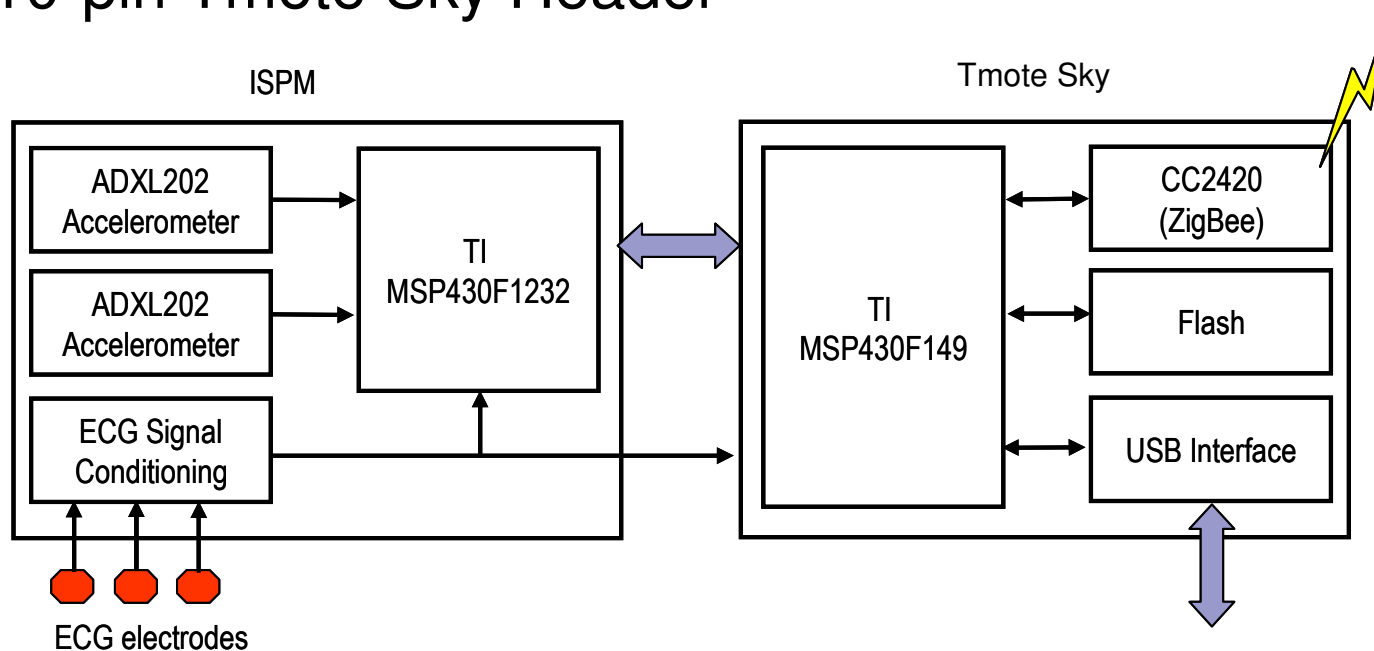
- Implement a Working WBAN
 - Activity Monitor / Motion Sensor
 - ECG Sensor
 - Network Coordinator
 - Personal Server
- Explore Challenges
 - Sensor Fusion
 - On-Sensor Processing
 - Communications
 - Power Efficiency

Hardware Architecture - Tmote Sky



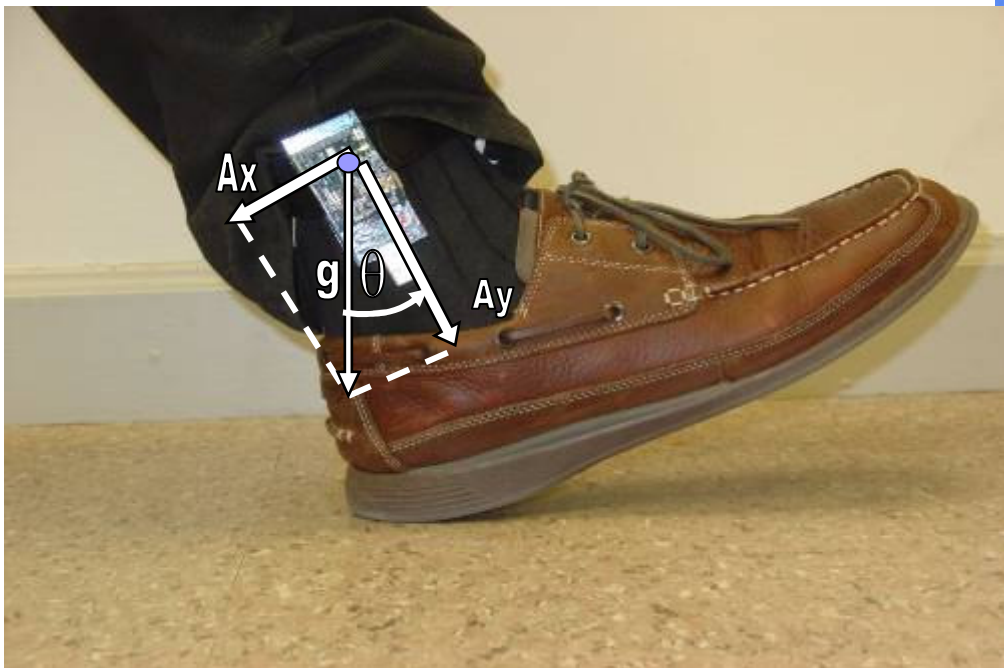
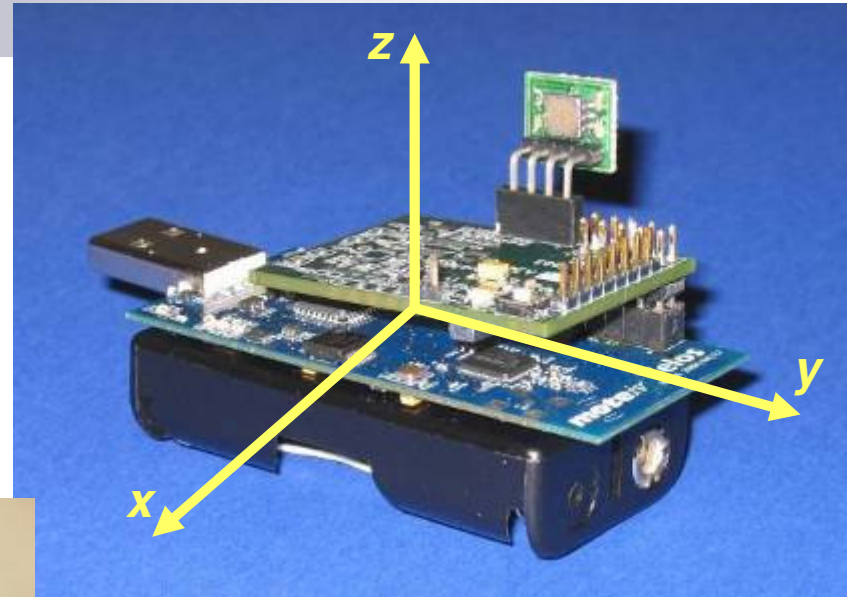
Hardware Architecture - ISPM

- MSP430F1232
 - 32KHz (ACLK) / ~4.6MHz DCO Clock (MCLK,SMCLK)
 - 8KB Flash / 256B RAM
- Two (2) ADXL202 Accelerometers
- Two Analog ECG Channels
- 10-pin Tmote Sky Header

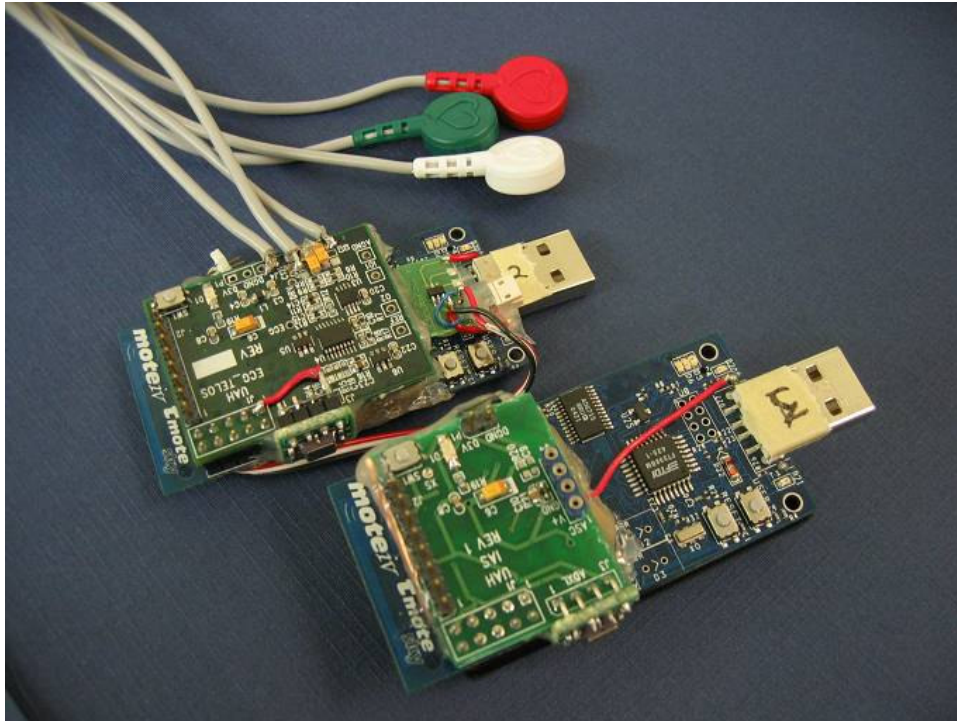


ActiS Sensor Nodes

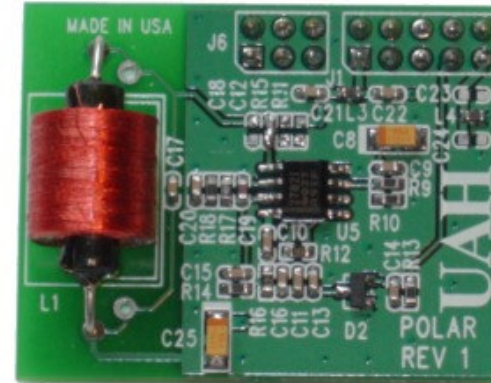
- 3 axis motion detection
- Step detection and gait analysis
- Activity induced Energy Estimation (AEE)



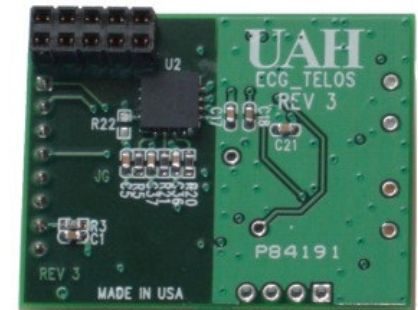
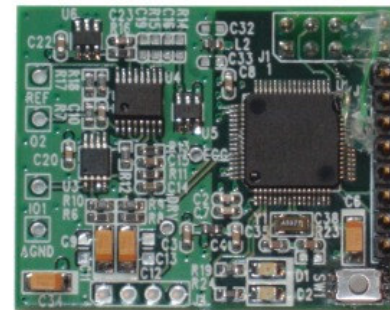
Intelligent Signal Processing Modules (ISPM)



ISPM for Activity / ECG



Polar Heart Rate Monitor



Single chip 3-axis Accelerometer

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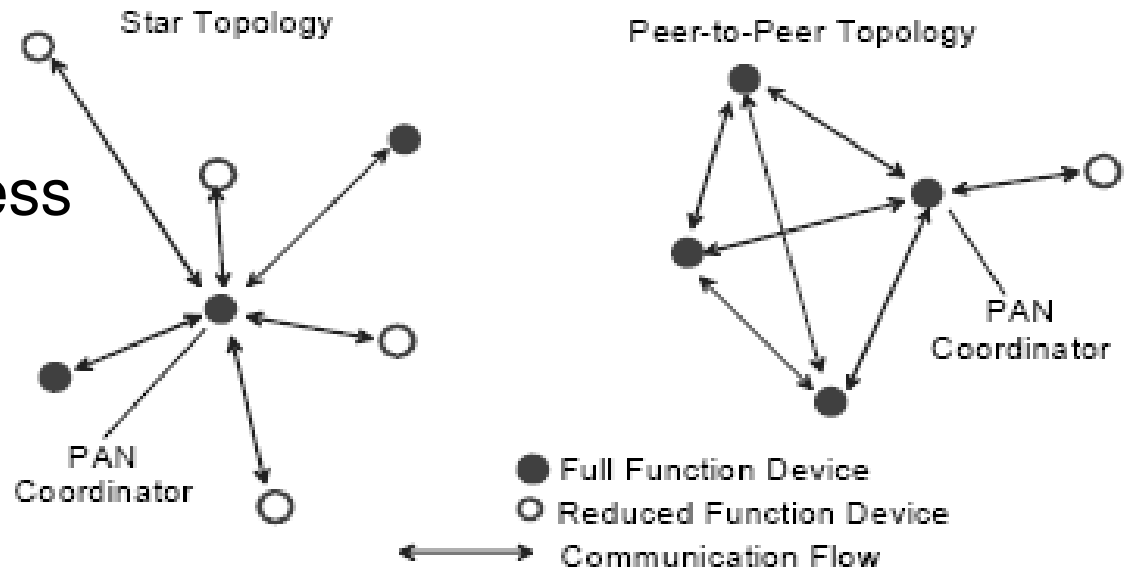
IEEE 802.15.4 and ZigBee

- IEEE 802.15.4

- LR-WPAN Access
- 250 Kbps
- CSMA-CA

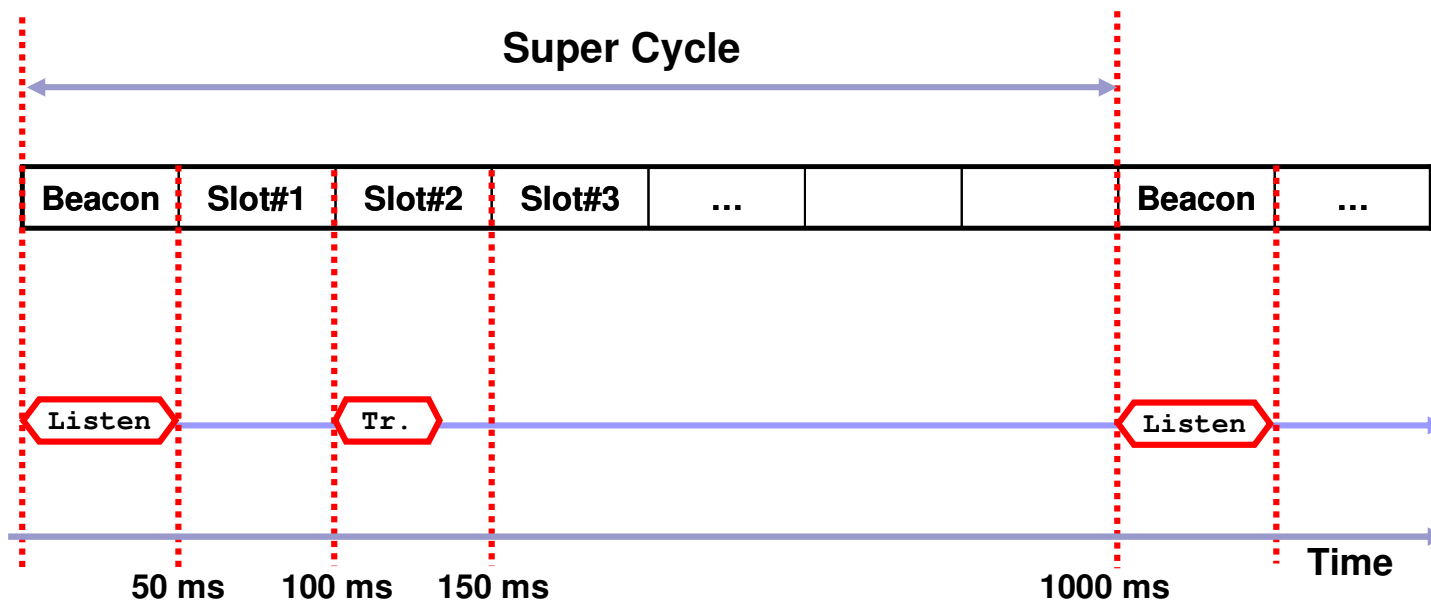
- ZigBee

- Network
- Application and Application Sublayer
- Security
- Star Network Topology**



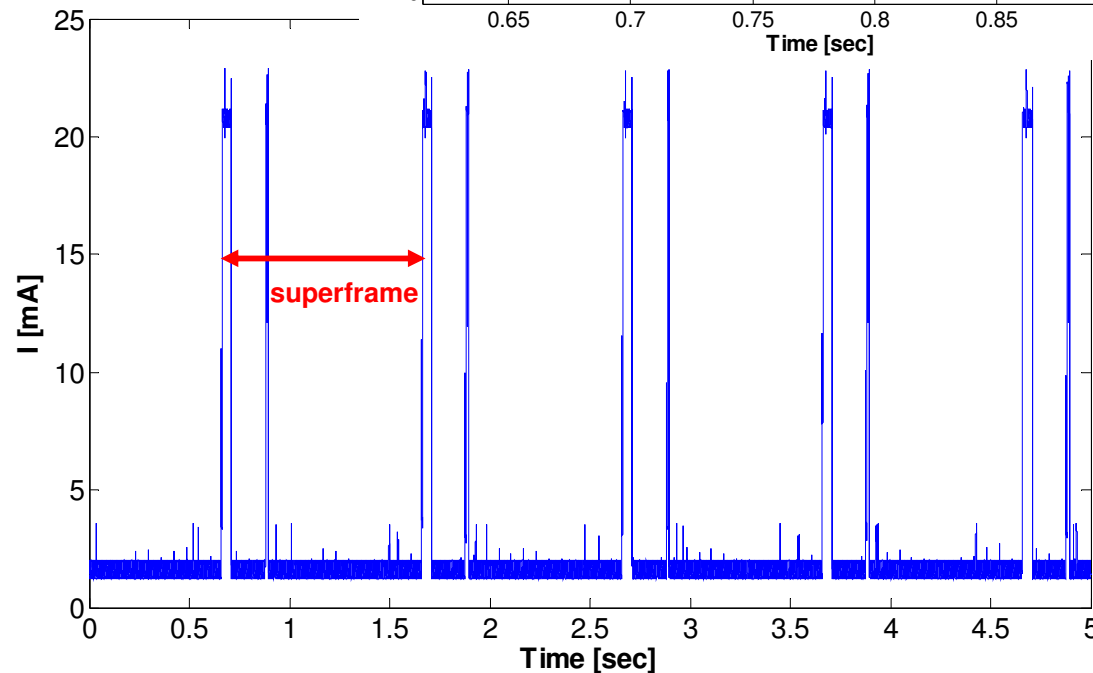
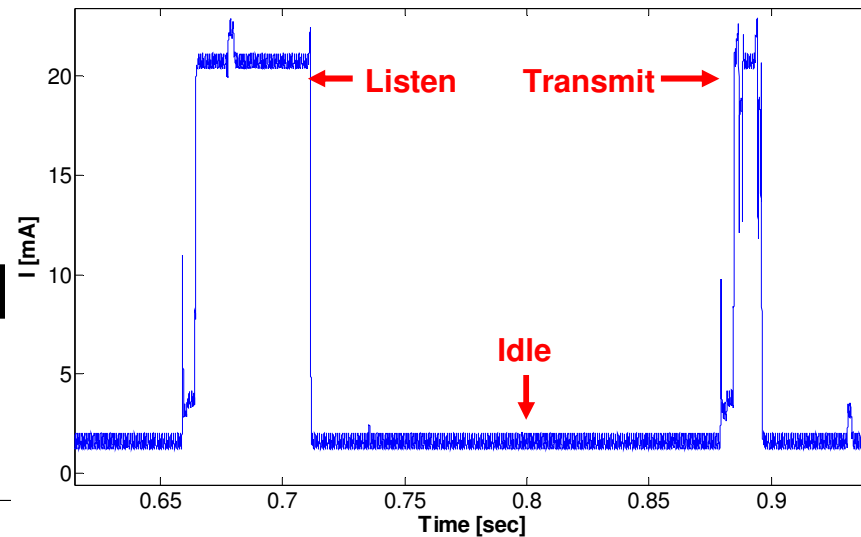
Power Efficient TDMA

- >90% Sensor Power from Radio
- Significant Power Savings From Disabling Radio
- Timeslots for Communication
 - Distributed Events → Concentrated Bursts
 - Allows Radio to be disabled
- Extended Battery Life / Lower Weight

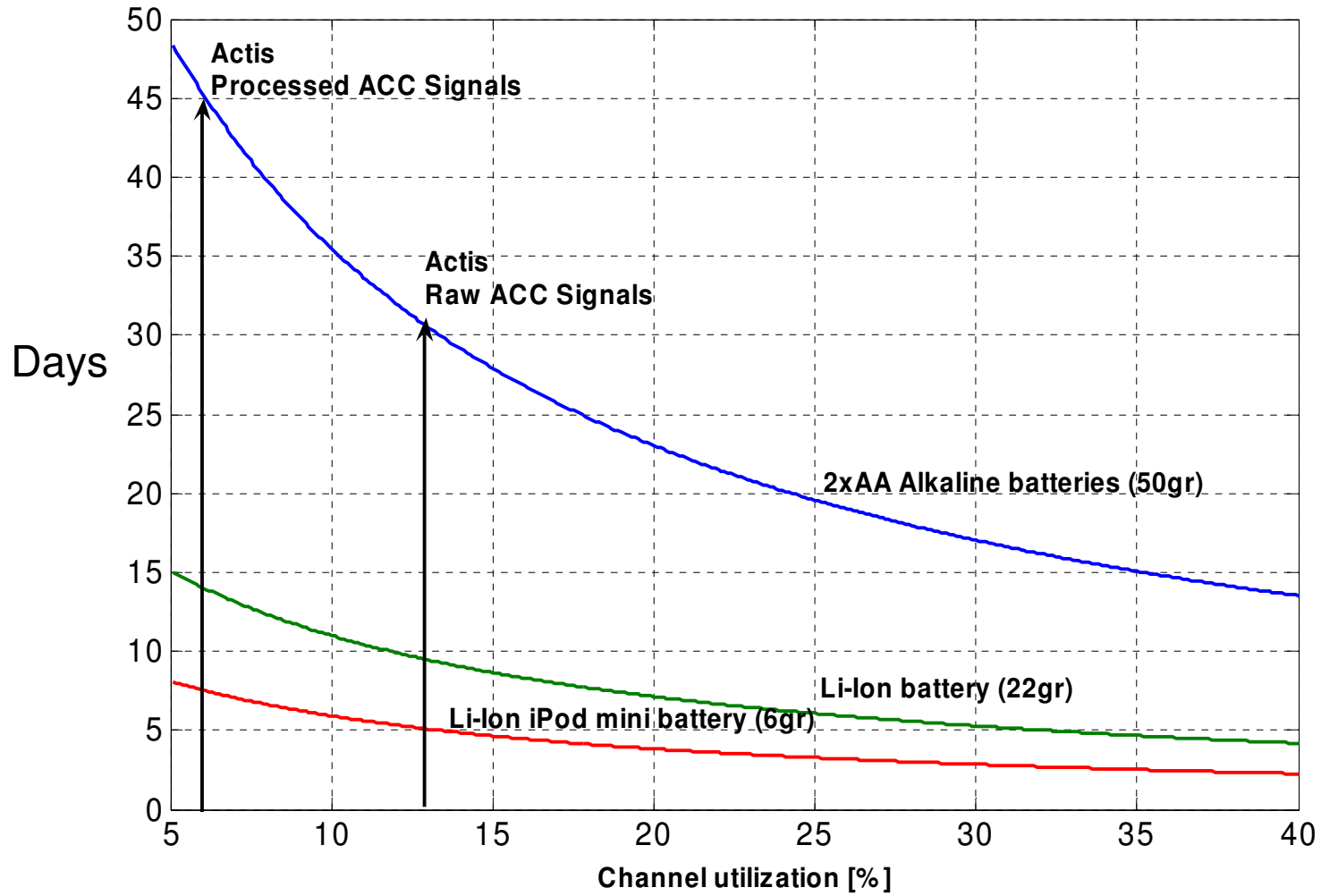


TDMA Means Low Power

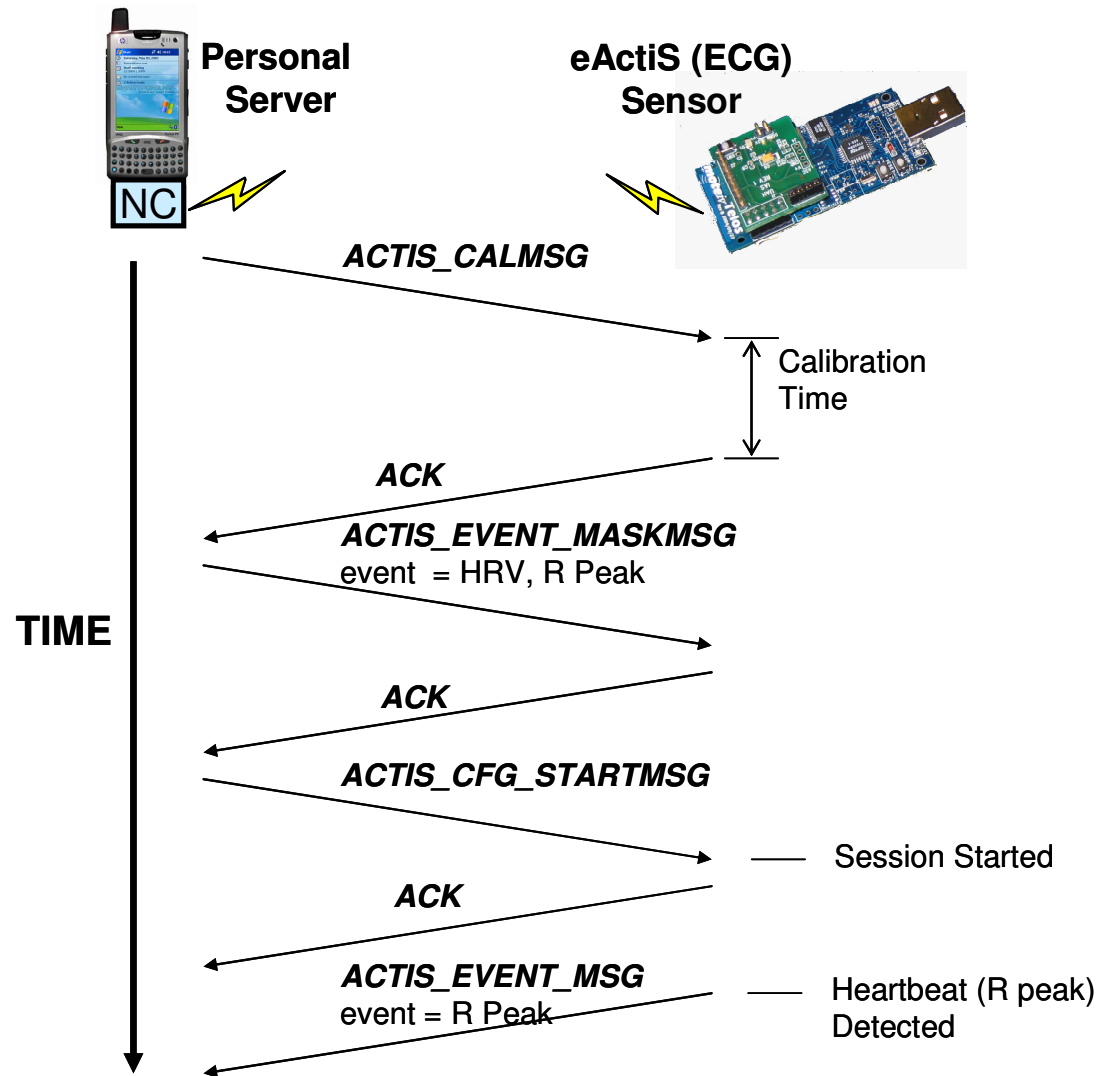
- Deterministic RF timeslots
- Radio can be disabled
- Extend battery life



Battery Life



Typical Message Flow



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Embedded Software - TinyOS



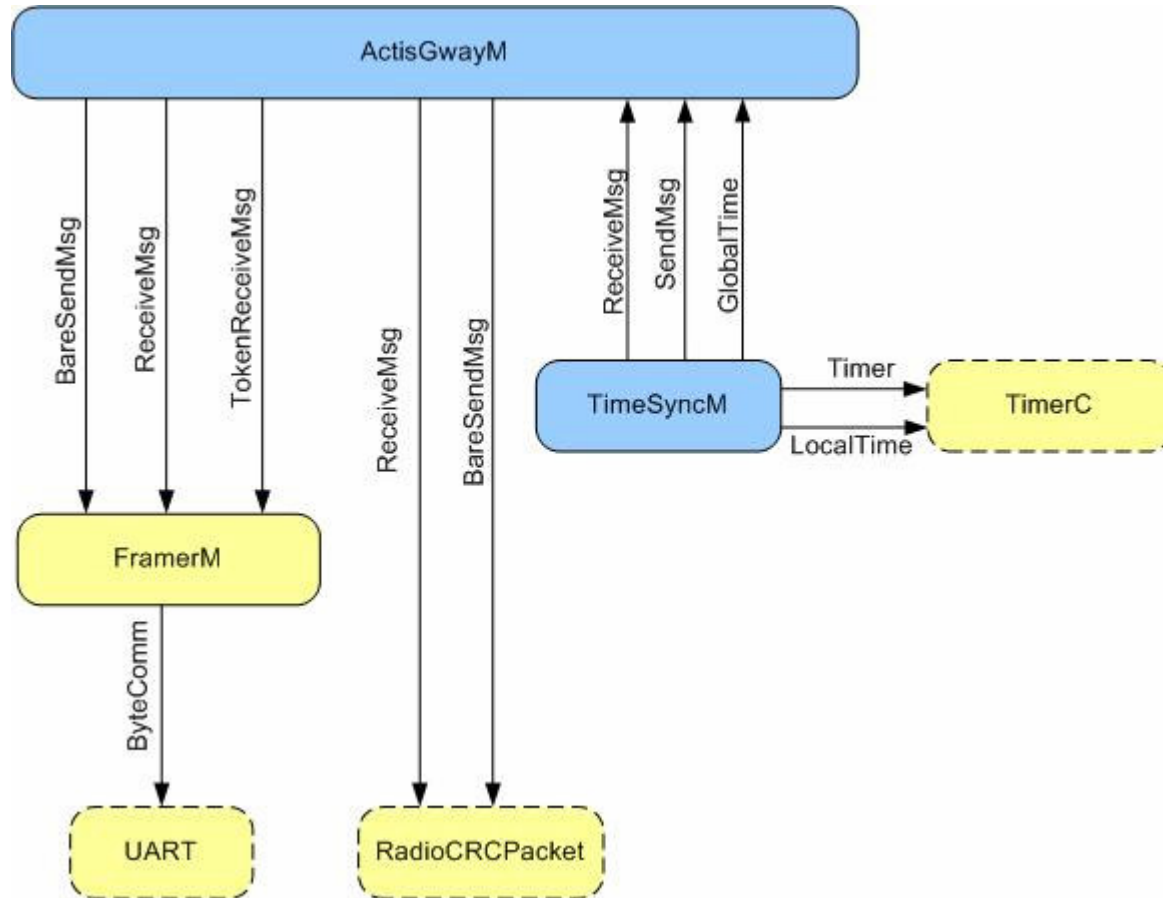
- Lightweight
- Open Source
- Configuration Defined at Compile Time
- nesC (for Networked Embedded Sensors)
 - Component model
 - Task support
 - Split-phase Operation (command / event model)

Network Coordinator



- WBAN Access for Personal Server
- Network Channel Management
- Distribute Global Timing

Network Coordinator



Time Synchronization - Motivation



- TDMA

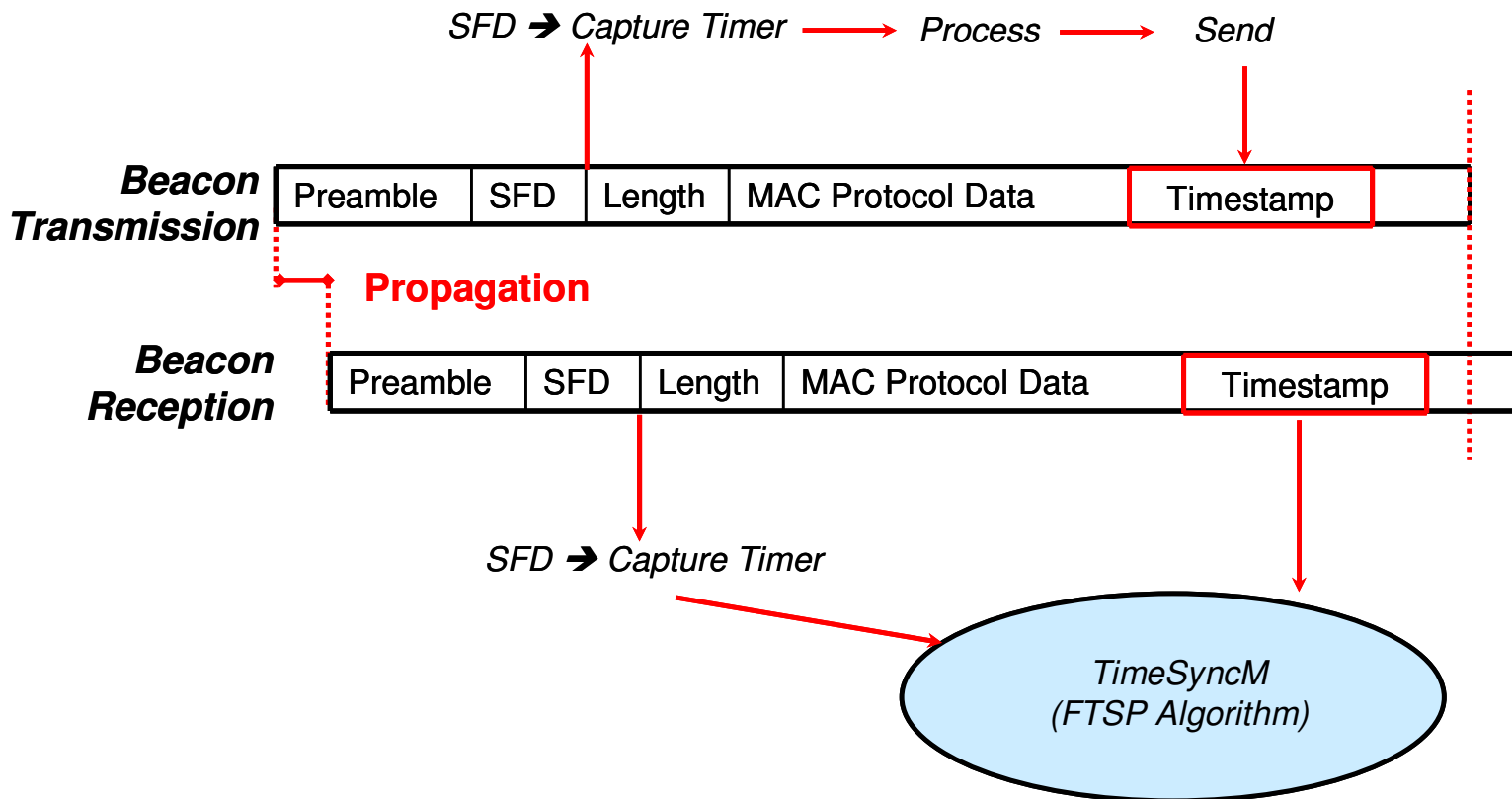
- Efficient Sharing of Communication Channels
- Timeslot Assignments
- Beacon Prediction (Maximize Radio off)

- Correlating Intra-WBAN events

- Relative timing is important
- Synchronizing start time

Time Synchronization Protocol

- Flooding Time Synchronization Protocol (FTSP)
 - MAC Layer Time Stamping
 - Skew Compensation with Linear Regression

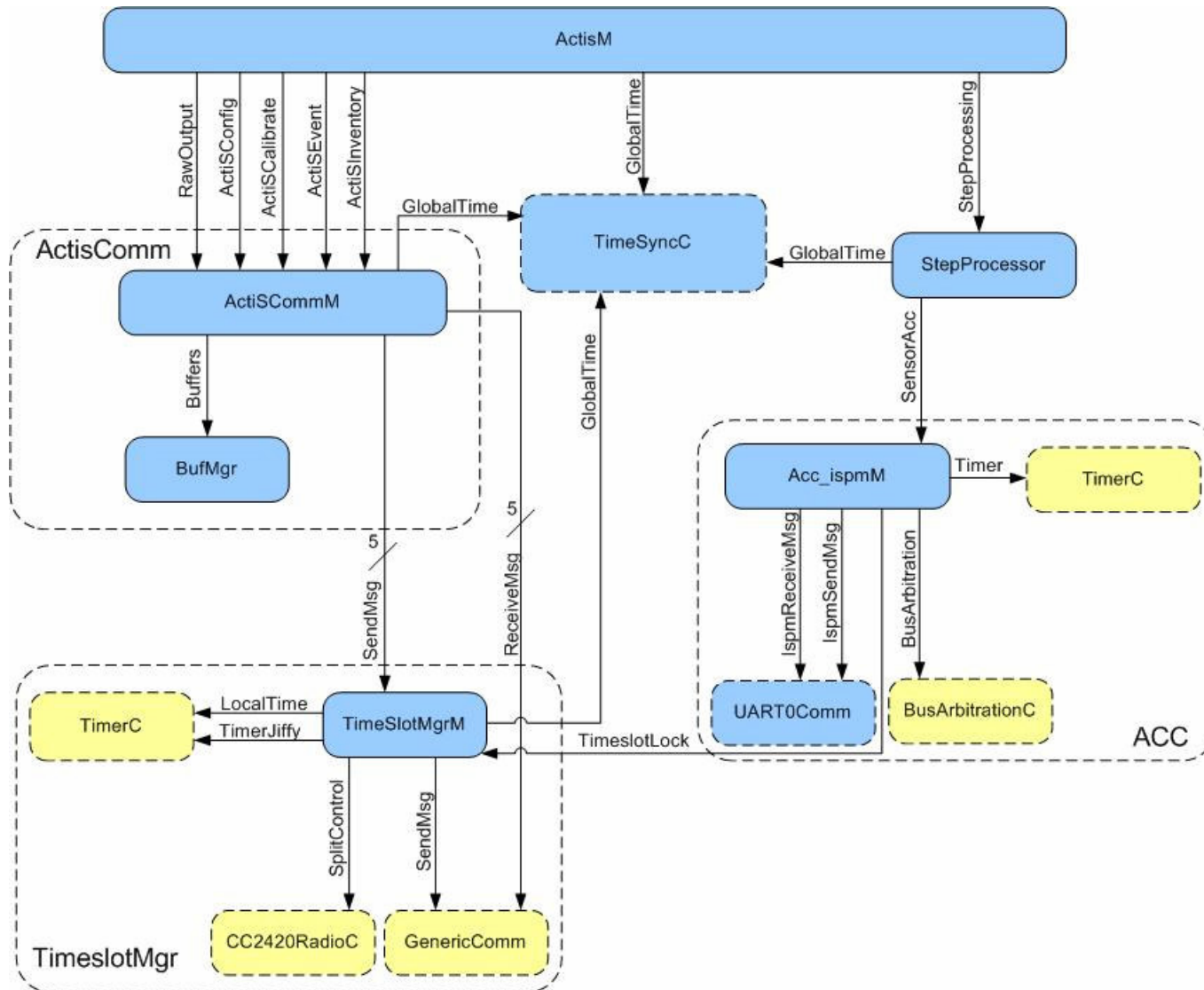


Sensor Nodes

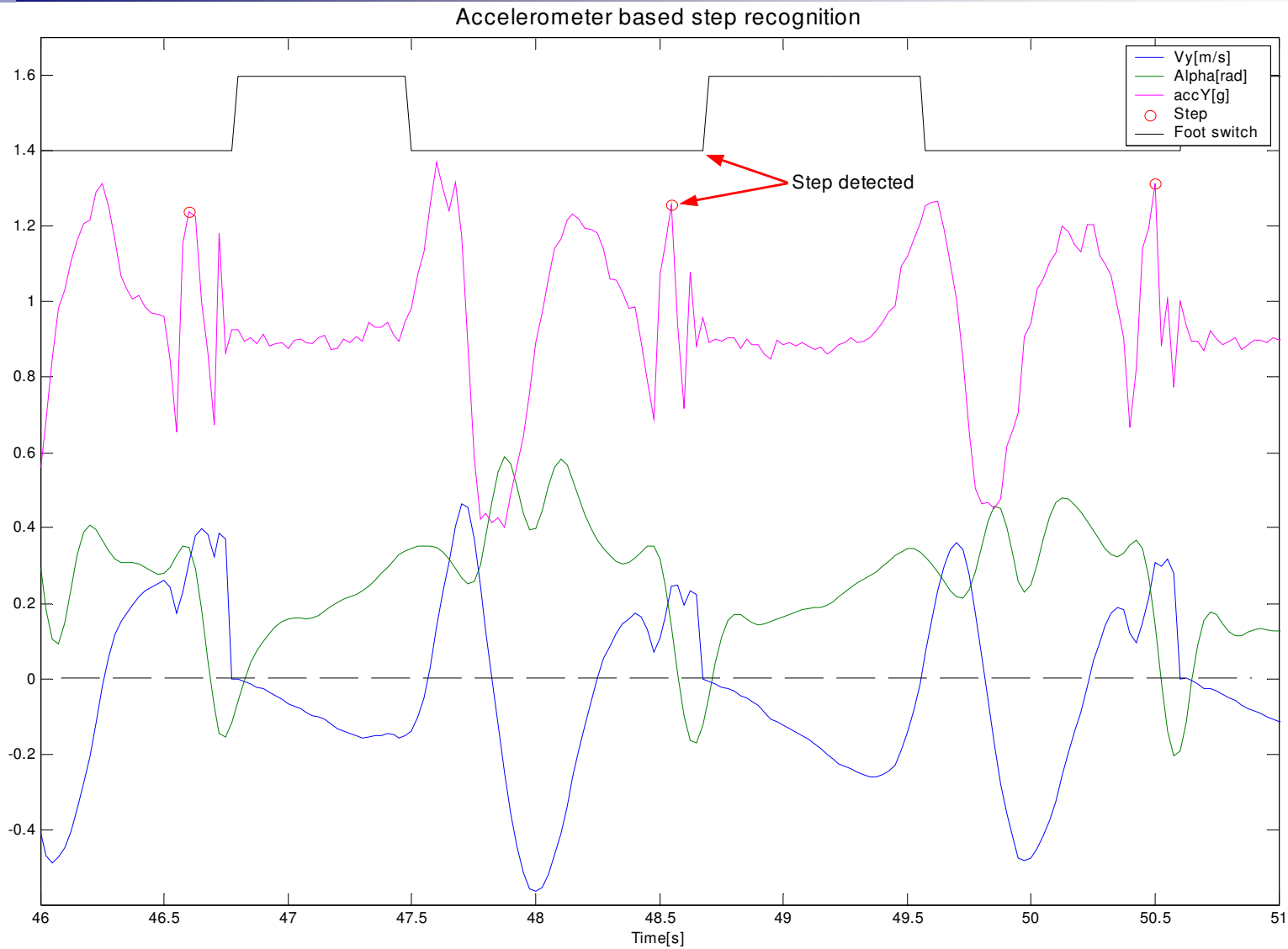


- Collect Physiological Data
- Process Data (Feature Extraction)
- Event Management
- Resource Management
- WBAN Communications

Sensor Nodes

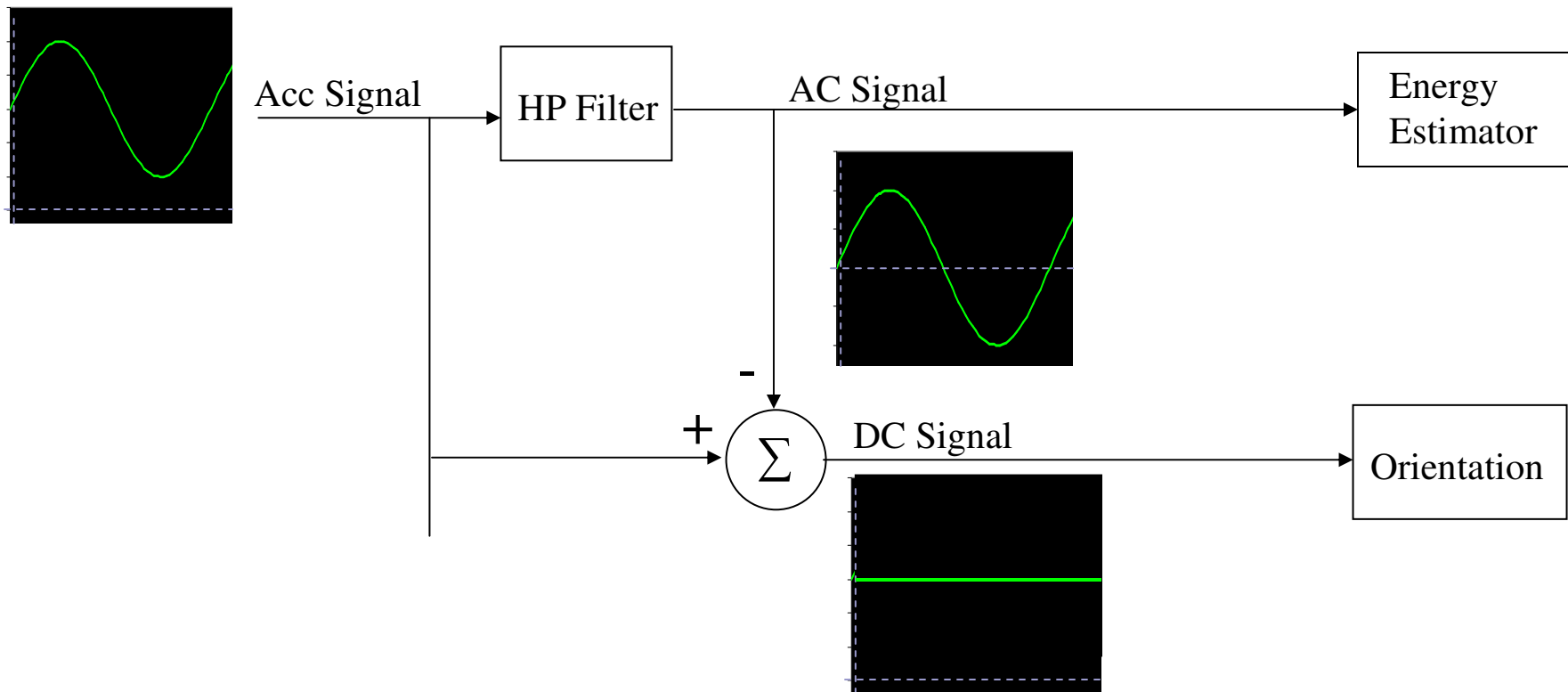


Feature Extraction – Step Detection

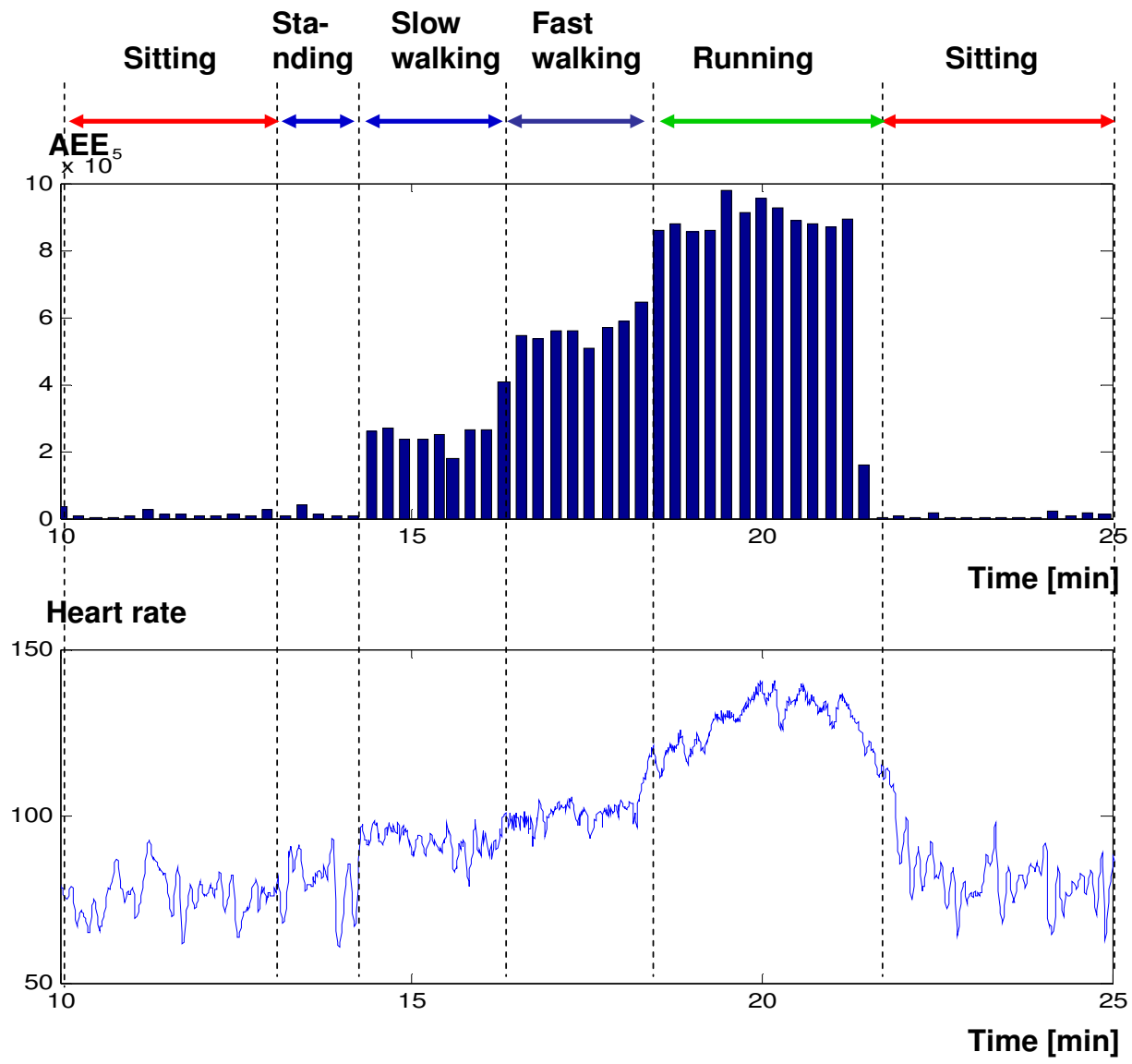


Feature Extraction – Activity Estimation

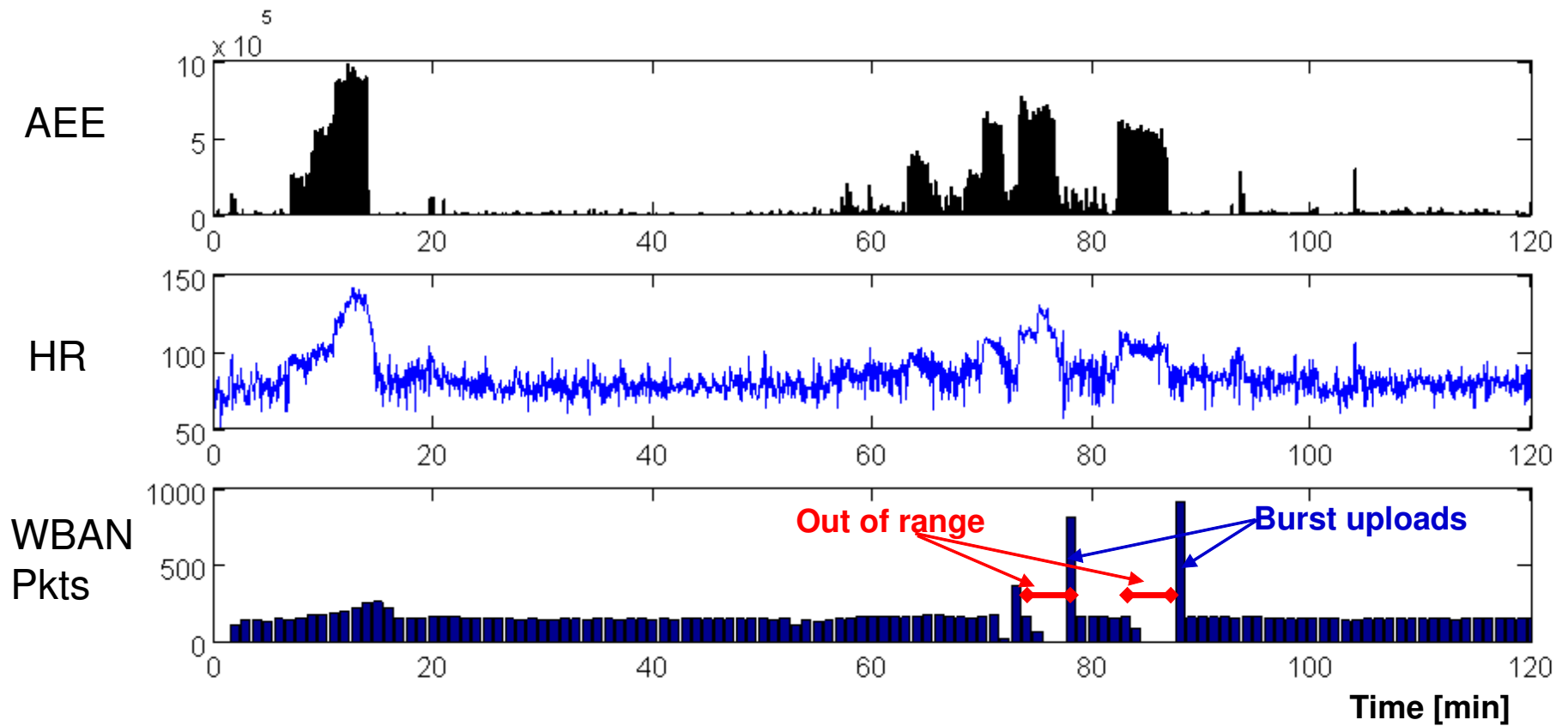
$$AEE_t = \int_{t-\delta}^t \sqrt{AC(a_x)^2 + AC(a_y)^2 + AC(a_z)^2} \cdot dt$$



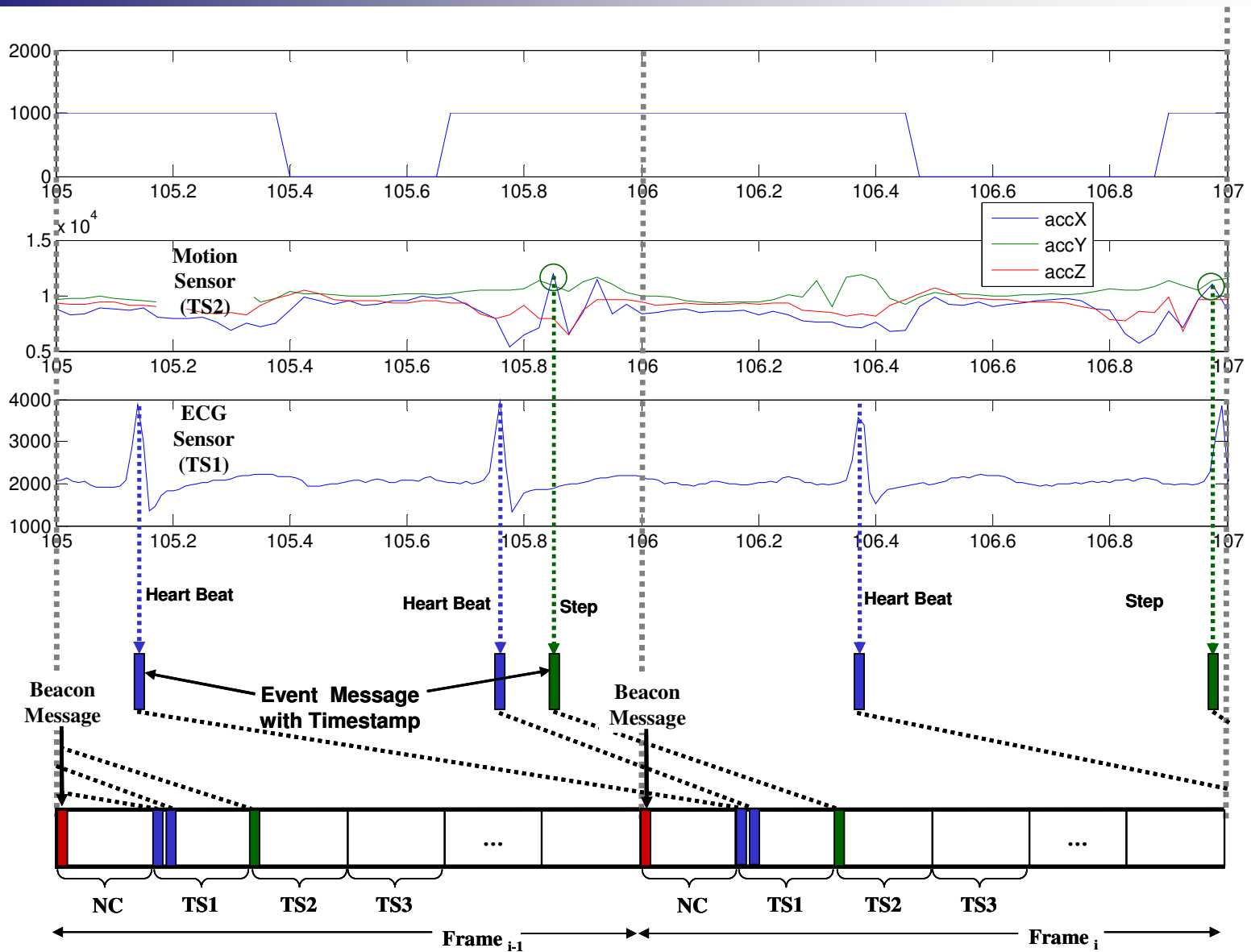
Feature Extraction – AEE and Heart Rate



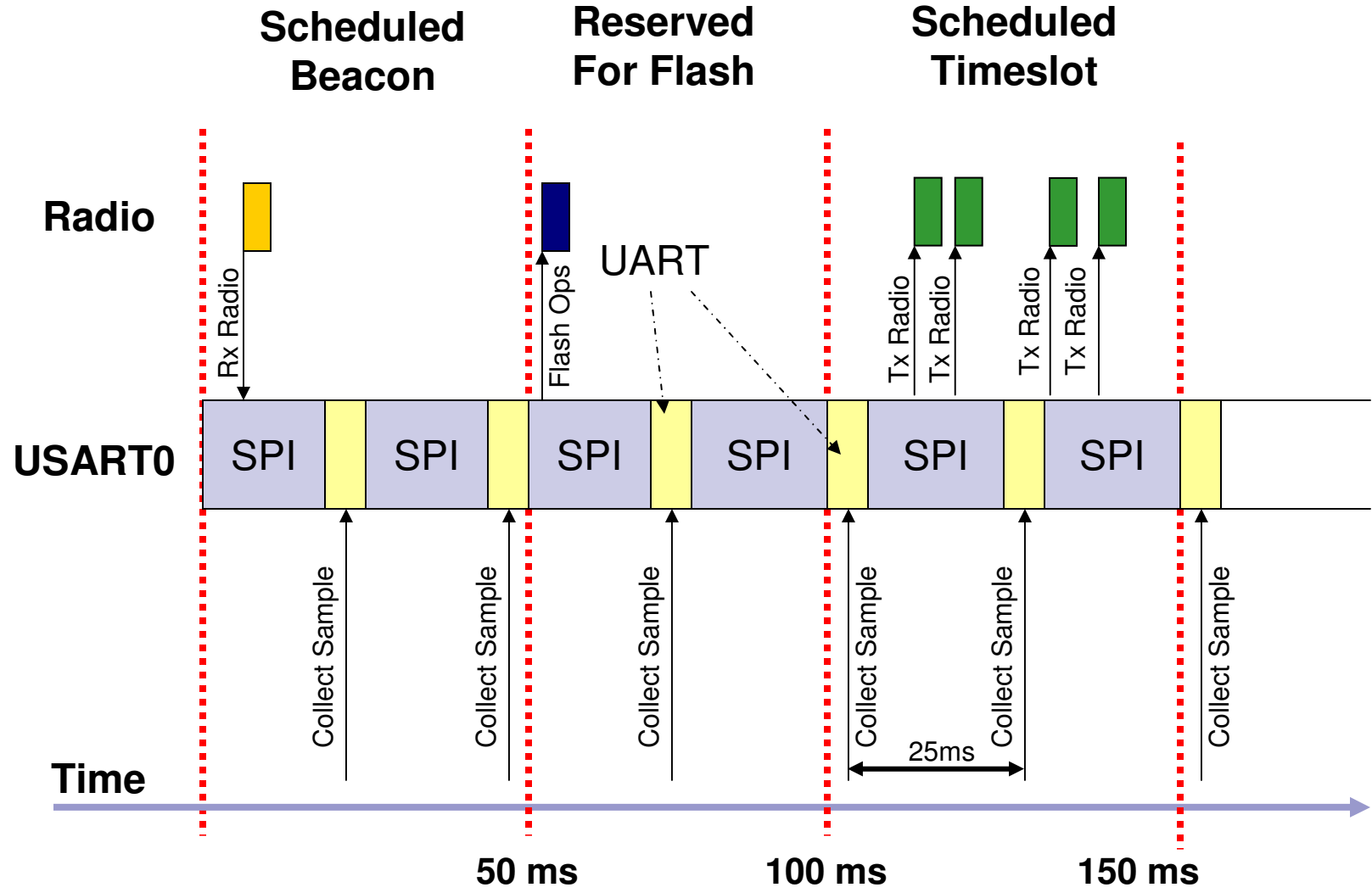
Event Management



Event Management



Resource Management – USART0



Outline



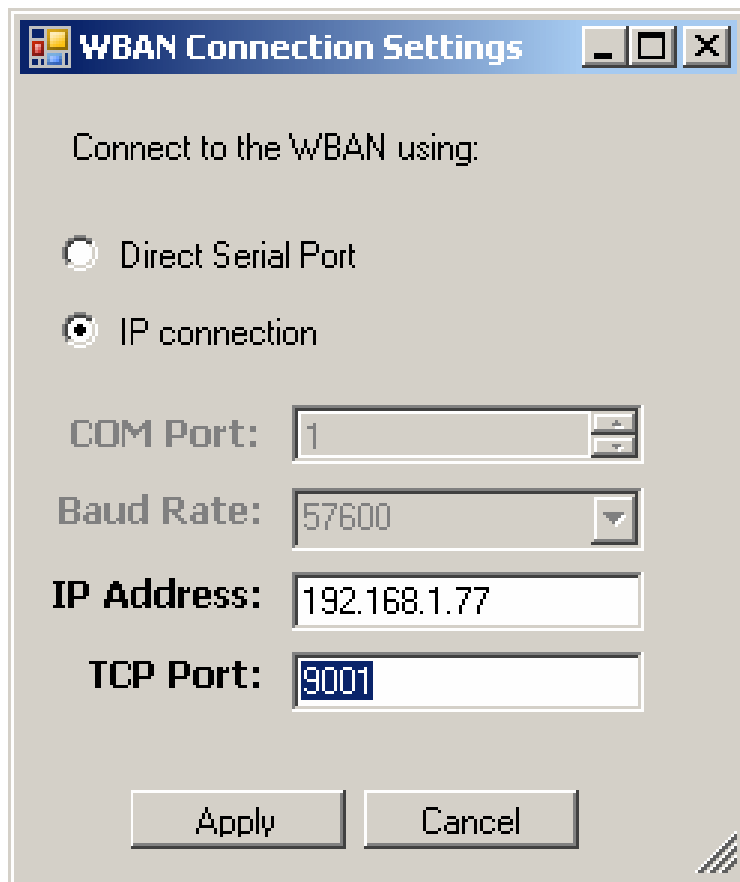
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Personal Health Server

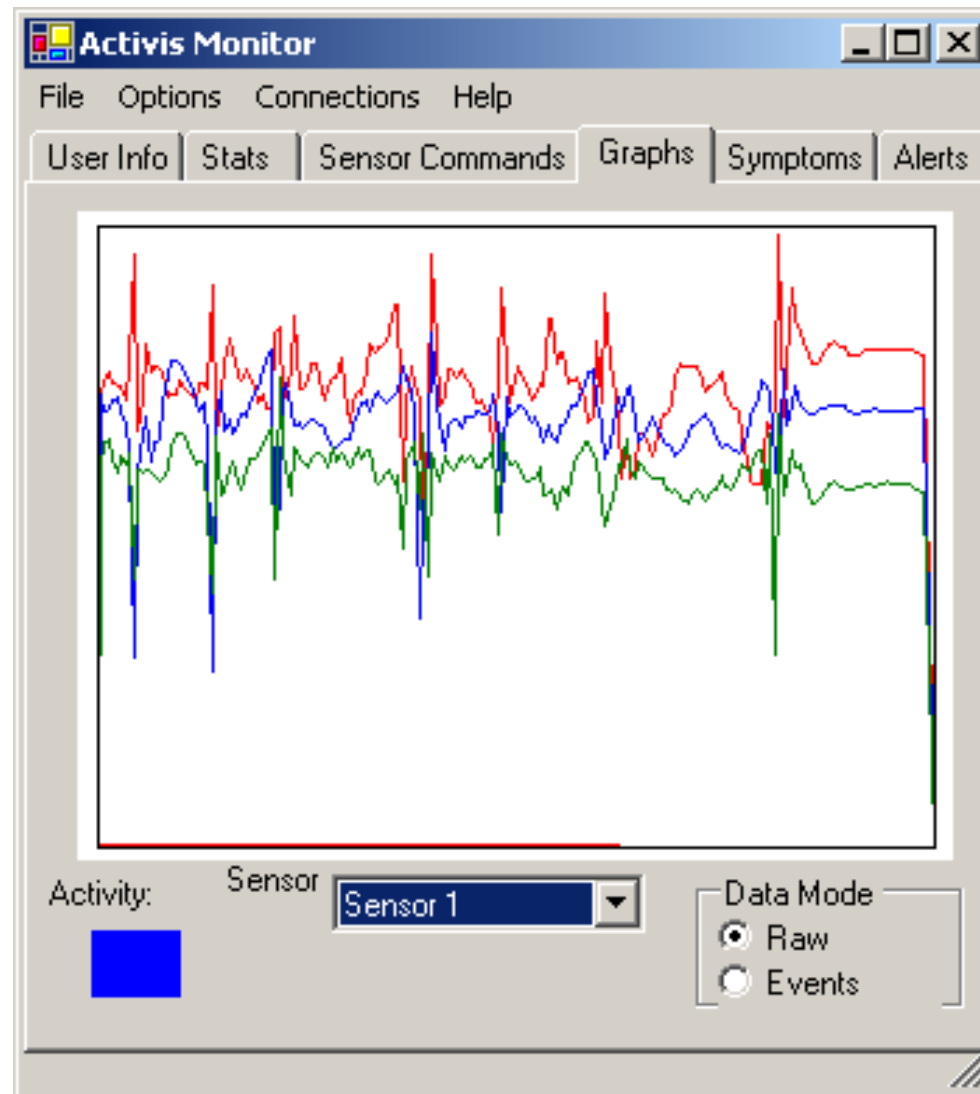


- Sensor Node Identification and Configuration
- Sensor Fusion
- Session File Management
- Graphical User Interface (GUI)

Health Server – Configuration



Health Server – Real-time Display



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Conclusions



- Working WBAN Prototype
 - Custom-designed ISPM daughter cards
 - Off-the-shelf wireless sensor platforms
 - Standard IEEE 802.15.4 communications
- Original Solutions
 - Health monitoring specific, Power Efficient TDMA Scheme
 - WBAN communication protocol
 - On-sensor real-time signal processing
- Promising Technology
 - Optimal Treatment of Disease Rehabilitation
 - Low Cost Early Diagnosis
 - Encourages Wellness Management
 - Improved Mobility
 - Low Weight (Increased Compliance)

Future Research



- Validation
- Security
 - Hardware encryption of wireless communications
 - Standard security mechanisms from the personal server to the upper levels of hierarchy
- Signal Processing
 - Discern category of activity
 - Improved Step Detection
 - Improve ECG Analysis
- Upper Tier Development
- Integration into Electronic Medical Records (EMR)

Acknowledgements



- Dr. Emil Jovanov, Dr. Alex Milenkovic
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