# Wireless System Integration, Issues and Applications

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UAH
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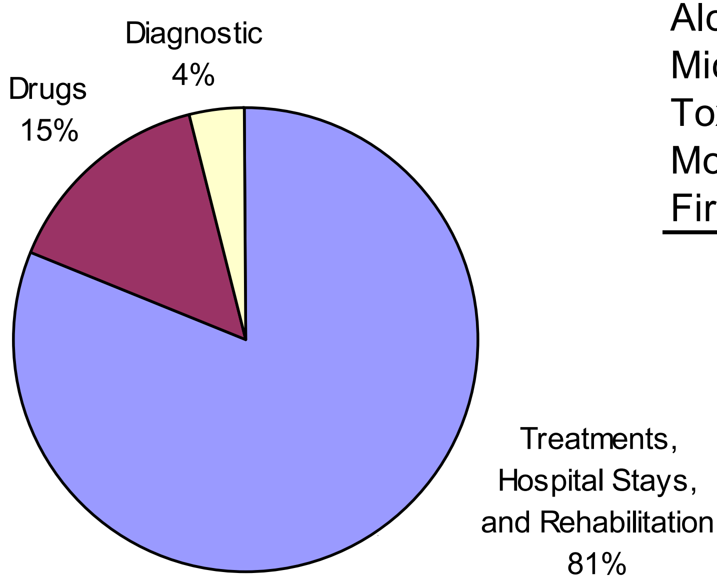
# Introduction

- Healthcare is the Largest Segment of US Economy
  - $1.8 Trillion in 2004 (15% of GDP)
  - $200 Million Informal Care Givers (1/3 of population)
  - $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% |

# Motivation

- Goal: ubiquitous and affordable healthcare
- mHealth
  - Mobile computing, Sensor technology, and Communication technologies
- WBAN – emerging integration technology
  - Promising technology for unsupervised, continuous, ambulatory health monitoring
  - Challenge: design WBAN for extended RT of physiological data and events.
  - Solution: hierarchical 3-tier ubiquitous monitoring system
- Opportunities:
  - Ambulatory health monitoring
  - Computer-assisted rehabilitation
  - Augmented reality systems
- Long-term benefits:
  - Promote healthy lifestyle
  - Seamless integration of data into personal medical records and research databases
  - Knowledge discovery through data mining
- Ultimate test?

# Outline

- Introduction
- Proposed Solution: WBAN System
- Data Flow and System Requirements
- System Design Issues
- Conclusions
- Demonstration

# 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

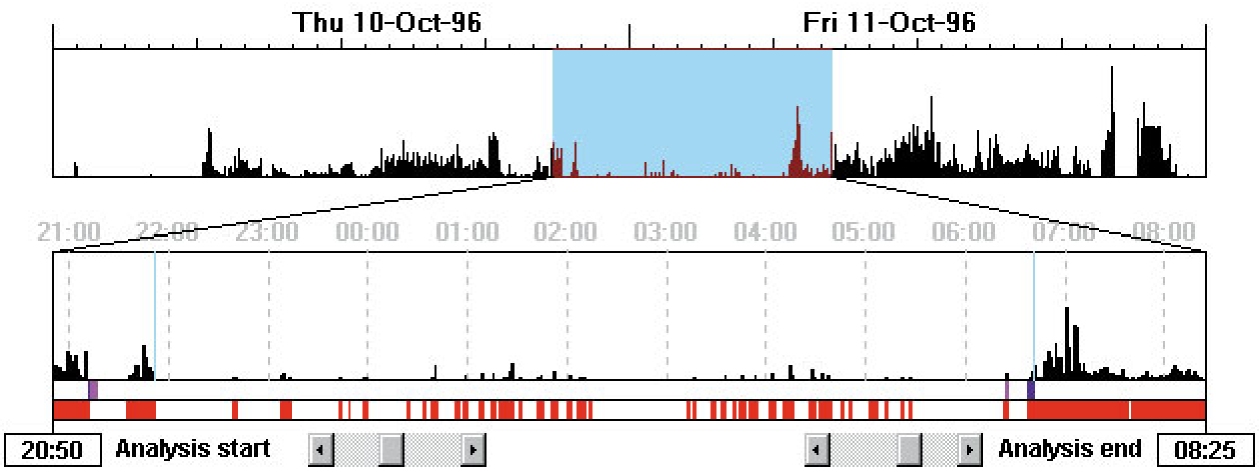
- Mobile Cardiac Outpatient Telemetry
- Wireless Sensor and Wireless Monitor
- Arrhythmic event detection

# 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

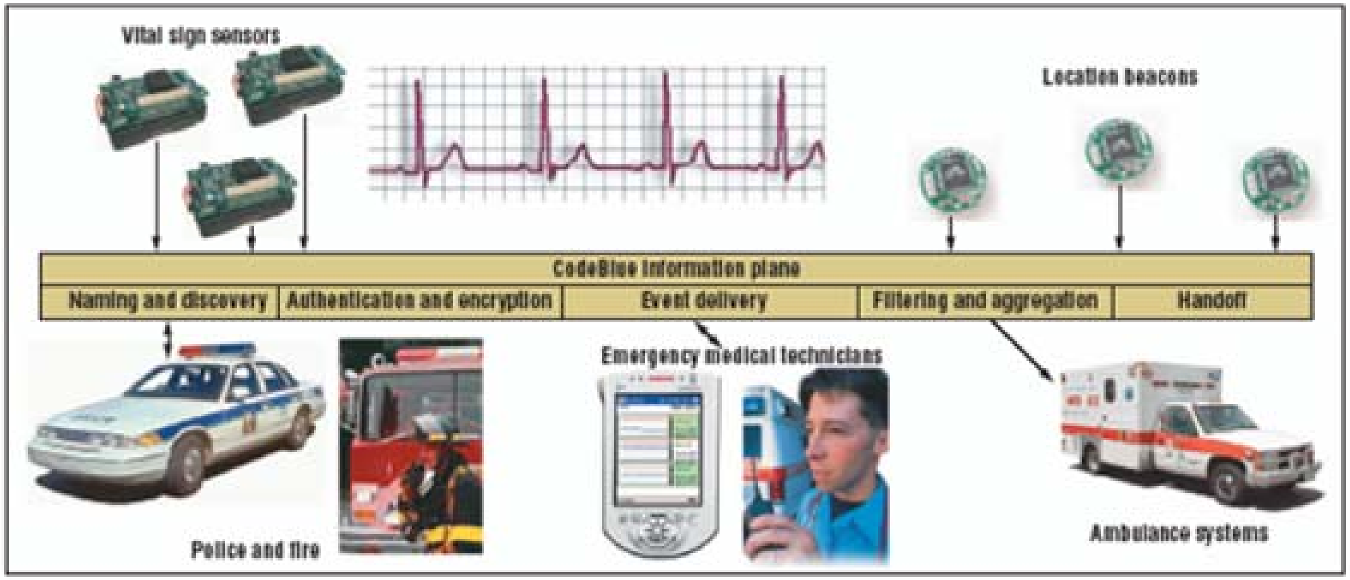



# Body Media (bodyBugg)

- 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

# CodeBlue

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



# Wireless technologies

- WLAN and WPAN technologies
- Bluetooth
  - Widespread, cell phones/PDAs
  - 720 kbps
  - Relatively high power consumption, protocol stack complexity
- ZigBee
  - Emerging standard
  - Very low power
  - 250 kbps
- UWB
  - High bandwidth
- Alternative solutions
  - MEMS resonators (100 $\mu$W)

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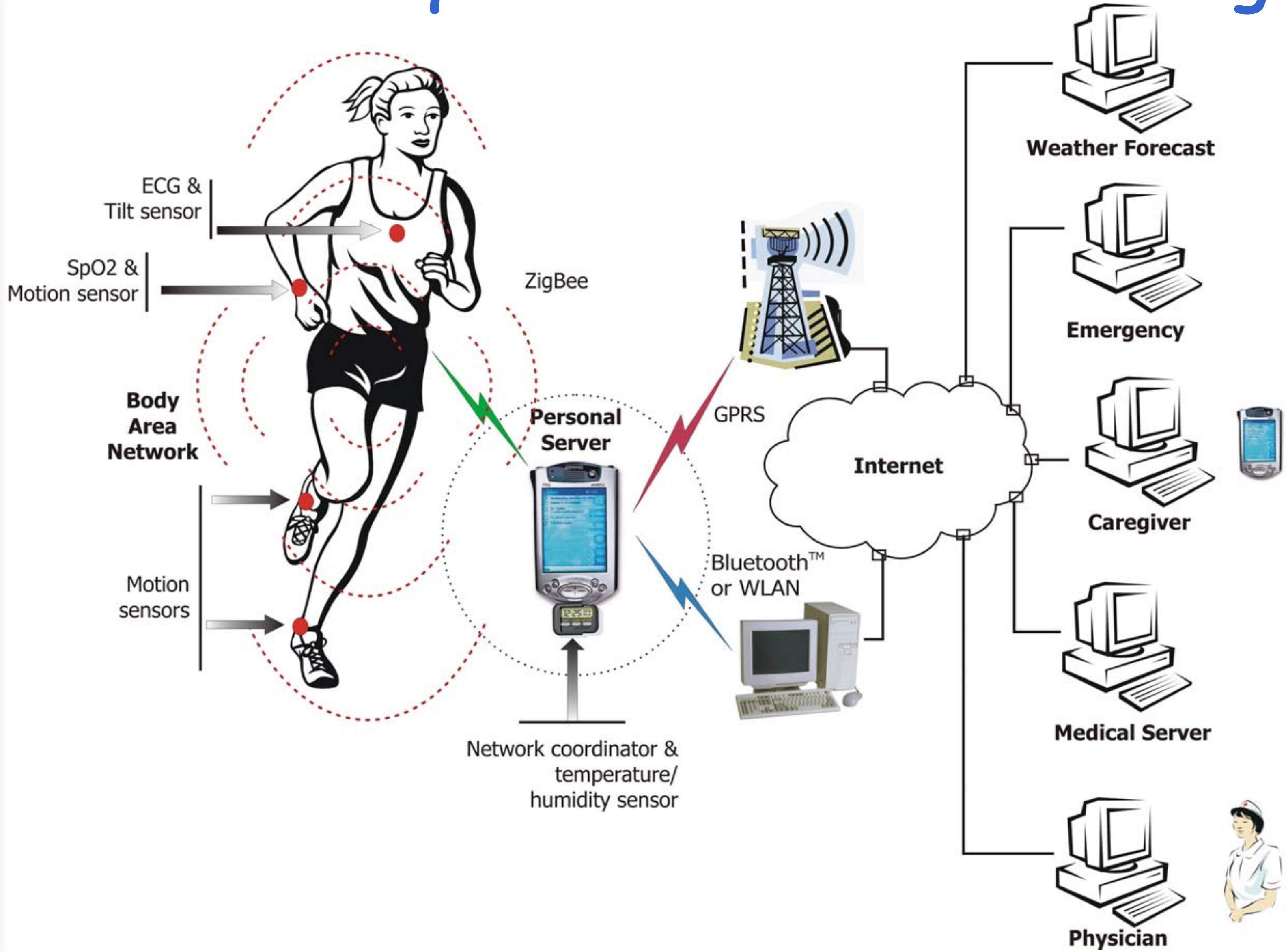
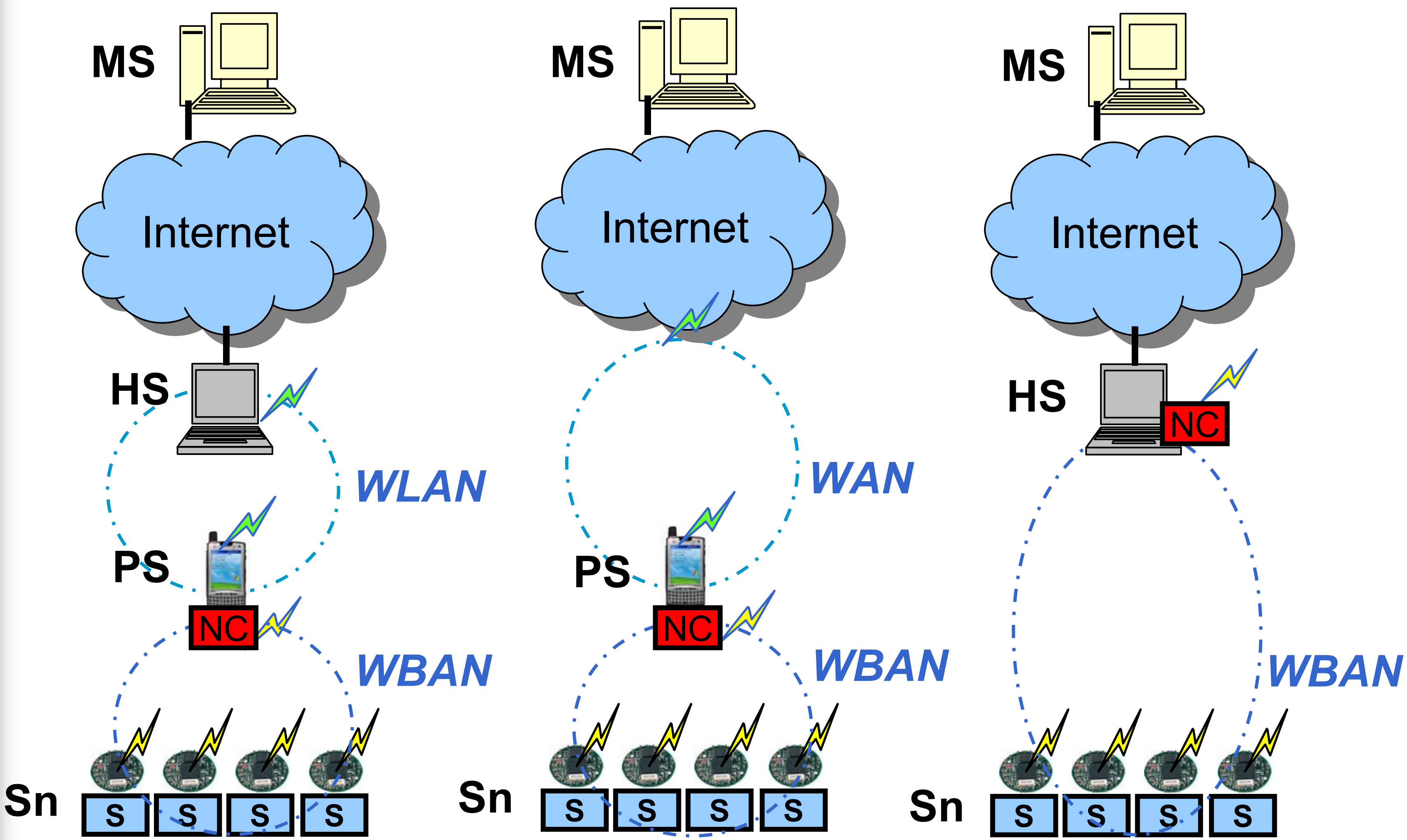
# WBAN Ubiquitous Health Monitoring



# WBAN Configurations



# WBAN – design goals

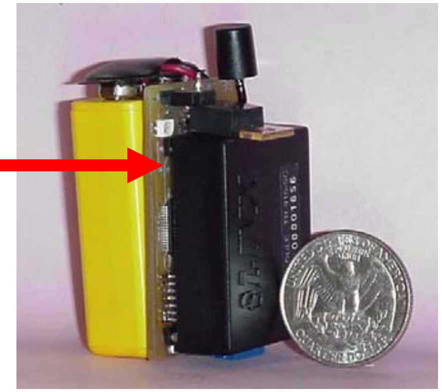
- minimization of weight and size of sensors,
- user's acceptance,
- portability,
- unobtrusiveness,
- ubiquitous connectivity,
- reliability, and
- seamless system integration.

# Hierarchical organization

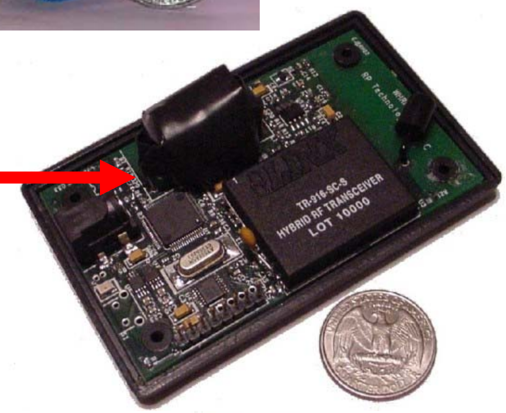
| Tier | 1. Sensor | 2. Personal server | 3. Medical server |
| --- | --- | --- | --- |
| Processing Power | 1-10 MIPS | ~ 100 MIPS | ~ GIPS |
| RAM | 1-10 KB | ~ 50 MB | ~ GB |
| Secondary memory | 10-100 KB, 1 MB (flash) | ~ 1 GB | ~ TB |
| Power consumption | 1-10mW proc. ~50mW comm. | ~ 100 mW | ~ 100 W |
| Other | Peripherals, timers, etc. | WAN communication | Internet connectivity |

# Wireless Body Area Networks at UAH

- 2000: Wireless Intelligent Sensors (WISE)



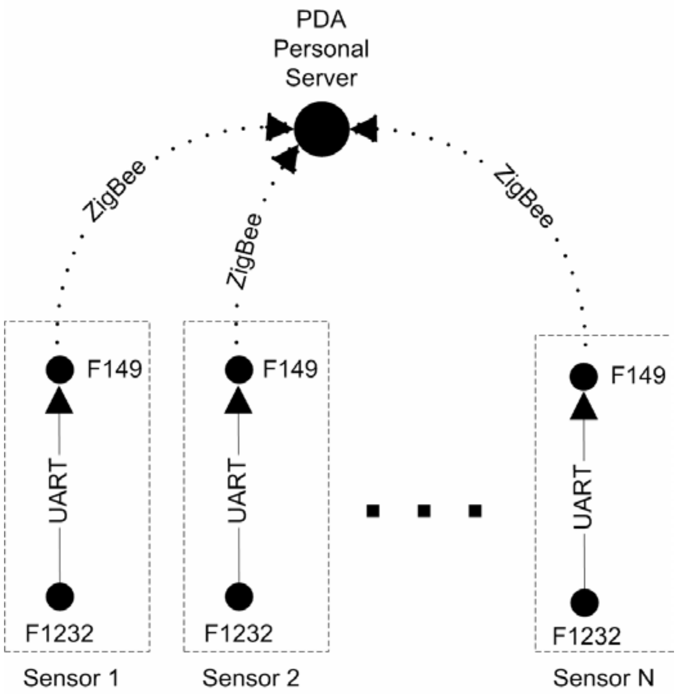
- 2002: Distributed Wireless System for Stress Monitoring




- 2004: ActiS – Activity Sensor
  - Standard sensor platforms and communication protocols


"A wireless body area network of intelligent motion sensors for computer assisted physical rehabilitation," Journal of NeuroEngineering and Rehabilitation, http://www.jneuroengrehab.com/content/2/1/6

# ActiS: Activity Sensor

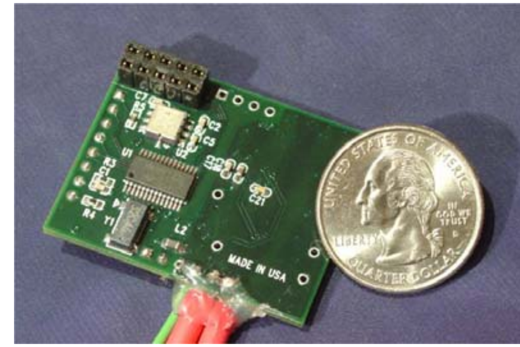


# Telos Wireless Platform

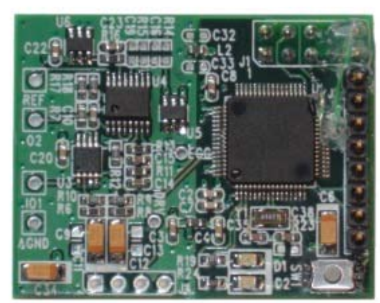
- 8MHz Texas Instruments 16-bit MSP430F1611 microcontroller
  - 10KB RAM, 48KB Flash
- Chipcon 2420, IEEE 802.15.4 compliant wireless transceiver
  - Hardware link layer encryption and authentication
  - 250kbps, 2.4GHz
  - programmable output power
- Onboard antenna
  - Range: 50 m / 125 m
- Integrated
  - humidity, temperature, and light sensors
  - ADC, DAC, DMA,Supply Voltage Supervisor
- TinyOS support

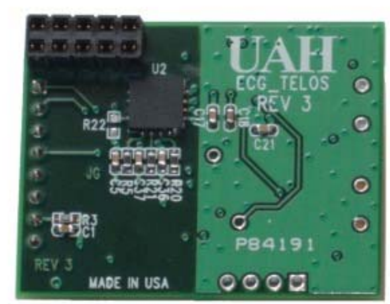
# Intelligent Signal Processing Modules

- First generation
  - MSP430F1232 microcontroller
    - 256B RAM, 8KB ROM
  - 2 Dual Axis ADXL202 Acc.
  - Bioamplifier (ECG, EMG)
  - Force resistor signal conditioning circuit (foot switch)



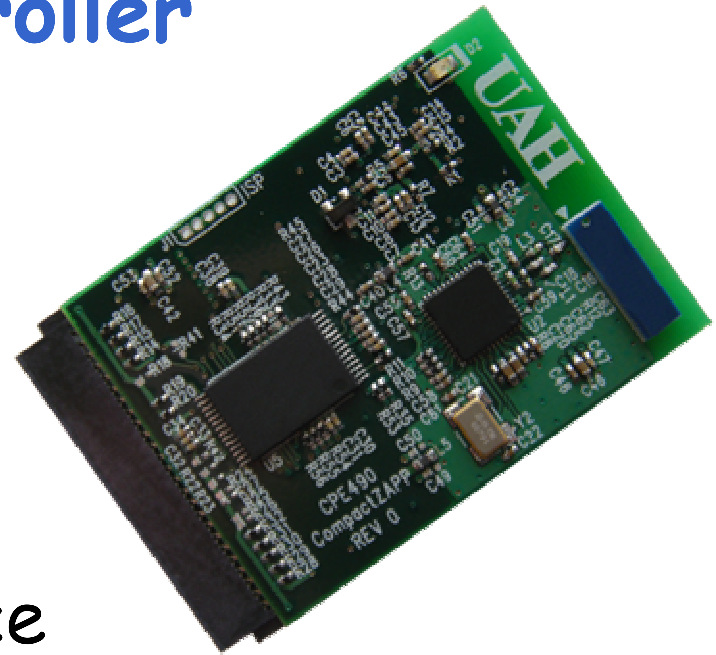

- Second generation
  - MSP430F1611 microcontroller
    - 10KB RAM, 48KB ROM
  - Single 3D Acc (Freescale)
  - Bioamplifier (ECG, EMG)

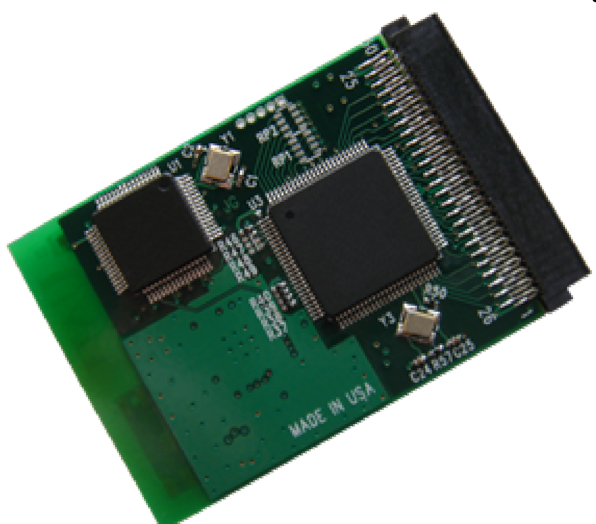




# ZigBee network controller

- Wireless gateway
- ARM7 processor
- ~60MIPS proc. power
- 64KB RAM
- Compact Flash interface
- ZigBee wireless interface



# Actis System Performance

| Tier | 1. Signal Processing Module | 2. Sensor Platform | 3. Wireless Gateway | 4. Personal Server |
|---|---|---|---|---|
| Processing Power | 1 MIPS | 1 MIPS | 60 MIPS | ~ 100 MIPS |
| RAM | 256B | 10 KB | 64 KB | ~ 64MB |
| Power consumption | 1 mW | 3mW | 60 mW | ~ 300 mW |

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# WBAN System Design

- WBAN is a collection of sensors
- Each sensor monitors one or more signals
- Signals can be used for raw data acquisition or on-sensor signal processing
  - Raw sample set
  - Processed events generated from raw data
    - e.g. step event or heart beat event
- Example: 3 channel ECG with upper body tilt may generate the following streams:
  - 3 ECG signal streams
  - 1 heart beat and 1 ischemia event stream
  - 3 accelerometer streams
  - 1 tilt stream

# WBAN System Design …

- Required system bandwidth (SBW):

$$SBW = \sum_{i=1}^{N} \sum_{j=1}^{Nch_i} Fs_i \cdot SS_i \cdot Rov_i$$

- where:
  - $N$ is the total number of sensors in the system (WBAN)
  - $Nch_i$ is the number of channels of the signal $i$
  - $Fs_i$ is sampling frequency of the signal $i$
  - $SS_i$ is sampling frequency of the signal $i$
  - $Rov_i$ is the record message overhead of the signal $i$:

$$Rov_i = \frac{Message\_overhead_i + primary\_data\_size_i}{primary\_data\_size_i}$$

# System Design – typical requirements

- ECG
  - $BW_i = Nch_i \cdot Fs_i \cdot SS_i$
  - $BW_i$ = [1..3]·[250..500] ·[12..16]
    = [3,000..24,000] bps
- EEG
  - $BW_i = Nch_i \cdot Fs_i \cdot SS_i$
  - $BW_i$ = [1..8]·[125..1000] ·[12..16]
    = [1,500..128,000] bps

# System design – on sensor processing

- On-sensor processing reduces required communication bandwidth - *SBW*
- Example: Heart beat events (Rpeak event)

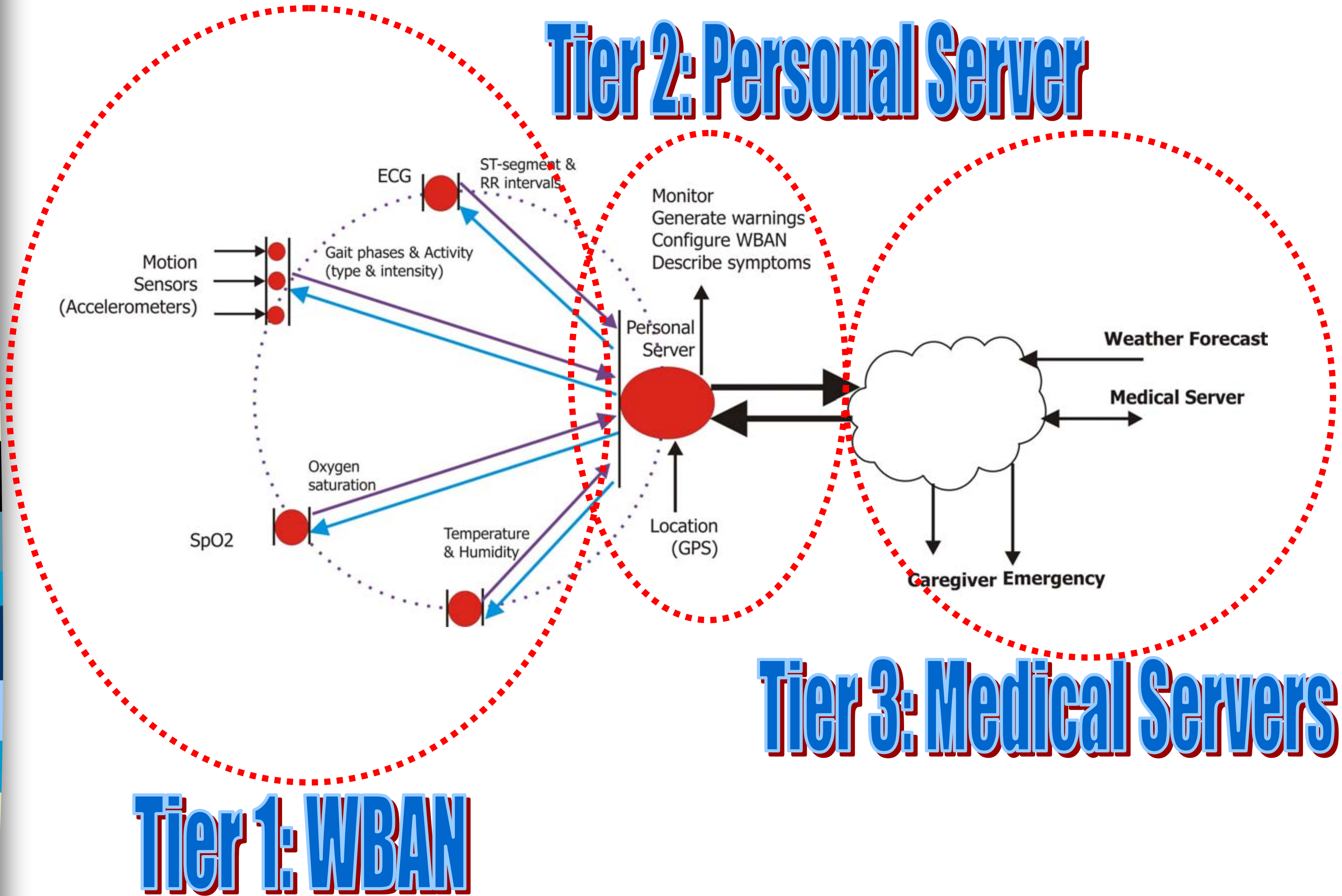
$Nch_i$ $Fs_i$ $SS_i$

- Rpeak
  - $BW_i$ = [1]·[0.6..4]·[16]
    = [9.6..64] bps

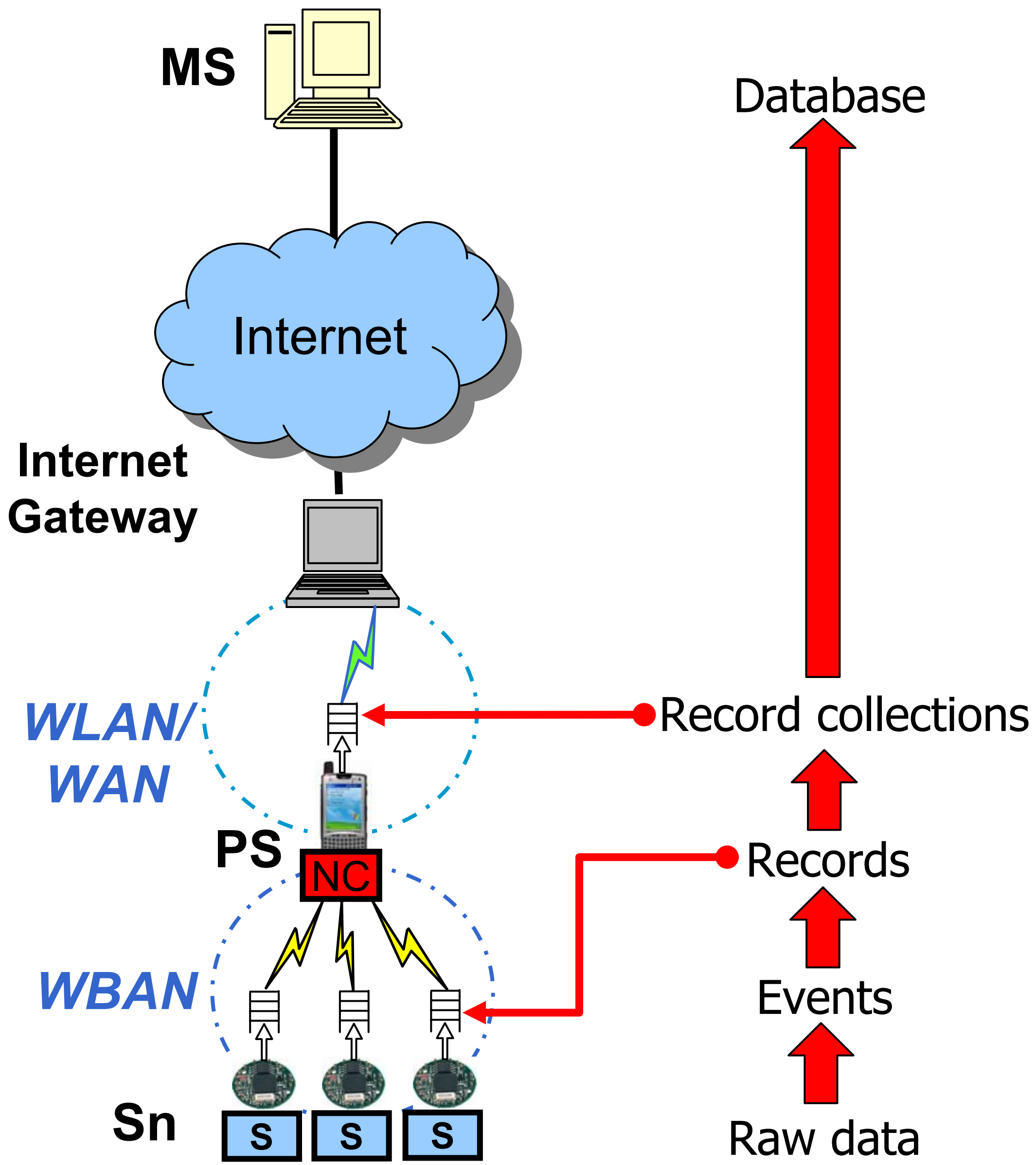
ECG: [3,000..24,000] bps

**Local Intelligence always pays off**

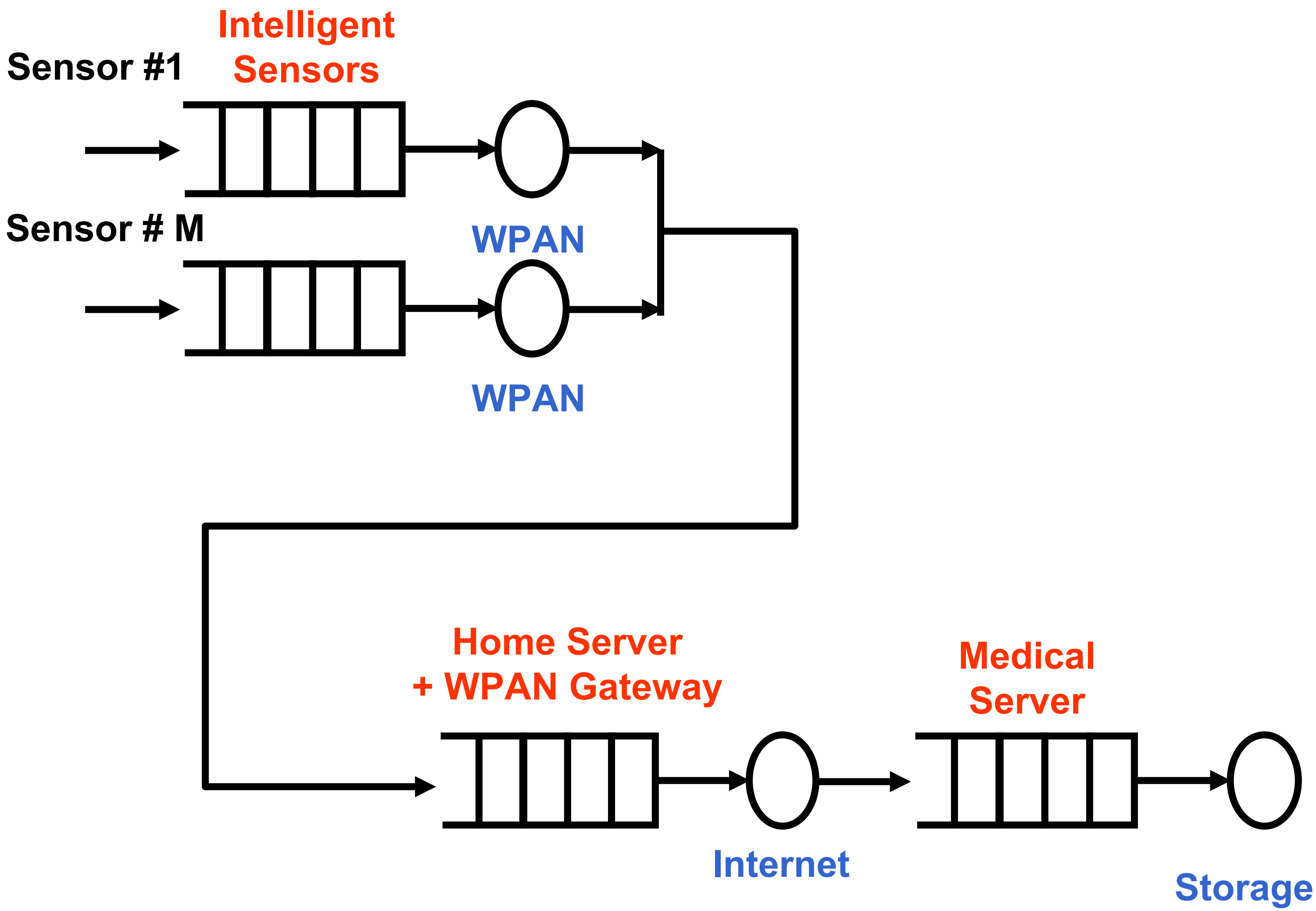
# 3-tier Hierarchical Organization



# Wireless Integration

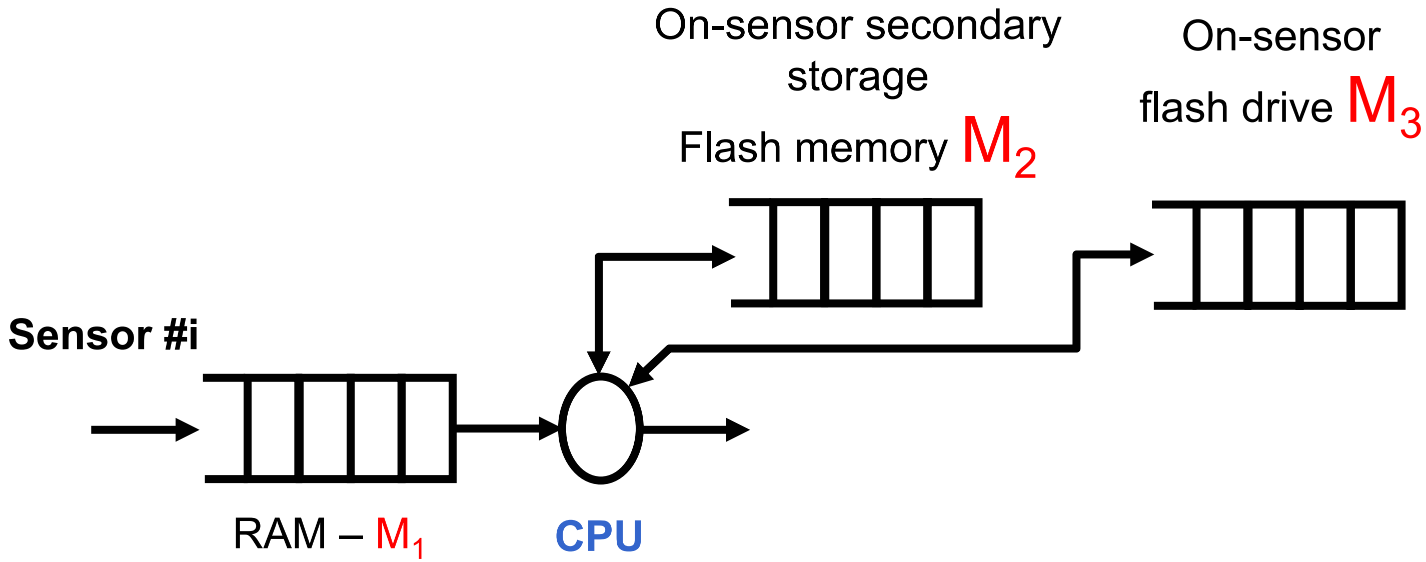


# Data Flow



Intelligent
Sensors
Sensor #1
Sensor # M
WPAN
WPAN
Home Server
+ WPAN Gateway
Medical
Server
Internet
Storage

# Data flow – memory requirements



# System Design – raw data buffering

- On-sensor memory storage
  - $M_1$ – RAM memory capacity (5KB)
  - $M_2$ – flash memory capacity (4Mb)
  - $M_3$ – flash disk capacity (1GB)
- System operation time (ECG sensor)
  - $OT = M_i / BW_i$
  - $OT_1(RAM) = M_1 / BW_{ECG}$
    $= 5\ KB * 8\ b/B / [3{,}000..24{,}000]\ bps \approx [2..14]\ s$
  - $OT_2(flash) = M_2 / BW_{ECG}$
    $= 4Mb / [3{,}000..24{,}000]\ bps \approx [0.4..3.1]\ hours$
  - $OT_2(flash\_disk) = M_3 / BW_{ECG}$
    $= 8Gb / [3{,}000..24{,}000]\ bps \approx [4..31]\ days$

# System Design – event buffering

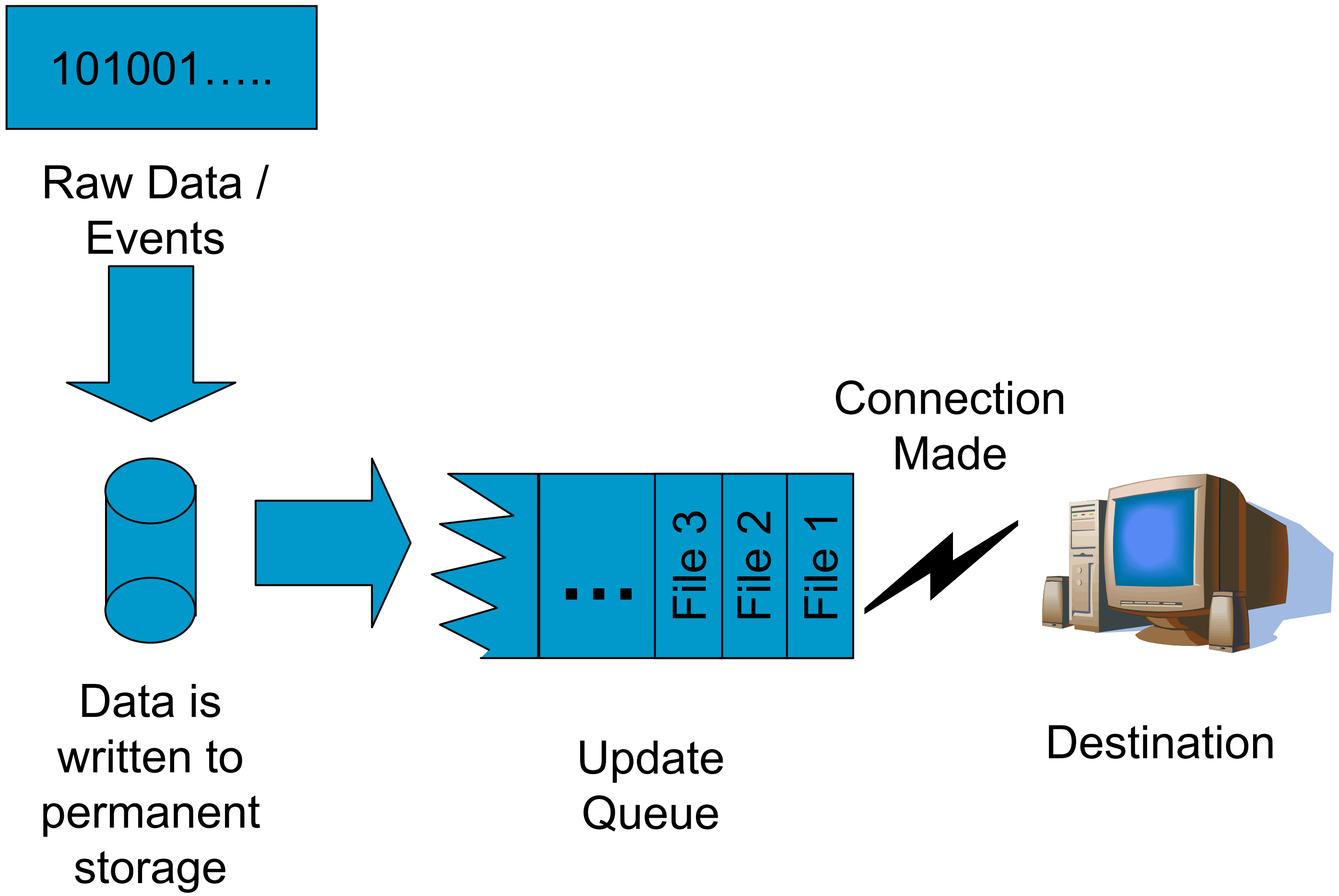
- On-sensor memory storage
  - $M_1$ – RAM memory capacity (5KB)
  - $M_2$ – flash memory capacity (4Mb)
  - $M_3$ – flash disk capacity (1GB)

- System operation time (Rpeak events)
  - $OT_1(RAM) = M_1 / BW_{Rpeak}$
    $= 5$ KB * 8 b/B/ [9.6..64] bps ≈ [11..71] min
  - $OT_2(flash) = M_2 / BW_{Rpeak}$
    $= 4$Mb / [9.6..64] bps ≈ [6..41] days
  - $OT_2(flash\_disk) = M_3 / BW_{Rpeak}$
    $= 8$Gb / [9.6..64] bps ≈ [4..28] years

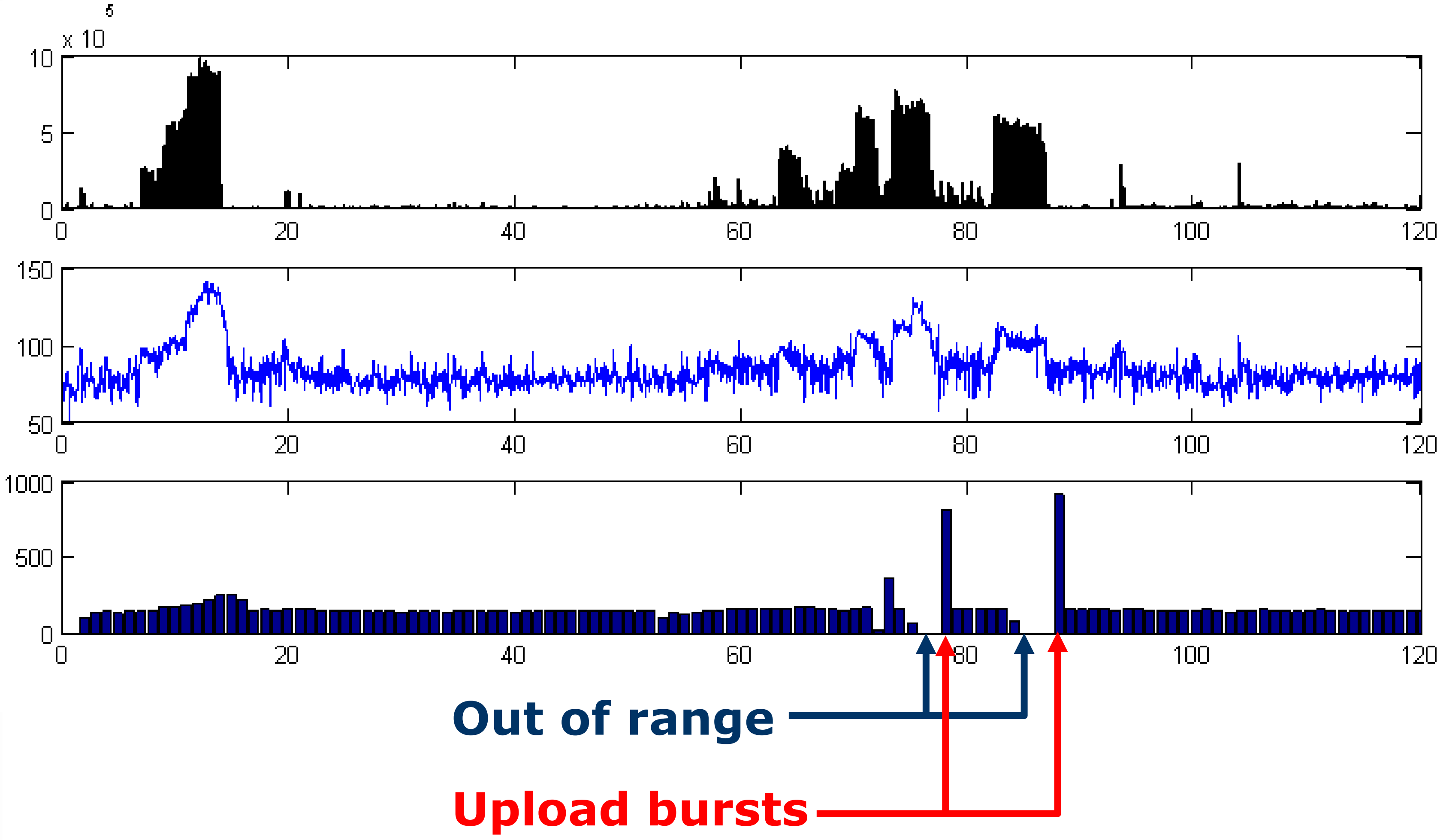
# WBAN @ UAH – on-sensor buffering

- Each sensor uses
  - RAM buffering as a primary storage
  - Flash buffering as a secondary storage
- Reliable operation
  - Out of range situations

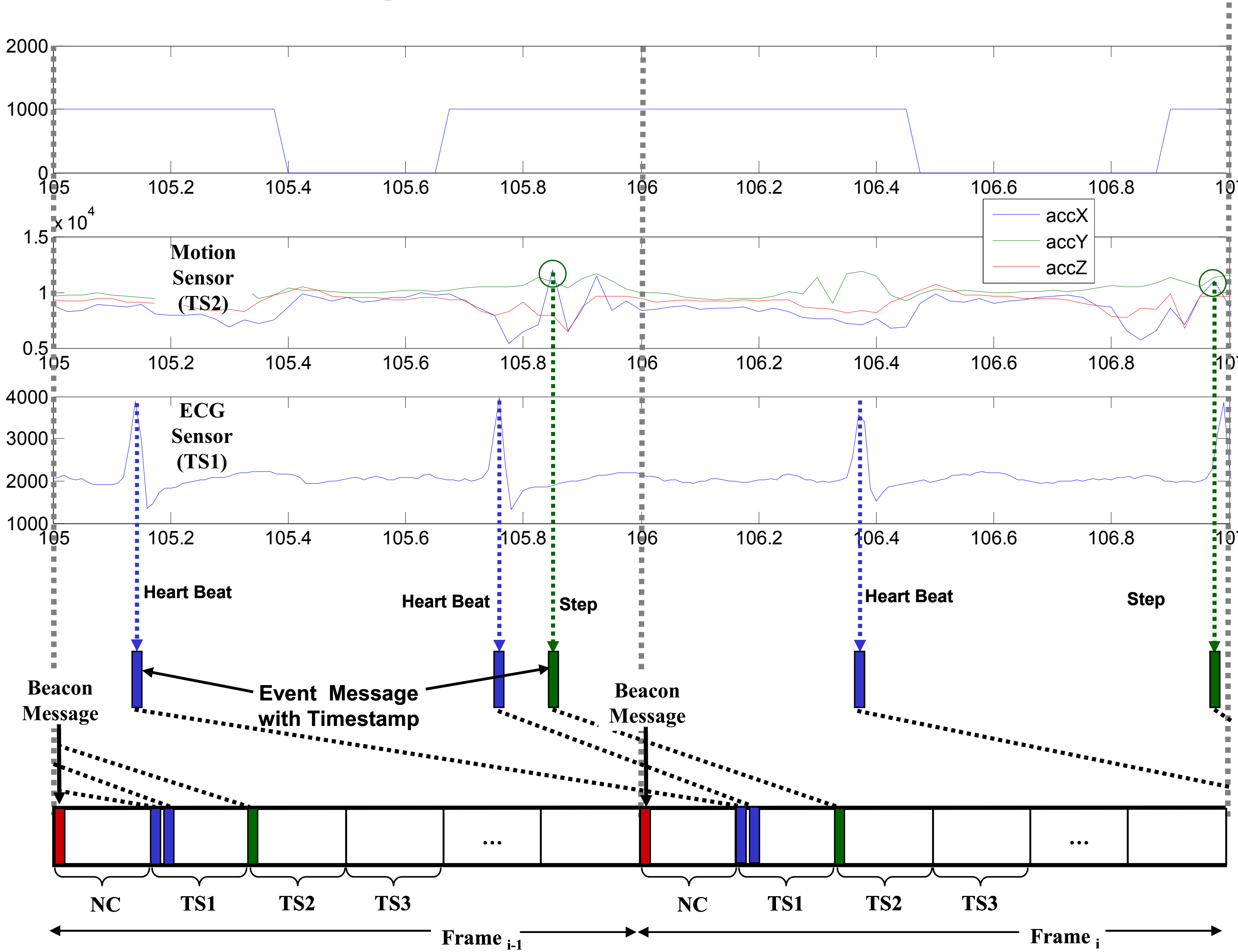
# Record Update Mechanism



# Packet uploads



# Event Management



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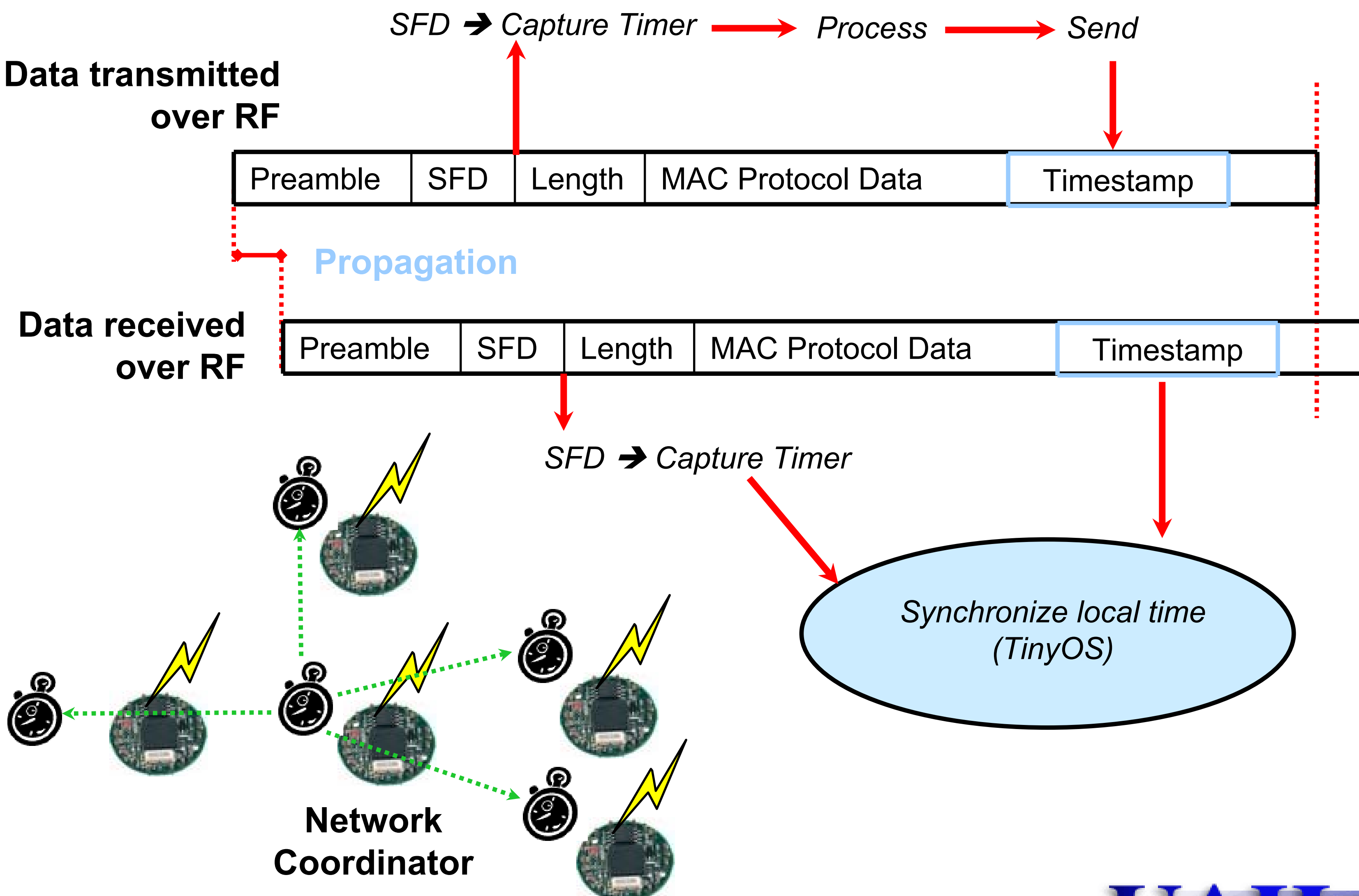
# System Design Issues

- Extremely low-power, low-weight, and small size
- Non-invasive and unobtrusive operation
- Reliable transmission using retransmissions
  - Time-stamping for collective processing and out of order message processing
- Interoperability requires standardization
  - Seamless connectivity
  - Application specific standards for wireless communications, messaging, and system support
- Seamless customization, configuration, and integration
- Sensor placement and mounting
  - Sensor commodization
- Security and Privacy
  - Communication and data storage
- User compliance, efective user interfaces

# Time Synchronization

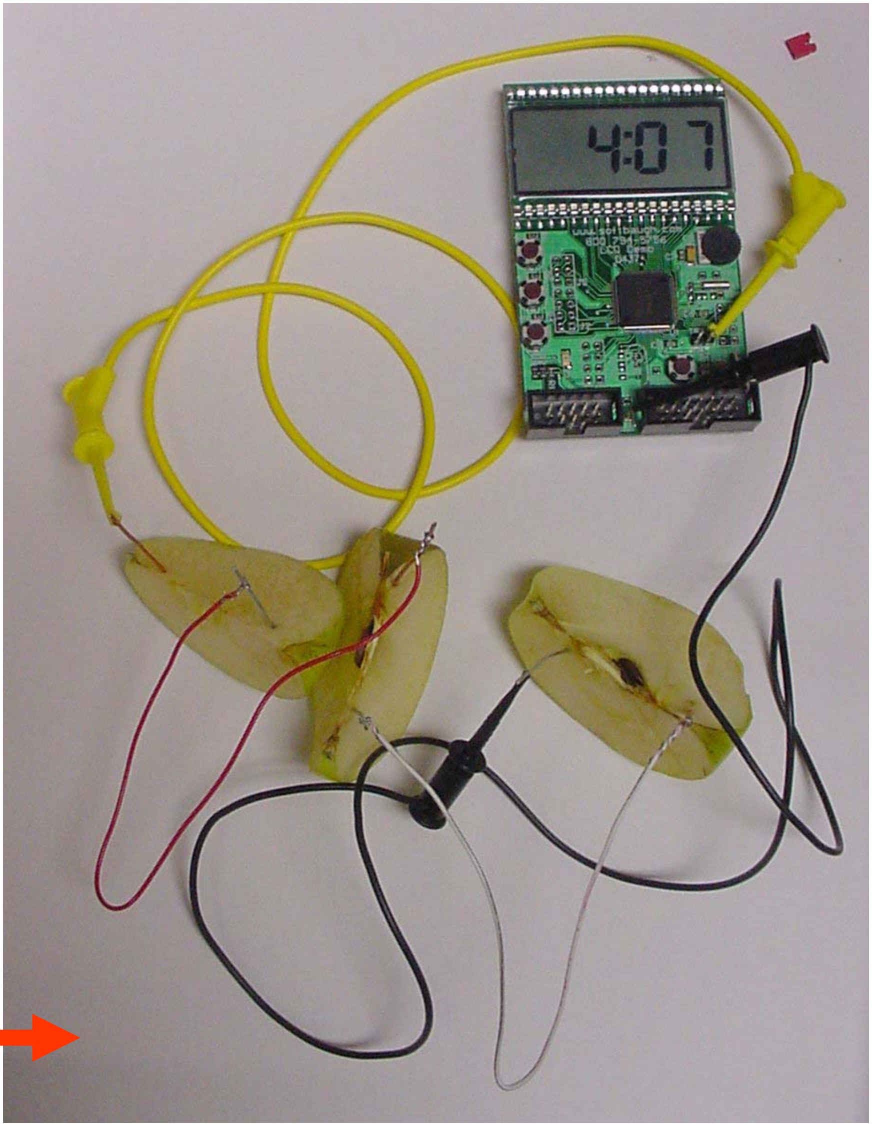
- Necessary for collective processing, data logging, power-efficient operation, etc.
- Problem:
  - High precision synchronization with low frequency clocks
    - 32 KHz on Telos
- FTSP FloodingTime synchronization protocols
  - Telos specific implementation at UAH
  - Implemented precision ~2 $\mu S$ with 32KHz crystal!

# Mechanism for Time Synchronization



# Power Consumption

- User's convenience
  - Battery life
  - Size and weight of batteries
- Battery Life
  - Battery Capacity [mAh]
  - $BL = BC / I_{ave}$
  - For simple time keeping and minimal processing average power is ~2.1μA, standard 750 mAh batteries will allow battery life:
  - BL = 750 mAh / 2.1 μA ≈ 44 years !!!
- Introducing: Apple Computers

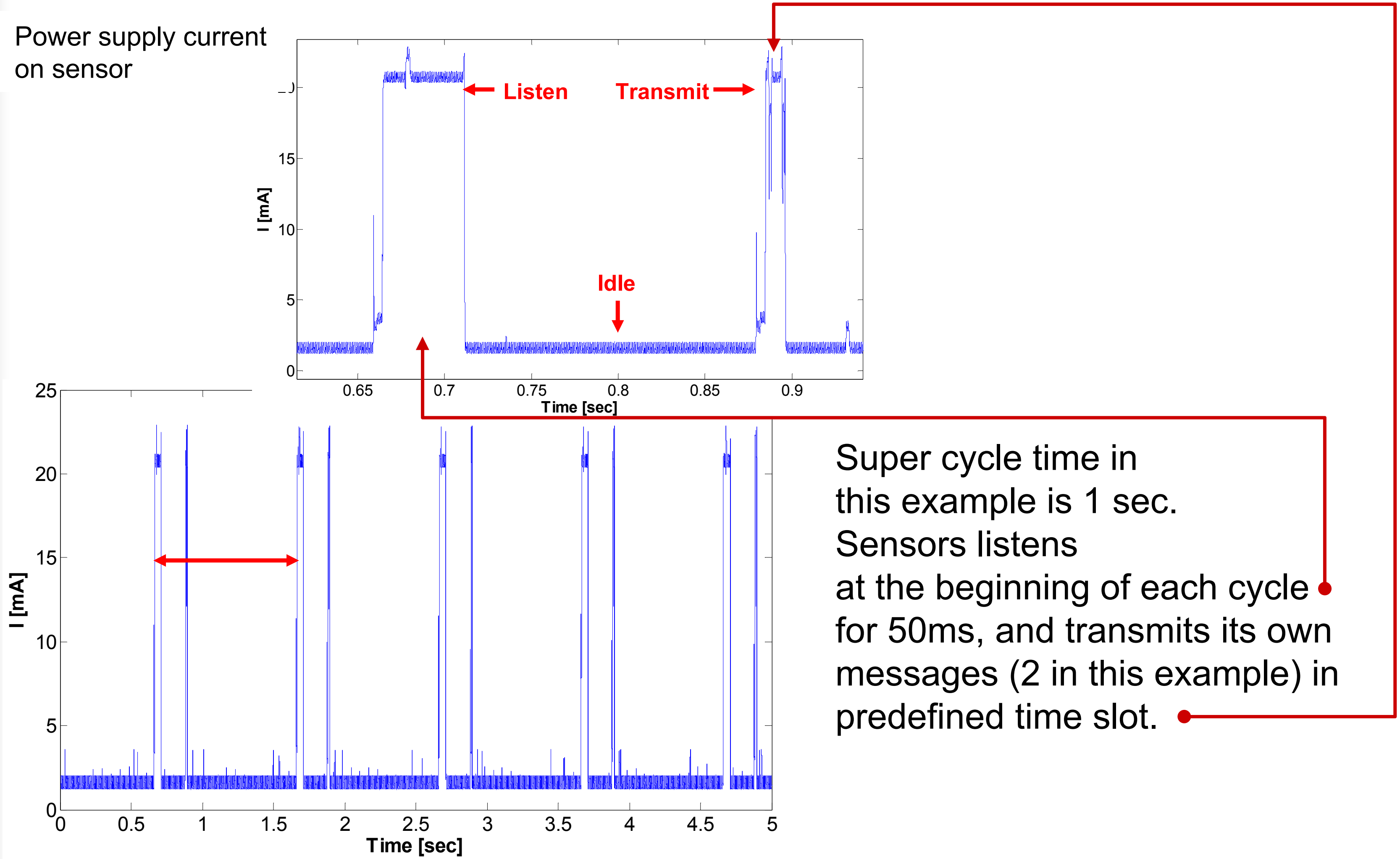


# Power efficient communication

- Wireless communication requires ~ 10 times more power than processing
  - Turn-off radio whenever you can
- Time slots
  - Time slot scheduling
  - Allow time slots for new sensors to join the club
- Design issues:
  - Battery life
  - Latency
  - Number of sensors

# Power efficient wireless communication - implementation

Power supply current on sensor

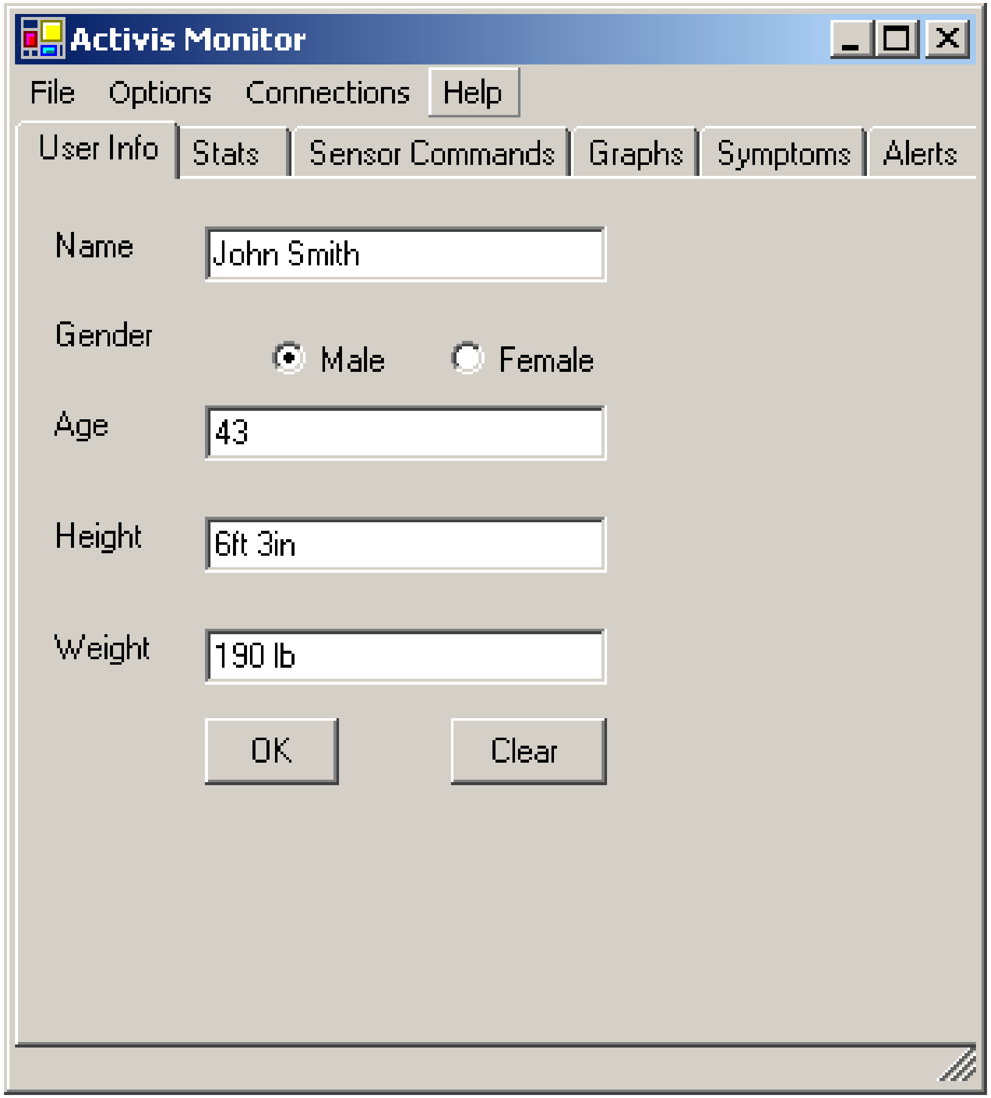



Super cycle time in this example is 1 sec. Sensors listens at the beginning of each cycle for 50ms, and transmits its own messages (2 in this example) in predefined time slot.

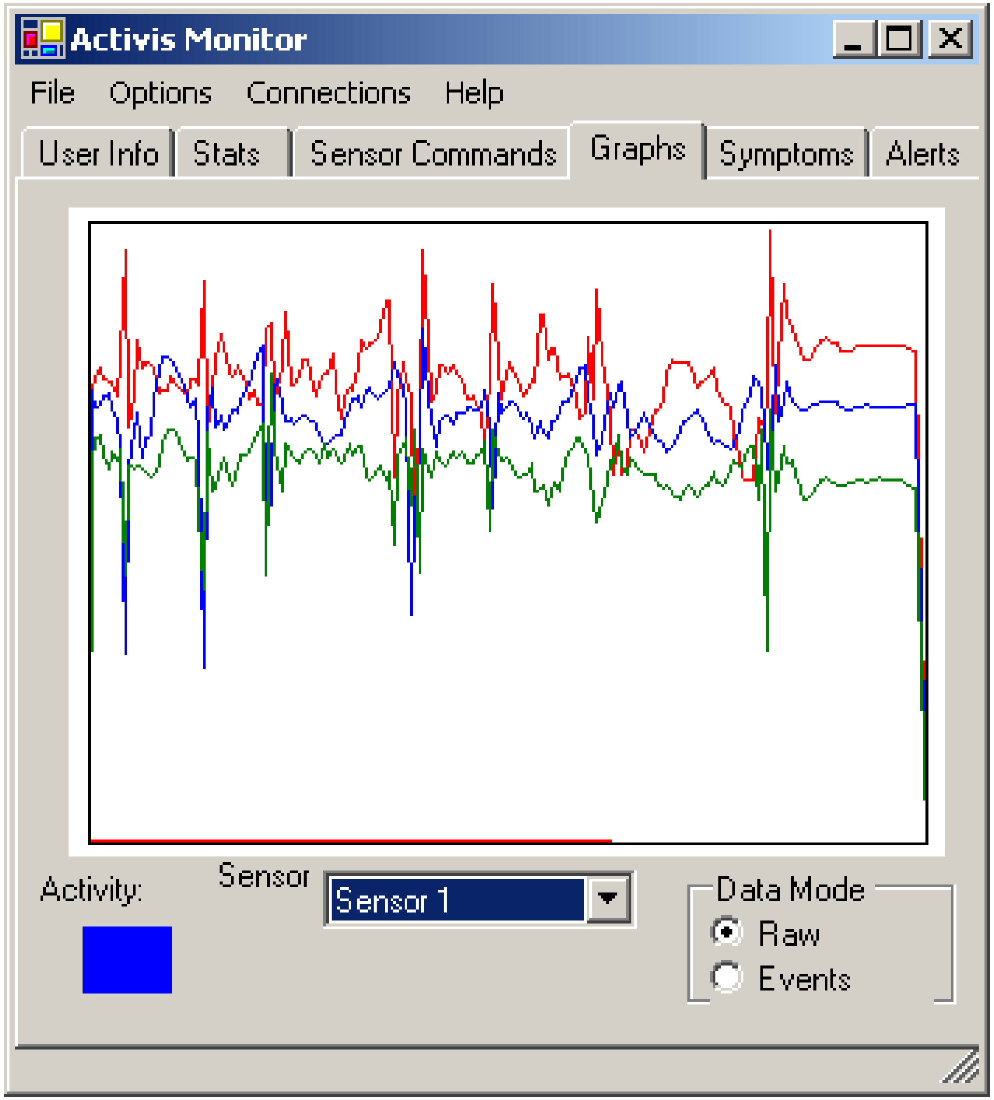
# Personal Server program

- Implemented on PC/PDA
- Controls the network of wireless sensors
- Collects data from sensors
- Communicates with servers on higher levels of hierarchy whenever the connection is available
- Provides feedback and alerts to the user
- Stores user's inputs

# ActiS Monitor – User's Info



# ActiS Monitor - Signals and Graphs



# Privacy and Security

- Hardware encryption of wireless communications
- Standard security mechanisms from the personal server to the upper levels of hierarchy

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# Conclusions

- Promising technology for
  - Ambulatory monitoring
  - Early detection of abnormal conditions
  - Supervised rehabilitation
- Advantages
  - Promotes healthy lifestyle / health awareness
  - Increased confidence and better quality of life
  - Data mining of huge research databases
    - Effects of drug therapies and rehabilitation procedures
- Need for standards for wireless communications, messaging, and system support

# Acknowledgments


- Aleksandar Milenkovic, Chris Otto, Corey Sanders, John Gober, Reggie McMurtrey, University of Alabama in Huntsville
- Piet de Groen, Bruce Johnson, Mayo Clinic
- Steve Warren, Kansas State University

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