Wireless Technology and System Integration in Body Area Networks for m-Health Application

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Introduction

- mHealth
  - special issue of IEEE Transactions on Information Technology in Biomedicine, Dec. 2004, M-Health: Beyond Seamless Mobility and Global Wireless Health-Care Connectivity
  - Mobile computing
  - Sensor technology
  - Communication technologies
- WBAN – emerging integration technology
  - Promising technology for unsupervised, continuous, ambulatory health monitoring
  - Challenge: design WBAN for extended real-time monitoring of physiological data and events.

WBAN: Motivation

- Goal: ubiquitous and affordable healthcare
- Conditions: demographic and technology trends
  - Informal caregivers (1/3 in the U.S.)
- Solution: 3-tier ubiquitous monitoring system
  - Tier 1: Wireless Body Area Network (WBAN)
  - Tier 2: Personal Server
  - Tier 3: Healthcare Provider Servers/Medical Servers
- 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

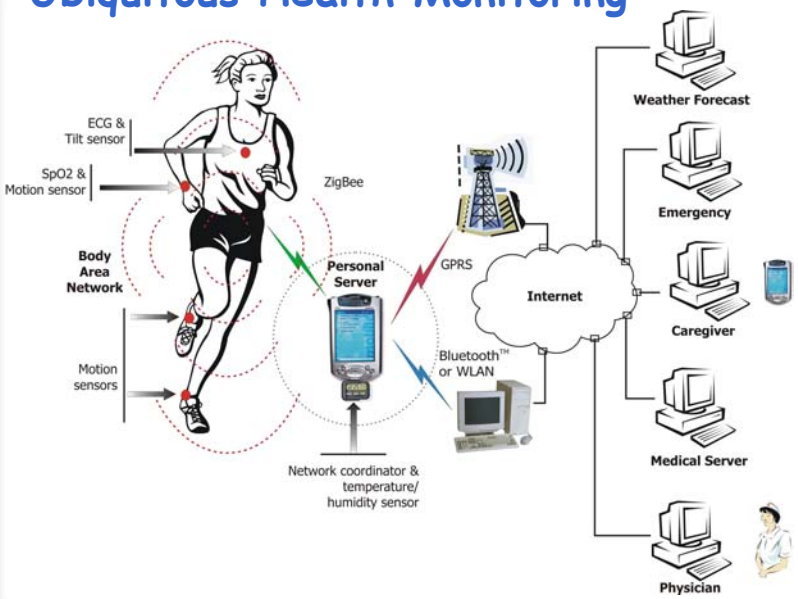
WBAN – design goals

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

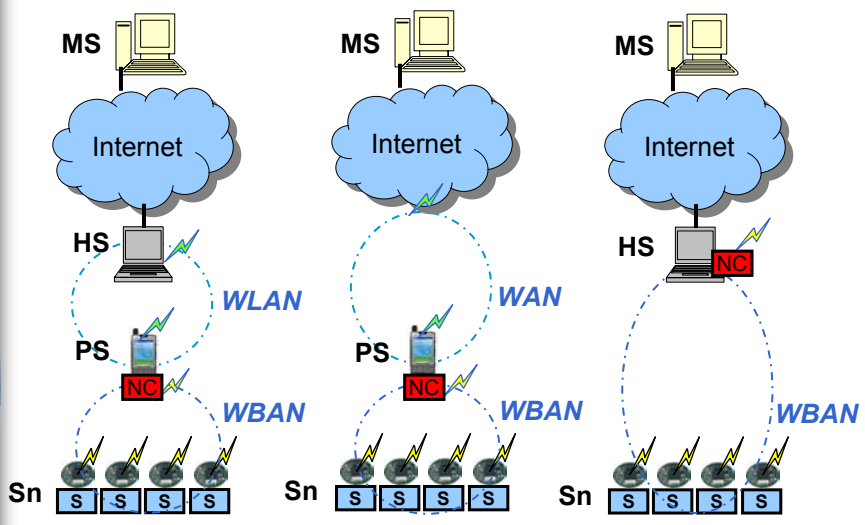
Wireless technologies

- 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 μW)

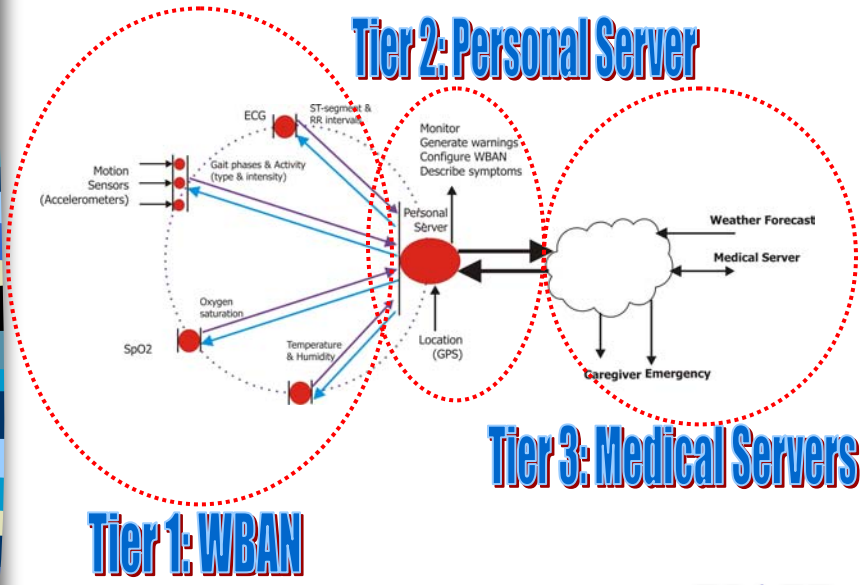
Ubiquitous Health Monitoring



WBAN Configurations



3-tier Hierarchical Organization



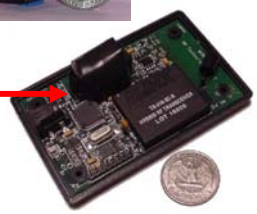
Hierarchical organization

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)

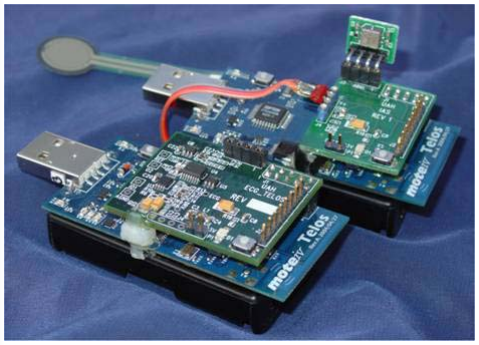
- 2002: Distributed Wireless System for Stress Monitoring

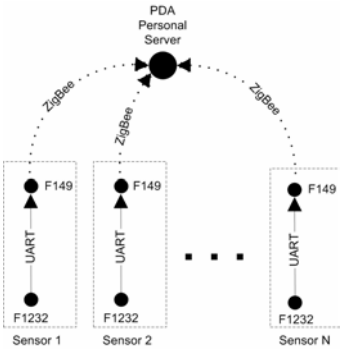


- 2004: ActiS – Activity Sensor
  - Standard sensor platforms and communication protocols

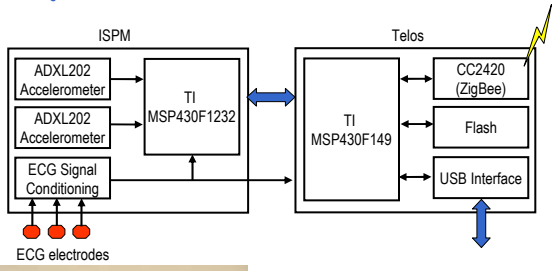
"A wireless body area network of intelligent motion sensors for computer assisted physical rehabilitation," Journal of NeuroEngineering and Rehabilitation, http://www.jneuroengrehab.com/content/2/1/6

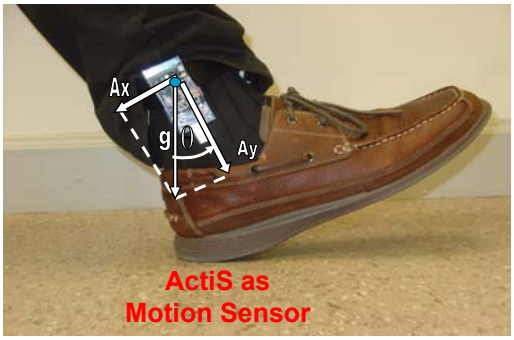
ActiS: Activity Sensor





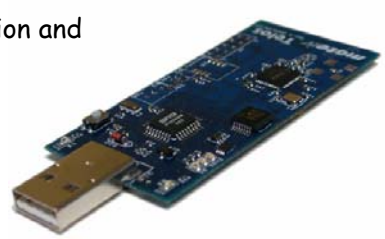
ActiS: Activity Sensor





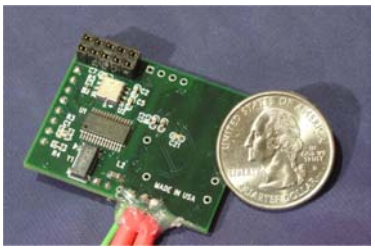
Telos Wireless Platform

- 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



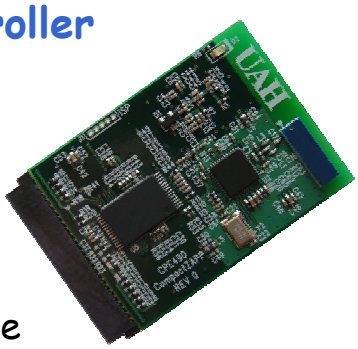
Intelligent Signal Processing Module ISPM

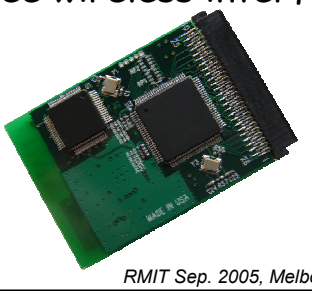
- 4MHz Texas Instruments 16-bit MSP430F1232 microcontroller (256B RAM, 8KB ROM)
- Multiple Dual Axis Analog Devices ADXL202 Accelerometers
- On-board bioamplifier (ECG, EMG) Texas Instruments INA321 Instrumentation Amp.
- Force resistor signal conditioning circuit
  - Foot switch



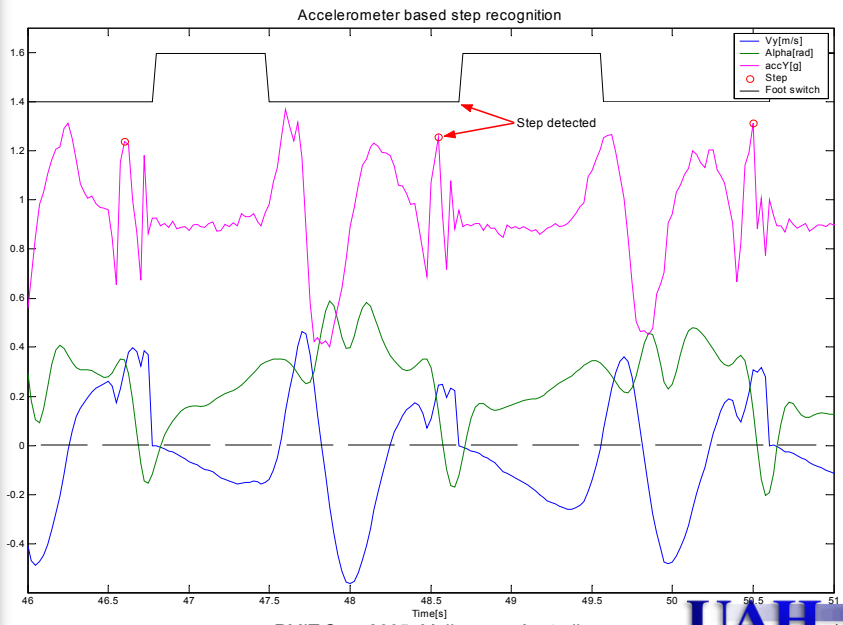
ZigBee network controller

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





ActiS: Signal Processing



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

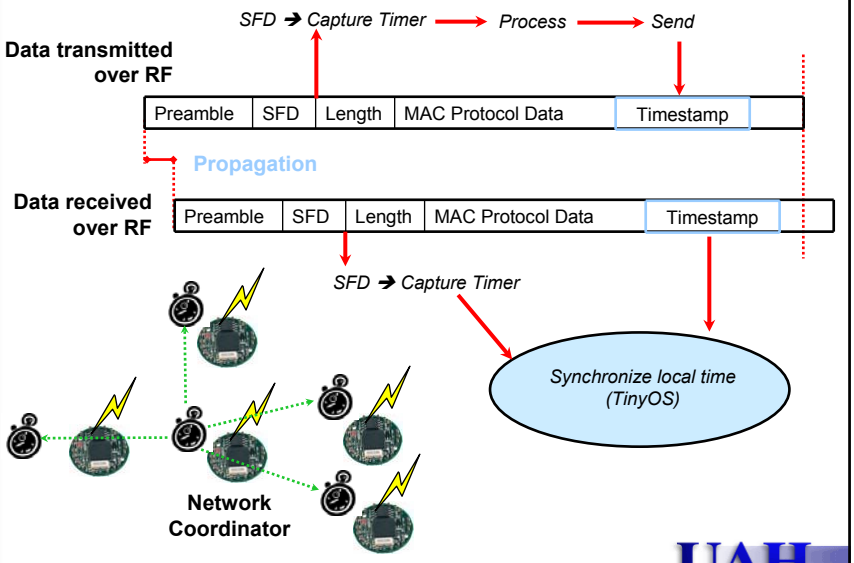
System Design Issues

- 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
- Effective user interfaces

Time Synchronization

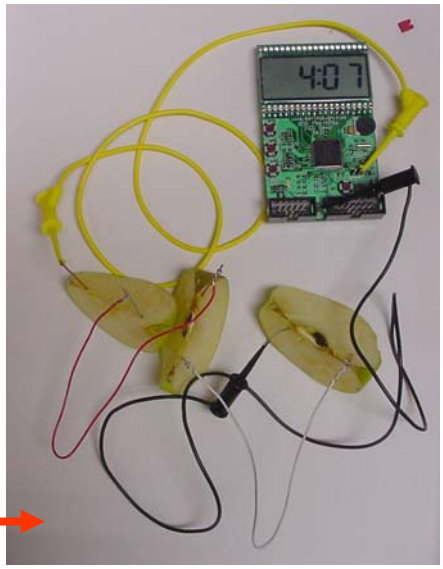
- Necessary for collective processing, data logging, power-efficient operation, etc.
- Problem:
  - High precision synchronization with low frequency clocks
    - 32 KHz on Telos
- FTSP FloodingTime synchronization protocols
  - Telos specific implementation at UAH
  - Implemented precision ~2 μS with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

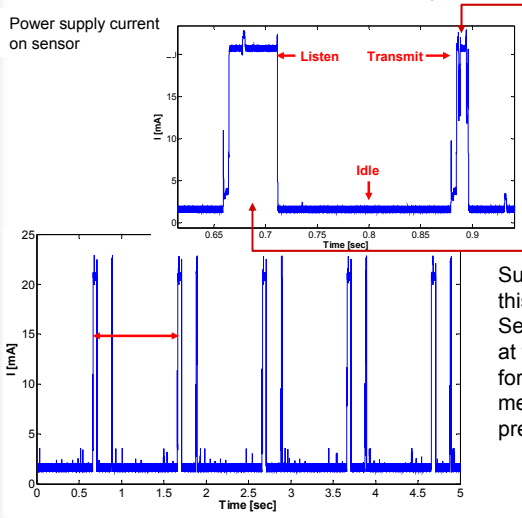


Power efficient communication

- 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

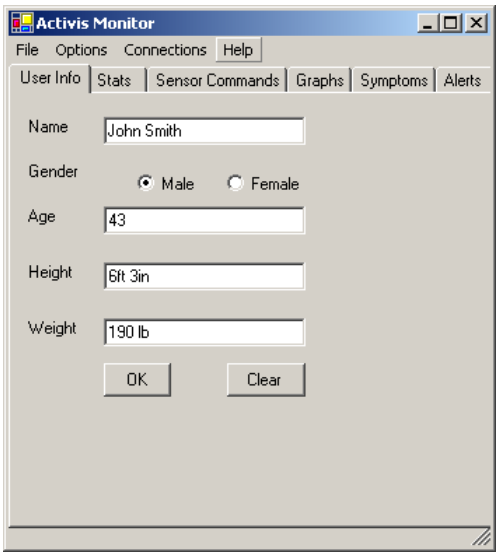


Super cycle time in this example is 1 sec. Sensors listens at the beginning of each cycle for 50ms, and transmits its own messages (2 in this example) in predefined time slot.

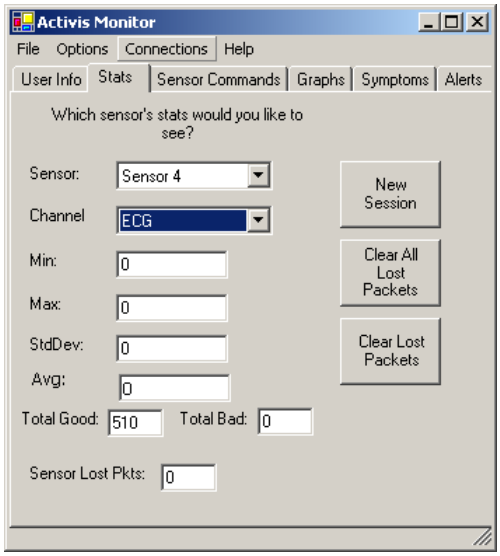
Personal Server program

- 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

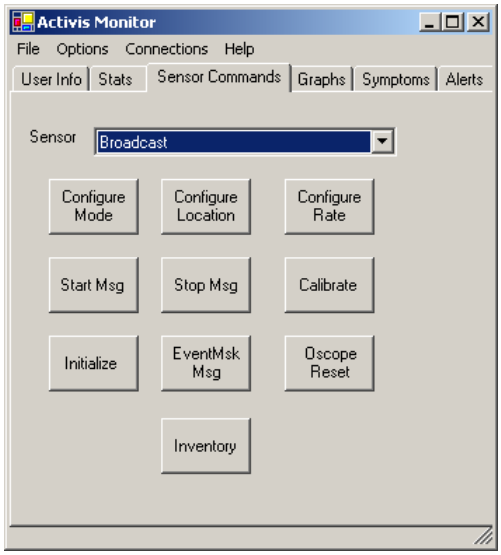
ActiS Monitor – User's Info



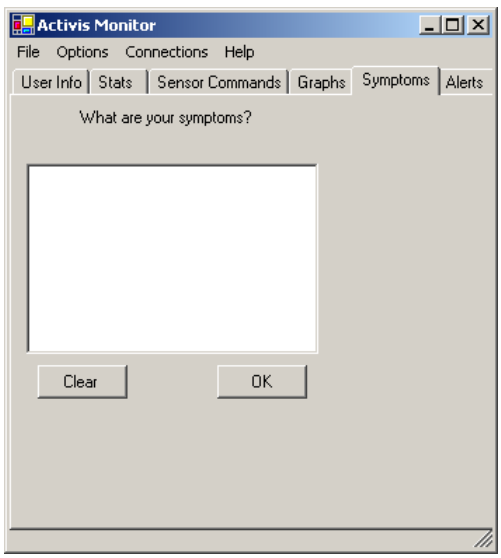
ActiS Monitor – Network health and Statistics



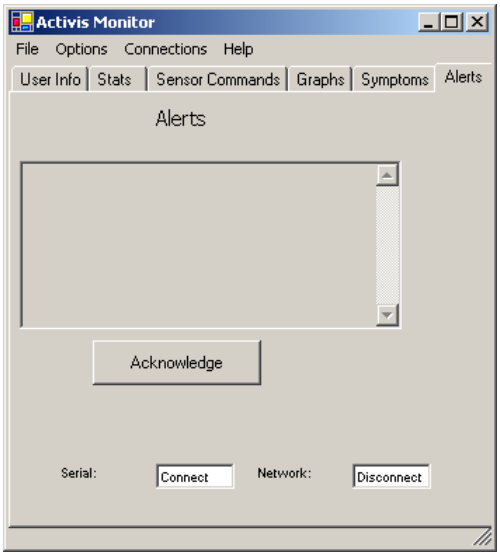
ActiS Monitor – Network Control



ActiS Monitor – Symptoms

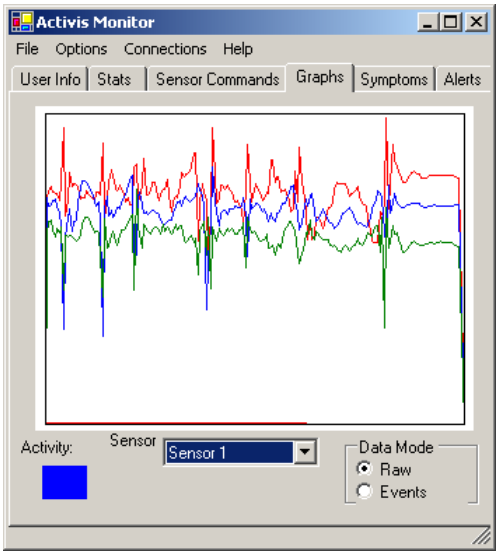


ActiS Monitor – Alerts



Actis Demo

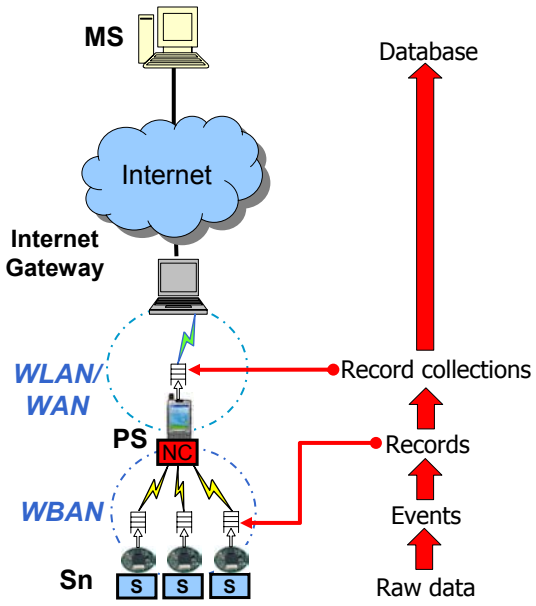
ActiS Monitor – Signals and Graphs



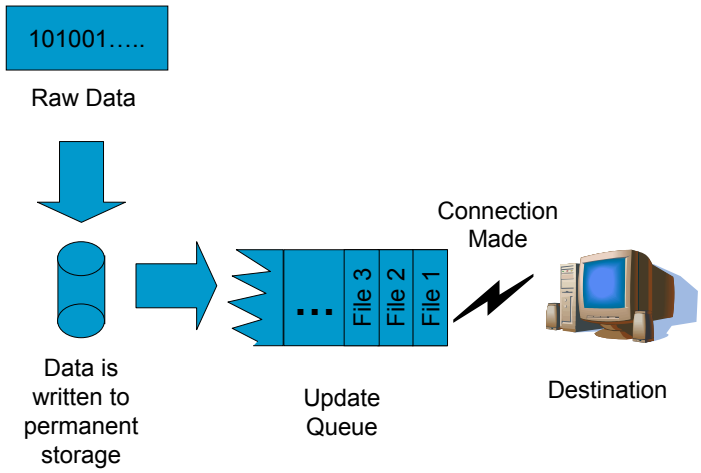
Software Organization

- ISPM Software
  - Physiological sensor interface
  - Preprocessing of signal data
  - Resource constrained, no operating system
- Telos Software
  - Developed in component framework of TinyOS
  - Significant signal processing
  - Defines Sampling Frequency
  - Server WBAN Communication

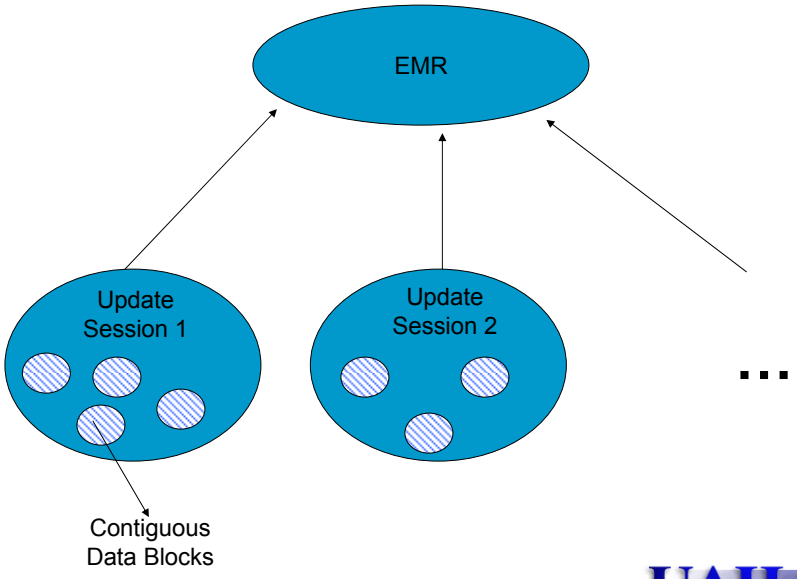
Wireless Integration



Record Update Mechanism



System organization - Sessions



Privacy and Security

- Hardware encryption of wireless communications
- Standard security mechanisms from the personal server to the upper levels of hierarchy
- EMBC05 paper: "Interoperability and Security in Wireless Body Area Network (WBAN) Infrastructures"

Conclusions

- Promising technology for
  - Ambulatory monitoring
  - Early detection of abnormal conditions
  - Supervised rehabilitation
- Advantages
  - Increased confidence and better quality of life
  - Promotes healthy lifestyle / health awareness
  - 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