CareNet: An Integrated Wireless Sensor Networking Environment for Remote Healthcare

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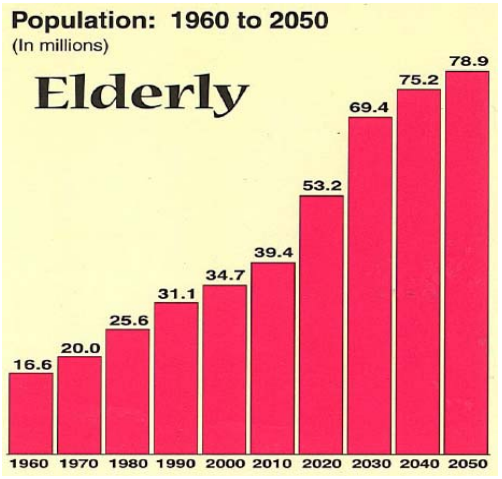
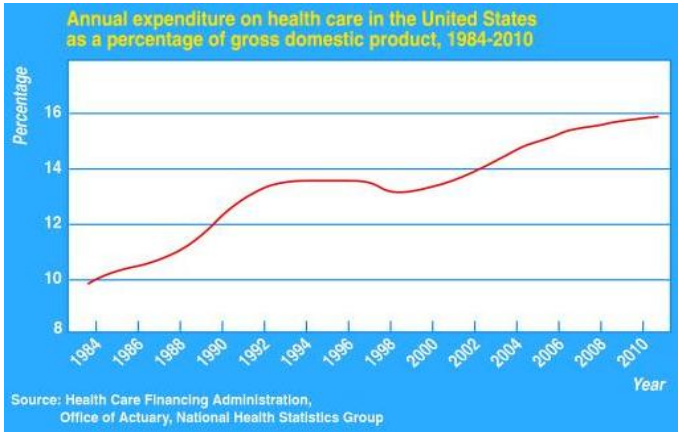
OUTLINE

- Motivation
- System Architecture and Hardware Platform
- Software Design and Prototype
- Experimental Study
- Conclusion

MOTIVATION

- Aging population
  - According to the U.S. Census Bureau, the number of people over the age of 65 is expected to hit 70 million by 2030, having doubled since 2000.
- Health care expenditures
  - Health care expenditures in the United States are projected to rise to 15.9% of the GDP ($2.6 trillion) by 2010.
  - The cost of health care for the nation's aging population has become a national concern.



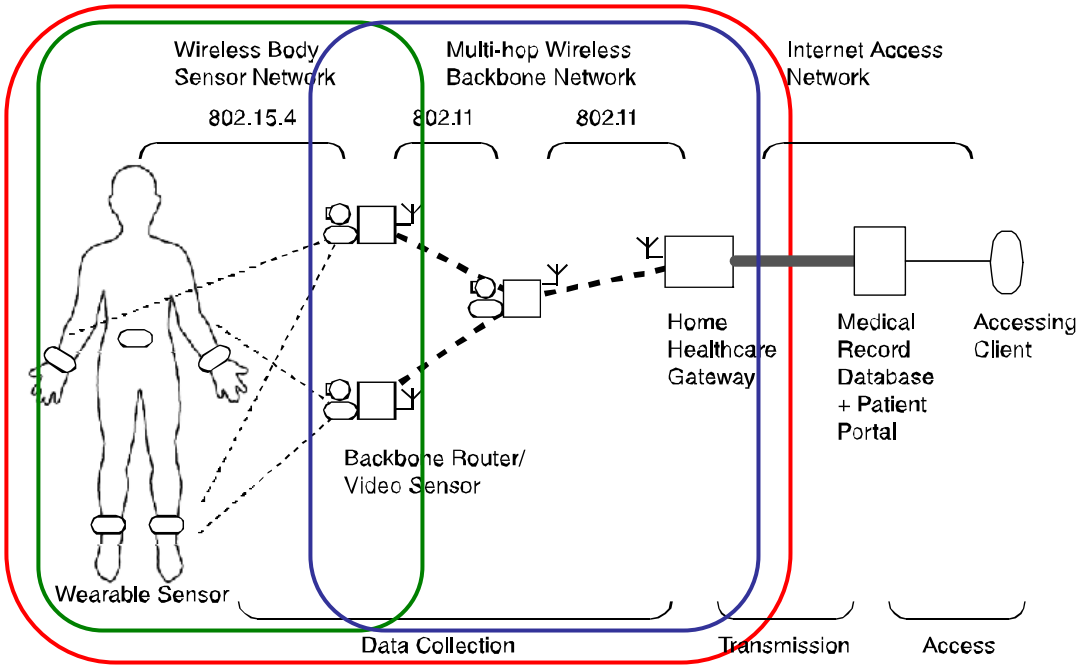


MOTIVATION

- Wireless/Body Sensor Networks
  - Deploy wearable sensors on the bodies of patients in a residential setting
  - Continuously monitor physiological signals (ECG, blood oxygen levels) and other health related information (physical activity)
- Advantages
  - Shift from a clinic-oriented, centralized healthcare system to a patient-oriented, distributed healthcare system
  - Reduce healthcare expenses through more efficient use of clinical resources and earlier detection of medical conditions
- Obstacle
  - A significant gap between the availability of the sensing technology and our ability to bring it into general use for home medical sensing

A medical sensing system must provide reliable and privacy-preserving information transmission between patients' homes and the care giver.

SYSTEM ARCHITECTURE

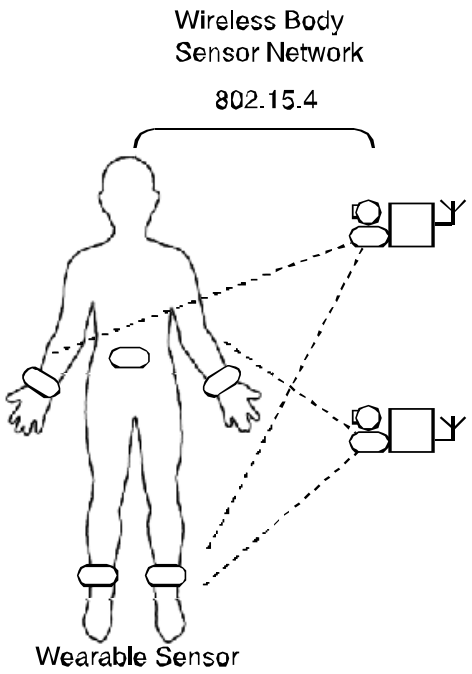


- Data Collection Phase
  - Networking and system design
  - A two-tier networking infrastructure is used to provide data sensing, collection, transmission, and processing functions

- Lower tier
  - A IEEE 802.15.4-based body sensor network consisting of lightweight wearable sensors for data sensing and transmission
  - Telos motes

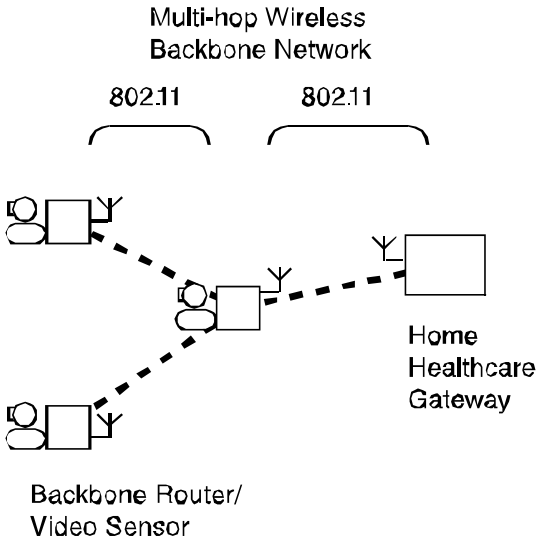
- Upper tier
  - A multi-hop IEEE 802.11-based wireless network providing a high-performance backbone structure for packet routing
  - Stargate single board computers

SYSTEM ARCHITECTURE



- Lower tier
  - The sensors can communicate with the base-station sensors (which are attached to the Stargates in the backbone wireless network) directly using IEEE 802.15.4 wireless standard.
  - For movement sensing and fall detection, these motes are equipped with accelerometers and gyroscopes.
  - Sensor devices are lightweight, wearable and mobile, which also means they have low computation, communication power and small amount of memory.
    - Only necessary computational and communication tasks are implemented at these devices.

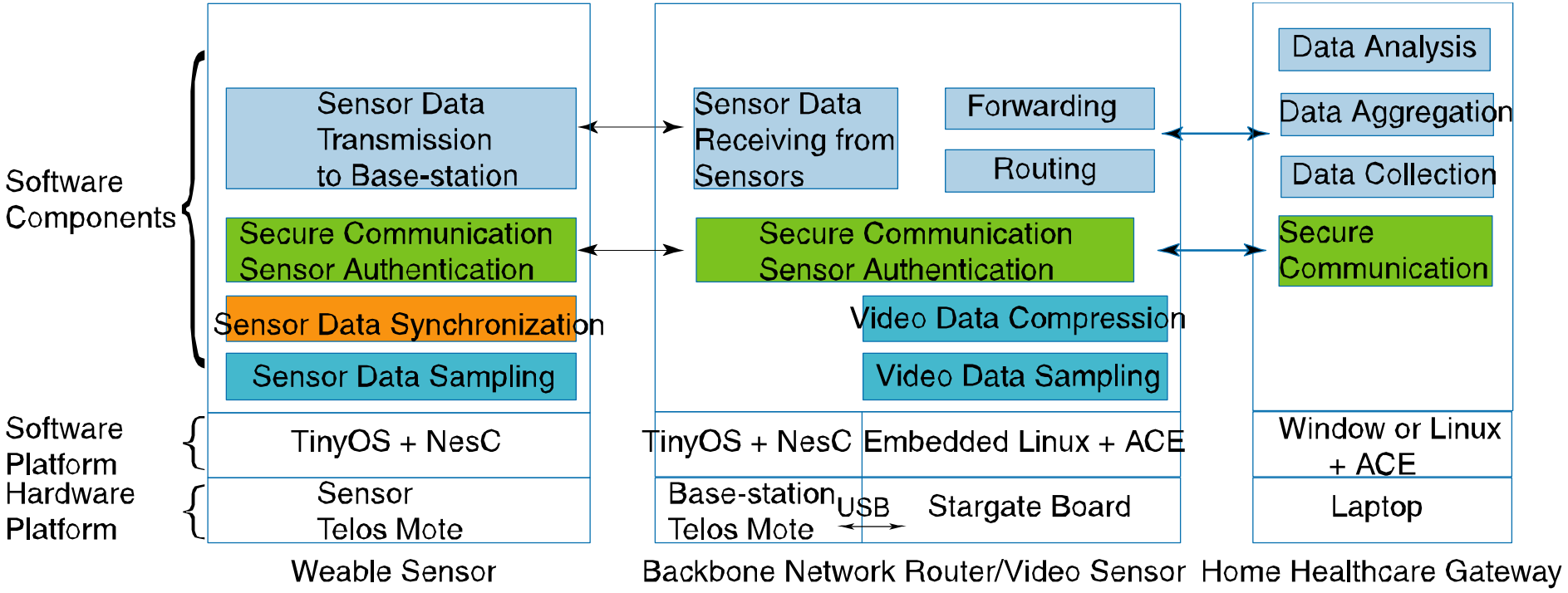
SYSTEM ARCHITECTURE



- Upper tier
  - The Stargate board can also be connected with a web camera and serves as a video sensor.
  - Equipped with IEEE 802.11 wireless adaptors, the backbone routers communicate with each other and relay the movement sensing data as well as video streams to the home healthcare gateway.
  - Using IEEE 802.11 wireless communication standard
    - Provides a high-performance and high-reliability packet routing and forwarding service
    - Scales much better
- Home healthcare gateway
  - Interface between the patient's home and the care giver's medical system, which processes all the sensing data and transmits them to the remote medical care system.

SOFTWARE DESIGN

- CareNet is also built upon a multi-layered software infrastructure based on the features and functions at each of the network tiers.



SOFTWARE DESIGN

- There are three major design considerations in the backbone network routing infrastructure.
  - Application-level routing
    - Implement a routing protocol among the backbone routers at the application level.
      - Easily deal with the data loss and replication in the wireless transmission
      - Portable upon various OSs
    - Use a semi-static routing table that can be either preconfigured manually or updated on demand or updated by HELLO messages every hour.
  - Multi-hop packet forwarding
    - Implement a multi-hop packet forwarding mechanism using TCP sockets and TCP streams. A TCP connection is established at each hop.
    - A backbone router may need to forward the data streams from more than one sensor.
      - The data streams will be forwarded simultaneously through different threads in the system.
      - We can also implement the queuing and scheduling mechanisms at each backbone router to better control packet loss.

SOFTWARE DESIGN

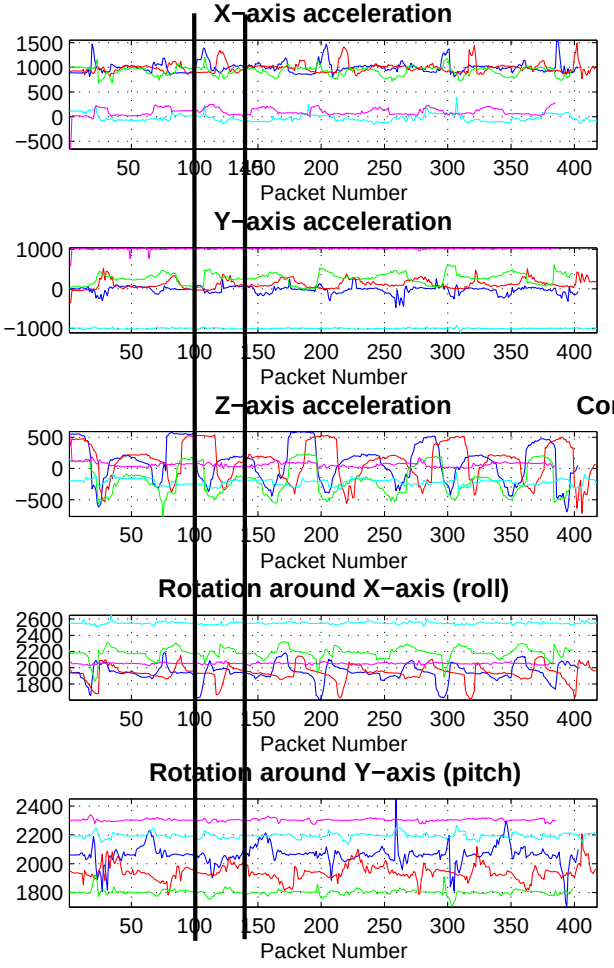
- Mobile sensor hand-off
  - To ensure reliable packet delivery during the mobile sensor and base-station hand-offs, packets from the mobile sensors will be received by all base-stations within their transmission ranges.
  - To remove the duplicate data packets from the backbone network, each sensor data packet is marked with a timestamp in its packet header.
  - Duplicate data packets that arrive late at the queue of a router will be dropped. The remaining duplicate and out-of-order packets will be dropped and sorted at the home healthcare gateway.

EXPERIMENT

- Collaborating with Vanderbilt Homecare Services, we identify four senior volunteers to participate the experiment
- Five sensor motes are mounted on each volunteer, two on the wrists, two on the ankles, and one on the waist
- Each sensor mote is capable of recording accelerations in three dimensions as well as rotations in two dimensions
- A controlled experiment, where volunteers are required to perform a set of designed movements
  - Vertical stretching of each arm and of both arms
  - Drinking water
  - Sit-to-stand and stand-to-sit
  - Raising each leg and both legs.
- An uncontrolled experiment, where volunteers can perform their daily physical activities

EXPERIMENT

"Sit-to-stand and stand-to-sit" experiment



Corresponding Image when Receiving No.100 Movement Packet

Corresponding Image when Receiving No.140 Movement Packet

- Received More than 400 movement packets from each of the five sensors
- For each packet, recorded the X-, Y-, Z-axis accelerations and the rotations around X-, Y-axis
- We synthesized the movement and video data based on their timestamps; The image data can be used for movement data verification and analysis

CONCLUSION

- High reliability and performance
  - Use IEEE 802.11 wireless network as the backbone structure to provide local area communication coverage
  - Use IEEE 802.15.4 sensor network to provide the communication between the wearable body sensors and the base-stations
    - This two-tier design greatly improves system reliability and performance
- Good scalability and extensibility
  - Using a backbone structure, our hybrid network design scales much better than a pure IEEE 802.15.4-based sensor network
  - Use ACE environment to build backbone network, which is commonly used to build extensible concurrent and networking applications
- Privacy aware data confidentiality protection
  - Use built-in secure communication components, which are adaptively implemented for different networking environments and used at all communication phases of the system
- Integration with web-based patient portal
  - Data from the patient centric sensor network will be collected in a web-based patient portal that is under development at Vanderbilt Medical School

THANKS!