Pervasive/Ubiquitous Computing

Wireless Networking

Healthcare Technology Today

Typical suite of home healthcare technology*

* Partners Home Care
Wireless Networks in Health Care

- Each day more and more equipment is going “wireless” from pulse-oximeters to more complex patient vital signs monitors and ventilators
- Environments must scale from a few clients to 100s on a single subnet
- External factors such as nearby TV and radio stations can affect overall performance.
- Interoperability profiles and standards are required to ensure plug-and-play operation in heterogeneous environments
IP Convergence

- Integration of data, voice, image, video on a single traffic network based on the Internet protocol
- Eliminates the maintenance of a parallel voice network
- Decreases considerably the expenses on phone calls and fax transmissions
- Interoperability of networks, applications and devices used in information technology
- Allows the reuse of the existing data-processing infrastructure

Mobile Devices

- Facilitates the mobility of doctors, practitioners and caregivers
- Allows access to patient information at any moment, everywhere and on real time
- Improves automatic data gathering through barcode or RFID reading
- Allows the immediate sharing of patient information and results
- Improves the internal communication within the caregiver team and with the support staff
- Helps to reduce paper
Room Topology

- Medical information collected by sensors on the patient’s body (WPAN) is displayed on a bedside monitor
- This information is also transmitted to another hospital location for remote monitoring, e.g., a nurses’ station
- In case of emergency, when the patient is moved from his/her room to the intensive care unit, these communications need to be maintained

Radio Frequency Identification

- Facilitates the management of assets (wheel chairs, scanners, ambulatory equipment, etc)
- Improves patient localization and helps caregivers to provide services without delays
- Enhances the process of drug administration (identification, distribution, localization, returns and disposal)
- Facilitates the automatic data capture and the follow-up of blood and biological samples
Telemedicine

- Utilization of different assets independent of their geographical location
- Multidisciplinary collaboration
- Facilitates the dissemination of medical knowledge to practicing doctors and medical students
- Allows doctors in remote and rural areas to consult with specialists in urban areas

Remote Monitoring

- Reduce the number of patients transferred to urban hospitals
- Allows tele-consultation and tele-diagnosis including the option of obtaining opinions of distant experts
- Facilitates the patient remote monitoring with instantaneous data transmission for analyses and follow-ups
- Allows remote handling of medical equipment (tele-surgery) and direct action of the expert on the patient
- Improves coordination of first-responders workers during in the event of catastrophes or emergency cases
The personal server can be implemented on an Internet-enabled PDA or a 3G mobile phone, or a regular laptop or desktop computer. It can communicate with remote upper-level services in a hierarchical type architecture. Its tasks include:

- Initialization, configuration, and synchronization of WBAN nodes
- Control and monitor operation of WBAN nodes
- Collection of sensor readings from physiological sensors
- Processing and integration of data from the sensors
- Secure communication with remote healthcare provider
Networking Basics

• Standards:
  – IEEE (Institute of Electrical and Electronics Engineers): Project 802
  – Three dominant standards:
    • 802.3 (Ethernet)
    • 802.5 (Token Ring)
    • 802.11 (Wireless)
  – Ethernet:
    • Most popular LAN technology, uses bus architecture
    • Easy to install, inexpensive
    • Data is broken into packets

802.3 (Ethernet)

Diagram showing a network with hub and connected computers.
OSI Reference Model

- Responsibilities of MAC layer include:
  - decide when a node accesses a shared medium
  - resolve any potential conflicts between competing nodes
  - correct communication errors occurring at the physical layer
  - perform other activities such as framing, addressing, and flow control

CSMA/CD

- Carrier Sense Multiple Access / Collision Detection
  - Carrier Sense: listen for inactivity on bus before transmitting
  - Multiple Access: multiple devices share same bus (wire)
  - Collision Detection: device detects if own transmission was corrupted (collision) and can retransmit at later time
Contention-Free Medium Access

- Collisions can be avoided by ensuring that each node can use its allocated resources exclusively.

- Examples of fixed assignment strategies:
  - **FDMA**: Frequency Division Multiple Access
    - the frequency band is divided into several smaller frequency bands
    - the data transfer between a pair of nodes uses one frequency band
    - all other nodes use a different frequency band
  - **TDMA**: Time Division Multiple Access
    - multiple devices use the same frequency band
    - relies on periodic time windows (**frames**)
      - frames consist of a fixed number of transmission slots to separate the medium accesses of different devices
      - a time **schedule** indicates which node may transmit data during a certain slot

- Examples of fixed assignment strategies (contd.):
  - **CDMA**: Code Division Multiple Access
    - simultaneous accesses of the wireless medium are supported using different codes
    - if these codes are orthogonal, it is possible for multiple communications to share the same frequency band
    - **forward error correction** (**FEC**) at the receiver is used to recover from interferences among these simultaneous communications

- Fixed assignment strategies are inefficient
  - it is **impossible to reallocate** slots belonging to one device to other devices if not needed in every frame
    - generating schedules for an entire network can be a daunting task
    - these schedules may require modifications every time the network topology or traffic characteristics in the network change
Contention-Based Medium Access

• Nodes may initiate transmissions at the same time
  – requires mechanisms to reduce the number of collisions and to recover from collisions

• Example 1: ALOHA protocol
  – uses acknowledgments to confirm the success of a broadcast data transmission
    • allows nodes to access the medium immediately
    • addresses collisions with approaches such as exponential back-off to increase the likelihood of successful transmissions

• Example 2: slotted-ALOHA protocol
  – requires that a station may commence transmission only at predefined points in time (the beginning of a time slot)
  – increases the efficiency of ALOHA
  – introduces the need for synchronization among nodes

Contention-Based Medium Access

• Carrier Sense Multiple Access (CSMA)
  – CSMA with Collision Detection (CSMA/CD)
    • sender first senses the medium to determine whether it is idle or busy
      – if it is found busy, the sender refrains from transmitting packets
      – if the medium is idle, the sender can initiate data transmission
  – CSMA with Collision Avoidance (CSMA/CA)
    • CSMA/CD requires that sender aware of collisions
    • instead, CSMA/CA attempts to avoid collisions in the first place
Hidden and Exposed Terminal Problem

- **Hidden-terminal problem**
  - senders A and C are able to reach B, but cannot overhear each other’s signals
  - it is possible for A and C to transmit data to B at the same time, causing a collision at B, without being able to directly detect this collision
- **Exposed-terminal problem**
  - C wants to transmit data D, but decides to wait because it overhears an ongoing transmission from B to A
  - B’s transmission could not interfere with data reception at C

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WLAN

![WLAN Diagram]
IEEE 802.11

- Published in 1999 by the Institute of Electrical and Electronics Engineers (IEEE)
  - specifies the physical and data link layers of the OSI model for wireless connections
- Often referred to as Wireless Fidelity (Wi-Fi)
  - certification given by Wi-Fi Alliance, a group that ensures compatibility between hardware devices that use the 802.11 standard
- Wi-Fi roughly based on CSMA/CA

Wireless Technologies (IEEE)

Local wireless networks

**WLAN 802.11**
- WiFi
  - 802.11a ➔ 802.11h
  - 802.11b ➔ 802.11i/e/.../n/.../z

Personal wireless nets

**WPAN 802.15**
- ZigBee
  - 802.15.1 ➔ 802.15.4 ➔ 802.15.4a/b/c/d/e
  - 802.15.2 ➔ 802.15.5, .6 (WBAN)
  - 802.15.3 ➔ 802.15.3b/c

Wireless distribution networks

**WMAN 802.16** (Broadband Wireless Access)
- WiMAX
  - [802.20 (Mobile Broadband Wireless Access)]
  - 802.16e (addition to .16 for mobile devices)

+ Mobility
Infrastructure versus Ad-hoc Mode

CSMA/CA

- Station ready to send starts sensing the medium (Carrier Sense based on CCA, Clear Channel Assessment)
- If the medium is free for the duration of an Inter-Frame Space (IFS), the station can start sending (IFS depends on service type)
- If the medium is busy, the station has to wait for a free IFS, then the station must additionally wait a random back-off time (collision avoidance, multiple of slot-time)
- If another station occupies the medium during the back-off time of the station, the back-off timer stops (fairness)
802.11b

- Europe (ETSI)
  - Channel 1
  - Channel 7
  - Channel 13

- US (FCC)/Canada (IC)
  - Channel 1
  - Channel 6
  - Channel 11

802.11a

- Center frequency = 5000 + 5 * channel number [MHz]
Bluetooth

- Basic idea
  - Universal radio interface for ad-hoc wireless connectivity
  - Interconnecting computer and peripherals, handheld devices, PDAs, cell phones – replacement of IrDA
  - Embedded in other devices, very cheap
  - Short range (10m), low power consumption, license-free 2.45 GHz ISM
  - Voice and data transmission, approx. 1 Mbit/s data rate

Versions

- 1.2:
  - Reduced interference with Wi-Fi
  - 1Mbit/s data rate
- 2.0:
  - Uses EDR (Enhanced Data Rate) technique to obtain speeds of 3Mbit/s
- 3.0:
  - Up to 24Mbit/s using co-located 802.11 link (+HS)
- 4.0:
  - Low energy, 24Mbit/s
Bluetooth Classes

<table>
<thead>
<tr>
<th>Power Class</th>
<th>Max Output Power</th>
<th>Max Output Power</th>
<th>Expected Range</th>
<th>Range in Free Space</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 1</td>
<td>100mW</td>
<td>20dBm</td>
<td>42m</td>
<td>300m</td>
</tr>
<tr>
<td>Class 2</td>
<td>2.5mW</td>
<td>4dBm</td>
<td>16m</td>
<td>50m</td>
</tr>
<tr>
<td>Class 3</td>
<td>1mW</td>
<td>0dBm</td>
<td>10m</td>
<td>30m</td>
</tr>
</tbody>
</table>

Piconet

- Collection of devices connected in an ad hoc fashion
- One unit acts as master and the others as slaves for the lifetime of the piconet
- Master determines hopping pattern, slaves have to synchronize
- Each piconet has a unique hopping pattern
- Participation in a piconet = synchronization to hopping sequence
- Each piconet has one master and up to 7 simultaneous slaves (> 200 could be parked)

M=Master
S=Slave
P=Parked
SB=Standby
Piconet

- All devices in a piconet hop together
  - Master gives slaves its clock and device ID
    - Hopping pattern: determined by device ID (48 bit, unique worldwide)
    - Phase in hopping pattern determined by clock
- Addressing
  - Active Member Address (AMA, 3 bit)
  - Parked Member Address (PMA, 8 bit)

Scatternet

- Linking of multiple co-located piconets through the sharing of common master or slave devices
  - Devices can be slave in one piconet and master of another
- Communication between piconets
  - Devices jumping back and forth between the piconets

Piconets (each with a capacity of 720 kbit/s)
Communication

Bluetooh/Zigbee

- IEEE 802.15.1 – Bluetooth
- IEEE 802.15.4 – Zigbee

Zigbee:
- Low data rate solution with multi-month to multi-year battery life and very low complexity
- Potential applications are sensors, interactive toys, smart badges, remote controls, and home automation
- Data rates of 20-250 kbit/s, latency down to 15 ms
- Master-Slave or Peer-to-Peer operation
- Up to 254 devices or 64516 simpler nodes
- Support for critical latency devices, such as joysticks
- Power management to ensure low power consumption
- 16 channels in the 2.4 GHz ISM band, 10 channels in the 915 MHz US ISM band and one channel in the European 868 MHz band
Zigbee

Clustered stars - for example, cluster nodes exist between rooms of a hotel and each room has a star network for control.

Full function device

Reduced function device

Comparison of Wireless Technologies

<table>
<thead>
<tr>
<th>Standard</th>
<th>Bandwidth</th>
<th>Power Consumption</th>
<th>Protocol Stack Size</th>
<th>Stronghold</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wi-Fi</td>
<td>Up to 5MHz</td>
<td>400mA TX, standby 20mA</td>
<td>~100KB</td>
<td>High data rate</td>
<td>Internet browsing, PC networking, file transfers</td>
</tr>
<tr>
<td>Bluetooth</td>
<td>1Mbps</td>
<td>40mA TX, standby 0.2mA</td>
<td>~100KB</td>
<td>Interoperability, cable replacement</td>
<td>Wireless USB, handset, headset</td>
</tr>
<tr>
<td>ZigBee</td>
<td>250kbps</td>
<td>30mA TX, standby 360 µA</td>
<td>34KB/14KB</td>
<td>Long battery life, low cost</td>
<td>Remote control, battery-operated products, sensors</td>
</tr>
</tbody>
</table>
Comparison of Wireless Technologies

Bluetooth in Health Care

- Workgroup formed in 2006 to develop standard to support existing and emerging medical devices and to bring compatibility and interoperability
- Medical device manufacturers, silicon suppliers, and other supporters of the Bluetooth standard worked together to produce a **Health Device Profile** that was approved in 2008
The Bluetooth Health Device Profile works with Bluetooth chips that support streaming data rates of up to 2.1Mbps.

That means that it can support medical devices as complex as ECGs, which need to stream data.

It is equally applicable for simple devices such as weight scales that only need to transmit small quantities of information.

### Capabilities

It builds on the underlying capabilities of the Bluetooth standard, which include:

- Excellent resistance to interference from wireless LANs, through the use of adaptive frequency hopping.
- Best-in-class security, including immunity from “man-in-the-middle” attacks, by utilizing public key cryptography.
- Low power consumption (devices frequently enter low power sleep states).
- A rigorous qualification program to ensure interoperability.
- Excellent range – up to 1km range products are available.
- Global applicability, using the 2.4GHz band.
- Low cost.
IEEE 11073 is a standard that describes how data is represented by medical devices and how these devices connect to each other.

- Real-time: data from multiple devices can be retrieved, time correlated, displayed, and processed in fractions of a second
- Plug-and-play: devices detect, configure, and communicate without human interaction

Bluetooth Health Device Profile

ISO/IEEE 11073-20601
Data Format
Data Model
Profile
HDP
SCENARIO 1: NON-STREAMING DATA

Configurations

SCENARIO 2: STREAMING DATA

Configurations
Configurations

**SCENARIO 3: CONCURRENT STREAMING AND NON-STREAMING DATA**

- Pulse Oximeter
- Weight Scale
- Bluetooth Device (SRC)
- Bluetooth Device (SRC)
- Computation Engine (SNK)
- PC

Configurations

**SCENARIO 4: DUAL ROLE DEVICE**

- Pulse Oximeter
- Weight Scale
- Bluetooth Device (SRC)
- Bluetooth Device (SRC)
- Dual Role Device (SRC/SNK)
- Computation Engine (SNK)
- Display Console
- PC
Configurations

SCENARIO 5: COMBINATION DEVICE

Pulse Oximeter with Thermometer Capability

Bluetooth Combination Device (SRC)    Computation Engine (SNK)

PC

Configurations

SCENARIO 6: SHARING OF DATA WITH REMOTE CARE PROVIDER

Blood Pressure Meter

Bluetooth Device (SRC)    Computation Engine (SNK)

Internet/Cell network

Physician or Care Provider

Not Part of Profile Spec, but requires coordination with other standards bodies
Bluetooth Low Energy

- The Bluetooth Low Energy standard is a further evolution of existing Bluetooth technology. It starts from the point of acknowledging that almost every mobile phone contains a Bluetooth chip. This allows mobile phones to connect to existing health devices.
- BT radio stays asleep for most of the time, without affecting interference, security, interoperability, license-free technology.

BT for Health Care

<table>
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<tr>
<th>INITIAL SUPPORTED HARDWARE</th>
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<tbody>
<tr>
<td><strong>Bluetooth Enabled Health Devices</strong></td>
</tr>
<tr>
<td>Blood Pressure Meters</td>
</tr>
<tr>
<td>Weight Scales</td>
</tr>
<tr>
<td>Pulse Oximeters</td>
</tr>
<tr>
<td>Glucose Monitors</td>
</tr>
<tr>
<td>Pulse/Heart Rate Monitors</td>
</tr>
<tr>
<td>Thermometers</td>
</tr>
</tbody>
</table>

Computer Science and Engineering - University of Notre Dame
Home Health Applications

Characteristics

- Information Security
  - HIPAA
  - Risk Analysis
  - AES, WPA2
Health Level 7 (HL7) standard is designed to enable different health care applications to exchange clinical and administrative data. The most recent version of the HL7 specification uses XML messaging as its foundation. HL7 also allows the use of trigger events, i.e. when a patient’s EKG waveform is available causes a request for that observation data to be sent to another information system.

Characteristics

- Interference
MICS

- Medical Implant Communication Service
  - 402-405MHz
  - Low power (25microWatts): reduce interference with other users
  - Low data rate
  - Couple of meters range (transceiver doesn’t have to touch skin)