Chapter 15: A Survey on Wireless Body Area Networks

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Outline

- Abstract
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- Paint Monitoring
- Taxonomy and Requirements
- Positioning WBANs
- Physical Layer
- Mac Layer
- Network Layer
- Cross-Layer Protocol
- Quality of Service
- Security
- Existing Projects
- Open Research Issues
- Conclusions
Abstract

- development of Wireless Body Area Networks (WBANs)
  - the increasing use of wireless networks
  - constant miniaturization of electrical devices
- position of sensors
  - attached on clothing
  - on the body
  - implanted under the skin
- application
  - measure the heartbeat
  - record Electrocardiogram (ECG)
- ultimate goal
  - improve health care
  - the Quality of Life
  - greater physical mobility
  - no longer compelled to stay in the hospital
Introduction

- the aging population in many developed countries and the rising costs of health care have triggered
- small and intelligent medical sensors attached on or implanted in the body
  - send data to an external medical server, analyze and store it
  - use a wired connection
    - cumbersome
    - high cost for deployment and maintenance
  - use a wireless interface
    - an easier application
    - cost efficient
- A Wireless Body Area Network
  - continuous health monitoring
  - real-time feedback
Sensor and Actuator

- **Sensors**
  - measure certain parameters of the human body
- **Actuators (actor)**
  - take some specific actions according to the data they receive from the sensors
  - through interaction with the user
  - drug delivery system
the differences between a Wireless Sensor Network and a Wireless Body Area Network:

- limited energy resources available
  - small form factor
  - impossible to recharge
- no redundant devices are available
- to minimize interference per node
- the waves are attenuated considerably before they reach the receiver
- robust against frequent changes in the network topology
- high reliability, low delay and security is required
Patient Monitoring

- According to the World Health Organization, worldwide about 17.5 million people die of heart attacks each year; in 2015, almost 20 million people will die from CVD.
- Worldwide, more than 246 million people suffer from diabetes, a number that is expected to rise to 380 million by 2025.
- These deaths can often be prevented with proper health care:
  - Continuous monitoring and the usefulness of WBANs.
- WBAN technology provides the connectivity to support the elderly in managing their daily life and medical conditions:
  - The patient will be able to move around freely.
  - The data obtained during a large time interval offers a clearer view to the doctors.
Cont.
Another area of application

- public safety
  - if toxics in the air, it warns the firefighters or soldiers
- train schedules of professional athletes.
- gaming purposes and in virtual reality
Taxonomy and Requirements (type of devices)

- Wireless Sensor node
  - respond to and gather data on physical stimuli
  - process the data
  - report this information wirelessly
  - sensor hardware, a power unit, a processor, memory and a transmitter or transceiver

- Wireless Actuator node
  - act according to data received from the sensors or through interaction with the user
  - actuator hardware, a power unit, a processor, memory and a receiver or transceiver

- Wireless Personal Device
  - gathers all the information acquired by the sensors and actuators and informs the user via an external gateway
  - a power unit, a processor, memory and a transceiver
  - also called a Body Control Unit (BCU), body gateway or a sink
Data Rates

- Data rates will vary strongly
  - The strong heterogeneity of the applications
  - Sent in bursts

### BER (bit error rate)
- A measure for the number of lost packets
- The reliability depends on the data rate
- While devices with a higher data rate require a lower BER

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<th>Application</th>
<th>Data Rate</th>
<th>Bandwidth</th>
<th>Accuracy</th>
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<tr>
<td>ECG (12 leads)</td>
<td>288 kbps</td>
<td>100-1000 Hz</td>
<td>12 bits</td>
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<tr>
<td>ECG (6 leads)</td>
<td>71 kbps</td>
<td>100-500 Hz</td>
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<td>EMG</td>
<td>320 kbps</td>
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<td>16 bits</td>
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<td>EEG (12 leads)</td>
<td>43.2 kbps</td>
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<td>Blood saturation</td>
<td>16 bps</td>
<td>0-1 Hz</td>
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</tr>
<tr>
<td>Glucose monitoring</td>
<td>1600 bps</td>
<td>0-50 Hz</td>
<td>16 bits</td>
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<tr>
<td>Temperature</td>
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<tr>
<td>Motion sensor</td>
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<td>Cochlear implant</td>
<td>100 kbps</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Artificial retina</td>
<td>50-700 kbps</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Audio</td>
<td>1 Mbps</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Voice</td>
<td>50-100 kbps</td>
<td>–</td>
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Energy

- consumption
  - sensing
  - communication: most power consuming
  - data processing

- restricted power available in the node
  - the size of the battery
  - some device should operate while supporting a battery lifetime
  - replacement or recharging induces a cost and convenience penalty

- scavenge energy
  - enhance a given battery capacity
  - during the operation of the system
  - large than the average consumed energy, system runs eternally
  - in fact, deliver small amount of energy
  - a thermoelectric generator (TEG)
    - transform the temperature difference between the environment and the human body into electrical energy
Cont.

- **SAR (specific absorption rate)**
  - During communication the devices produce heat which is absorbed by the surrounding tissue and increases the temperature of the body
  - To limit this temperature rise and the energy consumption should be restricted to a minimum
  - The power absorbed per mass of tissue and has units of watts per kilogram (W/kg)

\[
\text{SAR} = \int_{\text{sample}} \frac{\sigma(r)|\mathbf{E}(r)|^2}{\rho(r)} \, dr
\]

Where:

- \(\sigma\) is the sample electrical conductivity
- \(\mathbf{E}\) is the RMS electric field
- \(\rho\) is the sample density
Quality of Service and Reliability and Usability

- Quality of Service and Reliability
  - the monitored data is received correctly
  - messages should be delivered in reasonable time
  - in a worst case, it can be fatal

- Usability
  - a WBAN will almost be set up in a hospital by medical staff
  - the network should be capable of configuring and maintaining itself automatically
  - the network should be quickly reconfigurable, for adding new services
  - when a route fails, a back up path should be set up
  - the network should not be regarded as a static one
Security and Privacy

- the medical staff collecting the data needs to be confident that the data is not tampered with
- it can not be expected that an average person or the medical staff is capable of setting up and managing authentication and authorization processes
- the network should be accessible when the user is not capable of giving the password
Fig. 2  Example of intra-body and extra-body communication in a WBAN
Fig. 3  Positioning of a Wireless Body Area Network in the realm of wireless networks.
Fig. 4 Characteristics of a Wireless Body Area Network compared with Wireless Sensor Networks (WSN) and Wireless Local Area Network (WLAN). Based on [44].
Table 2  Schematic overview of differences between Wireless Sensor Networks and Wireless Body Area Networks, based on [45].

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<td>Bluetooth, ZigBee, GPRS, WLAN, . . .</td>
<td>Low power technology required</td>
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Physical layer

- **RF communication**
  - the radio signals experience great losses
    - Narrowband radio signals
    - Ultra Wide Band (UWB)
  - the transmitted power drops off with $d^n$
    - $d$ represents the distance between the sender and the receiver
    - $\eta$ the coefficient of the path loss (aka propagation coefficient)
  - multi-path propagation
    - induce fading of signals
    - take place
      - inside the body
      - along the body
RF communication

- In the Body
  - the propagation of electromagnetic (EM)
    - as the tissue is lossy and mostly consists of water
    - attenuated considerably before they reach the receiver
  - specific absorption rate (SAR)
    - determine the power lost due to heat dissipation
    - the path loss is very high
    - compared to
    - the free space propagation, an additional 30-35 dB
  - argue
    - energy consumption is not enough and that the tissue is sensitive to temperature increase
      - a patient’s body shape
      - position on the implanted radio transmitter
      - the difference between body shapes (i.e. male, female and child)
Along the Body

- most device attached on the body
- the curvature effects
  - in the former, not taken into account
- line of sight (LOS)
  - UWB signals were performed in a band between 3 to 6 GHz
  - narrowband system around 2.4 GHz
  - the path loss exponent $\eta$ is between 3 and 4
    - depending on the position of the device
    - e.g. the path loss on the arm is lower than the one on the trunk.
    - higher absorption in the larger volume of the trunk and the surface of the trunk is less flat
  - the closer the antenna is to the body, the higher the path loss
    - a difference of more than 20 dB is found for an antenna placed at 5mm and 5 cm
Along the Body

- non-line of sight (NLOS)
  - no direct view between the sender and receiver
  - higher path loss
    - diffraction around the body
    - absorption of a larger amount of radiation by the body
    - path loss exponent ranging from 5 to 6
  - ear-to-ear link, which can be regarded as a worst case scenario
    - missing line-of-sight component

in terms of energy efficiency

- the use of multi-hop communication in a WBAN could lead to a more optimal network topology
- Multi-hop relaying
Measured path loss versus the distance around (NLOS) and along the torso (LOS).
Movement of the Body

- arm motions to the front and side can have a small impact on the received power
- the movement of the limbs can induce an attenuation of 30 dB or more
- Loss rates of more than 50% were found when the body was in motion
Non-RF Communication

- body-coupled communication (BCC)
  - transfer electronic data by capacitive and galvanic coupling
  - low frequencies (10 kHz to 10 MHz)
  - experiment
    - interference-free ultra low power data communication through the human body.
      - High variations of the transmission attenuation have been observed at different locations of the body
    - a potential communication technology for sensor application on the thorax and for short distances on the limbs
    - exchange data from one body to another by shaking hands
  - low data rate
  - argue
    - equip the nodes with both RF and BCC
    - the BCC can be used to discover and identify sensor nodes on the same body
      - as a BCC is restricted to a person’s body
    - wake up RF radios
      - from low-power sleep mode
MAC layer

- WSN has some points in common with networking in WBANs
- contention-based
  - advantage
    - infrastructure-free ad hoc feature
    - good adaptability to traffic fluctuation,
      - especially for low load
  - reducing energy consumption
    - control the power
    - duty cycle of the radio

- schedule-based
  - free of idle listening
  - overhearing
  - packet collisions
    - lack of medium competition
    - require tight time synchronization
some implementations of WBANs use Bluetooth (IEEE 802.15.1)
- not support multi-hop communication
- compared to IEEE 802.15.4
  - a complex protocol stack
  - a high energy consumption
- not suited to be used in a WBAN

most current implementations of WBANs use IEEE 802.15.4 or ZigBee
- as most of the radios used in a WBAN are based on an IEEE 802.15.4

<table>
<thead>
<tr>
<th>MAC-protocol</th>
<th>IEEE 802.15.4 based</th>
<th>TDMA based</th>
<th>CSMA based</th>
<th>Star topology (master/slave)</th>
<th>Time Synchronization available in the protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timmons [71]</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>BSN-MAC [72]</td>
<td>✓</td>
<td></td>
<td>mixed</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Lamprinos [73]</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Omeni [74]</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>H-MAC [75]</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

Schematic overview of MAC protocols in a WBAN.
IEEE 802.15.4

- standard at 2.4 GHz was considered for a WBAN
  - the star network configuration
- BSN-MAC
  - coordinator controls the communication
    - by varying the superframe structure
    - divides the time axis
      - contention-free
      - contention-based
  - sensors provide real-time feedback to coordinator
    - application-specific and sensor-specific information
  - coordinator can make dynamic adjustments
    - for the length of the contention-free and contention-based period
    - achieve energy efficiency and latency
- specialized MAC protocols are needed
  - not scalable in terms of power consumption
  - not be used as a single solution for all applications
  - just quick and easy implementation
WBAN Specific Protocols

- by Lamprinos et al.
  - a master-slave architecture
  - to avoid idle listening
    - all slaves are locked in the Rx-slot of the master
    - go in standby at the same time
  - drawback
    - some slaves will have a low duty cycle
    - whereas the nodes that are serviced later have a higher duty cycle

- Omeni et al.
  - a star-networked WBAN that supports TDMA
    - to reduce the probability of collision and idle listening
  - central node assign each slave node to a slot
  - alarm occurs
    - the node can be assigned an extra slot for direct communication
IEEE 802.15.6

- a communication standard optimized for low power devices
- operation
  - on, in or around the human body (but not limited to humans)
- applications
  - medical, consumer electronics / personal entertainment
Network layer

- the available bandwidth is limited, shared and can vary
  - fading, noise and interference
- the nodes that form the network can be very heterogeneous
  - available energy or computing power

Temperature Routing

- important issues
  - radiation absorption
  - heating effects
- to reduce tissue heating
  - limit the radio’s transmission power
    - rate control
  - use traffic control algorithms
    - Thermal Aware Routing Algorithm (TARA)
    - Least Temperature Routing (LTR) and Adaptive Least Temperature Routing (ALTR)
    - Least Total Route Temperature (LRTT)
example of LTR and ALTR

**Fig. 6** An example of LTR and ALTR. The white arrows indicate the LTR-path. The shaded arrows show the adapted path of ALTR. When the path has three hops, the routing algorithm switches to shortest path routing.
Cont.

Cluster Based Routing

- Anybody
  - data gathering protocol
  - to reduce the number of direct transmissions to the remote base station
  - based on LEACH
  - improvement
    - change the cluster head selection
    - constructing backbone network of the cluster heads

- LEACH
  - randomly selects a cluster head
  - cluster head aggregates all data and sends it to the base station
  - assumes that all nodes are within sending range of the base station

- Hybrid Indirect Transmissions (HIT)
  - combine clustering with forming chains
  - energy efficiency
Cross-layer Protocols

- improve the efficiency of and interaction between the protocols in a wireless network by combining two or more layers

- Ruzelli et al.
  - a cross-layer energy efficient multi-hop protocol built on IEEE 802.15.4
  - divided into time zones
    - each one takes turn in the transmission
    - the nodes in the farthest timezone start the transmission
  - developed for regular sensor networks

- CICADA
  - use a data gathering tree
  - assign distributed slot
    - to control the communication
  - while the network flexibility is preserved
    - low packet loss and high sleep ratios
Quality of Service

- achieve the right balance between power consumption and the desired reliability of the system to obtain a lower packet loss
  ① the transmit power can be increased
  ② raise the energy consumption
Security

- **data confidentiality**
  - **define**
    - the transmitted information is strictly private
    - only be accessed by authorized persons
  - **method**
    - encrypt the information before sending it using a secret key

- **data authenticity**
  - the information is sent by the claimed sender

- **data integrity**
  - the received information has not been tampered with
  - inspected by verifying the Message Authentication Code (MAC)

- **data freshness**
  - **define**
    - the received data is recent
  - **method**
    - add a counter
Existing Projects

- This research mainly focuses on building a system architecture and service platform and in lesser extent on developing networking protocols.

- Otto et al.
  - A system architecture which both handles the communication within the WBAN and between the WBANs and a medical server
  - Slots are synchronized using beacons periodically sent by the sink
  - Use off-the-shelf wireless sensors to design a prototype WBAN

- CodeBlue project
  - Rapid disaster response scenarios
  - Wearable computer attached to the patient’s wrist
  - ECG, EMG, pulse oximeter sensor

- Ayushman
  - A sensor network based medical monitoring infrastructure
  - Collect, query and analyze patient health information in real-time
  - ECG, gait monitoring, environment monitoring
Open Research Issues

- physical layer, data link layer
  - movement of the body

- network layer
  - combination of thermal routing with more energy efficient mechanisms

- a globally optimal system
  - unite several of these mechanisms in a cross-layer protocol

- combination of lower energy protocols and energy scavenging
Conclusions

■ A WBAN is expected to be a very useful technology with potential to offer a wide range of benefits to society through continuous monitoring and early detection.

■ With the current technological evolution, sensors and radios will soon be applied as skin patches and the sensors will seamlessly be integrated in a WBAN.

■ These evolutions will bring us closer to a fully operational WBAN that acts as an enabler for improving the Quality of Life.
Homework #15:

2. Summarize the theorem of LTR and ALTR.
# Solutions

## Homework #1

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Homework #2

- The white arrows indicate the Least Temperature Routing (LTR-path).
- The shaded arrows show the adapted path of Adaptive Least Temperature Routing (ALTR).
  - Reduce unnecessary hops and loops by maintaining a list in the packet with the recently visited nodes.
  - Switch to shortest hop routing when a predetermined number of hops is reached.
  - To lower the energy consumption.