Chapter 15: A Survey on Wireless Body Area Networks

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- Paint Monitoring
- Taxonomy and Requirements
- Positioning WBANs
- Physical Layer
- Mac Layer
- Network Layer
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- Security
- Existing Projects
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- Conclusions

Abstract

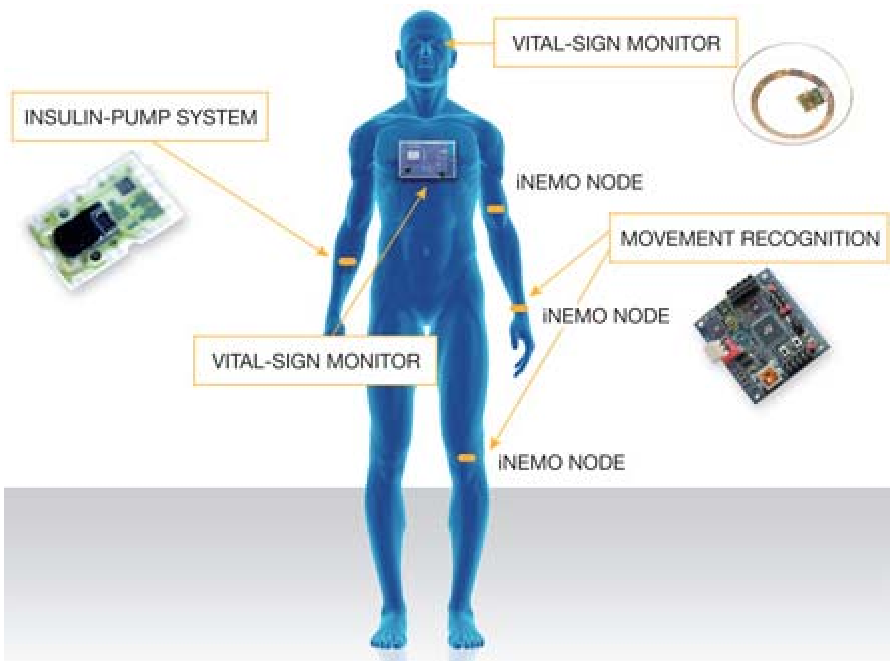
- development of Wireless Body Area Networks (WBANs)
  - the increasing use of wireless networks
  - constant miniaturization of electrical devices
- position of sensors
  - attached on clothing
  - on the body
  - implanted under the skin
- application
  - measure the heartbeat
  - record Electrocardiogram (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



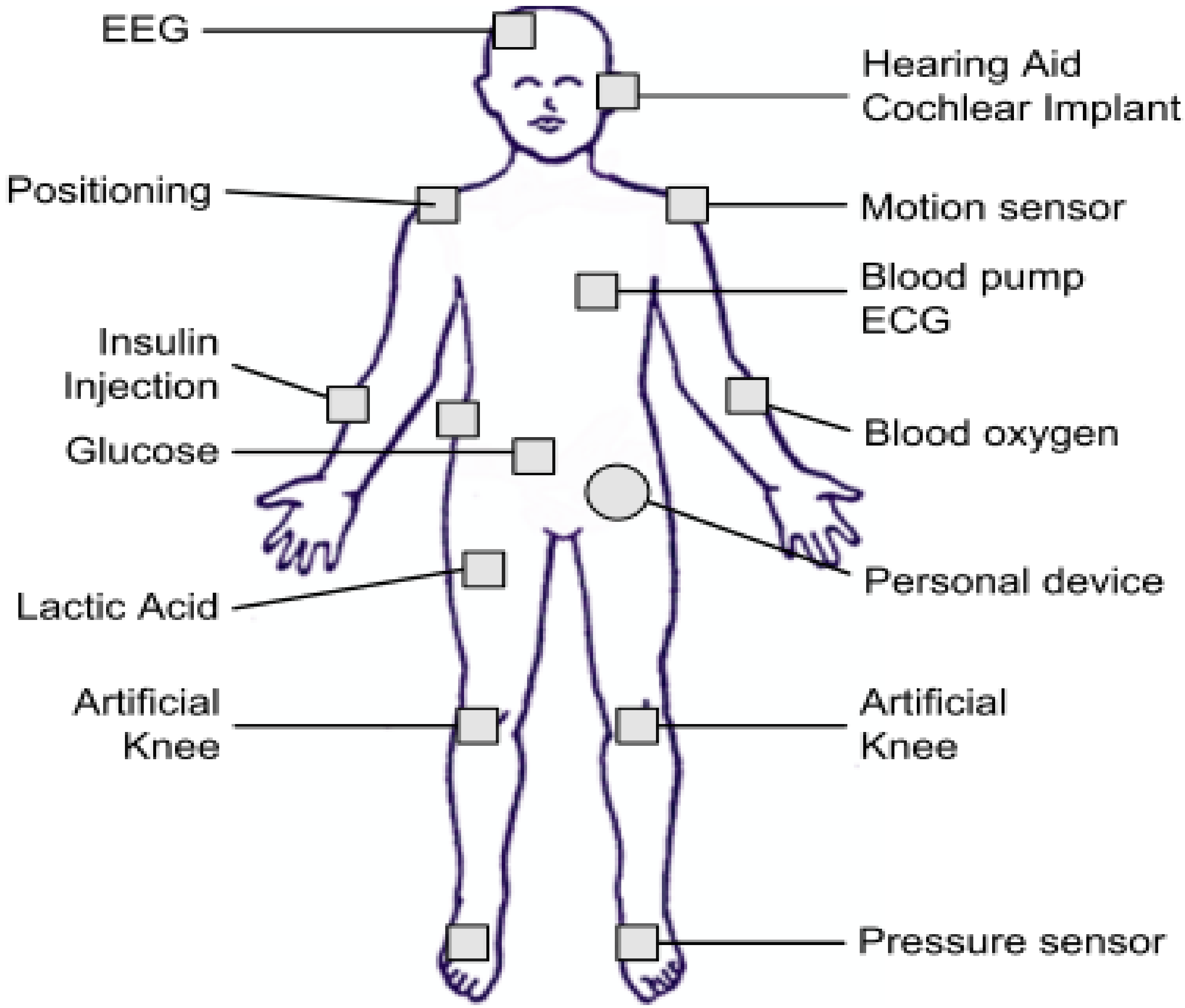
Cont.

- 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.


EEG
Hearing Aid
Cochlear Implant
Positioning
Motion sensor
Blood pump
ECG
Insulin
Injection
Glucose
Blood oxygen
Personal device
Lactic Acid
Artificial
Knee
Artificial
Knee
Pressure sensor

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

Application	Data Rate	Bandwidth	Accuracy
ECG (12 leads)	288 kbps	100-1000 Hz	12 bits
ECG (6 leads)	71 kbps	100-500 Hz	12 bits
EMG	320 kbps	0-10,000 Hz	16 bits
EEG (12 leads)	43.2 kbps	0-150 Hz	12 bits
Blood saturation	16 bps	0-1 Hz	8 bits
Glucose monitoring	1600 bps	0-50 Hz	16 bits
Temperature	120 bps	0-1 Hz	8 bits
Motion sensor	35 kbps	0-500 Hz	12 bits
Cochlear implant	100 kbps	–	–
Artificial retina	50-700 kbps	–	–
Audio	1 Mbps	–	–
Voice	50-100 kbps	–	–

- 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

Energy

- consumption
  - sensing
  - communication : most power comsuming
  - data processing
- restricted power available in the node
  - the size of the battery
  - some device should operate while supporting a battery life time
  - 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)

SAR can be calculated from the electric field within the tissue as:

$$\mathrm{SAR} = \int_{\text{sample}} \frac{\sigma(\mathbf{r})|\mathbf{E}(\mathbf{r})|^2}{\rho(\mathbf{r})} d\mathbf{r}$$

where

σ is the sample electrical conductivity

E is the RMS electric field

ρ 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

Positioning WBANs

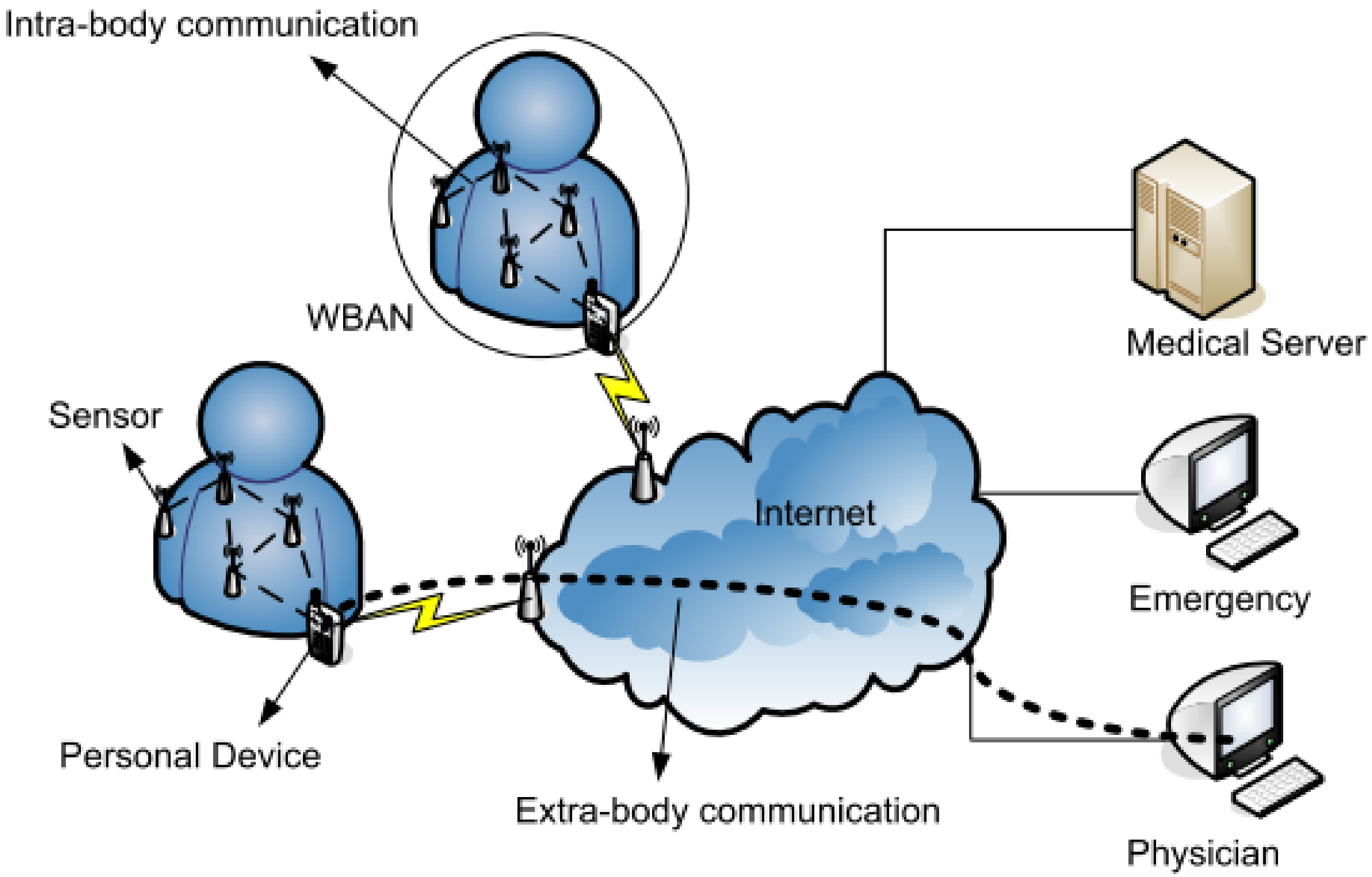


Fig. 2 Example of intra-body and extra-body communication in a WBAN

Cont.

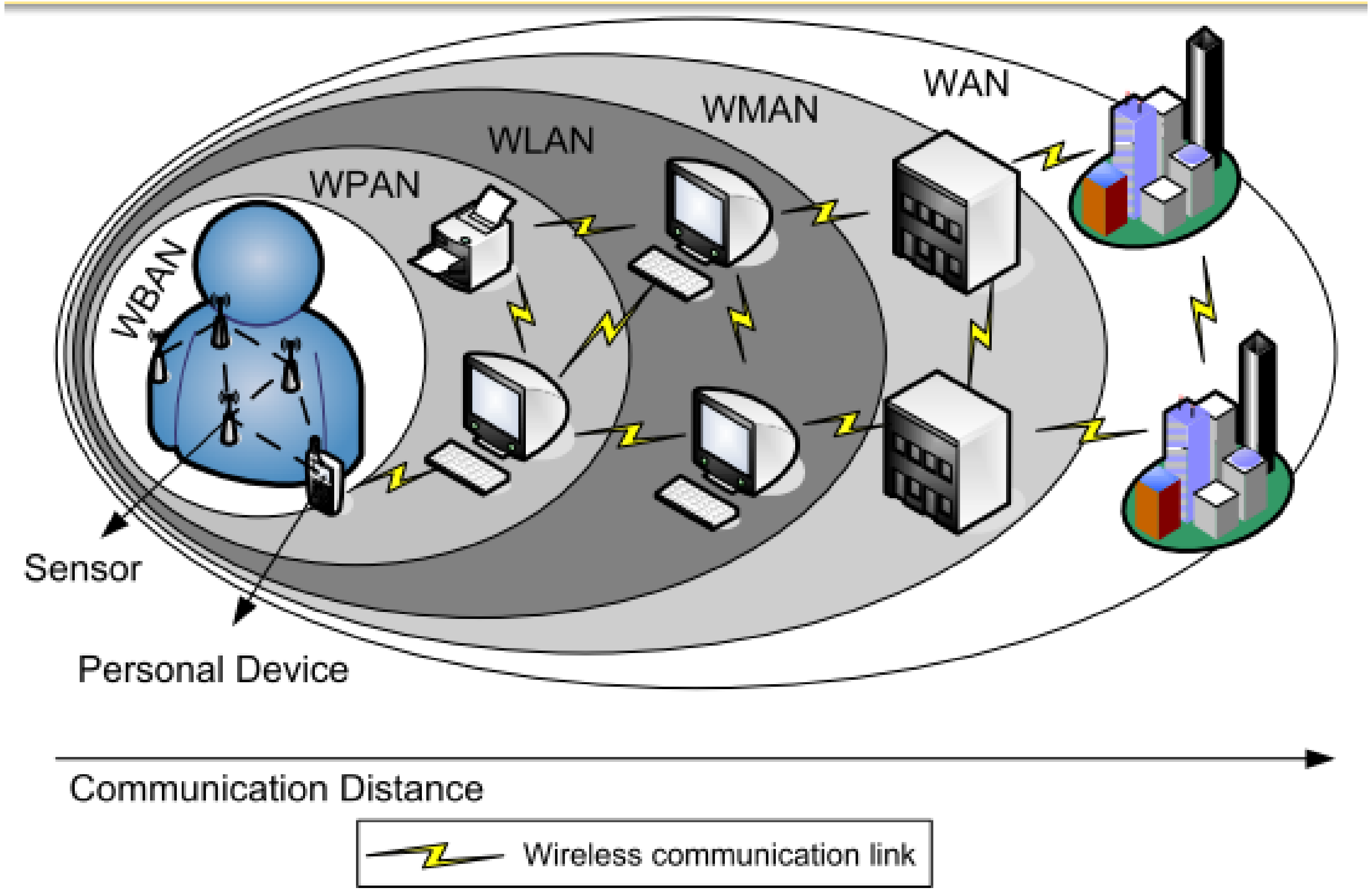


Fig. 3 Positioning of a Wireless Body Area Network in the realm of wireless networks.

Cont.

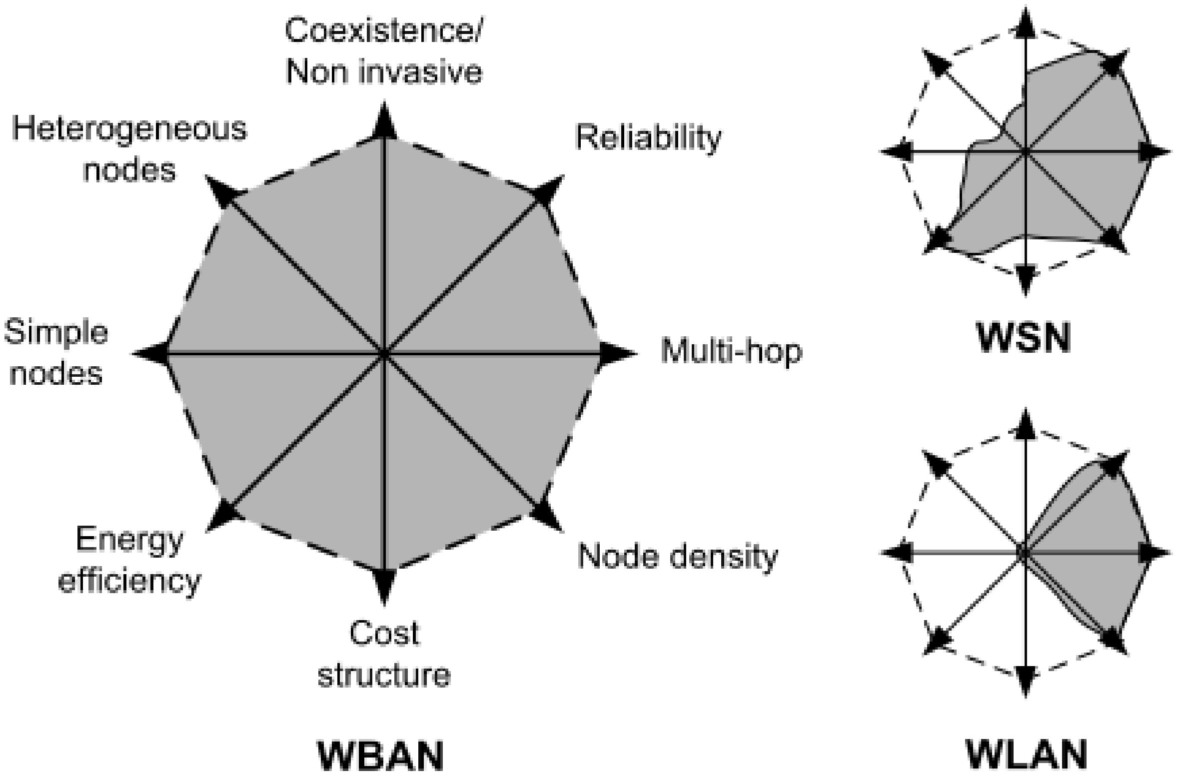


Fig. 4 Characteristics of a Wireless Body Area Network compared with Wireless Sensor Networks (WSN) and Wireless Local Area Network (WLAN). Based on [44].

Cont.

Table 2 Schematic overview of differences between Wireless Sensor Networks and Wireless Body Area Networks, based on [45].

Challenges	Wireless Sensor Network	Wireless Body Area Network
Scale	Monitored environment (meters / kilometers)	Human body (centimeters / meters)
Node Number	Many redundant nodes for wide area coverage	Fewer, limited in space
Result accuracy	Through node redundancy	Through node accuracy and robustness
Node Tasks	Node performs a dedicated task	Node performs multiple tasks
Node Size	Small is preferred, but not important	Small is essential
Network Topology	Very likely to be fixed or static	More variable due to body movement
Data Rates	Most often homogeneous	Most often heterogeneous
Node Replacement	Performed easily, nodes even disposable	Replacement of implanted nodes difficult
Node Lifetime	Several years / months	Several years / months, smaller battery capacity
Power Supply	Accessible and likely to be replaced more easily and frequently	Inaccessible and difficult to replaced in an implantable setting
Power Demand	Likely to be large, energy supply easier	Likely to be lower, energy supply more difficult
Energy Scavenging Source	Most likely solar and wind power	Most likely motion (vibration) and thermal (body heat)
Biocompatibility	Not a consideration in most applications	A must for implants and some external sensors
Security Level	Lower	Higher, to protect patient information
Impact of Data Loss	Likely to be compensated by redundant nodes	More significant, may require additional measures to ensure QoS and real-time data delivery.
Wireless Technology	Bluetooth, ZigBee, GPRS, WLAN, ...	Low power technology required

Physical layer

- RF communication
  - the radio signals experience great losses
    - Narrowband radio signals
    - Ultra Wide Band (UWB)
  - the transmitted power drops off with d^{η}
    - d represents the distance between the sender and the receiver
    - η 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)

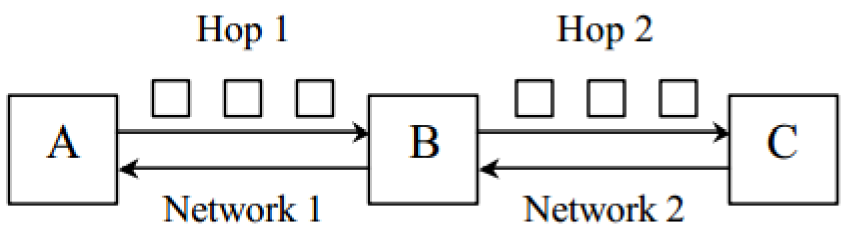
Cont.

- 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 η 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

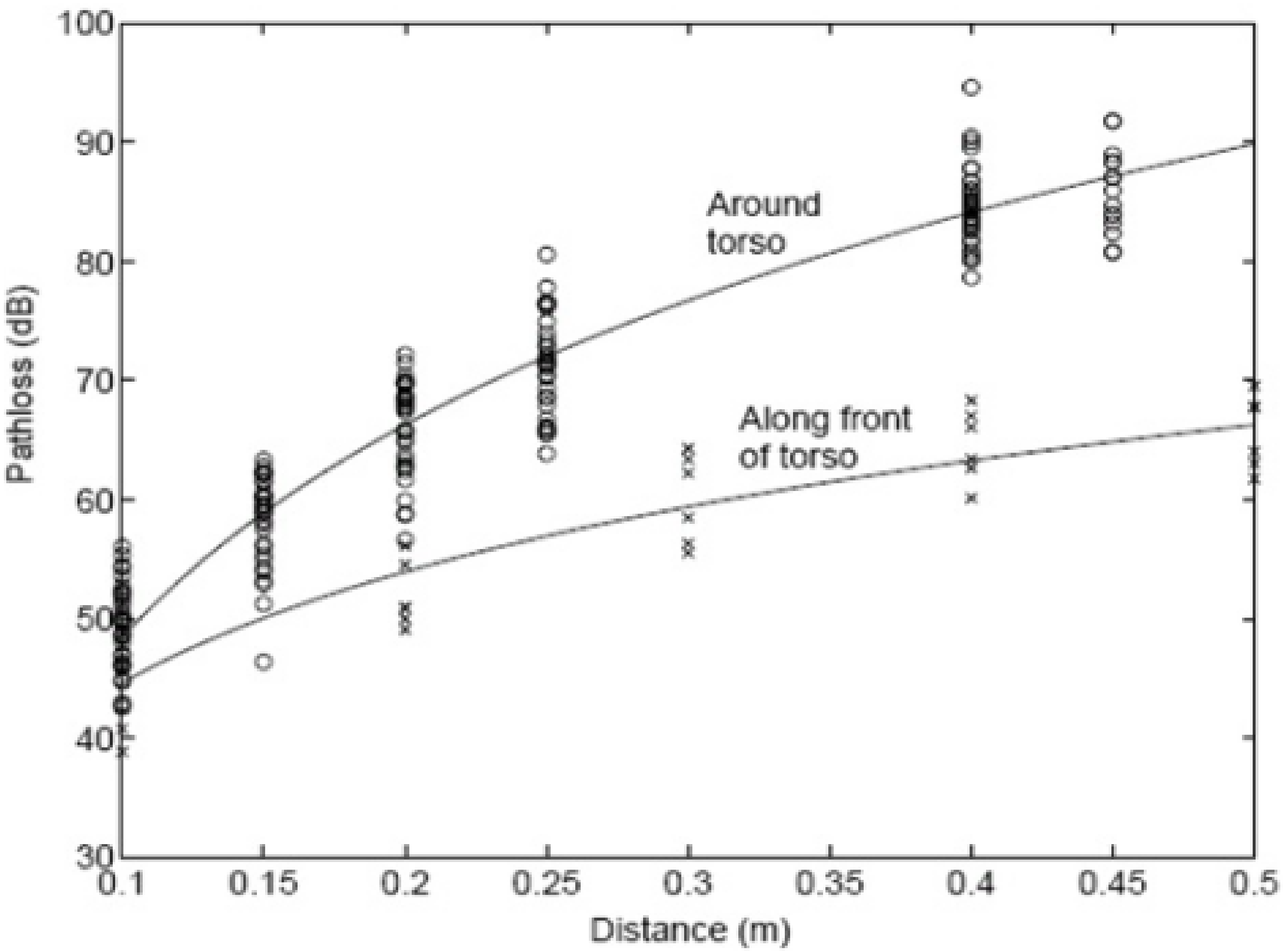
Cont.

- 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 effciency
  - the use of multi-hop communication in a WBAN could lead to a more optimal network topology
  - Multi-hop relaying



Measured path loss vesus 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% where 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 traffc 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

Cont.

- 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

MAC-protocol	IEEE 802.15.4 based	TDMA based	CSMA based	Star topology (master/slave)	Time Synchronization available in the protocol
Timmons [71]	√	√		√	
BSN-MAC [72]	√	mixed		√	
Lamprinos [73]		√		√	√
Omeni [74]		√		√	
H-MAC [75]		√		√	√

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 (LTRT)

example of LTR and ALTR

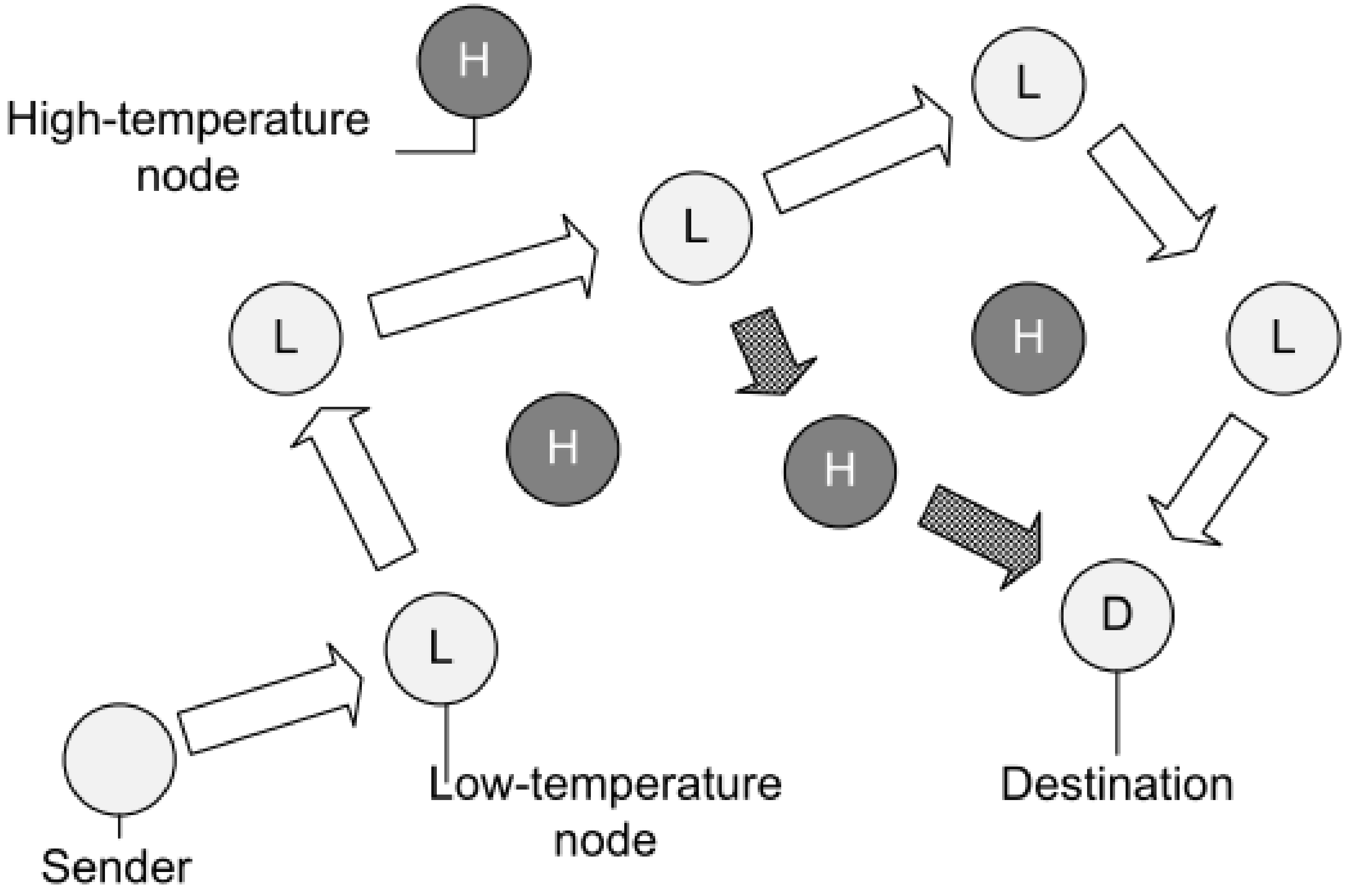


Fig. 6 An example of LTR and ALTR. The white arrows indicate the LTR-path. The shaded arrows show the adapted path of ALTR. When the path has three hops, the routing algorithm switches to shortest path routing.

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
      - constructia 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:

1. Write down five difference between Wireless Sensor Network and Wireless Body Area Network .
2. Summarize the theorem of LTR and ALTR.

Solutions

- Homework #1

Challenges	Wireless Sensor Network	Wireless Body Area Network
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Cont.

- 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