Wireless Sensor Aided Application Scenarios for Pervasive Healthcare

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World population is getting older

Percentage Change in the World’s Population by Age: 2010-2050

- 0-64: 22%
- 65+: 188%
- 85+: 351%
- 100+: 1004%

Old age comes with increased health challenges

- Cardiovascular diseases
- Cancer
- Respiratory diseases
- Diabetes
- Disabilities
- Dementia

The Increasing Burden of Chronic Noncommunicable Diseases: 2008 and 2030

And the strain on the healthcare system is rising

- Increased costs for long and frequent hospitalizations
- Shortage of caregivers
- Long-term care for chronic patients

Total health expenditure as a share of GDP, 2000-10, selected EU member states

Source: OECD Health Data 2012; Eurostat Statistics Database; WHO Global Health Expenditure Database.
**mHealth – The new paradigm**

- mHealth = the use of mobile and wireless technologies to improve healthcare delivery

- Remote monitoring of health status
- Support of independent aging
- Tracking of fitness activities
- Active Management of chronic diseases
Impact of mHealth

Cost reduction
- Reduced visits to doctor
- Reduced and shorter hospitalizations
- Reduced burden on caregivers

Quality of Life
- Aging independently “in place”
- Easier and unobtrusive disease management
- Prevention and well-being
Industry vs Academia

Telemonitoring Market

Cardiac Diseases

Hypertension

Diabetes

Pulmonary Diseases

Research Challenges

Interoperability

Energy efficiency

Security

mobility

Quality of Service (QoS)

Reliability

Wireless Sensor Networks (WSNs)
Scenarios for Pervasive Healthcare

Case 1: Single patient monitoring:
Scenarios for Pervasive Healthcare

Case 2: Multi-patient monitoring
Research Challenges

WSNs-aided pervasive healthcare applications

- Energy Efficiency
- Localization and context awareness
- Multihop Communication
- Security
- Error Resilience and QoS
# Technical Objectives

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<th>Energy Efficiency</th>
<th>Design energy-efficient MAC protocols with energy harvesting capabilities</th>
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<td>Multihop Communication</td>
<td>Investigate cooperative schemes for multihop and bidirectional communication</td>
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<td>Error Resilience and QoS</td>
<td>Apply Network Coding and Compressed Sensing schemes</td>
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<td>Security</td>
<td>Develop algorithms for security and confidentiality of medical data</td>
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<td>Localization and context awareness</td>
<td>Design distributed localization algorithms to track position and patient activity</td>
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Proposed Solutions (1)

Hybrid polling MAC protocol with Human Energy Harvesting capabilities (HEH-BMAC)
- Service differentiation
- Dynamic contention-free and contention-based access periods
- 56% normalized throughput gain
- 20% energy efficiency gain

Power-QoS Control Scheme for Energy Harvesting Body Sensor Nodes (PEH-QoS)
- Power-aware event detection
- Queue management to prevent the saturation of the data buffers
- Packet aggregation to minimize energy consumption

A cloud-aided NC-based MAC for mHealth applications
- Novel cloud architecture for relay coordination in NC-based WSNs
- Gains: 52% throughput, 65% energy efficiency, 28% total delay reduction, 100% successful packet delivery
Proposed Solutions (2)

Network Coding schemes for ECG compression in WBANs

- Low complexity encoding and decoding schemes for ECG compression / reconstruction
- Up to 44 reduction in compression ratio, up to 30 times faster execution times
A hybrid polling MAC with Human Energy Harvesting (HEH-BMAC)

- Service differentiation
- Dynamic contention-free and contention-based access periods
- 56% normalized throughput gain
- 20% energy efficiency gain
A hybrid polling MAC with Human Energy Harvesting (HEH-BMAC)

- Scenario
  - Star topology WBAN
  - Nodes powered by a rechargeable battery and a human energy harvester
A hybrid polling MAC with Human Energy Harvesting (HEH-BMAC)

- **HEH-BMAC Access**
  - *ID-polling*: collision-free medium access for high priority BNs
  - *PC-access*: contention-based probabilistic access for normal priority BNs

- **Key features**
  - Prioritization based on data criticality
  - Dynamically adjusted contention periods according to the energy levels of the BNs
  - Dynamic control of packet collisions
A hybrid polling MAC with Human Energy Harvesting (HEH-BMAC)

- Throughput and energy efficiency gains with respect to IEEE 802.15.6

A Power-QoS Control Scheme for EH Body Nodes (PEH-QoS)

Hybrid polling MAC protocol with Human Energy Harvesting capabilities (HEH-BMAC)

Power-QoS Control Scheme for Energy Harvesting Body Sensor Nodes (PEH-QoS)

- Power-aware event detection
- Queue management to prevent the saturation of the data buffers
- Packet aggregation to minimize energy consumption
A Power-QoS Control Scheme for EH Body Nodes (PEH-QoS)

• Scenario
  • Star topology
  • ECG node is connected to an energy harvester.
  • BNC node without energy constraints

• Motivation
  • The energy that is usually collected is not sufficient for the nodes’ operation.
  • Data packets usually remain stored for a long time
    • saturation of the data queue and loss of clinical validity of the data
A Power-QoS Control Scheme for EH Body Nodes (PEH-QoS)

• PEH-QoS
  • Power-aware event detection (PHAM)
  • Queue management to prevents the saturation of the data buffers (DQAC)
  • Packet aggregation to minimize energy consumption (PASS)
A Power-QoS Control Scheme for EH Body Nodes (PEH-QoS)

- Increased normalized throughput
- Increased energy efficiency
- Decreased packet loss
- Decreased average packet end-to-end delay.
- Higher detection and storage efficiency

E.Ibarra, E.Kartsakli, A.Antonopoulos, J.Rodriguez and Ch.Verikoukis
“Joint Power-QoS Control Scheme for Energy Harvesting Body Sensor Nodes”,
IEEE ICC 2014, Sydney, Australia.
A cloud-aided NC-based MAC (CLNC-MAC) for eHealth

- Hybrid polling MAC protocol with Human Energy Harvesting capabilities (HEH-BMAC)
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A cloud-aided NC-based MAC (CLNC-MAC) for mHealth

• Motivation
  • Reduce overhead due to collisions/idle slots
  • Overcome decoding failures in the presence of errors

• Cloud architecture
  • Cooperative network of relays forwards data from the source (WBAN) to the central unit
  • A central entity (cloud manager) coordinates relay transmissions
A cloud-aided NC-based MAC (CLNC-MAC) for eHealth

- CLNC-MAC: a cloud-assisted MAC protocol that improves RLNC performance through relay coordination
A cloud-aided NC-based MAC (CLNC-MAC) for eHealth

- 52% throughput gain
- 65% energy efficiency gain
- 28% end-to-end total delay reduction

E.Kartsakli, A. Antonopoulos, L.Alonso and Ch.Verikoukis
“A Cloud-assisted Random Linear Network Coding Medium Access Control Protocol for Healthcare Applications”
Sensors 2014, 14(3), 4806-4830;
Network Coding schemes for ECG compression in WBANs

- low complexity encoding and decoding schemes for ECG compression / reconstruction
- Up to 44 reduction in compression ratio, up to 30 times faster execution times
Network Coding schemes for ECG compression in WBANs

- Scenario: ECG Telemonitoring in WBANs
- Motivation
  - The PA in a WBAN transmitter consumes 66.5 µW of the total power of 90 µW.
  - Conventional ECG compression schemes cannot be applied
    - highly demanding computational operations at the sensor
  - Design Requirements that should be met:
    - Minimize the transmitted data
    - Minimize computational operations executed by the sensor
- We propose novel low-complexity encoding and decoding schemes for ECG compression and reconstruction
Network Coding schemes for ECG compression in WBANs

- Encoding Schemes:
  - Similar to RLNC (random linear combinations of recorded measurements).

- Decoding Schemes:
  - SoA: Classical Basis Pursuit Algorithm (BP)
    - Exploits signal sparsity (ignore samples with no critical info)
  - Proposed: Block Based Recovery (BSR)
    - Exploits block signal sparsity (ignore group of samples)
  - Proposed: Prewhitened Block BSR (PW BSR)
    - Combines BSR with pre-processing

- The SoA decoding schemes employ complex optimization algorithms → high computational requirements.

- We propose a novel low complexity Coordinate Descent based scheme (BCD) that achieves same performance with less operations.
Network Coding schemes for ECG compression in WBANs

- Up to 44% Compression Ratio Reduction
Network Coding schemes for ECG compression in WBANs

- Complexity reduction of the order of $O(N)$
Conclusions

• Significant improvements have been achieved
  • energy efficiency
  • QoS performance
  • robustness against errors and reliability
  • implementation complexity

• Open issues
  • Compressed sensing for biomedical signals
  • Bidirectional communication schemes for dense sensor deployments
  • Security schemes