Intra-body Communication Using Galvanic Coupling

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Abstract

Implanted wireless sensors promise the next generation of health-care by in-situ testing of abnormal physiological conditions, personalized medicine and proactive drug delivery to ensure continued well being. However, these sensors must communicate among themselves and with an external control, which raises questions on how to ensure energy efficient data delivery through the body tissues. Traditional forms of high power radio frequency-based communication find limited use in such scenarios owing the limited penetration of electromagnetic waves through human tissue, and the need for frequent battery replacements. Instead, we propose a radically different form of wireless communication that involves galvanic coupling extremely low power electrical signals, resulting in two orders of energy savings. In this scarcely explored paradigm, there are several interesting challenges that must be overcome including (i) modeling the body propagation channel, (ii) identifying the best placements of implants and auxiliary data forwarding nodes and (iii) devising scientific methods to characterize and improve channel capacity for information transfer.

To model the human tissue propagating characteristics, we developed a theoretical suite using equivalent circuits and validated through extensive simulations using finite element method. Using these models, we estimated the channel gain and obtained an estimate for achievable data rates. We could also identify the optimal transmission frequency and electrode placements for signal propagation. Our results reveal a close agreement with experimental findings. Further development of suitable physical and higher layer networking protocols that are reliable with minimum latency would make galvanic coupling an attractive technology for future intra-body networks.

Objective – Networking Body Sensors

- Future health-care relies on autonomous sensing of physiological signals and controlled drug delivery
- Need for implanted cyber-physical body sensor network (CP-BN) that can wirelessly communicate with an external control point

Why Galvanic Coupling

Existing RF based BNs
- not suitable for human tissues containing water
- consume more power
- does not propagate inside body tissues

Galvanic coupled CP-BN
- mimics body’s natural signalling (low frequency signals)
- low interference as energy is confined within body
- consumes two orders of magnitude less energy

Galvanic Coupling - Background

- Injects low power electrical signal to the tissues
- Weak secondary currents carry data to receiver
- Signal propagates radially across multiple tissues & suffer losses

Galvanic Coupling on Skin (a) Front View (b) Cross Section

10^6 10^5 10^4 10^3 10^2 [Ω]

Signal Propagation Through Tissue – Modeling Method

- Obtained an estimate for observed noise and achievable data rates.
- Identified optimal transmission frequency and electrode placements under varying tissue dimensions [2]
- Skin to muscle & intra-muscle links showed lower loss than on-skin links

Components and Network Architecture for Galvanic Coupled Cyber Physical Body Network

Components and Network Architecture for Galvanic Coupled Cyber Physical Body Network

Future Research Challenges

Implementation of Physical Layer

Objective: Establishing reliable & energy efficient CP-BN physical layer

Channel Capacity
- Building transmitter and receiver circuits with suitable modulation schemes that maximizes transfer rate
- Studying the impact of realistic noise figures on capacity

Physical Protocol

Link Quality Analysis
- Self Adaptation
- Synchronization

Protocol Design at Network Layer

- The spatio-temporal distribution should be analyzed and leveraged for multiple channel access Eg. TDMA
- The network should distinguish critical situations from normal deviations based on correlations derived from routine activities Eg. Abnormal Heart rate from heavy activity Vs emergency

Body Network Test-bed

Galvanic Coupled Body Network operation and performance needs to be evaluated by building test-beds using
- Human phantoms
- Animal experiments
- Clinical trials

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References


* Universitat Politècnica de Catalunya, Barcelona, Spain