PhD Subject in the context of the nano-tera WiseSkin project

(http://www.nano-tera.ch/projects/353.php#)

Context

Amputation of a hand or limb is a catastrophic event resulting in significant disability with major consequences for amputees in terms of daily activities and quality of life. Although functional myoelectric prostheses are available today (e.g. hand), their use remains limited due, in part, to a lack of sensory function in the prostheses. At the same time, as the world's population both grows and ages, the number of people living with disabilities, such as persons who have lost limbs for whatever reason e.g. trauma, diabetes or cancer, also increases. A sense of tactility is needed for providing feedback for control of prosthetic limbs and to perceive the prosthesis as a real part of the body, inducing a sense of "body ownership". Today, there is no solution for restoration of a natural sense of touch for persons using prosthetic limbs.

WiseSkin provides a solution for restoration of the sensation of touch. It embeds tactility sensors into the cosmetic silicone coating of prostheses, which acts like a sensory "skin" providing the sensation of touch, enabling improved gripping, manipulation of objects and mobility (walking) for amputees. Flexibility, freedom of movement and comfort demand unobtrusive, highly miniaturized, ultra-low power (ULP) sensing capabilities built into the "skin", which is then integrated with a sensory feedback system. The focus is on non-invasive (external actuation) sensory feedback mechanisms. The main elements of the project are:

- flexible, skin-like, material embedded with tactility sensors
- miniature, flexible, soft-MEMS based sensors (e.g. pressure, shear)
- ULP, event driven wireless communication (radio and protocol) between the sensors and processing / control module
- a conformal, stretchable powering system based on a metallic mesh grid
- use of the metallization layers as a waveguide
- a system for sensory feedback based on a tactile display (i.e., on the amputation stump or the back) using miniature actuators / electrodes
- Proof-of-Concept demonstrator (i.e., tested on volunteers) combined with brain imaging to investigate neural mechanisms of tactile perception

WiseSkin pushes the forefront of technology in miniature, ULP sensor and communication devices, materials and sensory feedback systems; putting nano-tera research at the forefront. It enhances the competitiveness of Swiss organizations in these domains, helping to open the door for Swiss industry to capture an early and substantial share in the market for advanced, high-density body sensor networks towards artificial skin and tactile robots. Importantly, WiseSkin enables new prosthetic products, with improved functionality, hopefully offering improved quality of life for amputees.

Objectives

The thesis subject is part of task 1 that will investigate and develop the multi-hop communication system between the miniature sensors and the control center (tactile display). The thesis covers the protocol aspects described below in subtasks 1.1 and 1.2 (the other subtasks are omitted here). As communication is the largest source of energy consumption, the challenge is to reduce consumption by duty cycling the network nodes while keeping the end-to-end latency very low (<10ms). The aim is to answer the following research questions:

- How to create a MAC protocol that allows the sensor nodes to sleep in absence of event and capable of waking-up rapidly when an event is detected either locally or by another sensor node?
- To which degree in-network processing will allow to reliably detect complex events such as slipping objects and reduce the quantity of information sent to the control center to a minimum? This is done to favour low latency by reducing network load.

- How to obtain a scalable routing protocol that favours local communication for event detection and provides energy efficient, reliable and timely event propagation to the control center?
- Is it possible to further improve the performances (energy & latency) by changing the propagation and communication principles? What are the propagation effects of the flexible waveguide? How can we make an effective, miniature, stretchable antenna?
- What is he appropriate radio architecture, frequency band and air interface (i.e. FM-UWB) for minimizing the power consumption?
- Can a hybrid UWB (e.g. for high data rate transmission > 2 Mb/s) and NB radio (for low data rate signalling) take advantage of the dense network, and extreme short range, to significantly reduce power consumption and still offer robustness?

T1.1 Low-latency, low-power MAC protocol - Low latency often requires that sensor nodes are always on. This is clearly impossible in our context at least concerning the communication circuitry. It is possible to detect local events (on the same node) quickly by turning-on the sensory electronics at high rate and checking for events. Provided the circuits are designed to turn on fast, it is possible to maintain a low duty cycle for the sensor part of the node. The challenge is to do the same on the communication side while keeping power consumption low in absence of event. Low power listening (LPL) protocols are a way to meet this challenge but are not able to cope with the latency requirements of the project. The idea is to switch from a LPL protocol (e.g. WiseMAC) to a more reactive one (e.g. CSMA when an event is detected). To avoid the classical global state problem, this must be done asynchronously. This combination will be studied to derive the best combination of parameters of both types of protocols. We hope that this will yield the necessary improvements. Additionally, we plan to investigate ways to synchronize the mode changes (e.g. sleep to fast transmit) while keeping energy consumption at an acceptable level. One way would be to increase emission power to wake-up the neighbor nodes more quickly. Both schemes will be compared and if possible merged.

T1.2 Routing and processing for fast and reliable event detection - Routing must support two types of interactions: 1) local exchange of information (publish-subscribe type) between the sensor nodes for information fusion leading to reliable event detection 2) propagation of events hop by hop (sensor to sensor) to the ACM and the possibility of settings from the ACM to the nodes (e.g. faster or slower update rate). The objective of this task is to study different metrics in existing CTPs (Collection Tree Protocols). WSN routing protocols were not designed for dense networks. In such networks, there is a trade-off between link quality and number of hops. Metrics that privilege link quality often lead to a large number of hops increasing load and latency. T1.2 will investigate news metrics that minimize the channel occupancy (or equivalently number of hops) and maximize delivery ratio. This will be completed to support the local exchange of information based on publish-subscribe models (e.g. CCBR). Each type of traffic will hence be handled in the optimal way. Further, as there is often a high redundancy in the sensor inputs from different sensor nodes by proper in-network processing, using local communications, the data may be fused to reduce the quantity of information and/or aggregated to limit the number of transmissions. T4.2 also implements the sensor processing and distributed reliable event detection algorithms and investigates information reduction based on this knowledge. Finally, it will study ways to optimize the operations of the protocols by violating the strict layering.