Making Time-critical Cyber Physical Systems Energy Efficient

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Wireless Sensor Networks (WSNs) promise breakthroughs in cyber physical systems (CPS). This study proposes a communication protocol for enabling WiseSkin (artificial skin for humans based on WSNs) to seamlessly convey tactile stimuli, thus addressing stringent adaptability, latency (<100 ms), reliability (>99%) and energy requirements. The protocol relies on concurrent transmissions enabled by constructive interference and this study shows that this approach is more energy efficient than the traditional one of avoiding concurrent transmissions. The solution has general applicability for WSNs in CPS (e.g., aerospace, industrial process control, robotics, etc.), infrastructure monitoring and alarms.

WiseSkin leverages WSNs to make possible a novel technology: artificial skin for humans capable of restoring tactile feeling [1] to those using prosthetic limbs. It consists of miniature nodes embedded in a polymer material that sense the pressure over the skin and transmit the data via a wireless multi-hop network to a control unit (CU), which transfers the stimuli to the nervous system (Figure 1, for additional details refer to [1]).

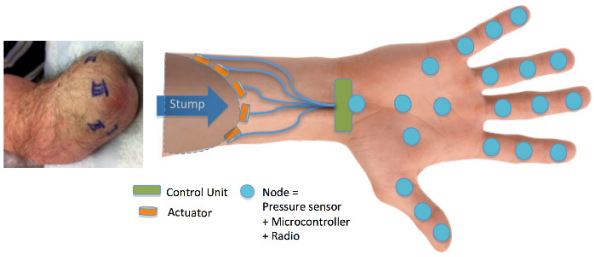

Figure 1: Schema of WiseSkin. A WSN embedded in a polymer senses the pressure over the skin, transmits the data via wireless multi-hop network to a CU, which transfers the stimuli to the nervous system of the user (source of the stump image: Lund University).

WiseSkin must convey the tactile stimuli in a manner that the user perceives as natural, which generates challenging requirements for the WSN: **adaptability** (to handle sporadic traffic surges), **responsiveness** (to ensure a worst-case end-to-end latency under 100 ms), **energy efficiency** (to maximize the lifetime of the nodes), and **reliability** (to maintain a packet delivery ratio over 99%).

The proposed protocol consists of two operating modes: low-traffic and high-traffic. The former aims at minimizing the energy consumption and the latter on conveying the tactile information when the skin is stimulated (extended report in [2]).

Both modes rely on simultaneous transmissions enabled by constructive interference at the symbol level [3], which ensures state-of-the-art reliability and a fast transition between modes. This technology has traditionally been used for periodic traffic (e.g., Glossy [3]), while in this project we propose a modified version that caters to sporadic traffic surges (Modified-Glossy).

The protocol for WiseSkin, which leverages concurrent transmissions, was compared with ContikiMAC, which is based on the classical approach of avoiding concurrent transmissions. The evaluation used 10 nodes and monitored the end-to-end latency (from the generation of the event until the arrival at the sink), energy consumption, and reliability. The results show that the Modified-Glossy protocol is more energy efficient, for targeting a given latency, while maintaining reliability over 99% (Figure 2). Moreover, the worst-case latency is highly predictable and the system naturally handles traffic surges (details in [2]).

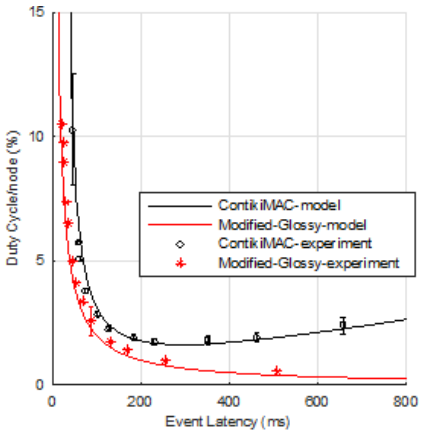

Figure 2: Duty cycle as a function of Latency. The Modified-Glossy protocol displays a lower duty-cycle in the entire range of latencies.

The proposed protocol has applications in multiple domains:

- Cyber Physical Systems: The high reliability and capability of providing predictable delays are ideal for enabling control loops in industrial processes, robotics or aerospace devices.
- Monitoring: The ability to accommodate traffic surges while also being energy efficient is ideal for networks that perform on-demand evaluations. For example, a WSN that can evaluate the water quality in an urban distribution network and that can reliably send the results of a requested analysis, while maintaining a battery life of several years.
- Alarms: The ability to seamlessly handle simultaneous transmissions ensures a reliable notification of an alarm even if multiple nodes aim to report it simultaneously. For example, a WSN that detects rocks falling on the train tracks can reliably convey an alarm triggered simultaneously by all the nodes, in case of a landslide.

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[1] "WiseSkin" project: http://www.nano-tera.ch/projects/353.php

[2] C. Rojas, J.-D. Decotignie, "Artificial skin for human prostheses, enabled through wireless sensor networks ", RTCSA IEEE Int. Conf. on Emb. and Real-Time Comp. Systems and Applic., (2017).

[3] F. Ferrari, *et al.*, "Efficient network flooding and time synchronization with Glossy", IPSN Int. Conf. on Information Processing in Sensor Networks, (2011).