Body Sensor Networks: A Holistic Approach from Silicon to Users

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Abstract—Body sensor networks (BSN) are emerging cyber-physical systems that promise to improve quality of life through improved health, augmented sensing and actuation for the disabled, independent living for the elderly, and reduced healthcare costs. However, the physical nature of BSNs introduces several new challenges. The human body, especially in the context of medical conditions, is a highly dynamic and unpredictable physical environment that creates constantly changing demands on sensing, actuation, and quality of service (QoS). At the same time, movement between indoor and outdoor environments and rapid physical movements of arms and legs constantly change the wireless channel characteristics. These dynamic application contexts can also have a dramatic impact on data and resource prioritization. Thus, BSNs must simultaneously deal with rapid changes to both top-down application requirements and bottom-up resource availability. This is made all the more challenging by the wearable nature of BSN devices, which necessitates a vanishingly small size and, therefore, extremely limited hardware resources and power budget. Current research is being performed to develop new principles and techniques for adaptive operation in highly dynamic physical environments, using new miniaturized, energy-constrained devices. This work uses a holistic cross-layer approach that simultaneously addresses all aspects of the system, from low-level hardware design to higher-level communication and data fusion algorithms, to top-level applications, in order to optimize the energy efficiency, system lifetime, and value to the user of the BSN. As an example of the holistic view, we are developing a suite of new asymmetric radio MAC protocols to simultaneously achieve low power, high data rate, and low response time. A MAC analysis for the asymmetric radio revealed that radio energy is dominated by receiver energy -- even when not receiving -- due to the need for signaling. This drove the design of "3-radio" MAC protocols that integrate a low-power "1-bit" receiver for efficient wakeup and signaling. It was also found that TDMA energy and periodic sampling are dominated by clock energy due to long waiting times. This is driving integration of low-accuracy clocks and a hierarchy of synchronization sources for ultra-low-power sleep modes and low-energy wake-up events.