Protocol Design for Control Applications using Wireless Sensor Networks

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Abstract

Given the potential benefits offered by wireless sensor networks (WSNs), they are becoming an appealing technology for process, manufacturing, and industrial control applications. In this thesis, we propose a novel approach to WSN protocol design for control applications. The protocols are designed to minimize the energy consumption of the network, while meeting reliability and packet delay requirements. The parameters of the protocol are selected by solving a constrained optimization problem, where the objective is to minimize the energy consumption and the constraints are the probability of successful packet reception and the communication delay. The proposed design methodology allows one to perform a systematic tradeoff between the control requirements of the application and the network energy consumption. An important step in the design process is the development of analytical expressions of the performance indicators. We apply the proposed approach to optimize the network for various communication protocols.

In Paper A, we present an adaptive IEEE 802.15.4 for energy-efficient, reliable, and low latency packet transmission. The backoff mechanisms and retry limits of the standard are adapted to the estimated channel conditions. Numerical results show that the proposed protocol enhancement is efficient and ensures a longer lifetime of the network under different conditions. Furthermore, we investigate the robustness and sensitivity of the protocol to possible errors during the estimation process.

In Paper B, we investigate the design and optimization of duty-cycled WSNs with preamble sampling over IEEE 802.15.4. The analytical expressions of performance indicators are developed and used to optimize the duty-cycle of the nodes to minimize energy consumption while ensuring low latency and reliable packet transmissions. The optimization results in a significant reduction of the energy consumption compared to existing solutions.

The cross-layer protocol called Breath is proposed in Paper C. The protocol is suitable for control applications by using the constrained optimization framework proposed in the thesis. It is based on randomized routing, CSMA/CA MAC, and duty-cycling. The protocol is implemented and experimentally evaluated on a testbed, and it is compared with a standard IEEE 802.15.4 solution. Breath exhibits a good distribution of the work load among the network nodes, and ensures a long network lifetime.