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End-to-end Quality of Service Guarantees for Wireless Sensor Networks

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Wireless sensor networks have been a key driver of innovation and societal progress over the last three decades. They allow for simplicity because they eliminate cabling complexity while increasing the flexibility of extending or adjusting networks to changing demands. Wireless sensor networks are a powerful means of filling the technological gap for ever-larger industrial sites of growing interconnection and broader integration. Nonetheless, the management of wireless networks is difficult in situations wherein communication requires application-specific, network-wide quality of service guarantees. A minimum end-to-end reliability for packet arrival close to 100 % in combination with latency bounds in the millisecond range must be fulfilled in many mission-critical applications.

The problem addressed in this thesis is the demand for algorithmic support for end-to-end quality of service guarantees in mission-critical wireless sensor networks. Wireless sensors have traditionally been used to collect non-critical periodic readings; however, the intriguing advantages of wireless technologies in terms of their flexibility and cost effectiveness justify the exploration of their potential for control and mission-critical applications, subject to the requirements of ultra-reliable communication, in harsh and dynamically changing environments such as manufacturing factories, oil rigs, and power plants.

This thesis provides three main contributions in the scope of wireless sensor networks. First, it presents a scalable algorithm that guarantees end-to-end reliability through scheduling. Second, it presents a cross-layer optimization/configuration framework that can be customized to meet multiple end-to-end quality of service criteria simultaneously. Third, it proposes an extension of the framework used to enable service differentiation and priority handling. Adaptive, scalable, and fast algorithms are proposed. The cross-layer framework is based on a genetic algorithm that assesses the quality of service of the network as a whole and integrates the physical layer, medium access control layer, network layer, and transport layer.

Algorithm performance and scalability are verified through numerous simulations on hundreds of convergecast topologies by comparing the proposed algorithms with other recently proposed algorithms for ensuring reliable packet delivery. The results show that the proposed SchedEx scheduling algorithm is both significantly more scalable and better performing than are the competing slot-based scheduling algorithms. The integrated solving of routing and scheduling using a genetic algorithm further improves on the original results by more than 30% in terms of latency. The proposed framework provides live graphical feedback about potential bottlenecks and may be used for analysis and debugging as well as the planning of green-field networks.

SchedEx is found to be an adaptive, scalable, and fast algorithm that is capable of ensuring the end-to-end reliability of packet arrival throughout the network. SchedEx-GA successfully identifies network configurations, thus integrating the routing and scheduling decisions for networks with diverse traffic priority levels. Further, directions for future research are presented, including the extension of simulations to experimental work and the consideration of alternative network topologies.

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