Architectures and Protocols for Performance Improvements of Real-Time Networks

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Abstract

When designing architectures and protocols for data traffic requiring real-time services, one of the major design goals is to guarantee that traffic deadlines can be met. However, many real-time applications also have additional requirements such as high throughput, high reliability, or energy efficiency. High-performance embedded systems communicating heterogeneous traffic with high bandwidth and strict timing requirements are in need of more efficient communication solutions, while wireless industrial applications, communicating control data, require support of reliability and guarantees of real-time predictability at the same time. To meet the requirements of high-performance embedded systems, this thesis work proposes two multi-wavelength high-speed passive optical networks. To enable reliable wireless industrial communications, a framework incorporating carefully scheduled retransmissions is developed. All solutions are based on a single-hop star topology, predictable Medium Access Control algorithms and Earliest Deadline First scheduling, centrally controlled by a master node. Further, real-time schedulability analysis is used as admission control policy to provide delay guarantees for hard real-time traffic.

For high-performance embedded systems an optical star network with an Arrayed Waveguide Grating placed in the centre is suggested. The design combines spatial wavelength reuse with fixed-tuned and tuneable transceivers in the end nodes, enabling simultaneous transmission of both control and data traffic. This, in turn, permits efficient support of heterogeneous traffic with both hard and soft real-time constraints. By analyzing traffic dependencies in this multichannel network, and adapting the real-time schedulability analysis to incorporate these traffic dependencies, a considerable increase of the possible guaranteed throughput for hard real-time traffic can be obtained.

Most industrial applications require using existing standards such as IEEE 802.11 or IEEE 802.15.4 for interoperability and cost efficiency. However, these standards do not provide predictable channel access, and thus real-time guarantees cannot be given. A framework is therefore developed, combining transport layer retransmissions with real-time analysis admission control, which has been adapted to consider retransmissions. It can be placed on top of many underlying communication technologies, exemplified in our work by the two aforementioned wireless standards. To enable a higher data rate than pure IEEE 802.15.4, but still maintaining its energy saving properties, two multichannel network architectures based on IEEE 802.15.4 and encompassing the framework are designed. The proposed architectures are evaluated in terms of reliability, utilization, delay, complexity, scalability and energy efficiency and it is concluded that performance is enhanced through redundancy in the time and frequency domains.

Keywords - Real-time communication, predictable deadline guarantees, real-time scheduling analysis, timing analysis, admission control, deterministic medium access, MAC, Quality of Service parameters, reliability, redundancy, retransmission scheme, ARQ, truncated ARQ, Automatic Repeat Request, wireless networks, IEEE 802.11, IEEE 802.15.4, fibre-optic networks, AWG, multichannel networks, industrial communications, embedded systems.