January 30, 2019

Enabling Time- and Mission-Critical Applications in Industrial Wireless Sensor Networks

Author licentiate thesis: Hossam Farag

STC Research Centre
Mid Sweden University

Abstract

Nowadays, Wireless Sensor Networks (WSNs) have gained importance as a flexible, easier deployment/maintenance and cost-effective alternative to wired networks, e.g., Fieldbus and Wired-HART, in a wide-range of applications. Initially, WSNs were mostly designed for military and environmental monitoring applications where energy efficiency is the main design goal. The nodes in the network were expected to have a long lifetime with minimum maintenance while providing best-effort data delivery which is acceptable in such scenarios. With recent advances in the industrial domain, WSNs have been subsequently extended to support industrial automation applications such as process automation and control scenarios. However, these emerging applications are characterized by stringent requirements regarding reliability and real-time communications that impose challenges in the design of Industrial Wireless Sensor Networks (IWSNs) to effectively support time- and mission-critical applications.

Typically, time- and mission-critical applications support different traffic categories ranging from relaxed requirements, such as monitoring traffic to firm requirements, such as critical safety and emergency traffic. The critical traffic is mostly acyclic in nature and occasionally occurs at unpredictable time instants. Once it is generated, it must be delivered within strict deadlines. Exceeding the delay bound could lead to system instability, economic loss, or even endanger human life in the working area. The situation becomes even more challenging when an emergency event triggers multiple sensor nodes to transmit critical traffic to the controller simultaneously. The unpredictability of the arrival of such a type of traffic introduces difficulties with regard to making a suitable scheduling that guarantees data delivery within deadline bounds. Existing industrial standards and related research work have thus far not presented a satisfactory solution to the issue. Therefore, providing deterministic and timely delivery for critical traffic and its prioritization over regular traffic is a vital research topic.

Motivated by the aforementioned challenges, this work aims to enable real-time communication for time- and mission-critical applications in IWSNs. In this context, improved Medium Access Control (MAC) protocols are proposed to enable a priority-based channel access that provides a timely delivery for acyclic critical traffic. The proposed framework starts with a stochastic modelling of the network delay performance under a priority-oriented transmission scheme, followed by two MAC approaches. The first approach proposes a random Clear Channel Assessment (CCA) mechanism to improve the transmission efficiency of acyclic control traffic that is generated occasionally as a result of observations of an established tendency, such as closed-loop supervisory traffic. A Discrete-Time

Continues on the next page

Sensible Things that Communicate

PART OF MID SWEDEN UNIVERSITY

Markov Chain (DTMC) model is provided to evaluate the performance of the proposed protocol analytically in terms of the expected delay and throughput. Numerical results show that the proposed random CCA mechanism improves the shared slots approach in WirelessHART in terms of delay and throughput along with better transmission reliability.

The second approach introduces a slot-stealing MAC protocol based on a dynamic deadline-aware scheduling to provide deterministic channel access in emergency and event-based situations, where multiple sensor nodes are triggered simultaneously to transmit time-critical data to the controller. The proposed protocol is evaluated mathematically to provide the worst-case delay bound for the time-critical traffic and the numerical results show that the proposed approach outperforms TDMA-based WSNs in terms of delay and channel utilization.