Flexible-Schedule-Based TDMA Protocols for Supporting Fault-Tolerance, On-Demand TDMA Slot Transfer, and Peer-to-Peer Communication in Wireless Sensor Networks

THIS THESIS IS

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Abstract

This thesis develops a scheduled protocol (time division multiple access, TDMA) called *flexible-schedule-based TDMA Protocol* (FlexiTP), to address the problem of providing *end-to-end guarantees on data delivery*, whilst also respecting severe *resource constraints* of wireless sensor networks. FlexiTP achieves this balance through a distributed, synchronised, and loose slot structure in which sensor nodes can build, modify, or extend their schedules based on their local information. In FlexiTP, it is not necessary to predetermine the number of slots required for a network. FlexiTP's local repair scheme allows nodes to adjust their schedules dynamically and autonomously to recover from node and communication faults. Hence, it maintains a reliable and self-organising multihop network.

Most sensor network protocols designed for data gathering applications implicitly assume a periodic rate of data collection from all nodes in the network to the base station. However, nodes may want to report their data more rapidly or slowly depending on the significance and importance of their data to the end-user. The problem is that traditional TDMA-based protocols are not flexible to changes in traffic patterns because of their rigid slot structure schemes. This thesis aims to solve this problem by developing an *on-demand TDMA slot transfer* method that leverages the flexible-slot structure algorithm of FlexiTP to transfer time slots from one part of the network to another part. Hence, it allows wireless sensor networks to be adaptive to dynamic traffic patterns in the channel.

Many wireless sensor networks are designed with a specific communication pattern such as broadcast from the base station to all sensor nodes in a network, or convergecast from

all nodes in a network towards the base station. While these communication patterns are sufficient for monitoring applications, individual sensor nodes may need to send their data to multiple destination nodes across the network in order to execute a distributed cooperative-function based on their local environment. This *peer-to-peer communication pattern* makes sensor networks more reactive to triggers from the environment. This thesis attempts to solve the problem of lack of peer-to-peer communication in the design of a TDMA-driven protocol by extending the idea of on-demand TDMA slot transfer method to allow each sensor node in the network to claim extra time slots to communicate with any other nodes (peers) in the network, without going through the base station.

Nodes in the network may have different priorities of data because of event-triggering sensor readings or various types of sensor readings (e.g., light, temperature, and humidity) they provide. When nodes with high priority packets increase the frequency of their data collections, the network bandwidth may be dominated by these nodes. It is desirable to allow nodes with low priority packets to aggregate their packets and so enabling these nodes to send their data to the base station under the current available network bandwidth. This thesis proposes an *on-demand data aggregation* algorithm that enables sensor nodes to perform an in-network-aggregation based on their current sensing requirements and network capacity constraints.

In summary, this thesis describes the design, implementation, and evaluation of protocols for wireless sensor networks that focus on achieving energy-efficiency, provisioning performance assurances, and supporting reactivity and adaptability in constantly changing environment.

Preface

Recent trends in the pervasive computing community move towards implementing wireless networks of resource-constrained sensor nodes in a whole new range of applications, including telemonitoring of human physiological data, habitat monitoring of wildlife, automated and smart homes video surveillance, traffic monitoring, vehicle tracking and detection for battlefield surveillance, tracking and monitoring doctors and patients inside a hospital, environmental detection of fire and flood, microclimate monitoring for precision agriculture, and vibration-based structural condition monitoring. Sensor nodes gather information by observing the physical world at fine granularity and transmitting information to more powerful hardware that can process it.

This thesis focuses on designing energy-efficient, fault-tolerant, reactive, and adaptive TDMA protocols for wireless sensor networks. The proposed protocols are implemented, using C++ and OTcl, into the network simulator (NS-2). All of the software and protocols implementation developed in this thesis are available online at:

`http://www.csse.uwa.edu.au/~winnie/programs`

The thesis work has been carried out from March 2004 to July 2007 at the School of Computer Science and Software Engineering. This thesis consists of eight chapters. Four chapters contain papers that are accepted by or intended for international journals or proceedings. These chapters cover the report of our proposed scheduling and routing protocol, traffic-adaptive protocol, peer-to-peer-driven protocol, and network management protocol, for wireless sensor networks.

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Publications

International Journal Publication (*Fully Refereed*)

[1] Winnie Louis Lee, Amitava Datta, and Rachel Cardell-Oliver, "FlexiTP: a flexible-schedule-based TDMA protocol for fault-tolerant and energy-efficient wireless sensor networks", accepted to appear in *IEEE Transactions on Parallel and Distributed Systems*.

The paper forms Chapter 4 of this thesis.

[2] Winnie Louis Lee, Amitava Datta, and Rachel Cardell-Oliver, "On-demand TDMA slot transfer for supporting adaptive sensing in wireless sensor networks", submitted to *ACM Transactions on Sensor Networks*.

The paper forms Chapter 5 of this thesis.

[3] Winnie Louis Lee, Amitava Datta, and Rachel Cardell-Oliver, "Peer-to-peer multi-casting overlay over TDMA schedule for reactive wireless sensor networks", submitted to *Elsevier Ad Hoc Networks*.

The paper forms Chapter 6 of this thesis.

Book Chapter Publication (*Fully Refereed*)

[4] Winnie Louis Lee, Amitava Datta, and Rachel Cardell-Oliver, "Network management in wireless sensor networks", accepted to appear in *Handbook of Mobile Ad Hoc and*

Pervasive Communications, edited by Mieso K. Denko and Laurence. T. Yang, published by American Scientific Publishers.

The comprehensive literature review presented in this paper contributed towards Chapter 7 of this thesis.

International Conference Publications (*Fully Refereed*)

[5] Winnie Louis Lee, Amitava Datta, and Rachel Cardell-Oliver, "FlexiMAC: a flexible TDMA-based MAC protocol for fault-tolerant and energy-efficient wireless sensor networks", in *Proceedings of the 14th IEEE International Conference on Networks (ICON'06)*, volume 2, pages 1-6, September 2006.

The preliminary ideas of this paper were refined and extended to contribute towards [1].

[6] Winnie Louis Lee, Amitava Datta, and Rachel Cardell-Oliver, "A novel systematic resource transfer method for wireless sensor networks", in *Proceedings of the 49th IEEE Global Telecommunications Conference (GLOBECOM'06)*, pages 1-6, December 2006.

The preliminary ideas and results of this paper were refined and extended to contribute towards [2].

International Conference Publications (*Refereed on the Basis of Abstract*)

[7] Winnie Louis Lee, Amitava Datta, and Rachel Cardell-Oliver, "Peer-to-peer multicasting overlay over TDMA schedule for reactive wireless sensor networks", submitted to the fifth ACM Conference on Embedded Networked Sensor Systems (SenSys'07).

The preliminary ideas and results of this poster abstract were refined and extended to contribute towards [3].

Contribution of Candidate to Published Papers

My contribution in all the papers was 85%. I developed and implemented the protocols, performed the simulations and wrote the papers. My supervisors, Associate Professor Amitava Datta and Associate Professor Rachel Cardell-Oliver, reviewed the papers and provided useful feedback for improvement.

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