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Design, Implementation and Testing of a Cost Function Based Scheduling Mechanism for a Water Management System

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Abstract

The IEEE 802.15.4 standard for low data rate and low power devices is currently in use by many Internet of Things (IoT) networks and control networks based on wireless sensor networks. One such application area is the water management systems for water supply and usage control. With the implementation of this standard in Contiki, no mechanism is present for control messages when other packets are being transmitted as well in the network. The gateway devices in these networks are usually exposed to more load in the network. During periods of high demand, packet dropping can occur at these nodes as well as other intermediate nodes that forward data. To address the high packet loss and congestion that takes place when the load level is high in a water telemetry management network, we propose a novel scheduling mechanism. This scheduling mechanism was implemented in the COOJA simulator using the Contiki operating system for wireless sensor nodes as an enhancement to carrier sense multiple access with collision avoidance (CSMA/CA). The results show that with the application of the proposed cost function (CF) scheduling strategy, packet loss is reduced and throughput is improved in multi-hop networks over the default scheduling mechanism. This mechanism can also be implemented in other rapid growing Internet of Things (IoT) networks and can improve performance when carrying high loads.

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Keywords: Wireless Sensor Networks; CSMA/CA; IEEE802.15.4; Water Management

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1. Introduction

The standard IEEE 802.15.4 for wireless sensor network (WSN) does not have a differentiated services mechanism[1,2]. Some service differentiation schemes for some application like home automation exist in literature[3,4,5]. Wireless sensors are being implemented in many networks such as smart grid networks, smart homes, weather stations, smart utility networks such as water and gas, smart cities and many more.

There are a few WSN operating systems that exist and are in use. These include TinyOS, Contiki, Riot and a few others. The Contiki operating system can be found in many implementations[6]. Contiki is based on carrier sense multiple access with collision avoidance (CSMA/CA) which treats all type of data the same and does not give priority to any kind of data.

With the implementation of this standard in Contiki, no mechanism is present for control messages when other packets are being transmitted as well in the network. In a water management system, packets with different priority are present and carried. These packets can be classified as having type 1, type 2 or type 3 priorities. Type 1 can be referred to as the highest priority, while type 3 as the lowest priority. Type 1 data consist of control monitoring data from the different monitoring sites to the supervisory control and data acquisition (SCADA) for fault detections and alarms. Type 2 data consists of data from flow meters and pipes on pipe bursts and leakage detections to prevent water wastage as well. Type 3 data consists of data from automated meter reading (AMR) and advanced metering infrastructure (AMI) systems. An efficient water management system for resource management is very important in countries such as Saudi Arabia[7], Botswana and South Africa that are facing water shortages and droughts[8]. Water is a valuable resource and it is highly required to prevent water wastage when pipes burst or if it is being misused[9].

A telemetry network such as a water management system consists of a large number of sensor nodes that communicate their information over the backbone part of the network. Gateway and intermediate nodes that are usually subjected to heavy loads drop packets if the queue becomes full. The Intermediate nodes forward data from other nodes in other domains. To address the high packet loss that takes place under high traffic demands, we propose a novel cost function (CF) based scheduling strategy. The strategy considers load as well as the priority of the data for scheduling. In this work, each node is made up of three queues namely high, medium and low priority. The work is built using the Contiki operating system. The different data priority queues use different values of back-off exponent (BE) and contention window (CW). The main contribution of this paper is a novel heterogeneous scheduling strategy to reduce packet loss.

The remaining of this paper is presented as follows. Section 2 presents a brief overview of the IEEE802.15.4 standard and the Contiki operating system for wireless sensors. Section 3 presents the proposed CF scheduling strategy. Section 4 presents the simulation setup, section 5 the results obtained and finally, section 6, the conclusion.

2. Overview of the IEEE 802.15.4 standard and the Contiki operating system

This section presents a brief overview of the IEEE 802.15.4 standard and the Contiki operating system that is used by the nodes under study in this work.

The IEEE 802.15.4 standard is the standard for low data rate wireless personal area network (LR-WPAN) communications[10]. With the IEEE 802.15.4 standard, a device can be set to operate in the beacon-enabled mode or the non beacon enabled mode[11]. In the slotted mode, the slots are aligned with the beacon frames sent periodically by the PAN coordinator. With the un-slotted mode, there are no beacon frames[5]. This work of this paper is based on the un-slotted non beacon-enabled mode. The operation of CSMA/CA in this un-slotted mode is briefly explained here.

When a node has a packet for transmission, the number of back-offs (NB) and the back-off exponent (BE) are initialized to $NB = 0$ and $BE = 3$. The back-off period duration is determined by choosing by a random number in the range of $[0, 2^{BE} - 1]$. In this un-slotted non beacon-enabled mode, the BE value is initially set to BEmin which is 3 by default and BE_{max} is set to 5 by default. When the back-off duration finishes, the strategy carries out one *CCA* to verify if the channel is busy or free. If the channel is busy, the *NB* and *BE variables* are incremented by one. This process can only be repeated until NB is less than the set maximum allowed transmissions. After the limit is reached, the packet gets dropped. If the channel is idle when the CCA is performed, a transmission is attempted. Figure 1 presents a flowchart for the stages of operation of this un-slotted non beacon-enabled mode with CSMA/CA. A few embedded operating systems for IoT devices exist. These include Tiny OS, MagnetOS, Contiki, MantisOS, Riot among others[12,13]. The Contiki operating system is a popular operating systems for embedded systems for IoT applications currently in use[6]. It is an open source operating system written in C language by the