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Investigating Energy Efficiency and Timeliness for Linear Wireless Sensor Networks

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Abstract

Wireless sensor networks (WSNs) keep attracting the attention of researchers due to the newly emerging areas of application fueled by the development of inexpensive sensors and advanced communication technologies. A large group of applications - monitoring of pipelines, roads and bridges, as well as recently evolving IoT applications - specifically requires linear topology. Compared to traditional WSNs, these linear wireless sensor networks (LWSN) pose additional challenges in terms of overall delay and energy efficiency. Even though there are numerous and also very successful MAC protocols for WSN, very few of them take into consideration the specifics of linear topologies. Thus our aim is to address these challenges by proposing LINE-MAC, a MAC protocol tailored especially for LWSN. Our simulation results show that LINE-MAC achieves significant improvement in end-to-end delay, energy consumption and packet delivery ratio (PDR) compared to a general, energy and delay efficient MAC protocol for WSN.

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1. Introduction

In recent years with the proliferation of wireless sensor nodes hardware and software a number of new wireless sensor network (WSN) topology and traffic patterns have emerged. In many WSN applications the deployment imposes linear topology where the collection of data is done over a long string of nodes connected to a sink at one end. Examples include monitoring of highway, gas, oil and water pipelines^[1]. Such structures are usually very long and the distance from one end point to another can vary from several hundred meters to tens of kilometers which would make them vulnerable to a large number of possible failures, unacceptable delays and high probability of

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errors. The newly established concept of the “Internet of Things” (IoT) also opens the road to many new scenarios that employ line topology. The “Smart Lighting” project is an example of IoT concept adopted in a real-life application, where the WSN provides diverse services such as luminosity control for street lightening, lamp monitoring, emergency and tracking of elder people [2]. The proposed system utilizes sensor nodes mounted on existing lamp posts, located densely in the streets and is a perfect example of a long line topology WSN. Another example of WSN with line topology is the PipeNet system that collects pressure and vibration data at high sampling rates to provide near-real-time data pipe monitoring [3]. Also related to pipe-monitoring is the water monitoring system, “Streamflood and Waterflood Tracking System” which is designed to detect, identify and locate important abnormalities such as obstruction or leakage in the pipeline without human intervention [4]. Railway, bridge and tunnel monitoring [5] as well as bridge monitoring [6] are other applications that employ line topology. In this paper we refer to these types of networks as linear wireless sensor networks (LWSNs).

LWSNs differ from other WSN in terms of the way communication is carried out. The long chained transmission, increased network delays, single neighbor transmissions and the well-known “relay burden problem” are additional challenges posed by line topology. Most of the research mentioned above is based on solving these challenges at the routing layer. However, it is well known that the operation of the MAC protocol in WSN provides significant possibilities to effectively regulating important network performance parameters as throughput, energy efficiency, latency and network lifetime. That is the reason why in this paper we focus on exploiting the tools and functions at the MAC layer to provide higher energy efficiency, latency and PDR for LWSNs.

The rest of paper is organized as follows. Section 2 provides a short overview of some of the latest WSN MAC protocols and their relation to linear topology. Section 3 presents the proposed system model and protocol operation. Section 4 presents simulation scenarios and results. The last section concludes the paper.

2. Related Work

LWSN pose two major challenges: ensuring successful end-to-end delivery and providing a reasonable packet delivery timeframe. The main reason for these is that linear topology limits the number of neighbors and thus the possible transmission routes, so data delivery is more exposed to failure than in traditional WSNs. Besides critical node failures and energy exhaustion, failures can also occur due to increased number of retransmissions which results in higher packet collision rate and traffic congestion. There are several MAC protocols which focus on minimizing packet loss in LWSN. In [1] the authors propose a “long-chain” MAC protocol where the forwarding nodes book in advance and forward packets to reduce end-to-end delay in “long sensor networks” without sacrificing energy efficiency. In [4], the authors describe SWATS (Stream-flood and Water-flood Tracking System) a multi-dimensional linear sensor network. For communication and energy efficiency a MAC protocol with low duty cycle is designed that allows idle listening avoidance. In [7], the authors study the impact of the choice of MAC protocol (TDMA or CDMA) on the behavior of LWSNs in terms of lifetime and congestion avoidance. They suggest cooperative communications of sensor nodes sharing their physical resources particularly their antennas to create virtual multiple transmission paths. In [10], the authors present DiS-MAC which reaches the considerable channel utilization of 1/2, but requires every node to direct the radiation beam of its antenna.

The protocols mentioned above improve the performance of the network but require increased node complexity and lack in energy efficiency. The AREA-MAC (Asynchronous, Real-time, Energy-efficient and Adaptive MAC) is a very recent MAC protocol that addresses both time critical and energy-efficient WSN applications [11, 12]. The nodes in AREA-MAC use low power listening (LPL) and wake up very shortly to check the channel activity without actually receiving any data. They go back to sleep if the channel is idle, otherwise receive the data. Different from previous protocols like [13], [14], and [15], nodes in AREA-MAC use short and adaptive preambles with destination address and acknowledgement combination. It solves many of the problems which arise with long preambles, such as energy consumption, overhearing at non-target receivers, and excess latency at each hop [16]. Neighboring nodes wake up for a small period of time and check the destination address. The target node acknowledges the source node immediately, which causes the source node to stop sending further preambles and to start transmitting data packets. All the other non-target nodes go back to sleep immediately. This minimizes the possibility of a collision, idle listening and overhearing. Over-emitting with AREA-MAC is also improved with adaptive duty cycling. While sending a data packet, a node that still has more data to send indicates this to the receiving node by enabling the

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