Joint Adaptive Modulation and Adaptive MAC Protocols for Wireless Sensor Networks

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ABSTRACT
This paper introduces cognitive MAC-layer techniques to wireless sensor networks (WSN) to optimize Network survivability. We compare Adaptive Modulation (AM) over flat-fading channels, with data rate and transmit power being varied according to channel conditions with two variants: Adaptive Modulation with Idle mode (AMI) and a new Adaptive Sleep with Adaptive Modulation (ASAM) which dynamically adjusts the transmission and sleep modes based upon shared global information on channel conditions. These introduced cognitive methods assume power allocation schemes that improve energy efficiency and this node life assuming multi-hop relay networks.

Simulation results indicate that a notable reduction in energy consumption can be achieved by jointly adapting the data rate and the transmit power in WSNs. The proposed ASAM algorithm can considerably improve node lifetime compared to AM and AMI. The optimal power control values and optimal power allocation factors are further considered for multi-hop relay networks, respectively, thus reducing the need for higher layer network protocols in local switching.

General Terms
Wireless Sensor Networks, MAC Protocols

Keywords
Cognitive WSNs, Adaptive Modulation, Cross-layer protocols

1. INTRODUCTION
Wireless Sensor Networks (WSNs) have been applied in many fields such as healthcare, surveillance, manufacturing, transportation, military, agriculture, water, energy, environment, etc. A WSN is composed of a network of sensor nodes that operate in complex environments with limited human intervention for long periods of time. Recent advances in research have led to the development of network infrastructure and hardware platforms that allow small, inexpensive and long lasting sensor nodes. These sensor nodes can collect a great amount of information about the surrounding environment such as images, video, temperature, humidity, pressure, noise level, air quality, GPS position, etc. [1]. WSNs are gaining increasing popularity due to their attractive features such as flexibility, cost-effectiveness, scalability, fault tolerance, and self-organizing capabilities [2, 3, and 4]. The WSN technology, therefore, enables monitoring, controlling, and analyzing complex phenomena over wide areas [2]. The inherent requirements for WSNs to work under complex conditions introduce a number of constraints. One of the most important issues is power management. The energy available to the nodes, usually in the form of a battery, is very limited. The fact that most WSN applications require long operating lifetimes emphasizes the importance of improving their energy efficiency [4]. Consequently, energy-aware algorithms that maximize the network lifetime are sought-after. In order to efficiently use energy, transmission schemes should be able to adapt to channel conditions through estimation and global feedback.

Adaptive modulation (AM), or link adaptation, allows for dynamic adjustment of transmission parameters to radio link conditions, such as available power level, channel path loss, signal interference and sensitivity of the receiver [5]. The parameters for adjustment can include: symbol rate, modulation schemes or constellation size, transmit power, and coding parameters [6]. These parameters can be varied either individually or jointly, according to channel conditions and quality of service (QoS) requirements. More recently [7] a “cognitive approach” is formalized for WSNs where global context information is used to optimize network performance at all layers. This new paradigm applies to this paper also for the special case where networking requirements are simplified and limited to lower layer performance to maximize node availability.

This paper first applies AM to single-hop WSNs. Then it proposes an Adaptive Sleep with Adaptive modulation (ASAM) algorithm for minimizing energy expenditure and enhancing the network lifetime. The ASAM algorithm dynamically changes the modulation scheme while adjusting the node sleep periods and power levels. We investigate several variations of these schemes and analyze and compare their performance under various channel conditions based on extensive computer simulations. Moreover, the power allocation problem is extended to multi-hop networks, where the algorithms are tested and evaluated under various fading scenarios.

The paper is organized as fellows: Sections II and III present the system model and the energy optimization problem, respectively. In Sections IV and V, AM, AMI and ASAM protocols are applied multi-hop relay networks. Finally, the simulation results are presented and analyzed in Section VI, followed by conclusions in Section VII.

2. SYSTEM MODEL
2.1 System Architecture
Figure 1 illustrates the system model for an adaptive transmission system. Unlike traditional communication systems, here the modulation level and transmit power are dynamically controlled by the transmitter. Through the feedback channel, the receiver exchanges information with the transmitter and collects the current Channel State Information (CSI) data. The transmitter can then make decisions on the proper transmission parameters to use. The Receiver model has two functionalities: signal demodulation and channel estimation. During the estimation and feedback