Self-organizing MAC Protocol Switching for Performance Adaptation in Wireless Sensor Networks

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Abstract. This paper presents a distributed MAC protocol switching mechanism for maximizing network throughput in the presence of traffic and topology heterogeneity. The key idea behind dynamic MAC switching is for each node to use its local topology and traffic density information to decide the most suitable MAC protocol that can maximize the MAC layer throughout in the neighborhood. A formal MAC switching rule is developed using analytical formulation of the MAC throughput available in the literature. NS2 based simulation experiments demonstrate that with the proposed MAC switching strategy, nodes in a mesh network are able to achieve maximum MAC throughput by adaptively choosing the appropriate MAC protocol in the presence of heterogeneity in terms of data rate and node population.

Keywords: MAC, Self Organization, Protocol Switching.

1 Introduction

1.1 Background

Wireless sensor networks are motivated by applications such as intrusion detection, battle-field surveillance, and environment and health monitoring. Although there have been significant recent innovations at different protocol layers, maximizing network throughput at the MAC layer in a multi-mission network is still a key design challenge. The traffic heterogeneity in a multi-mission network can manifest through: a) spatial and temporal variance in data rates [1] across different parts of a network supporting different applications, and b) temporal variance in number of active transmitters at a given time and at a given part of the network. The problem we address in this paper is how to develop a self organizing MAC layer that can maximize network throughput in the presence of the above traffic and network heterogeneity.

1.2 Related Work

The existing MAC layer self-organization can be divided into two broad categories, namely, intra-MAC and inter-MAC approaches. The intra-MAC approaches include contention-based [2-4] and schedule-based [5-7] protocols. The intra-MAC self-organization is achieved by dynamically adjusting the state machine and parameters
of a specific MAC protocol. CSMA/CA [2] and TDMA [5-7] are two examples of such intra-MAC approaches. CSMA/CA has the advantages of simplicity, flexibility and robustness, and it does not need any infrastructure support or clock synchronization. The most notable advantage of CSMA/CA is that a node can access all available wireless bandwidth in its neighborhood in an as-needed manner. However, the medium access collisions and the corresponding unbounded access delay are a concern for CSMA/CA and all other protocols in that category, mainly because of their underlying random access. TDMA protocols, on the other hand, allocate fixed, collision-free, and guaranteed bandwidth for all nodes in the network. While guaranteeing maximum delay bounds, the primary disadvantage of TDMA is that it does not perform well under dynamic bandwidth requirements. In other words, TDMA performs well under highly symmetrical load, but performs poorly under asymmetric load. Under the latter situation, CSMA based protocols outperform TDMA.

The authors in [8] propose an inter-MAC self-organization called Funneling-MAC. This is designed to address the traffic funneling effect near sink nodes caused by gradual aggregation of multipoint-to-point traffic. With Funneling-MAC, nodes near a sink (i.e. those with heavy traffic) are said to belong within an intensity area and they run a TDMA protocol which is managed by the sink node. Nodes outside the intensity area (i.e. those with relatively lighter traffic) run CSMA without any coordination from the sink. The Funneling-MAC [8] provides beacon based protocol syntaxes that the sink uses for dynamically deciding the boundary of the intensity area. Through a dynamic depth-tuning algorithm, the network throughput is maximized and the packet loss rate is minimized at the sink point. Although it provides a novel way of accomplishing inter-MAC (i.e. between CSMA and TDMA) self-organization, one notable limitation of Funneling-MAC is that it is suitable only for multipoint-to-point applications and not for peer-to-peer traffic, which is often required by sensor applications with distributed data fusion requirements.

1.3 Proposed Dynamic MAC Protocol Switching

In the proposed approach in this paper the operating MAC protocol within a node is dynamically switched between CSMA and TDMA based on the instantaneous traffic and topological property of the neighborhood of the node. The mechanism is designed to be general so that unlike Funneling-MAC [8], it can be applied for handling both multipoint-to-point and peer-to-peer data traffic. Each node monitors its neighborhood traffic and topology conditions, determines the appropriate individual MAC protocol to run, and switches its protocol as needed.

The contributions of the paper are as follows. First, it proposes a self organizing MAC protocol switching paradigm to address the problem of how to achieve the maximum throughput in a network with traffic heterogeneity. Second, it introduces syntax extensions to the protocols CSMA/CA and TDMA so that they can co-exist in immediately neighboring nodes. Third, it develops dynamic protocol switching rules based on an analytical model. Finally, a detailed simulation model is developed for experimentally validating the concept of dynamic MAC protocol switching in wireless networks.