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Ad Hoc Networks 3 (2005) 51–68
Ad Hoc Networks
www.elsevier.com/locate/adhoc

On-demand power management for ad hoc networks ☆

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Received 17 August 2003; accepted 6 September 2003
Available online 26 November 2003

Abstract

Battery power is an important resource in ad hoc networks. It has been observed that in ad hoc networks, energy consumption does not reflect the communication activities in the network. Many existing energy conservation protocols based on electing a routing backbone for global connectivity are oblivious to traffic characteristics. In this paper, we propose an extensible on-demand power management framework for ad hoc networks that adapts to traffic load. Nodes maintain soft-state timers that determine power management transitions. By monitoring routing control messages and data transmission, these timers are set and refreshed on-demand. Nodes that are not involved in data delivery may go to sleep as supported by the MAC protocol. This soft state is aggregated across multiple flows and its maintenance requires no additional out-of-band messages. We implement a prototype of our framework in the ns-2 simulator that uses the IEEE 802.11 MAC protocol. Simulation studies using our scheme with the Dynamic Source Routing protocol show a reduction in energy consumption near 50% when compared to a network without power management under both long-lived CBR traffic and on–off traffic loads, with comparable throughput and latency. Preliminary results also show that it outperforms existing routing backbone election approaches.

Keywords: Ad hoc networks; Energy conservation; Power management; Soft state; On demand

1. Introduction

With the proliferation of portable computing platforms and small wireless devices, ad hoc wireless networks have received more and more attention as a means for providing data communications among devices regardless of their physical locations. Wireless communication has the advantage of allowing untethered communication, which implies reliance on portable power sources such as batteries. However, due to the slow advancement in battery technology, battery power continues to be a constrained resource.

It has been observed that in ad hoc networks, energy consumption does not always reflect active communication in the network [1]. Experimental results reveal that the energy consumption of wireless devices in an idle state is only slightly smaller than that in a transmitting or receiving state. Therefore, it is in general desirable to turn the radio off when it is not in use, termed as power

☆ The work is sponsored in part by MURI/AFOSR under contract number F49620-00-1-0330 and National Science Foundation grant number ANI-0081308.
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1570-8705/$ - see front matter
doi:10.1016/j.adhoc.2003.09.008

management. Motivated by these observations, several energy conservation protocols [2,3] have been proposed to take advantage of the route redundancy in dense ad hoc networks by turning off devices that are not required for global network connectivity. However, in these protocols, the decision about which set of nodes to leave on is only based on geographical/topological information, thus is oblivious to the actual traffic load in the network. Since many applications of ad hoc networks are data-centric, maintenance of global connectivity is costly and unnecessary when no traffic or only localized traffic is present in the network.

Various techniques, both in hardware and software, have been proposed to reduce energy consumption for mobile computing devices in wireless LANs [4,5]. In contrast, power management in ad hoc networks is a more difficult problem for two reasons. First, in ad hoc networks, a node can be both a data source/sink and a router that forwards data for other nodes and participates in high-level routing and control protocols. Additionally, the roles of a particular node may change over time. Second, there is no centralized entity such as an access point to control and maintain the power management mode of each node in the network, buffer data and wake up sleeping nodes. Therefore, power management in ad hoc networks must be done in a distributed and cooperative fashion. A major challenge to the design of a power management framework for ad hoc networks is that energy conservation usually comes at the cost of degraded performance such as lower throughput or longer delay. A naive solution that only considers power savings at individual nodes may turn out to be detrimental to the operation of the whole network.

In this paper, we propose an on-demand power management framework targeting generic ad hoc networks. To achieve reduced energy consumption while maintaining effective communication, our framework integrates routing information from on-demand ad hoc routing protocols and power management capabilities from the MAC layer. Energy conservation is achieved by judiciously turning on and off the radios of specific nodes in the network. The novelty of our framework is that such power management decisions are driven by active communications in the network. For the purpose of energy conservation, connectivity is only maintained between pairs of senders and receivers and along the route of data communication.

Transitions between power management modes for each node are associated with a soft-state timer that is established and refreshed by data and control messages in the network. Once the soft state is established, subsequent data delivery can be expedited without incurring additional delays from waking up sleeping nodes along the route. The length of the soft-state timer reflects the adaptiveness of the power management framework to variations in traffic load. Since the operations of transmitting to a sleeping node and an active node are different, we present mechanisms to discover a neighbor's power management mode. In this context, neighbor discovery is challenging because a node in power-save mode cannot monitor the channel consistently. Therefore, any neighbor information may be ambiguous. This situation is even worse if nodes are mobile.

Our framework is not limited to any specific routing or MAC protocols. This extensibility is a key benefit of our design since it enables the use of our framework in various scenarios and allows the integration of new protocols as they become available. To verify our framework, we present a prototype using the IEEE 802.11 MAC protocol and evaluate it using Dynamic Source Routing (DSR) [6] and greedy geographical forwarding protocol in the ns-2 [7] simulator. Under a wide range of traffic patterns and load, our prototype achieves 40–60% savings in power consumption as compared to a network without power management. In addition, our prototype minimally increases latency during the initial setup stage, but achieves an average latency comparable to a network without power management.

The rest of the paper is organized as follows. We first layout the design space for power management protocols in ad hoc wireless networks and give a brief overview of existing approaches in Section 2. Then we discuss how each approach fits into the design space. In Section 3, we present the building blocks and technical details of our on-