Chapter 61
Power Issues and Energy Scavenging in Mobile Wireless Ad-Hoc and Sensor Networks

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ABSTRACT

Wireless ad-hoc and sensor networks are experiencing a widespread diffusion due to their flexibility and broad range of potential uses. Nowadays they are the underlying core technology of many industrial and remote sensing applications. Such networks rely on battery-operated nodes with a limited lifetime. Although, in the last decade, a significant research effort has been carried out to improve the energy efficiency and the power consumption of the sensor nodes, new power sources have to be considered to improve node lifetime and to guarantee a high network reliability and availability. Energy scavenging is the process by which the energy derived from external sources (i.e. temperature and pressure gradients, movement, solar light, etc.) is captured, translated into an electric charge and stored internally to a node. At the moment, these new power sources are not intended to replace the batteries, since they cannot generate enough energy; however, working together with the conventional power sources they can significantly improve node lifetime. Low-power operation is the result of a complex cross-layer optimization process, for this reason, this chapter thoroughly reviews all the traditional methods aimed at reducing power consumption at the network, MAC and PHY levels of the TCP stack, to understand advantages and limitations of such techniques, and to justify the need of alternative power sources that may allow, in the future, the design of completely self-sustained and autonomous sensor nodes.

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INTRODUCTION

A mobile ad-hoc network (MANET) is a collection of mobile nodes that are dynamically and arbitrarily located in a certain region. The dynamic character of the nodes implies that the interconnections among them, the network actual topology, may change with time frequently. The main feature of these networks is that routing is performed by the nodes in the absence of a fixed infrastructure. The nodes act as routers which discover and maintain routes to other nodes in the network. The network itself emerges as the result of a collective effort of self-configuration of the nodes deployed.

Mobile ad-hoc networks and wireless sensor networks (WSNs) share many common features. Both rely on ad-hoc protocols that require no fixed infrastructure or base station and in which each node has routing capability. In addition, both kinds of network have resource-constrained and battery-operated nodes. Finally, both MANETs and WSNs communicate through a wireless channel. On the other hand, MANETs differ from WSNs in their high mobility that leads to extremely-changing network topologies which, in turn, require dynamic routing protocols capable to sustain the modification in the network structure and to maintain, repair, and discover new routes among the network nodes. Another key difference between MANETs and WSNs is the resource availability. WSNs are even more constrained than MANETs, since the nodes usually are extremely tiny devices with reduced processing capability and memory storage.

Ad-hoc networks have been proposed in many communication and remote-sensing settings among which it is worth mentioning habitat and environment monitoring, smart transportation and logistics, cold-chain management, telemedicine, and domotics. Since mobile nodes are required to probe their surroundings trying to find routing nodes, and nodes are essentially hand-held terminals or simple sensors operated with batteries, power consumption is of paramount importance in the operation of these networks. Power requirements are even more stringent in the case of WSNs since this kind of networks consists of a large number of unattended devices deployed in hard-to-reach areas where battery replacement is often extremely difficult or impossible.

The main purpose of this chapter is to thoroughly review all the techniques aimed at reducing network power consumption and at improving node availability. As stated before, ad-hoc wireless networks have some peculiar characteristics that make them structurally different from infrastructure wireless networks. This, in turn, entails the development of new energy management techniques. However, the problem of energy efficiency cannot be isolated to a single protocol layer or hardware component. Power efficiency is the result of an optimization effort that involves several parts of a system. For this reason, we will discuss power optimization techniques aimed at improving the energy efficiency of the first three levels of the TCP stack (namely, network, medium access control, and physical level) in a top-down fashion.

First we will focus on medium-access and power-aware and routing techniques in single and multi-hop networks. These techniques rely on topology control to reduce interference and energy consumption. Low power consumption is achieved as well by reducing broadcast and multicast, and by increasing routes lifetimes to delay as much as possible the high energy-consumption route discovery process. On the other hand, if only few nodes are used to forward traffic to all the other nodes, the nodes acting as relays will soon exhaust their energy reserves and will no longer be part of the network, and the network itself must undergo a new route discovery process. It is therefore necessary to carefully select the routes to maximize network lifetime. However, network lifetime is a figure of merit hard to define, since it depends largely on the application scenario.

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