Chapter 3

OPTIMAL DESIGN OF WIRELESS AD-HOC NETWORKS

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Abstract This paper investigates the optimal design and deployment of wireless ad-hoc networks. Wireless ad-hoc networks are a new form of wireless communications that do not rely on any fixed infrastructure like wired base stations to keep the network up and running. Instead, hosts in a wireless ad-hoc network rely on each other to keep the network connected over either radio or infrared. Since direct communication is allowed only between adjacent nodes, distant nodes in an ad-hoc network communicate over multiple hops. We examine the optimal design of such networks by modeling the problem as a mixed integer mathematical program, and deriving solution procedures based on Lagrangean Relaxation (LR). Using the LR, we were able to decompose the network design problem into two fairly-easy-to-solve sub-problems. We present algorithms for each sub-problem, and an overall heuristic based on LR to solve the design problem. From the computational experiments we have done, our Lagrangean relaxation based algorithms can generate solutions within 2.20-13.16% of optimality. In addition, our algorithm also solves the design problem very rapidly, within a few minutes in the most complex case.

Keywords Wireless Ad-hoc Network, Network Design, Integer Programming, Lagrangean Relaxation, Subgradient Method, Heuristic
1. INTRODUCTION

When it comes to wireless networking, most people think of cell phones and wireless cellular networks. However, a new wireless networking paradigm is emerging that has vast ranging implications: wireless ad-hoc networks. Unlike traditional wireless cellular networks, wireless ad-hoc networks do not rely on any fixed infrastructure like wired base stations to keep the network up and running. Instead, hosts in a wireless ad-hoc network rely on each other to keep the network connected over either radio or infrared. Since direct communication is allowed only between adjacent nodes, distant nodes in an ad-hoc network communicate over multiple hops.

Although military tactical and other security-sensitive operations are still the main applications of ad-hoc networks, there is a trend to adopt ad-hoc networks for commercial uses, from the conventional narrow-band applications up to the emergent broadband services, due to their unique properties. Examples where ad-hoc networking can affect significant benefits include but are not limited to the following applications (Corson et al. 1999):

- **The digital battlefield**: soldiers who need to communicate with each other are deployed over an unfamiliar terrain where no fixed network infrastructure exists or has failed.

- **Disaster relief**: a large amount of disposable sensors are scattered into an unlivable circumstance to collect background data in the events like earthquakes, nuclear disasters, airplane disasters, etc. The sensors coordinate to establish a communications network and then send the data back to the master-site which has abundant power supply and computation capability for more intensive analysis.

- **Wireless office LAN connections**: different office entities (intelligent devices like PCs, notebooks, mobile phones, PDAs etc.) that want to communicate with each other form a temporary network without cabling, and use each participating node as both host and router to facilitate the process.

There has been considerable amount of work on wireless ad-hoc networks (Corson et al. 1999), and most of it has focused on routing protocols. Traditionally these routing protocols are evaluated in terms of packet loss rates, routing message overhead, and routing length (Iwata et al. 1999, Gafni and Bertsekas 1981, Chlamtac and Farago 1999, Sharony 1996). However, since most of the communication devices in wireless ad-hoc networks rely on batteries for energy, power consumption should be a critical design criterion as well. The main idea is that significant reductions in energy consumption can be achieved if wireless networks are designed specifically for minimum energy consumption.