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Ad Hoc Networking An Introduction

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In recent years, mobile computing has enjoyed a tremendous rise in popularity. The continued miniaturization of mobile computing devices and the extraordinary rise of processing power available in mobile laptop computers combine to put more and better computer-based applications into the hands of a growing segment of the population. At the same time, the markets for wireless telephones and communication devices are experiencing rapid growth. Projections have been made that, by the year 2002, there will be more than a billion wireless communication devices in use, and more than 200 million wireless telephone handsets will be purchased annually. The rise of wireless telephony will change what it means to be "in touch"; already many people use their office telephone for taking messages while they are away and rely on their mobile telephone for more important or timely messages. Indeed, mobile phones are used for tasks as simple and as convenient as finding one's associates in a crowded shopping mall or at a conference. A similar transformation awaits mobile computer users, and we can expect new applications to be built for equally mundane but immediately convenient uses.

Much of the context for the transformation has to do with keeping in touch with the Internet. We expect to have "the network" at our disposal for the innumerable little conveniences that we have begun to integrate into our professional lives. We might wish to download a roadmap on the spur of the moment so that we can see what is available in the local area. We might wish to have driving suggestions sent to us, based on information from the global positioning system (GPS) in our car, using the services offered by various web sites. The combination of sufficiently fast and inexpensive wireless communication links and cheap mobile computing devices makes this a reality for many people today. In the future, the average traveler is likely to take such services for granted.

Today we see a great expansion in the production of technology to support mobile computing. Not only are the computers themselves getting more and more capable, but many new applications are being developed and wireless data communications products are becoming available that are much improved over those available in the past. The bandwidth now available to laptop computers over radio and infrared links is easily 10 to 100 times more than that available just ten years ago.

Such rapid technological advance has spurred equally impressive growth in mobile connectivity to the Internet. In the wired Ethernet domain, we have plug-and-play hardware and software so that laptop computers can be reconnected with ease according to the form factors of the local network outlets. The Internet is available around the world to those willing to make a dial-up connection to a local phone number. People are getting used to the advantages of having frequent and convenient Internet access. As a result, more and more network functionality will be taken for granted by typical laptop users.

As wireless network nodes proliferate and as applications using the Internet become familiar to a wider class of customers, those customers will expect to use networking applications even in situations where the Internet itself is not available. For instance, people using laptop computers at a conference in a hotel might wish to communicate in a variety of ways, without the mediation of routing across the global Internet. Yet today such obvious communications requirements cannot be easily met using Internet protocols. Providing solutions to meet such requirements is the subject of this book. The proposals to be described allow mobile computer users with (compatible) wireless communication devices to set up a possibly short-lived network just for the communication needs of the moment—in other words, an *ad hoc* network.

At the same time, there is a huge potential market for embedded network devices in our vehicles, our mobile telephones, and perhaps even in our toys and personal appliances. Surely the day is not far off when a typical child's doll will have a microprocessor and a remote control device and will depend on network access to interact with the home's television and computer games. Embedded networking could represent the "killer app" for wireless networks.

Anyone reading this book will agree that the modern age of networking represents one of the great achievements of humanity. We already take many aspects of it for granted. In particular, we often take for granted the infrastructure currently needed to support our vast networking enterprise. The things we do with our networks do not inherently depend on the network infrastructure; rather, having the infrastructure extends the reach of network applications immeasurably.

Once we have grown accustomed to the power of network communications and to accomplishing our daily tasks with the aid of applications that rely on networking, we will want the applications to be available at all times. In fact, many network researchers predict that some day in the not too distant future we will put our applications to use "anytime, anywhere," perhaps by way of the rapidly expanding satellite communications systems now under construction. The communications satellites girding the earth will complement the cellular (wireless) telephone infrastructure, which is itself growing even more rapidly in most developed countries.

Indeed, the authors of this book suggest that mobile computers and applications will become indispensable even at times when and at places where the necessary infrastructure is not available. Wireless computing devices should physically be able to communicate with each other, even when no routers or base stations or Internet service providers (ISPs) can be found. In the absence of infrastructure, what is needed is that the wireless devices themselves take on the missing functions.

In this introductory chapter, we consider some general topics that provide context for the rest of the chapters in this book. In the next section, we describe a general model of operation for ad hoc networks and some of the factors affecting the design decisions that various approaches have taken. In Section 1.2, we list a few of the commercial opportunities that may await vendors of wireless products when the necessary protocols are available. This will naturally include a look at some of the applications enabled by ad hoc networking. Following that, Section 1.3 will discuss some of the technical drivers for the resurgence of interest in ad hoc networking. The needs of military communications have been very influential in creating this renewed interest. Discussion of military ad hoc networking, however, is not included in that section because it is covered much more completely in Chapter 2. Because many of the approaches to ad hoc networks use variations on existing routing protocols, some very general comments about routing protocols are presented in Section 1.4. Finally, a capsule summary of each chapter in the book is presented in Section 1.5.

1.1 MODEL OF OPERATION

This book is concerned with ways (past and present) that wireless mobile computing devices can perform critical network topology functions that are normally the job of routers within the Internet infrastructure. Keeping track of the connections between computers is something so basic that a computer network, almost by definition, cannot exist without it.

There are many kinds of protocols available today that are supported by network infrastructure, either in a particular enterprise or in the Internet at large. These other protocols deserve consideration, but need adaptation before they can be useful within a network no longer connected to the Internet infrastructure. Some of them may not be appropriate for use when the infrastructure is unavailable; credit card validation and network management protocols come to mind.

As a matter of definition, an ad hoc network is one that comes together as needed, not necessarily with any assistance from the existing Internet infrastructure. For instance, one could turn on 15 laptop computers, each with the same kind of infrared data communications adapter, and hope that they could form a network among themselves. In fact, such a feature would be useful even if the laptops were stationary.

There are a bewildering variety of dimensions to the design space of ad hoc networks. We take a particular slice of that design space that should serve a large number of user requirements and yet allow discussion of a number of interesting and illuminating techniques. Besides *ad hoc networking,* similar techniques have been proposed under the names *instant infrastructure* [Bagrodia+ 1996] and *mobile-mesh networking* [SDT 1995].

Consider, for example, whether the range of wireless transmission should be large or small compared to the geographic distribution of the mobile wireless nodes. If all of the wireless nodes are within range of each other, no routing is needed, and the ad hoc network is, by definition, fully connected. While this might be a fortunate situation in practice, it is not a very interesting routing problem to solve. Plus, the power needed to obtain complete connectivity may be impractical, wasteful of battery power, too vulnerable to detection, or even illegal.

Thus, we discuss only proposals that offer solutions to the case in which some of the wireless nodes are not within range of each other. Combined with the lack of infrastructure routers, the restricted range of wireless transmission indicates the need for *multihop* routing.

As another example, we might suppose that wireless computer users could measure their relative positions and subsequently configure their laptop computers using the measured distances, so that the appropriate link information could be available at each mobile node. This would work, but it would not be very convenient. Worse yet, the link information would be likely to change whenever the users moved relative to each other. We are not interested in simplifying the problem space at the expense of user convenience, however, so we restrict our attention only to those proposals that provide automatic topology establishment (eschewing user configuration steps) and dynamic topology maintenance (enabling user mobility). In fact, we make the slight additional restriction of considering only proposals that are self-starting, except possibly for an enabling or mode setting step

performed by the user, who should be able to exert necessary controls over the performance of the ad hoc networking operation.

In this book, most of the discussion focuses on the interesting cases that have the following characteristics:

- The nodes are using IP, the Internet Protocol [Postel 1981a], and they have IP addresses that are assigned by some usually unspecified means.
- The nodes are far enough apart so that not all of them are within range of each other.
- The nodes may be mobile so that two nodes within range at one point in time may be out of range moments later.
- The nodes are able to assist each other in the process of delivering packets of data.

The discussion in this book focuses on the protocol engineering that underlies the establishment of the paths by which the ad hoc network nodes can communicate with each other. Thus, address autoconfiguration in particular, a very interesting subject, is largely absent from this book, but is ripe for exploration very soon.

As an example of a small ad hoc network, consider Figure 1.1 (taken from Chapter 3), illustrating a collection of eight nodes along with the links between them. The nodes are able to move relative to each other; as that happens, the links between them are broken and other links may be established. In the picture, MH_1 moves away from MH_2 and establishes new links with MH_7 and MH_8. Most algorithms also allow for the appearance of new mobile nodes and the disappearance of previously available nodes.

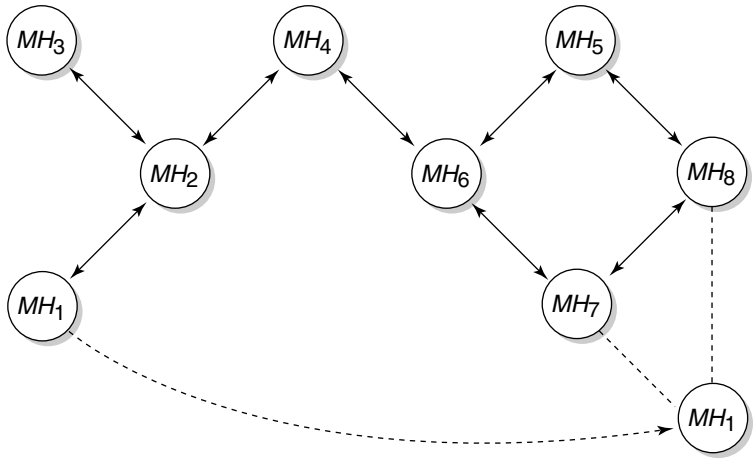

Figure 1.1. An Ad Hoc Network of Mobile Nodes

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