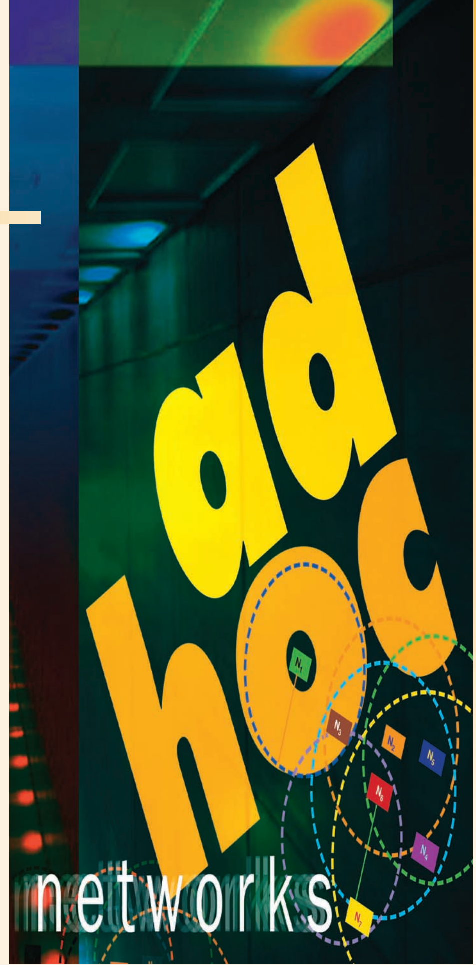
Ad Hoc Networks

Recent developments offer potential solutions to problems encountered in ad hoc networks including topology control, data communication, and service access.



Jie Wu
Florida Atlantic University

Ivan Stojmenovic
University of Ottawa

Ad hoc networks are a key factor in the evolution of wireless communications. Self-organized ad hoc networks of PDAs or laptops are used in disaster relief, conference, and battlefield environments.

These networks inherit the traditional problems of wireless and mobile communications, such as bandwidth optimization, power control, and transmission-quality enhancement. In addition, their multihop nature and the possible lack of a fixed infrastructure introduce new research problems such as network configuration, device discovery, and topology maintenance, as well as ad hoc addressing and self-routing.

Various approaches and protocols have been proposed to address ad hoc networking problems, and multiple standardization efforts are under way within the Internet Engineering Task Force, as well as academic and industrial research projects.

NETWORK TOPOLOGY

In ad hoc networks, wireless hosts can communicate with each other in the absence of a fixed infrastructure.[1] These networks typically consist of equal nodes that communicate over wireless links without central control.

Sensor networks,[2] also called *hybrid ad hoc networks,* are linked to monitoring centers that collect data such as temperature, chemical detection, or movement. In recent years, government agencies in several countries have supported research on sensor networks. For example, the US National Science Foundation launched a multidisciplinary program on sensors and sensor network research in 2003 (www.nsf.gov/pubs/2003/nsf03512/nsf03512.htm).

Some ad hoc networks are linked to a fixed infrastructure via access points. For example, mesh or rooftop networks (www.sonic.net/sales/rooftop/faq.shtml) consist of antennas placed on top of buildings to provide wireless Internet access.

Vehicles on a highway can create an ad hoc network for use in disseminating traffic information. They can operate as a pure ad hoc network in which an individual vehicle detects traffic events and initiates a broadcast to other vehicles. Alternatively, cellular or Internet access points placed near the road can transmit the information.

Multihop cellular networks[3] have recently emerged as a communication alternative at events where huge numbers of users are concentrated in a small area such as a stadium.

Peer-to-peer networks are ad hoc networks in which an overlay network is built on the Internet. In a P2P network, two or more peers can use appropriate information and communication systems to collaborate spontaneously without requiring central coordination.

AD HOC NETWORK COMMUNICATION

Communication between two hosts in an ad hoc network is not always direct—it can proceed in a *multihop* fashion so that every host is also a router.

Ad hoc networks are a key factor in the evolution of wireless networks.

Ad hoc network hosts can use protocols such as the IEEE 802.11 media-access control standard to communicate via the same frequency, or they can apply Bluetooth or other frequency-hopping technology.

Because power consumption is directly proportional to the distance between hosts, direct *single-hop* transmissions between two hosts can require significant power, causing interference with other such transmissions. To avoid this *routing problem*, two hosts can use multihop transmission to communicate via other hosts in the network.

With IEEE 802.11 technology, avoiding collisions—transmission interferences—is difficult because of the *hidden station problem*: Two hosts that do not communicate directly can transmit messages simultaneously to a common neighbor on the same frequency.

In addition to maintaining an ongoing routing task or facilitating route establishment, mobile networks also must support location management by keeping track of the host's location.

NETWORK LAYER PROBLEMS

The problems encountered in the network layer of ad hoc networks include topology control, data communication, and service access.

Topology control problems include discovering neighbors, identifying position, determining transmission radius, establishing links to neighbors, scheduling node sleep and active periods, clustering, constructing the dominating set (each node either belongs to or has a neighbor from the dominating set), and maintaining the selected structure.

Data communication problems include

- *routing*—sending a message from a source to a destination node,
- *broadcasting*—flooding a message from a source to all other nodes in the network,
- *multicasting*—sending a message from a source to a set of desirable destinations,
- *geocasting*—sending a message from a source to all nodes inside a geographic region, and
- *location updating*—maintaining reasonably accurate information about the location of other nodes.

Service access problems include Internet access, cellular network access, data or service replication upon detection or expectation of network partition, and unique IP addressing in merge or split-network scenarios.

IN THIS ISSUE

The articles in this special issue review emerging ad hoc networking technologies, techniques, algorithms, and protocols, with emphasis on recent developments offering potential solutions to problems encountered in these networks.

In "Cooperative Cache-Based Data Access in Ad Hoc Networks," Guohong Cao, Liangzhong Yin, and Chita Das propose efficient solutions to the data-caching problem. In cooperative caching, some nodes in an ad hoc network replicate data from servers, using replicated files rather than original files to satisfy other nodes' access demands. This should reduce traffic in the network or even provide service if the server becomes disconnected in the meantime. The proposed solutions include caching data paths toward replicated copy, making another copy of data at the node, and using some novel hybrid methods.

An emerging area of research in sensor networks is area coverage and monitoring. In "Energy-Efficient Area Monitoring for Sensor Networks," Jean Carle and David Simplot-Ryl classify sensor data reporting into two categories: *event-driven* and *on-demand*. They propose dividing the area-monitoring problem into three subproblems, each of which requires an energy-efficient solution. These subproblems consist of constructing a broadcast tree (request propagation), selecting sensors for area coverage, and reporting sensor data with data aggregation. The protocols implement periodic changes in sensor roles to extend network life. The proposed solutions use dominating sets and localized minimal spanning trees.

In "Cross-Layering in Mobile Ad Hoc Network Design," Marco Conti and coauthors describe a European project that overcomes manet performance problems by allowing protocols belonging to different layers to cooperate, sharing network status information while still maintaining separate layers. The authors propose applying triggers to the Network Status so that it can send signals between layers. This lets each layer maintain network information and adapt its performance accordingly. This innovative cross-layering approach addresses, in particular, security and cooperation, energy management, and quality-of-service issues.

Many potential mobile ad hoc network applications involve collaboration among a group of nodes. Group communication models include one-to-many, one-to-any, many-to-many, and one-to-all patterns that facilitate collaboration among a group of nodes. In "Group Communications in Mobile Ad Hoc Networks," Prasant Mohapatra, Chao Gui, and Jian Li describe various techniques for group communications in ad hoc networks, including multicasting, broadcasting, anycasting, and geocasting and discuss representative protocols for each of these categories. They also provide an overview of related issues such as protocol design, state maintenance, and performance; examine issues such as reliability, power conservation, quality of service, and security; and comment on future research directions for group communications in ad hoc networks.

In "Routing and Security in Mobile Ad Hoc Networks," Nikola Milanovic and coauthors provide a survey of routing, flooding for routing, and security issues, based on current IETF drafts. The authors describe four nonposition-based routing algorithms: on-demand reactive dynamic source routing, ad hoc on-demand distance vector routing, proactive table-based optimized link-state routing, and topology broadcast based on reverse-path forwarding. They also discuss a recently proposed hybrid approach that combines the advantages of on-demand and optimized link-state routing for wireless sensor networks. To establish secure routing, the hybrid approach uses a mechanism similar to multipoint relays that applies threshold cryptography and attempts to find a fault-free path to each node only when needed.

Instead of using the traditional IP-based network layer to implement multicast routing protocols, in "Prioritized Overlay Multicast in Mobile Ad Hoc Environments," Li Xiao and coauthors propose a model that improves the efficiency and robustness of overlay multicast in manets by building multiple role-based prioritized trees, possibly with the help of location information about member nodes. Like P2P networks, POM forms a virtual network, consisting of only member nodes, on top of the physical infrastructure. Member nodes can form a short-term multicast group to perform certain important tasks. Overlay trees can have different levels of priority depending on the importance of the service they perform. This approach avoids the need to change the application layer tree when the underlying network changes.

We thank all the authors for their submissions to this special issue. We are indebted to the many referees who reviewed each paper promptly and professionally. We also extend special thanks to *Computer*'s staff for their professional guidance in editing the papers selected for publication. ■

References

1. S. Basagni et al., eds., *Mobile Ad Hoc Networking*, IEEE Press, 2003.
2. I.F. Akyildiz et al., "A Survey on Sensor Networks," *IEEE Comm.*, Aug. 2002, pp. 102-114.
3. Y-D. Lin and Y-C. Hsu, "Multihop Cellular: A New Architecture for Wireless Communications," *Proc. IEEE Infocom 2000*, IEEE Press, 2000, pp. 1273-1282.

Jie Wu *is a professor in the Department of Computer Science and Engineering at Florida Atlantic University. His research interests are in the areas of wireless networks and mobile computing, routing protocols, fault-tolerant computing, and interconnection networks. Wu received a PhD in computer engineering from Florida Atlantic University. He is a member of the IEEE Computer Society and the ACM and is a senior member of the IEEE. Contact him at jie@cse.fau.edu.*

Ivan Stojmenovic *is a professor of computer science in the School of Information Technology and Engineering and director of the Ottawa-Carleton Institute for Computer Science at the University of Ottawa. His research interests include wireless ad hoc, sensor, and cellular networks. Stojmenovic received a PhD in mathematics from the University of Zagreb, Croatia. Contact him at ivan@site.uottawa.ca.*