Mobile Ad Hoc Wireless Networks

Mario Gerla, Carla-Fabiana Chiasserini, Kenichi Mase, Eytan Modiano, and Jason Redi

As the name "ad hoc" indicates, an ad hoc network is a wireless network designed to satisfy a "special purpose" application, often of short duration. An ad hoc network must be deployed rapidly and is frequently reconfigured to adjust to changes. The temporary nature and the high rate of change set the ad hoc network apart from other more permanent wireless structures such as urban mesh networks or environmental sensor networks. A prime example of an ad hoc environment is the battlefield. It is no surprise that much of the early work on ad hoc nets was supported by the Department of Defense, through the DARPA Packet Radio program that began just a couple of years after the introduction of the ARPANET. Civilian applications (natural disaster management, homeland defense, etc.) have followed closely the military model and in fact share many of its requirements. Commercial applications have just begun to emerge, in most cases as "opportunistic extensions" of the network infrastructure (wired or wireless). One promising commercial application is car-to-car ad hoc networking. The vehicular network application is in part propelled by the Department of Transportation plan to develop a "standard" vehicular radio architecture – DSRC (Digital Short Range Communications) – for navigation safety. Once the radio is installed on each car for a civilian purpose (e.g., safe driving), one can speculate that a number of commercial applications will rapidly spring up. Most of the vehicle applications will revolve around wireless Internet access; but, some will be based on fully distributed applications, e.g., car-to-car file sharing and games. Besides vehicular ad hoc networking, other commercial applications are now emerging which include multihop extensions of the urban "mesh networks" to mobile momentarily out of reach. This trend is fueled by the proliferation of IEEE 802.11 wireless LAN products and services together with development of ad hoc protocol standards in IETF MANET.

The unprecedented growth of existing (mostly military) applications and the emergence of commercial applications have given new momentum to ad hoc network research in both industry and academia. One issue central to ad hoc networks (whether military or commercial) is mobility. In fact, this is what sets these networks apart from other wireless networks. Mobility affects virtually all layers of the wireless architecture, from radio to applications. It is a major challenge to the designer and it must be reckoned with, whether it contrasts performance, or it enhances it (as with data mules for example). In this special issue, we want to recognize the importance of mobility in ad hoc network design and have thus solicited papers that specifically deal with mobility at any of the layers of the architecture. Our effort has been amply rewarded. Out of over 90 submissions, we have selected 10 excellent papers which capture the impact of mobility at physical, MAC, network, and transport layers.

For the readers' convenience, the papers have been organized in three categories: (a) Physical and MAC layers; (b) scalable routing and multicast, and; (c) transport and mobility management. In the sequel, we summarize paper content and review the unique contributions.

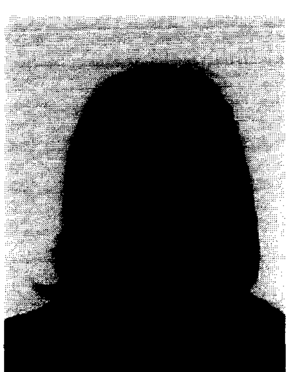
The first section of this special issue includes three papers dealing with physical and medium access control (MAC) issues. The paper, "An Air-Interface for Ad Hoc Networks Supporting High Mobility" by M. Lott *et al.*, presents a novel air-interface for a vehicle network. The air-interface is a modified version of UMTS/TDD, adapted so as to suite the needs of a mobile, self-organizing environment. The required changes at the physical and MAC layer are described, and the performance of the proposed system is shown under realistic mobility models. The paper, "Adaptive EY-NPMA: A Medium Access Protocol for Wireless LANs" by G. Dimitriadis and F.-N. Pavlidou, proposes an enhancement to the EY-NPMA protocol, which is known for providing service differentiation and reduced collision probability but has been found to be insensitive to traffic conditions. The mechanism introduced by the authors allows the operating parameters of the protocol to adapt to the offered traffic, thus solving the weakness of the previous protocol version. The last paper of this section, "MIMO Ad Hoc Networks: Medium Access Control, Saturation Throughput, and Optimal Hop Distance" by M. Hu and J. Zhang, explores the impact of using MIMO techniques on MAC and routing in mobile ad hoc networks. First a MAC that accounts for the use of spatial diversity is devised; then the authors characterize the saturation throughput of the system and the optimal hop distance that minimizes end-to-end traffic delay.

The second group of papers in this special issue deals with the topic of routing and packet forwarding in mobile ad hoc networks. Two different, yet related themes are addressed – routing scalability and multicast. In "Mobility-Aware Mesh Construction Algorithm for Low Data Overhead Multicast Ad Hoc Routing," Ruiz considers the complexity of the computation of minimal data multicast mesh, and then goes on to propose minimal data multicast protocols based on epidemic algorithms as well as a multicast protocol that can adapt to mobility using probabilistic path selection. This is followed by the paper by Cedric Adjih *et al.*, "Fish Eye OLSR Scaling Properties," which studies scalability properties of link state routing protocols in ad hoc networks. The paper exposes the limitations of link state routing protocols and shows that scalability can be significantly enhanced through the use of the "Fish Eye" routing techniques. The paper by Lin and Shroff, "Towards Achieving the Maximum Capacity in Large Mobile Wireless Networks under Delay Constraints," studies the capacity of mobile ad hoc networks, with a large number of nodes, under delay constraints. The paper investigates tradeoffs between capacity and delay and computes the upper bound on the maximum per-node capacity of a large mobile wireless network under given delay constraints. The final paper of this section, titled "PDAODMRP: An Extended PoolODMRP Based on Passive Data Acknowledgement" from Cai, Wang, and Yang, expands on the ODMRP protocol in a variety of novel ways including dynamic local route maintenance and route information collected from data packets, in order to achieve improved performance. This group of papers provides a significant cross-section of recent relevant research in the field of routing for ad hoc networks.

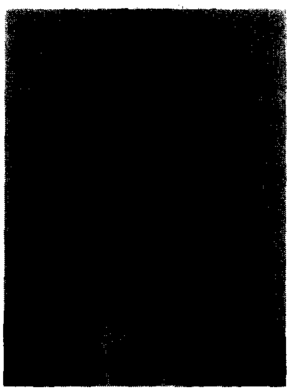
The last three papers are concerned with upper layer issues – transport, application, and mobility management. The original TCP design does not tolerate well the abuse of mobility in ad hoc networks. Thus, researchers have strived to help TCP with "hints" from below (i.e., network layer) – with mixed results. The paper, "An Efficient Transport Protocol for Ad Hoc Networks: An End-to-End Freeze TCP with Timestamps" by S. Cho *et al.*, takes a different approach. It advocates "end-to-end only" operations. The proposed recipe includes a "rater", a "window delimiter", and a "freezer". The results are surprisingly good considering no lower layer feedback. Mobility and path breakage can have a devastating effect not only on TCP, but also on real time video delivery (frequent interruptions due to packets lost while a new route is computed). The paper, "Mitigating the Impact of Mobility on H.264 Real-Time Video Streams Using Multiple Paths" by C. Calafate *et al.*, attempts to mitigate the path breakage problems by introducing redundancy (multiple DSR paths) and/or by anticipating the break, and therefore quickly computing a new path. Moreover, the video streams are carefully multiplexed on the various paths keeping into account the specific video coding characteristics. All the above procedures can make use of efficient methods for locating destinations and anticipating path breakage. The third paper, "A Taxonomy of Location Management in Mobile Ad Hoc Networks", comes to our assistance in the location determination/prediction camp. The paper provides an excellent overview of the location based techniques, from structured to unstructured, extroverted to introverted, etc. It also discusses the O/H introduced by location procedures, and strikes a balance between accuracy and time to get it.

In summary, we believe this special issue on mobile ad hoc wireless networks has made an important contribution to the understanding of mobility and its impact on the various layers of an ad hoc network architecture. Out of over 90 submissions, we have selected 10 representative papers that address different problems at different layers and offer innovative solutions. Naturally, we have barely scratched the surface of this broad field. Much more work remains to be done in the area of mobility, for instance in terms of characterizing, modeling, combating, and exploiting it. We expect many future special issues to address the topic of mobility; and we encourage researchers to continue the exploration of this promising area.

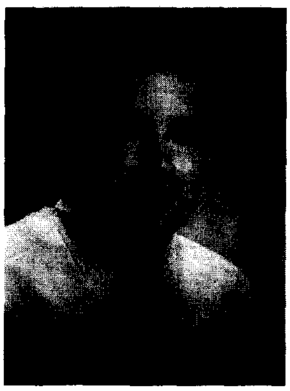
Mario Gerla received a graduate degree in engineering from the Politecnico di Milano and the Ph.D. degree from UCLA in 1973. After working for Network Analysis Corporation from 1973 to 1976, he joined the Faculty of the Computer Science Department at UCLA where he is now Professor. His research interests cover the performance evaluation, design, and control of distributed computer networks. He has worked on various wireless network protocols and architectures under government and industry support (WAMIS and GloMo projects). Currently, he is leading the ONR sponsored MINUTEMAN project, which is about the design of a robust, distributed wireless network architecture for unmanned intelligent agents, with defense and homeland security applications. Other interests include QoS wireless routing, multicasting, and TCP transport for the Next Generation Internet (see www.cs.ucla.edu/NRL for recent publications). Prof. Gerla is an IEEE Fellow.



Carla-Fabiana Chiasserini graduated with a summa cum laude degree in Electrical Engineering from the University of Florence in 1996. She did her graduate work at the Politecnico di Torino, Italy, receiving the Ph.D. degree in 1999. Since then she has been with the department of Electrical Engineering at Politecnico di Torino, where she is currently an Assistant Professor. Since 1999, she has worked as a visiting researcher at the University of California, San Diego, California. Her research interests include architectures, protocols, and performance analysis of wireless networks for integrated multi-media services. She is a member of the editorial board of the Ad Hoc Networks Journal (Elsevier), and has served as an associate editor of the IEEE Communications Letters since 2004.



Kenichi Mase received the B.E., M.E., and Dr. Eng. Degrees in Electrical Engineering from Waseda University, Tokyo, Japan, in 1970, 1972, and 1983, respectively. He joined Musashino Electrical Communication Laboratories of NTT Public Corporation in 1972. He was Executive Manager, Communications Quality Laboratory, NTT Telecommunications Networks Laboratories from 1994 to 1996 and Communications Assessment Laboratory, NTT Multimedia Networks Laboratories from 1996 to 1998. He is now Professor, Graduate School of Science and Technology, Niigata University, Japan. He received IEICE best paper award for the year of 1993 and the Telecommunications Advanced Foundation award in 1998. His research interests include communications network design and traffic control, quality of service, and mobile ad hoc networks. He is IEEE and IEICE Fellow.



Eytan Modiano received his B.S. degree in Electrical Engineering and Computer Science from the University of Connecticut at Storrs in 1986 and his M.S. and Ph.D. degrees, both in Electrical Engineering, from the University of Maryland, College Park, MD, in 1989 and 1992, respectively. He was a Naval Research Laboratory Fellow between 1987 and 1992 and a National Research Council Post Doctoral Fellow during 1992-1993 while he was conducting research on security and performance issues in distributed network protocols.

Between 1993 and 1999, he was with the Communications Division at MIT Lincoln Laboratory where he designed communication protocols for satellite, wireless, and optical networks and was the project leader for MIT Lincoln Laboratory's Next Generation Internet (NGI) project. He joined the MIT faculty in 1999, where he is presently an Associate Professor in the Department of Aeronautics and Astronautics and the Laboratory for Information and Decision Systems (LIDS). His research is on communication networks and protocols with emphasis on satellite, wireless, and optical networks.

Jason Redi received a B.S. in Computer Engineering from Lehigh University in 1992, and M.S. and Ph.D. degrees in Computer Engineering from Boston University in 1994 and 1998, respectively. He is presently a Division Scientist in the Mobile Networking Systems department of BBN Technologies where he leads numerous projects involved in the design and implementation of mobile ad hoc wireless networks. His other current work includes ad hoc networking designed for autonomous robots, ad hoc networking for MIMO radios, and low power communications.

Dr. Redi is author of over thirty papers and patents in the area of mobile computing and communications, including the best classified paper at MILCOM 2002. He has previously been the Editor-in-Chief of the ACM SIGMOBILE Mobile Computing and Communications Review (MC2R), and is currently on the editorial board of Wiley's Wireless Communications and Mobile Computing Journal. He's a senior member of the IEEE and a member of ACM, Tau Beta Pi, and Sigma Xi.