Opportunistic Channel Selection Strategy for Better QoS in Cooperative Networks with Cognitive Radio Capabilities

Ala Al-Fuqaha, Bilal Khan, Ammar Rayes, Mohsen Guizani, Osama Awwad, Ghassen Ben Brahim

***Abstract*—Mission-oriented MANETs are characterized by implicit common group objectives which make inter-node cooperation both logical and feasible. We propose new techniques to leverage two optimizations for cognitive radio networks that are specific to such contexts: *opportunistic channel selection* and *cooperative mobility*. We present a new formal model for MANETs consisting of cognitive radio capable nodes that are willing to *be moved* (at a cost). We develop an effective decentralized algorithm for mobility planning, and powerful new filtering and fuzzy based techniques for both channel estimation and channel selection. Our experiments are compelling and demonstrate that the communications infrastructure—specifically, connection bit error rates—can be significantly improved by leveraging our proposed techniques. In addition, we find that these cooperative/opportunistic optimization spaces do not trade-off significantly with one another, and thus can be used simultaneously to build superior hybrid schemes. Our results have significant applications in high-performance mission-oriented MANETs, such as battlefield communications and domestic response & rescue missions.**

***Index Terms*—Cognitive radio, Cooperation, Quality of Service, Ad-hoc network, filter, fuzzy logic.**

I. INTRODUCTION

MOBILE wireless ad-hoc networks (MANETs) serve as an important building block for modern networks, having found fruitful applications in both consumer and mission-oriented settings. Examples of the latter include battlefield and public safety scenarios where MANETs are considered especially well-suited because they support the rapid establishment of communications for mobile platforms over a shared wireless medium, and obviate the need to invest time and expense in developing a fixed infrastructure.

In the military setting, MANETs have been used to enable communication between mobile infantry units, command and control, field intelligence, aerial surveillance, etc. They can be built using Radio Frequency (RF) communication links both between and within infantry formations, ground armored vehicles (e.g., armored vehicles, tanks), airborne units (e.g., fighters, bombers), and naval/amphibious platforms (e.g., destroyers, troop carriers). The demanding requirements of end users in military and public-safety sectors have led to the development of a variety of unmanned platforms [12]. More specifically, end-user demands have driven the development of Unmanned Ground Vehicles (UGVs) and Unmanned Air Vehicles (UAVs) for use within battlefield and public safety missions, e.g., the UAV-Ground Network [3]. These devices are mobile, mission-capable, and well-suited for use in dull, dirty, difficult, and dangerous settings, including collection of data from sensors [7]. In particular, the ability to maneuver UAVs and UGVs in small increments over a wide variety of terrains makes them well-suited to serve as relays, maintaining mobile communication links by optimizing the reception and transmission of signals among end users.

Surprisingly, while MANETs have been applied in mission-oriented rapid-deployment applications such as battlefield communications and domestic response & rescue missions, much of MANET research has not made a concerted effort to leverage the central difference between consumer MANETs and mission-oriented rapid-deployment MANETs: namely that the latter brings with them implicit common group objectives which make inter-node cooperation both logical and feasible. This willingness to cooperate provides designers of rapid-deployment mission-oriented MANETs additional opportunities for new optimizations which have not been thoroughly explored. In this paper, we will consider two such optimizations and describe the tradeoffs inherent between them.

Cooperative Mobility. Application-level cooperation has been studied in the context of specific tasks (e.g., in [10], Kuwata et al. describe how a group of UAVs can coordinate their activities by solving local optimization problems and then conveying aspects of these solutions to their neighbors). The objective of such investigations is to determine how team members should share and exchange high-level information to best achieve team objectives. In this work, we consider more fundamental questions on the role that cooperation can play in supporting *communication itself*. Prior work on the question of how cooperation can benefit communication [13], [8], [4], [6], [20], [19] has approached this issue from the vantage point of a node's willingness to forward messages along the next hop (toward the intended destination) along a multi-hop path. Almost all prior research adopts the consumer MANET model, where node mobility is considered the sacrosanct domain of the user, autonomously determined and non-negotiable. While this is an appropriate conception of current consumer (e.g., cell phone and laptop) applications, it fails to leverage the

Manuscript received March 1, 2007; revised August 15, 2007.

Ala Al-Fuqaha, Mohsen Guizani, Osama Awwad, and Ghassen Ben Brahim are with Western Michigan University (e-mail:alfuqaha@cs.wmich.edu, mguizani@gmail.com, oaawwad@cs.wmich.edu, Ghassen.BenBrahim@boeing.com).

Bilal Khan is at John Jay College, City University of New York (e-mail: bkhan@jjay.cuny.edu).

Ammar Rayes is with Cisco Systems (e-mail:rayes@cisco.com).

Digital Object Identifier 10.1109/JSAC.2008.080114.

[17] D.C. Montgomery. *Introduction to Statistical quality control, John Wiley and Sons,Inc., Third Edition, 1997*.
[18] D. Niyato and E. Hossain. Cognitive Radio for Next Generation Wireless Networks: An Approach to Opportunistic Channel Selection in IEEE 802.11-based Wireless Mesh. IEEE Communications Magazine, 2007.
[19] A. Nosratinia, T. E. Hunter, and A. Hedayat. Cooperative Communication in Wireless Networks. IEEE Communi. Mag., Oct. 2003.
[20] C. Politis, T. Oda, N. Ericsson, S. Dixit, A. Schieder, H. Lach, M. Smirnov, S. Uskela, , and R. Tafazolli. Cooperative Networks for the Future Wireless World. IEEE Commun. Mag., Sept. 2004.
[21] J. G. Proakis. *Digital Communications, McGraw Hill, 2001*.
[22] L. Raju, S. Ganu, B. Anepu, I. Seskar, and D. Raychaudhuri. Beacon assisted discovery protocol (bead) for self-organizing hierarchical ad hoc networks. IEEE Globecom Telecommunications Conference, Dallas, Nov. 2004.

Ala Al-Fuqaha (S'00-M'04) received his M.S. and Ph.D. degrees in Electrical and Computer Engineering from the University of Missouri, in 1999 and 2004 respectively. Currently, he is an Assistant Professor at the Computer Science Department of Western Michigan University. Before joining Western Michigan University, Dr. Al-Fuqaha was a senior member of technical staff at LAMBDA Optical Systems in Reston, Virginia where he worked on the design and development of embedded routing protocols and network management systems. Prior to LAMBDA, Dr. Al-Fuqaha was a Software Engineer with Sprint Telecommunications Corp. where he worked as part of the architecture team. His research interests include intelligent network management and planning, QoS routing and performance analysis and evaluation of high-speed computer and telecommunication networks. Dr. Al-Fuqaha has served as Technical Program Committee member of many IEEE conferences.

Osama Awwad received his B.S. degree in Computer Engineering from Jordan University of Science and Technology in 2003 and an M.S. degree in Computer Science from Western Michigan University in 2006. During his Master's degree, he has interned at Lambda OpticalSystems. Currently he is a Ph.D. candidate in the Dept. of Computer Science at Western Michigan University. His research interests include performance analysis of computer networks, hybrid RF/FSO channels, QoS routing in wireless and optical WDM networks.

Ghassen Ben Brahim (S'04) received his B.Sc. degree in Computer Science from the National School of Computer Science in Tunisia, MS degree from the University of Missouri Columbia, and Ph.D. degree from Western Michigan University. His research area focuses on QoS based routing protocols in wireless networks. He was a visiting researcher at the Naval Research Laboratory (NRL) in Washington DC during the year 2000, where he contributed to the ATDNET/MONET project. In January 2001, he joined Lambda Optical Systems as a Member of Technical Staff. He was involved in the design and implementation of line and path protection frameworks for all-optical switches based on the MEMS technology as well as the design and implementation of the extensions for the OSPF routing protocol to provide QoS and source routing in all-optical networks. Currently, he is a System Engineer in the Integrated Defense System at Boeing.

Bilal Khan received his Ph.D. in Mathematics from City University of New York, M.Sc. in Computer Science from Johns Hopkins, and B.Sc. in Mathematics and Computer Science from MIT. He has served as a (contractor) Research Scientist at the Center of Computational Sciences of the U.S. Naval Research Laboratory, Washington D.C. Presently he is Associate Professor of Mathematics, Computer Science and Forensic Computing at John Jay College of Criminal Justice, City University of New York.

Mohsen Guizani (S'89-M'90-SM'98) is currently a Professor and the Chair of the Computer Science Department at Western Michigan University. He received his B.S. (with distinction) and M.S. degrees in Electrical Engineering; M.S. and Ph.D. degrees in Computer Engineering in 1984, 1986, 1987, and 1990, respectively, from Syracuse University, Syracuse, New York. His research interests include Computer Networks, Wireless Communications and Mobile Computing, and Optical Networking. He currently serves on the editorial boards of six technical Journals and the Founder and EIC of "Wireless Communications and Mobile Computing" Journal published by John Wiley (http://www.interscience.wiley.com/jpages/1530-8669/). He is also the Founder and General Chair of the IEEE International Conference of Wireless Networks, Communications, and Mobile Computing (IEEE WirelessCom 2005). He is the author of three books and in the process of writing another two.

Ammar Rayes received his Doctor of Science degree in Electrical Engineering from Washington University in St. Louis, Missouri, in 1994. Dr. Ammar Rayes is a Senior Manager at the Advanced Technology Support group at Cisco Systems. He has managed several solutions including Customer Advocacy Platform Architecture, wireless, broadband access, subscriber and security management; triple play over Ethernet, VPN, performance and traffic engineering, IOS embedded management, and SNMP infrastructure and tools. Prior to joining Cisco Systems, He was a Director in the Traffic Capacity Management and Planning Department at Telcordia Technologies. Dr. Rayes has authored/Co-authored over fifty patents and papers on advances in numerous communications-related technologies including a book on ATM switching and network design(McGraw Hill-1999). He is currently chairing Cisco CA Patent Council and serving on the board of the International Journal of Software Architecture and Network Management Research Council.