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CROSS-LAYER PROTOCOL ENGINEERING FOR WIRELESS MOBILE NETWORKS: PART 1

Growth of wireless packet data applications (e.g., wireless Web access, interactive mobile multimedia applications, and interactive gaming) drives the rapid evolution of next-generation wireless networks. One of the key challenges for next-generation broadband wireless networks is to devise end-to-end protocol solutions across wired and wireless by leveraging IP technologies. The unique characteristics of wireless networks such as user mobility, frequent link failure, limited link capacity, and limited battery and computational resources of mobile devices along with the diverse quality of service (QoS) requirements for the wireless applications pose significant challenges in designing radio link level, routing, and transport protocols for high-speed wireless networks.

Traditionally wireless network protocol design has been based on a layered approach in which each layer in the protocol stack is designed and operated independently, with interfaces between layers that are static and independent of the individual network constraints and applications. This is to exploit the advantage of modularity in system design. The system dynamics representing the interactions among the protocols at the different layers is fairly complex because of the existence of numerous parameters and the nonlinear nature of the protocol state machines at the different layers. However, careful exploitation of some cross-layer protocol interactions can lead to more efficient performance of the transmission protocol stack (and hence better application-level protocol performance) in different wireless networking scenarios (e.g., cellular, ad hoc, sensor). This is particularly true for wireless ad hoc networks where unpredictable variables such as node mobility, node density, and network dimensions make the QoS requirements of applications even more difficult to satisfy.

Cross-layer protocol engineering is an emerging research area; some results have recently been published, but it holds greater potential for comprehensive results addressing relevant issues to support emerging applications. Also, the development of related concepts and technologies is critical. Research on cross-layer design and engineering is interdisciplinary in nature and involves several research areas such as signal processing, adaptive coding and modulation, channel modeling, traffic modeling, queuing theory, and network protocol design and optimization techniques.

The response to our call for papers on this feature topic of *IEEE Communications Magazine* was overwhelming; we received a very large number of articles (over 50). All the papers were reviewed by experts in the relevant area, and the articles selected for publication went through a rigorous two-round review process. It was decided to publish the articles in two back-to-back issues. This special issue presents part 1 of this two-part series, which consists of six articles covering various aspects of cross-layer design involving physical (PHY), medium access control (MAC), routing, and application layers for different wireless access technologies such as code-division multiple access (CDMA), orthogonal frequency-division multiplexing (OFDM), orthogonal frequency-division multiple access (OFDMA), and ultra-wideband (UWB) technologies.

The first article, "Cross-Layer Design: A Survey and the Road Ahead" by V. Srivastava and M. Motani, presents a literature survey of cross-layer design proposals with examples and presents categorization of the initial proposals for cross-layer interaction implementations. The authors also highlight some open challenges in this area.

The second article, "Cross-Layer Design for Resource Allocation in 3G Wireless Networks and Beyond" by H. Jiang, W. Zhuang, and X. Shen, provides an overview of cross-layer design approaches for resource allocation in 3G CDMA networks, summarizes state-of-the-art research results, and suggests future research directions. To this end, a cross-layer radio link design approach for video streaming over CDMA networks is presented that exploits the PHY and application layer information. Simulation results are presented to demonstrate the effectiveness of the proposed approach.

The third article, "Utility-Based Resource Allocation and Scheduling in OFDM-Based Wireless Broadband Networks" by G. Song and Y. Li, presents a cross-layer utility-based resource management framework for QoS provisioning in OFDM-based broadband wireless networks. The capacity, fairness, and stability issues for the radio resource management framework are analyzed considering diverse performance objectives of heterogeneous traffic in the network. The authors provide a solution to effective resource allocation for heterogeneous traffic with diverse QoS requirements.

The fourth article, "Design and Implementation of Simulator Based on Cross-Layer Protocol between MAC and PHY Layers in a WiBro Compatible 802.16e OFDMA System" by

T. Kwon e*t al.*, presents a cross-layer design framework for 802.16e OFDMA systems that are compatible with the Wireless Broadband (WiBro) technology in Korea. In particular, this article deals with a wireless MAN–OFDMA radio interface defined in the 802.16 standard and presents a cross-layer (PHY and MAC layers) link adaptation framework for efficient radio resource allocation. Also, based on this framework, a simulator is designed and implemented. Typical performance evaluation results obtained using the simulator are also presented.

The fifth article, "Trade-off Analysis of PHY-Aware MAC in Low-Rate Low-Power UWB Networks" by A. E. Fawal *et al.*, investigates the MAC layer design trade-offs in very-low-power impulse radio UWB networks assuming that the MAC protocol has access to some or all of the PHY layer parameters. In particular, the article discusses various functions to be considered in a PHY-aware MAC protocol and implementation aspects, and provides a list of many building blocks from the literature. The authors propose a method of evaluating energy consumption existing in the design phase of IR-UWB systems. To this end, some design guidelines for low-rate and low-power UWB networks are provided.

The sixth and final article in this issue, "Topology-Aided Cross-Layer Fast Handoff Designs for IEEE 802.11/Mobile IP Environments" by C.-C. Tseng *et al.*, reviews some state-of-the-art handoff techniques (at layers 2 and 3) suitable for IEEE 802.11 networks. A cross-layer handoff technique is proposed to minimize the overall layer 2 plus layer 3 handoff delay. The proposed technique proposes to use a pre-handoff layer 2 trigger to execute layer 3 handoff related activities prior to the associated layer 2 handoff. The experimental results show that with the proposed cross-layer handoff technique the delay requirements for the voice over IP (VoIP) applications can be met.

In closing, we would like to thank all the authors for their excellent contributions. We also thank the reviewers for their dedicated time in reviewing the papers and providing valuable comments and suggestions for refining the quality of the articles. We appreciate the advice and support from Dr. Roch Glitho, Editor-in-Chief of *IEEE Communications Magazine*, and Sue Lange for her help in publication process. Finally, we hope that the readership will find this feature topic interesting and stay tuned for part 2 in the January 2006 issue.

BIOGRAPHIES

SASTRI L. KOTA [SM '86] received his B.S in physics from Andhra University, his B.S.E.E from Birla Institute of Technology and Science (BITS), Pilani, and his M.S.E.E. from Indian Institute of Technology (IIT) Roorkee, India. He received an electrical engineer's degree from Northeastern University, Boston, Massachusetts, and a Ph.D. in electrical and information engineering from the University of Oulu, Finland. He is a senior scientist at Harris Corporation. Prior to that he held various technical and management positions, and contributed to military and commercial communication systems in broadband network architectures and protocols, satellite communication systems design, wireless networks, and performance modeling and analysis at Loral Skynet, Lockheed Martin, SRI International, Ford Aerospace, The MITRE Corp, Xerox Corp, and Computer Sciences Corp. He was on the faculty of the Electronics and Communication Engineering Department of Indian Institute of Technology (IIT), Roorkee. He is an active participant at various standardization organizations and currently is the U.S. chair for ITU-R Working Party 4B and International Rapporteur for Ka-Band Fixed Satellite Systems. He was the chair of the Wireless ATM Working Group and has been an ATM Forum Ambassador. His research interests include wireless mobile ad hoc networks, satellite IP networks, QoS and traffic management, broadband satellite access, and ATM networks. He is the principal author of *Broadband Satellite Communications for Internet Access* (Kluwer Academic, 2003), co-edited *Emerging Location Aware Broadband Wireless Ad Hoc Networks* (2004), and has contributed book chapters to *Encyclopedia of Telecommunications* (Wiley, 2003), *High Performance TCP/IP Networking* (Prentice Hall, 2003), and *Modeling and Simulation Environment for Terrestrial and Satellite Networks* (Kluwer Academic, 2002). He has published and presented over 100 technical papers in journals and conference proceedings. He served as a guest editor for special issues of *IEEE Communications Magazine* and *International Journal of Satellite Communications and Networking*. He currently serves on the editorial boards of *International Journal of Satellite Communications and Networking* (Wiley Interscience) and *International Journal of Space Communications* (IOS Press). He also serves as an Industry Advisory Board member of academic institutions. He served as executive committee member, technical chair, and technical program committees of numerous IEEE, AIAA, SPIE, and ACM conferences and workshops. He is the recipient of the Golden Quill Award from Harris Corporation, publication awards from Lockheed Martin, and the ATM Forum Spotlight award. He is an associate fellow of AIAA and a member of ACM.

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AHMED KARMOUCH [M] received his M.S. and Ph.D. degrees in computer science from the University of Paul Sabatier, Toulouse, France, in 1976 and 1979, respectively. From 1976 to 1983 he was a research engineer at Institut National de Recherche en Informatique et en Automatique (INRIA), Paris, France. He first worked in distributed databases with the Sirius Project, and then with the Kayak Project where he researched office information systems and was responsible for the Multimedia Distributed Message System Research Group. From 1984 to 1988 he was with Bull SA, Paris, France, as a senior manager in the Department of Advanced Studies. He was responsible for the Distributed Multimedia Document Management Group. From 1988 to 1991 he was director of research on multimedia distributed databases and architectures at the Ottawa Medical Communications Research Group, University of Ottawa. Since 1991 he has been a professor of electrical and computer engineering and computer science at the School of Information Technology and Engineering, University of Ottawa. He also holds an Industrial Research Chair from the Ottawa Carleton Research Institute and Natural Sciences and Engineering Research Council. He has been director of the Ottawa Carleton Institute for Electrical and Computer Engineering. He is involved in several projects with the Telecommunications Research Institute of Ontario, Nortel Networks, Bell Canada, Mitel, Ericsson Canada, National Research Council Canada, Centre National de Recherche Scientique in France, March Networks, CANARIE, Communications & Information Technology Ontario (Cito), and TeleLearning National Center of Excellence. He is a partner in "Wireless World Initiative: Ambient Networks," a European Sixth Framework Integrated Project. His current research interests are in distributed multimedia systems and communications, mobile computing, home architecture and services, context-aware ad hoc communications, ambient networks, and mobile software agents for telecommunications. He has published over 200 papers in the areas of multimedia systems, mobile communications mobile computing, context awareness, and mobile agents for telecommunications. He is a member of ACM, has served on several program committees, organized several conferences and workshops, edited several books, and served as Guest Editor for *IEEE Communications Magazine*, *Computer Communications*, *Multimedia Tools and Applications*, and others.