Guest editorial for special issue on cross-layer design in ad hoc and sensor networks

For well over a decade, the international research community has invested significant effort on wireless ad hoc and sensor networks. Initially, the classical layered network architecture was followed in the design of such systems, but to obtain higher gains in performance, the cross-layer approach emerged. For example, this may include the introduction of new interfaces between adjacent and non-adjacent layers, the coupling of layer design, vertical calibration of parameters across layers, and the formation of a super-layer by merging the services of adjacent layers.

It is our great pleasure to bring you this special issue presenting state-of-the-art research contributions that include aspects of cross-layer design in ad hoc and sensor networks. A total of thirty-nine manuscripts were received in response to our solicitation. Each paper underwent a round of rigorous review. After two additional rounds of review we decided to accept eight papers for publication (an acceptance rate of about 20.5%).

We organize this issue in a bottom-up fashion, presenting cross-layer design involving the physical layer (PHY) up to the application layer.

We begin with an article by Koutsopoulos and Tassiulas that exploits interactions between the PHY and medium access control (MAC) protocols. It studies the problem of fast neighbor positioning in wireless networks with directional antennas. Fast neighbor positioning is a prerequisite for speeding up other network functionalities, such as medium access. Using a polling methodology combined with use of directional beams, a tradeoff between user positioning and medium access delay is explored. Methodologies for minimizing the delay by appropriately selecting the beam width and the persistence probability of the collision resolution protocol are investigated. Simulations assess the effectiveness of the proposed framework.

Leonardi, Palazzo, Rametta, and Knightly propose CSMA/CARD, a receiver-initiated MAC protocol to mitigate starvation in multi-hop wireless networks arising from asymmetry in channel state. Receivers sense collisions at the physical layer and construct a historical profile to predict if a sender attempted to initiate a transmission. The receiver then uses this extra state information to decide whether it should participate in the CSMA/CA-style handshake. Through analysis and simulation, the proposed protocol is shown to alleviate the problem of starvation in some network scenarios. CSMA/CARD uses a cross-layer design, introducing a new interface between the PHY and MAC layers.

In the article by Elbatt interactions between the PHY and MAC layers are explored through tradeoffs in scheduling, multiplexing, and diversity in MIMO ad hoc networks. A unified framework for the scheduling-multiplexing and scheduling-diversity sub-problems is presented. Each sub-problem is addressed as a cross-layer optimization problem to jointly decide the scheduling and MIMO stream allocation for a given set of single-hop links, given the signal-to-interference-and-noise-ratio (SINR); the optimization problem is described as a non-convex integer programming problem. The work shows that two apparently different problems lead to structurally similar SINR-based decision rules. This forms the basis for a resource allocation algorithm that achieves significant gains for an arbitrary number of links.

Moving up in the protocol stack, the article by Camillo, Nati, Petrioli, Rossi, and Zorzi proposes the IRIS system for integrated interest dissemination and convergecasting in wireless sensor networks (WSNs). Interest dissemination is used to build and maintain the network topology, and for task assignment. Convergecasting is used for gathering data at the sink. IRIS tightly couples the MAC and network layers. Energy usage is minimized by exploiting sleep modes, duty cycle control, traffic intensity, and density estimation in a distributed and autonomous manner. The performance of IRIS is evaluated through experimentation in simulation and in a testbed.

Also related to topology formation is the article by Cuomo, Abbagnale, and Cipollone. Here the problem considered asks which interior node of the cluster-tree should serve as the root, or the personal area network (PAN) coordinator. More specifically, the question is posed for an IEEE 802.15.4/ZigBee wireless sensor network.
– this is the name of the scheme – is proposed as a cross-layer solution, coupling the MAC protocol with topology formation. Not only it is compliant with the standard, but it is fully self-configuring. By minimizing the height of the cluster-tree, simulations demonstrate that PANEL improves performance by reducing delay and extending the network lifetime by saving energy.

Feng, Demirkol, and Heinzelman address emerging heterogeneous wireless networks where the expectation is that multiple protocols execute concurrently within a layer. The traditional protocol stack cannot support this type of concurrency. Accordingly, a new cross-layer protocol architecture, Universal Protocol Stack (UPS), is proposed. It provides unified support for cross-layer interactions between layers, while allowing the coexistence of multiple communication protocols within each layer of the protocol stack. Experimentation in simulation and in a testbed show that with limited overhead, UPS achieves significant performance improvements.

Moving to the higher layers, the article by Tahir and Farrell presents a distributed cross-layer framework that achieves an optimal tradeoff between network lifetime and its utility, while also providing end-to-end delay-robustness. The latter metric can be exploited by the application layer to achieve any desired level of quality-of-service. The optimal tradeoff problem is decomposed into network lifetime, utility, and delay-robustness subproblems, resulting in a cross-layer paradigm involving the PHY and application layers. Simulation results provide insight to protocol designers.

Finally, the article by Medagliani, Ferrari, Gay, and Leguay addresses the problem of designing and operating long-lasting surveillance mobile target detection applications for unattended WSNs. In particular, the cross-layer interactions between the sensing layer, that detects mobile targets crossing a monitored area, and the communication layer that transmits the alerts, from a sensing node to the sink are explored. The cross-layer interaction between the two layers is achieved using a model for the network lifetime based on the average energy depletion at the node level. Experimental results show that the network topology and the MAC protocol have an impact on sensing and communication system capabilities.

It has been our pleasure to put together this special issue with articles that highlight recent advances in cross-layer design for ad hoc and sensor networks. We thank the authors for their submissions, and the anonymous referees for their timely and conscientious reports. The result is a fine collection of articles that we are confident you will enjoy reading!


Guest Editors
Laura Galluccio
Elettronica ed Informatica University of Catania V.le A. Doria 6, 95125 Catania, Italy
Tel.: +39 095 738 2384; fax: +39 095 738 2397.
E-mail address: laura.galluccio@dieei.unict.it

Klara Nahrstedt
Ralph M. and Catherine V. Fisher Professor, Thomas M. Siebel Center for Computer Science, University of Illinois, MC258, 201 N. Goodwin Avenue, Urbana, IL 61801-2302, USA
Tel.: +1 217 244 6624; fax: +1 217 244 6869.
E-mail address: klara@cs.uiuc.edu

Violet R. Syrotiuk
School of Computing, Informatics and Decision Systems Engineering, Arizona State University, P.O. Box 878809, Tempe, AZ 85287-8809, USA
Tel.: +1 480 965 7034; fax: +1 480 965 2751.
E-mail address: syrotiuk@asu.edu

Available online 12 November 2011

Laura Galluccio received her laurea degree in Electrical Engineering from University of Catania, Italy, in 2001. In March 2005 she got her Ph.D. in Electrical, Computer and Telecommunications Engineering at the same university. Since 2002 she is also at the Italian National Consortium of Telecommunications (CNR), where she worked as a Research Fellow within the VICOM (Virtual Immersive Communications) and the SATNEX Projects. Since November 2010 she is Assistant Professor at University of Catania. From May to July 2005 she has been a Visiting Scholar at the COMET Group, Columbia University, NY under the guidance of Prof. Andrew T. Campbell. She is the Guest Editor for a Special Issue of the Wireless Communications Magazine on Wireless communications at the nanoscale and serves in the editorial boards of Wiley Wireless Communications and Mobile
Klara Nahrstedt is a full professor at University of Illinois at Urbana-Champaign, Computer Science Department. She is the recipient of the Early NSF Career Award, the Junior Xerox Award, the IEEE Communication Society Leonard Abraham Award for Research Achievements, the University Scholar Award and the Humboldt Research Award. She was the editor-in-chief of the ACM/Springer Multimedia Systems Journal (2000–2007), associate editor of ACM Transactions on Multimedia Computing, Communications and Applications (2005–now), associate editor of IEEE Transactions on Information Forensics & Security, general co-chair of ACM Multimedia 2006, general chair of ACM NOSSDAV 2007, general chair of IEEE PerCom 2009, and Ralph and Catherine Fisher Professor (2002–2011). She was elected to serve as the chair of the ACM SIG Multimedia (2007–2013).

Violet R. Syrotiuk earned her Ph.D. in Computer Science from the University of Waterloo (Canada). She started her academic career at the University of Texas at Dallas in 1999, and joined Arizona State University in 2002 where she is currently an Associate Professor of Computer Science and Engineering. Her research has been supported by grants from NSF, ONR, DSTO (Australia) and contracts with LANL, Raytheon, General Dynamics, and ATC. She serves on the editorial boards of Computer Networks, Computer Communications, and the International Journal of Communication Systems, as well as on the technical program and organizing committees of several major conferences sponsored by ACM and IEEE. Her research interests include MAC and higher layer protocols for multi-hop wireless networks.