Global Communications Newsletter

July 2005

Cross-Layer Optimization for Wireless Systems: A European Research Key Challenge

By C. Verikoukis (CTTC), L. Alonso (UPC), and T. Giamalis (INA)

A new design paradigm has recently arisen in wireless communications research: so-called cross-layer optimization. In fact, this implies the redefinition of the overall design strategies for this kind of system as it breaks the classical open systems interconnection (OSI) model. The endless need for higher bit rates, stringent quality of service (QoS) requirements, and need for anytime anywhere wireless connections lead to the necessity of squeezing to the outmost the available radio bandwidth. Cross-layer plays a key role in achieving this goal. Literature on ross-layer-related issues is still relatively scarce, but recently published results show that the potential obtainable gains deserve the increasing attention cross-layer is getting. European research efforts on this topic have been increasing in the last years, and currently active research lines on this topic are gaining relevance.

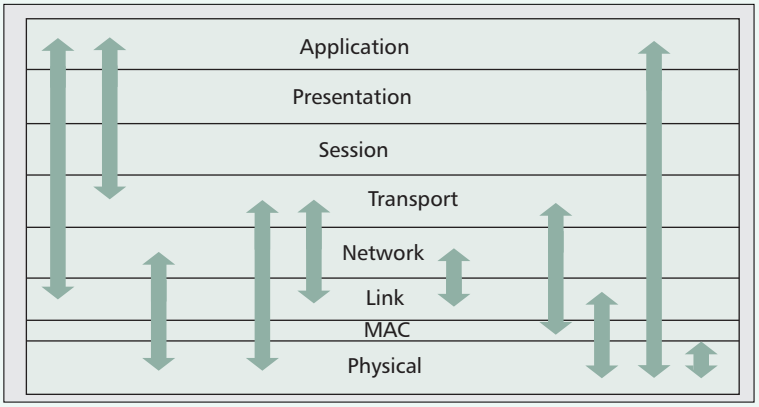

Figure 1. *Possible cross-layer communications.*

New Design Concept

During the last decade, significant growth of digital wireless communications systems has arisen. Wireless networks initially inherited the traditional OSI-layer-based architecture from wired networks, where each layer is worked out based on its parameters as a separate entity. The OSI model is a widely known, well accepted framework for communication systems [1, 2]. With this model, systems are decomposed in seven layers (physical, link, network, transport, session, presentation, and application). Each is responsible for a subset of the system's operational functions. Messages are interchanged between entities of the same layer in both the transmitter and receiver. Each layer is aware of its own messages and embeds its information into upper layer messages when they go down in the layer stack, while it discards the lower layers' information when messages go up.

This model has proved to be quite useful for developing smart algorithms and techniques for different communication systems, achieving proper working mechanisms. However, advances attained in the different OSI layers have barely taken into account those achieved in other layers. Traditionally each layer's research has widely ignored the other layers. Even though this consideration simplifies protocol design and treatment, it seems to be suboptimal for wireless communication systems. This is due to the fact that the wireless medium is available to multiple users who intend to get access and transmit their information, and its inherent variability in both the time and frequency domains.

Although a variety of different layer schemes have been designed for wireless systems in order to efficiently manage the scarce radio resources and provide certain QoS requirements to mobile users, the performance of such systems can be optimized by considering some vertical coupling between layers. Among all the possible combinations of layers involved in this interlayer interaction, the inherent variability of the physical layer in wireless systems makes this the most suitable layer for participating in such kinds of mechanisms. Indeed, system components such as medium access control (MAC) protocols, radio link control mechanisms, radio resource management schemes, and routing algorithms can benefit from some degree of awareness of the time and frequency varying characteristics of the radio channel. Seemingly the knowledge of certain information about the physical layer state allows higher protocol layers to adapt their behavior in order to improve network performance.

Apparently system performance improvements could arise from some communications between different layers, considering certain smart interactions between them in the system design. This general concept is known as cross-layer optimization [3, 4].

Figure 1 shows the OSI layered model and a subset of the possible interactions that can be considered in cross-layer design. This figure allows us to see out the vast field of research to explore in this area.

Is This New Design Structure Worth Considering?

In general, cross-layer designs and their achievable benefits are not free. Extra cost in the system is present at least in terms of additional signaling needed to extract relevant parameters from one layer that could be useful to other layers

(Continued on page 3)

IEEE Aerospace, Electronic and Systems, Communications, and Laser and Electro-Optics Society Chapter, India

Major Technical Activities: 2004

Awards and Recognitions

1. The Chapter Chair has been nominated as:

- Vice Chair, APB Chapters' Coordination Committee of IEEE Communications Society
- Member, ComSoc 2004–2005 Membership Programs Development Board
- Member, Program Committee of SYMPOTIC 2004
- Member, 9th biennial Vietnam Conference on Radio Electronics (REV 2004) organized by REV and sponsored by Vietnam Ministry of Post and Telematics (MPT)
- Member, 2nd International Conference on Computing, Communication and Control Technologies, CCCT '04
- Member, World Congress on Lateral Computing, December 2004

2. The Chapter has supported the following lectures, seminars, conferences, workshop, and Distinguished Lecture Tours both technically and financially:

International Radio Science and India, Special Lecture by Dr. A. P. Mitra, Former DG, CSIR January 2004

Annual technical festival, Tryst 2004, at Indian Institute of Technology (IIT) Delhi, January 2004, on the following topics:

- Emerging Ideas in Semiconductor Technologies
- Neural Networks and NeuroInaging
- Wireless Communication

"Information Storage: Where Are We Heading?" Prof. D. K. Pandya, IIT Delhi January 2004

"Architectural Planning and Risk Assessment through e-Governnance for Governments, Large Corporations and Non-Governmental Organizations," James N. Richhman, Intel Corporation, February 2004

Bridging Knowledge and Innovation Divide: Within and Among Communities, and Formal and Informal Science," Prof. Anil K. Gupta, IIM Ahmedabad, February 2004

"Shared Services in Government," Steve Bittinger, Gartner, February 2004

A student festival, AMITECH 2004, at Amity School of Engineering and Technology, Delhi, March 2004

National seminar, "Cutting Edge Technologies in Electronic Communications," at Sant Longawal Institute of Engineering and Technology, Panjab March 2004

One-day seminar, "Project Management — Latest Trends," IEEE DS EMS Chapter, March 2004

One-day workshop, "Wireless Networking and Mobile Computing (WNMC 2004), Indian Institute of Cultivation of Science, Jadavpur, Kolkatta, March 2004

"CDMA Technology: Advanced Wireless Services for Today and Tomorrow," IEE, April 2004

4th Annual International Conference on Governance, i-Assurance and Forensic, by e-Information Systems, Security and Audit Association, New Delhi, July 2004

"Information Communication Technologies," K Subramanian DDG, NIC, July 24, 2004

ENCOMIUM '04, two-day national technical festival, Jamia Millia Islamia, September 2004

"Design Patterns in Software Engineering," Prof. V. K. Vaishnavi, IEEE Fellow, October 2004

2nd Joint IST Workshop on Mobile Future and Symposium Trends in Communications, Bratislava, Slovakia, October 2004

Regional Student Awareness Congress (Regional SPAC), the IEEE Student Branch of the National Institute of Technology, Warangal, October 2004

The Fourth Biannual Student Meet, organized by IEEE Student Branch, Indira Gandhi Institute of Technology (a women's engineering college), Delhi, October 2004

"The Legal and Policy Framework for Addressing Cyber Crime," Rishi Chawla, IEDP, Delhi, October 2004

"Digital Signal Processing: Road to Future," Sanjit K.Mitra, University of California, November 2004

All India Seminar on Revolutionizing ICTs to Attain Progress, Parity and Peace for Al, IEI, Jharkhand State Center, November 2004

International Conference on Speech and Language Systems for Human Communication by DIT and Oriental COCOSDA Nov 2004

Organizing a workshop on"Eembedded Systems" November–December 2004, Prof. Rajkamal, Guru Nanak Engineering College, Hyderabad

"Seminar on Recent Advances in Optics and Photonics Organized," Indian Institute of Technology Delhi, November 2004

The Sixth Annual National IT Seminar- IT in Industry Verticals, XLRI, Jamshedpur, November 2004

"Highlights on Product Reliability and Manufacturing Research," Bharat Thakkar, Illinois Institute of Technology, December 2004

Asia-Pacific Microwave Conference 2004, University of Delhi, December 2004

"Life and Work of Shrinivas Ramanujan, The Mathematical Genius," K Shrinivas Rao, December ,2004

Two-day professional training program on dense wavelength-division multiplexing (DWDM), Bombay and Bangalore

Professional training program on fundamentals of fiber optics, optical communication, and networking

Professional training program on fundamentals of GSM/CDMA

3. The Chapter arranged and participated in the Electronics & Information Technology Exposition 2004 (ELITEX '04), the annual event of the Department of Information Technology (DIT), held April 26–27, 2004 at India Habitat Centre, Lodi Road, New Delhi. The eventcomprised an exhibition, technology-focused seminars, and a showcase of products and services developed under the aegis of the DIT. The event was inaugurated by R. A. Mashelkar, DG, CSIR and Secretary, DSIR. The keynote address was delivered by Shri K. K. Jaswal, Secretary, DIT. During their speeches the guests of honor mentioned the importance of Technology Vision: India in 2010. The role of close association between academia, R&D institutions, and industry has very clearly emerged and was emphasized.

Dr. Mashelkar appreciated the efforts made by DIT in organizing ELITEX '04 and showcasing their achievements in terms of products and services for commercialization.

The Honorable Minister visited the exhibition on the second day and appreciated the efforts in showcasing technologies developed with support from DIT. He desired the continuation of ELITEX as an annual feature of DIT.

The following products and technologies were transferred and released:

- A general-purpose ccontrol system developed by CDAC Trivandrum
- A distribution automation system developed by CDAC Trivandrum
- Solder paste for hybrid circuits and surface mount technologies developed by C-MET
- A vehicle underside scanner developed by IIT Delhi
- A software application system, Manus Granthavali, developed by the National Informatics Centre

(Continued on page 4)

[5], and also in terms of the control plane information that should be exchanged and the corresponding required transmission resources occupied, and the increase in computation complexity of all the protocols involved as well. Regarding this latter topic, the realistic computational capabilities of existing hardware or its anticipated evolution should be carefully taken into account when designing cross-layer mechanisms. Indeed, computational capability can be vastly different for different types of user terminals (laptop, PDA, cell phone, etc.). Then a trade-off between overhead and efficiency improvement arises. Whether using a cross-layer approach is convenient or not in order to achieve a real net enhancement should be carefully analyzed in each study case.

In this sense, the identification and selection of relevant cross-layer parameters to be exchanged among layers will depend on the functionalities being considered for cross-layer interaction, and possibly on specific end-user application constraints and objectives. However, a generic classification can be established for cross-layer potential useful information to be exchanged between layers [6]:

1. Channel state information (CSI), including channel impulse response estimation, both in time and frequency domains, location information, terminal speed, signal strength, interference level, interference modeling, and condition number

2. QoS-related parameters, including delay, throughput, bit error rate (BER), and packet error rate (PER) measurements for each layer involved in cross-layer interaction, especially concerning the end-to-end requirements

3. Resources made available in the corresponding node, such as multi-user reception capabilities, number and type of antennas, and battery depletion level

4. Traffic pattern offered by each layer to the others, including data traffic information, knowledge of the data rate (constant or variable), data burstiness, data fragmentation, packet sizes, and information about queue sizes

Thus, another huge field of research exploration appears when considering all the possibilities for exchanging and using this control information. In each system layout, the designer should be able to select the most appropriate scheme from the available ones, and then consider the convenient use of adequate cross-layer information exchange and the proper algorithms and mechanisms in order to optimize the obtainable gain in terms that should be relevant for overall system performance.

European Research Funded Projects on Cross-Layer

Nowadays, some R&D projects funded by the European Commission deal with the study of cross-layer interactions. Two IST STREP projects, 4G MC-CDMA Multiple-Antenna System on Chip for Radio Enhancements, (4MORE, IST-507039) [7] and Jointly Optimizing Multimedia Transmission in IP-Based Wireless Networks (PHOENIX, IST-001812) [8], address cross-layer issues.

The objective of the 4MORE project is to research, develop, integrate, and validate a cost-effective low-power system on chip (SoC) solution for multi-antenna multicarrier code-division multiple access (MC-CDMA) mobile terminals, based on joint optimization of layer 1 and 2 functions. Part of the work deals with the MC-CDMA physical layer, but it is also an objective of the project to deal with baseband algorithm related activities, intended to optimize the physical and MAC layer algorithms with strong emphasis on layer 1 and 2 feedback. The aim of the PHOENIX project is to develop a scheme offering the possibility to let the application world (source coding, ciphering) and the transmission world (channel coding, modulation) talk to each other over an IPv6 protocol stack (network world), so they can jointly develop an end-to-end optimized wireless communication link. Despite the improvements cross-layer coupling could bring into wireless communication systems, research in cross-layer issues in those projects does not constitute the main topic.

The goals of Project E of the IST Network of Excellence on Wireless Communications (NEWCOM, IST-507325) [9] include identification of the existing gaps in European knowledge in cross-layer, and preparation of an action plan for filling them by capitalizing on project researchers' skills. The research objective of the project aims at investigating the potential benefits of cross-layer in wireless network design in relation to the methodology of separate layer design. In addition, the project intends to consider thecoupling of the higher layers with the physical layer and elaborate the information to be exploited from the physical in order to optimize network performance. Furthermore, the project aims to define and implement common software platforms realizing the agreed common frameworks/models to be successively integrated and maintained.

Enhanced Radio Resource Algorithms Based on Cross-Layer Issues for 4G Networks (ERACLIN, MKTIK-2004-517518) Marie-Curie Transfer of Knowledge project objectives include the analysis of different cross-layer techniques that can be used to enhance the efficiency of wireless communication systems, and the study of the potential benefits that can be obtained from using these techniques in different environments and in particular, the explicit shift toward decentralized and adaptive MAC, radio resource management, and routing approaches. Furthermore, study of the potential benefits of incorporating channel estimation information about the future channel state in the adaptability of all the layers, and analysis of the trade-off between overheads and enhanced performance in cross-layer approaches are also among the project's objectives.

Conclusions

The main characteristic of European research in wireless networks has been focused up to now on the design and optimization of single communication layers. Significant research efforts have been made recently in order to exploit the potential benefits to be gained from interaction between layers in wireless communications systems. As a consequence, cross-layer optimization constitutes a key research topic of some European Commission funded research projects, while an integration project aims to describe the current situation in order to coordinate all research activities and fill the research gaps. A great number of industrial and academic partners are involved in these projects, and their efforts in this vast research field are growing rapidly. Furthermore, European industry and telecommunications suppliers should take into consideration cross-layer coupling and introduce it in current and future wireless communications systems.

References

[1] D. Wetteroth, *OSI Reference Model for Telecommunications*, McGraw-Hill, 2001
[2] T. S. Rappaport, A. Annamalai, R. M. Buehrer, and W. H. Tranter, "Wireless Communications: Past Events and a Future Perspective," *IEEE Commun. Mag. 50th Anniv. Commemorative Issue*, May 2002.
[3] Sanjay Shakkottai, Theodore S. Rappaport, Peter C. Karlsson, "Cross-Layer Design for Wireless Networks," IEEE Commun. Mag., vol. 41, no. 10, Oct. 2003, pp.74–80.
[4] G. Carneiro, J. Ruela, and M. Ricardo, "Cross-Layer Design in 4G Wireless Terminals," *IEEE Wireless Commun.*, vol. 11, no. 2, Apr. 2004, pp. 7–13.
[5] Qi Wang; Abu-Rgheff, M.A., "Cross-Layer Signaling for Next-Generation Wireless Systems", IEEE WCNC 2003, vol. 2, Mar. 2003, pp. 1084–89.
[6] NEWCOM DRE.1 "Report on the Knowledge Gaps to Be Filled and the Action Plan."
[7] http://www.ist-4more.org
[8] http://www.ist-phoenix.org
[9] http://newcom.ismb.it/public/index.jsp

- Shruti Drishti software developed by Media Lab Asia
- A cell phone jammer for both GSM and CDMA developed by SAMEER-Chennai
- A 2-RF-Channel CDMA receiver developed by SAMEER-Chennai
- Two highly calligraphic fonts for the Devanagri language developed by CDAC
- A C-VPN developed By CDAC
- Pressure sensors developed by SCL Ltd
- An IPR manual for industrial design
- A patent sampler
- A cyber law book
- IPR public outreach CDs
- A fine-tuned search engine
- Software code compliance developed by Centre for Reliability, Chennai
- Software Test Coverage, Centre for Reliability, Chennai

The seminar sessions were held on the theme of ELITEX '04, "Technology Vision: India in 2010," including Innovation Exchange; High Performance and Grid Computing; Human Computer Interface; Next Generation Wireless Technologies; India — A Global R&D Hub for ICTE; IT Security : Emerging Scenario; Software Technology Trends; Trends in Nano-Technologies; E-Governance: Implementation Issues and Strategies; and Broadband Economy. Besides creating awareness about DIT technologies, ELITEX '04 promoted R&D–industry linkages essential for absorption of indigenous technology by industry and stimulating innovations. The seminar deliberations were available online via direct webcast on www.elitexlive.nic.in and www.elitexindia.com, and also at all the videoconferencing centers of NIC. The videoconferencing centers attracted a large number of visitors to watch the proceedings.

Global Communications Newsletter

www.comsoc.org/pubs/gcn

NICOLAE OACA
Editor

Calea Mosilor No. 241
Bl. 47, Sc. 3, Ap. 71
Sector 2, Bucharest 020874
Romania
Tel: 00 40 766 505 784
Fax: 00 40 21 210 12 24
E-mail: nicolae_oaca@yahoo.com
gcn@comsoc.org

OCTAVIAN FRATU AND SIMONA HALUNGA, Associate Editors
Email:
octavian.fratu@elcom.pub.ro, simona.halunga@elcom.pub.ro
JACOB BAAL-SCHEM, Chapters Corner Editor

Regional Correspondents
HOSSAN AFIFI, France • BORHANUDIN MOHD ALI, MALAYSIA
JACOB BAAL-SCHEM, Israel • DINKO BEGUSIC, Croatia
OMAR CHERKAOUI, CANADA • PAULO DE SOUSA, European Union
VOULA GEORGOPOULOS, Greece • SILVIA GIORDANO, Switzerland
RAM G. GUPTA, India • CARLOS HIRSCH, Mexico
MILAN JANKIVIC, SERBIA • LIANG XIONG JIAN, China
HENRICH S. LANTSBERG, RUSSIA • ARTUR LASON, Poland
JOSÉ MARIA MALGOSA-SANAHUJA, Spain • NICOLAE OACA, ROMANIA
IRADJ OUVEYSI, AUSTRALIA • ALGIRDAS PAKSTAS, UK
GIANCARLO PIRANI, Italy • K. R. SUBRAMANIAN, Singapore
HELIO WALDMAN, Brazil

A publication of the
IEEE Communications Society

Promotional Activities

4. Worked in cooperation with IEEE Communications Society Karachi Chapter in Pakistan in the areas of cellular mobile phones, fixed line telecommunications (long distance and international, LDI, and local loop, LL), and satellite communications.

5. Supported and initiated a scheme for IETE networking and e-education, making IETE a virtual institute of learning through IETE's VPN connecting 50-odd centers/subcenters all over the country.

6. Celebrated along with IETE World Telecommunication Day; a special lecture was organized: "ICTs: Leading the Way to Sustainable Developments," V. K. Aatre, DRDO, May 2004.

7. Collaborated with Durrani to assist projects abroad that employ telecommunications to improve quality of life, and bring economic and social benefits to people living in remote areas. Typical examples are projects in telemedicine, distance learning, and disaster relief. Current focus is on six countries in South Asia: Afghanistan, Bangladesh, India, Nepal, Pakistan, and Sri Lanka.

8. The Chapter has taken initiatives to form IEEE Women in Engineering Chapters. The activity has now been picked up by other centers.The objective of the Women in Engineering (WIE) affinity group is to help support the advancement of women in technical and scientific professions, and recognize achievements of women in this field.

9. The Chapter has taken initiatives to renew the membership of some members after a gap of five to ten years. These members had lost interest in IEEE; it is now revived.

10. The Chapter sponsored Prof. B. Pal for the Distinguished Lectures Program of LEOS and ComSoc.

11. The Chapter has sent its technical input to *Global Communications Newsletter*, and members have been published in *IEEE Communications Magazine* from time to time.

12. The Chapter has widely circulated the offers made by IEEE-LEOS Society for free membership and half-year free memberships to ComSoc for students. Thirty-four applications were sent to the LEOS office.

13. The Chapter sponsored 10 applications for elevation to IEEE Senior Members.

14. The Chapter coordinated the DLT Programs arranged by the Communications Society in India.

15. The Chapter has widely circulated Notifications and New Conferences announcements from various IEEE societies.

16. The Chapter provided the proceedings of various conferences organized by IEEE in India to some developing countries free of cost.

17. The Chapter motivated members from India to participate in the IEEE Annual Elections and also in the IEEE ComSoc and LEOS Society Elections.

18. The Chapter provided functional support to IEEE ComSoc in maintaining Sister Society cooperation with the Institution of Electronics and Telecommunications Engineers, India.

19. The Chapter provided technical support in reviewing some articles for IEEE publications.

20. The Chapter Chair participated in the Regional Chapter Chairs Congress (RCCC) organized by the AP Region of ComSoc, and presented a presentation and initiated discussion on "How to Promote ComSoc Activities in AP Region" at the AP RCCC, Beijing, China, August 2004.

21. The Chapter provided necessary input for publication of *IEEE India Council Bulletin and Delhi Section Magazine*.

22. The Chapter provided technical support in providing IT Education and training in Vietnam through the Indian Organization NIIT.

23. The Chapter donated free copies of IEEE magazines to some engineering colleges, particularly women's engineering colleges.