

Guest Editorial

Analysis and Synthesis of MAC Protocols

I. INTRODUCTION

IN RECENT years, we have experienced an unprecedented growth in the development and deployment of multimedia multiservice wireless and wireline telecommunications systems and networks. Because of the incredible advance in optical communication technology, it is becoming very cheap to deploy network capacity when it is required in large quantities. This is exemplified in the backbone network where it is now feasible to provide terabit/s capacity on a single fiber. As a result, the high-speed telecommunications backbone networks are being designed based on architectures that are much simplified in their networking intelligence taking advantage of the high capacity and the relatively smooth traffic resulted from heavy multiplexing. In contrast, the capacity required by access nodes is between one-thousandth and one-millionth of the capacity available in the backbone. Despite the fact that the overall utilization in the access network is typically very low, especially in the residential component of the network, many user applications induce highly bursty traffic flows that result in periods of congestion. In addition, unlike core backbone networks, access networks rely, in many cases, on the wireless medium. Hence, capacity is limited and more expensive than in the case of optical fiber, and transmission is more error prone requiring further capacity for error correction and packet retransmission. Consequently, the access part of the network has been, and will likely continue to be, the most costly part of the information infrastructure. It is therefore important to design the access network to be cost-effective, and an important part of such a design is an efficient and reliable medium access control protocol (MAC).

The MAC protocol layer functions just above the physical layer and is designed to ensure orderly and fair access to a shared medium. It manages and controls the apportionment of access capacity among many active end users. A capable MAC protocol should allow the network service provider to synthesize services that meet specified quality of service (QoS) requirements, while its implementation should be efficient, fair, and simple. Meeting these conflicting requirements has been a challenge for MAC designers since the invention of the ALOHA protocol in the late 1960s. Significant research efforts have been made in this area, which led to many ideas, solutions, implementations, and standards. However, despite this extensive research effort, there is still a strong need for continuing MAC research.

The evolution of new telecommunications media such as wireless and hybrid-fiber-coax, the continual improvement in computing and DSP speeds, and the introduction of new multimedia applications and services present new challenges and opportunities to MAC designers.

The Guest Editors have selected for this issue a group of papers that represent the current state of the art in MAC technology research. The 19 papers appearing here have been chosen out of 70 submissions. These papers cover a wide range of MAC related topics, including new ideas on performance analysis and enhancement, QoS improvements, and efficient operation. This issue is especially focused on MAC design and analysis for emerging applications. These include MAC's for mobile, wireless, *ad hoc*, satellite, cable modem, and personal communications networks. Design goals include the implementation of an efficient multiple-access communications network system that meets QoS objectives for the support of multimedia services and applications.

II. MAC TRADEOFFS: POLLING/RESERVATION VERSUS CONTENTION

The fundamental MAC tradeoff between polling, typically by reservation, and contention, or, equivalently, the tradeoff between efficiency and simplicity, has been an important issue debated and analyzed for the last 30 years. The paper entitled "Activity Polling and Activity Contention in Media Access Control Protocols," by Charzinski, provides analytical performance evaluation and quantitative means for comparison between the two approaches. The next paper, "CSMA with Reservations by Interruptions (CSMA/RI): A Novel Approach to Reduce Collisions in CSMA/CD," by Foh and Zukerman, presents a scheme which is a compromise between the two approaches, where collisions are significantly, but not entirely, reduced for the cost of some additional complexity. A performance comparison to other collision and reservation protocols then follows.

III. QoS AND SCHEDULING

One of the prominent trends in design of modern MAC protocols is to employ a central rather than a distributed architecture. Request signals are sent by users to a central controller which allocates bandwidth based on a given scheduling algorithm. The use of such a scheduler allows some control over the capacity allocated to different services, and hence the control and provision of QoS requirements. This section provides several examples of

the effective use of such a scheduler applied to a range of MAC protocols.

Bushmitch *et al.*, in the paper "Supporting MPEG Video Transport on DOCSIS-Compliant Cable Networks," propose a new enhanced scheduling algorithm for variable bit rate (VBR) video over data over cable system interface specification (DOCSIS). The advantage of the new scheme over the existing one is demonstrated by simulations. In the paper "Polling- and Contention-Based Schemes for TDMA-TDD Access to Wireless ATM Networks," by Musumeci *et al.*, the authors demonstrate that in the case of TDMA-TDD wireless ATM access, an adaptive scheduler can improve QoS and efficiency for a contention-based scheme beyond that of polling for nonreal-time VBR and UBR traffic conditions. A MAC for broadband wireless local loop, based on multicarrier CDMA having dynamic bandwidth allocation capabilities, is proposed and studied in the paper "IP QoS Delivery in a Broadband Wireless Local Loop: MAC Protocol Definition and Performance Evaluation" by Baiocchi *et al.*

The paper "Contention-Free Distributed Dynamic Reservation MAC Protocol with Deterministic Scheduling (C-FD³R MAC) for Wireless ATM Networks," by Kang *et al.*, provides a MAC which implements a scheduling algorithm which aims to maximize efficiency while meeting QoS requirements for the real-time-VBR traffic class. Fantacci and Nannicini, in their paper "Performance Evaluation of a Reservation TDMA Protocol for Voice/Data Transmission in Personal Communication Networks with Nonindependent Channel Errors," propose and study the performance of a new random reservation TDMA scheme. They demonstrate that efficient integration of voice and data is achievable.

IV. INTELLIGENT MACS

Traditionally, MAC's were designed to be simple. The need for speed and simplicity in the MAC layer outweighed the benefit of efficiency. This is still evidenced by the wide use of Ethernet. However, with the rapid advances in computing speed, it is becoming plausible to design more complex MAC protocols in order to improve efficiency. For example, intelligent software could support MAC protocols in achieving better utilization and in meeting QoS requirements. We have three examples of such intelligent MACS.

In the paper "Intelligent Medium Access for Mobile *Ad Hoc* Networks with Busy Tones and Power Control," by Wu *et al.*, the authors demonstrate that an increase in utilization can be achieved by implementing a MAC which adaptively controls the power in mobile *ad hoc* networks. Yuang and Tien, in their paper "Multiple Access Control with Intelligent Bandwidth Allocation for Wireless ATM Networks," propose an integrated MAC/bandwidth allocation system incorporating, in particular, a self-constructing neural-fuzzy inference network for self-similar traffic prediction. Through analysis and simulation, they demonstrate the benefit of their approach with respect to network utilization, QoS satisfaction, and efficiency. Instead of using a specific MAC protocol, the paper "Meta-MAC Protocols: Automatic Combination of MAC Protocols to Optimize Performance for Unknown Conditions," by Farago *et al.*, pro-

poses that a collection of MAC protocols will be used, and the choice for the best one to use should be done automatically in response to changing and unpredictable network conditions.

V. MACS FOR MOBILE WIRELESS AND SATELLITE NETWORKS

Access control is a key issue in the next-generation broadband mobile wireless and satellite networks. Generic bandwidth allocation and efficient spectrum utilization are most critical in the system design. This section covers many of the most important research issues in the area of wireless MACs. In the paper "SEAMA: A Source Encoding Assisted Multiple Access Protocol for Wireless Communications," Alasti and Farvardin present a new access protocol which exploits the time variations of the speech coding rate, through statistical multiplexing, to efficiently use the available bandwidth and to increase the link utilization. The second paper, "A Near-Optimum MAC Protocol Based on the Distributed Queueing Random Access Protocol (DQRAP) for a CDMA Mobile Communication System," by Alonso *et al.*, gives an overview of a new near-optimum MAC suitable for a CDMA system and minimizes the total number of spreading codes needed to achieve a given throughput.

The next paper, "Design of a Medium Access Control Feedback Mechanism for Cellular TDMA Packet Data Systems," by Balachandran *et al.*, deals with the introduction of a simple and robust packet channel feedback mechanism for an IS-136 based TDMA packet data channel with flexible resource allocation on both the uplink and the downlink. In the paper "A Nonpreemptive Priority-Based Access Control Scheme for Broadband *Ad Hoc* Wireless ATM Local Area Networks," Deng and Chang describe a nonpreemptive priority based access control scheme which modifies the CSMA/CA protocol in the contention period supporting various qualities of service while maintaining high bandwidth utilization. The paper "Design of an Access Mechanism for a High Speed Distributed Wireless LAN," by Gummalla and Limb, presents a novel wireless transceiver architecture that mitigates the hardware cost by overlaying the data channel and the feedback channel in the same frequency band. The proposed protocol called wireless collision detect (WCD) greatly decreases the collision probability. Finally, Koraitim and Tohme, in their paper "Performance Analysis of Multiple Access Protocols for Multimedia Satellite Networks," analyzes several TDMA-based packet multiple access protocols for multimedia satellite networks and proposes new mechanisms for access optimization.

VI. IEEE AND ETSI STANDARDS

The Institute of Electrical and Electronic Engineers (IEEE) and the European Telecommunications Standards Institute (ETSI) are very active in the standardization of MAC protocols for wireless LANs and hybrid fiber coaxial (HFC) networks. This section includes three papers facing specific issues related to standard MAC protocols: IEEE 802.14, IEEE 802.11, and HIPERLAN Type 1. The latter is being specified by ETSI.

In a two-way hybrid fiber coaxial (HFC) network, such as the existing IEEE 802.14 standard, the headend determines how many minislots to allocate to manage collisions. The paper "Sta-

tistically Optimized Minislot Allocation for Initial and Collision Resolution in Hybrid Fiber Coaxial Networks,” by Yin and Lin, proposes a minislot allocation (SOMA) algorithm to optimize minislot throughput based on statistical estimation.

The capacity of the MAC protocol adopted in the IEEE 802.11 standard for WLANs is analyzed in the paper “IEEE 802.11 Protocol: Design and Performance Evaluation of an Adaptive Backoff Mechanism,” by Cali *et al.* The paper presents an algorithm for the dynamic tuning of the backoff parameters. Through a Markovian analysis, it is shown that the capacity of the IEEE 802.11 protocol with the dynamically tuned backoff approaches its theoretical throughput limits in all the configurations analyzed.

The paper “HIPERLAN/1 MAC Protocol: Stability and Performance Analysis,” by Anastasi *et al.*, analyzes the MAC protocol by focusing on the influence of traffic burstiness on protocol performance, and on the capability to differentiate service provided to delay-sensitive and best-effort traffic classes.

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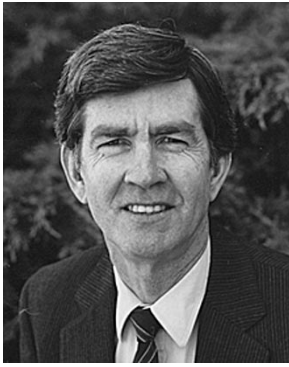
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Luciano Lenzini received the degree in physics from the University of Pisa, Italy.

He joined CNUCE, an institute of the Italian National Research Council (CNR) in 1970. Starting in 1973, he spent a year and a half at the IBM Scientific Center in Cambridge, MA, working on computer networks. He has since directed several national and international projects including (in chronological order): RPCNET, the first Italian packet switching network; STELLA, the first European broadcasting satellite network and OSIRIDE, the first Italian OSI network. His current research interests include integrated service networks, the design and performance evaluation of both LAN/MAN MAC protocols and packet-based radio access mechanisms for third generation mobile systems. He is author or coauthor of numerous publications in these fields. He is currently on the Editorial Board of Computer Networks and ISDN Systems and a Member of IEEE Communications Society. He has been on the program committees of numerous conferences and workshops, and served as chairman for the 1992 IEEE

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John O. Limb (SM'72—F'78) received the Ph.D. degree in electrical engineering from the University of Western Australia in 1967.

He joined Bell Laboratories, Holmdel, NJ, in 1967 and became Department Manager, Visual Communications Research Department in 1971. He worked for a number of years on the coding of color and monochrome picture signals to reduce channel capacity requirements and has published widely in this area. He also worked and published in the areas of visual perception, office information systems and local/metropolitan area networks. In 1984 he joined Bell Communications Research and in 1986 he was appointed Director of the Networks and Communications Laboratory at Hewlett-Packard Laboratories, Bristol, England. In June 1989, he returned to the U.S. with Hewlett-Packard as Lab Manager, Technology Analysis, Cupertino, CA. In 1992 he returned to HP Labs as Lab Director, Media Technology Lab. In July 1994 he joined Georgia Institute of Technology to accept the Eminent Scholar in Advanced Telecommunications chair in

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Dr. Limb is past Editor-in-Chief of the IEEE TRANSACTIONS ON COMMUNICATIONS and the IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS. He was co-recipient of the 1990 IEEE Alexander Graham Bell Medal.



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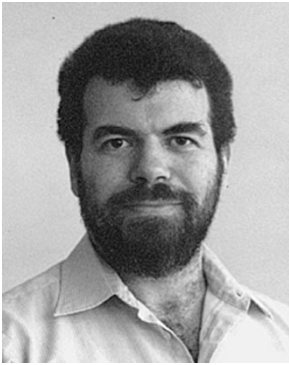
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Since 1970, he has been on the faculty of the UCLA School of Engineering and Applied Science where he is currently a Professor in the Electrical Engineering Department. He has had extensive research, publications, consulting, and industrial experience in the design and analysis of commercial and military computer communications and telecommunications systems and networks. At UCLA, he is leading a large research group. He also serves as President of IRI Computer Communications Corporation, a leading team of computer communications and telecommunications experts engaged in software development and consulting services.

Dr. Rubin served as co-chairman of the 1981 IEEE International Symposium on Information Theory; as program chairman of the 1984 NSF-UCLA workshop on Personal Communications; as program chairman for the 1987 IEEE INFOCOM conference; and as program co-chair of the IEEE 1993 workshop on Local and Metropolitan Area networks. He was elected Fellow of IEEE for his contributions to the analysis and design of computer communications networks. He has served as editor of the IEEE TRANSACTIONS ON COMMUNICATIONS, of the ACM/Baltzer *Journal on Wireless Networks*, of the *Kluwer Journal on Photonic Network Communications*, and of the *Wiley InterScience International Journal on Communications Systems*.



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