PROTOCOLS FOR ATM NETWORKS: SURVEY, CLASSIFICATION AND NEW TRENDS

José Luis González-Sánchez (*) and Jordi Domingo-Pascual (**)

(*) Deparment of Computer Science, Universidad de Extremadura, Escuela Politécnica de Cáceres. Avda. Universidad S/N. (10.071) Cáceres (Spain)
Phone: +34 927 257 259 Fax.: +34 927 257 202 E-Mail: jlgs@unex.es

(**) Deparment of Computer Architecture, Universitat Politècnica de Catalunya Campus Nord, Modul D6, Jordi Girona 1-3 (08034) Barcelona (Spain)
Phone: +34 93 401 6981 Fax: +34 93 401 7055 E-Mail: (jordi.domingo@ac.upc.es)

Abstract

This paper surveys novels and/or sophisticated concepts which are included in the development of the new protocols to provide current networks with the high performance that the multimedia applications need for their definitive implantation. We pay special attention to the concept of native-mode ATM (i. e. N^3, CONGRESS and kStack) and transport protocols developed for ATM technology (i. e. SHiPP). SMART, MCMP or MWAX are the most representative examples of many-to-many (multicast) ATM protocols. We also shall present several proposals to support IP over ATM technology (classical IP-over-ATM, EPD, RED, IP switching, MPOA, etc). This work concludes with a discussion of new research or new trends such as the active (programmable) networks, or mobile agents.

1.- INTRODUCTION AND MOTIVATIONS

The current and growing demand of applications related to multimedia information such as video-conferencing, audio-conferencing, video on demand or colaboratories (whiteboards, tele-working, tele-medicine), and their coexistence with more classical applications (data, file transfer, WWW, etc.) requires communications thecnologies capable of offering high performance. This high performance is directly related to the Quality of Service (QoS) and, particularly, with easily measured techniques such as the bandwidth and the bit rate transmission (throughput), the delay of transfers; the variations in delays (jitter); the reliability in transmissions; the characteristics of multicast to dispersed groups of users and the possibility of managing different classes of service or information flows in multiclass networks. However, in order to provide applications with these characteristics, we need to revise, enhance and to extend the current architectures, services and communications protocols. In the last couple of years the research has discussed very important contributions whose principal goals are to offer some of the above mentioned characteristics to the new applications currently demanded. The main goal of this paper is to present an overview, without being exhaustive, of past and current communication protocols for ATM networks. We shall also review typical concepts and new proposals in this active area in networking.

The rest of the paper is organised as follows: Section 2 surveys the concept of native-mode protocols in the context of ATM networks and describes several transport protocols. Section 3 discusses the multicast transfers as an important goal for a connection-oriented technology such as ATM. At present, point-to-multipoint and multipoint-to-multipoint transfers are generating interesting research as regards some multicast protocols at the transport layer for these kinds of high-speed networks. Section 4 summarizes the different proposals of IP traffic over ATM technology in an attempt to integrate the more extended flows of information over the more advanced technology. In section 5 we present the new trends and open issues in aspects such as active networks, protocol boosters and mobile agents. We conclude at section 6.

2.- NATIVE-MODE ATM STACK PROTOCOLS AND TRANSPORT PROTOCOLS

This section shows some attempts [1-13] to develop native-mode ATM protocols and it is an important issue to be tackled in future research. Furthermore, the ATM Forum has defined the specifications, but there is also very important research on [1,5] native-mode ATM protocols. In this section we shall review the most important current work in native ATM protocols.

- Reference [2] show the design, implementation, and performance of one of the first end-to-end ATM transport services to provide flow controlled data transfer specifically for ATM networks. The stack proposed minimizes overhead, takes advantage of AAL-5 functionality and compares the transport layer with TCP.
- Article [3] presents N^3 (*Native Non-broadcasting medium access Networking*) a native-ATM protocol stack which provides lightweight native communications protocols. The N^3 stack has been designed to provide advanced multimedia services to broadband residential communities. This document describes an architecture to provide native ATM applications.
- Paper [5] describes the semantics of such a protocol stack and explores a new protocol architecture tailored for an ATM environment and suitable for multimedia applications. The design is based on three basic principles: separation of control and data flows; minimal overhead and duplication of functions, and applications access to ATM level QoS guarantees.
- Reference [6] provide a native-mode ATM service architecture capable of offering full access to ATM's capabilities for native mode ATM applications. The elements of the architecture proposed are responsible for efficient data transfer over ATM such as end-to-end error, flow and congestion control; datagram transfer and VC multiplexing.
- Paper [7] introduces CONGRESS (CONnection oriented Group-address RESolution Service), another efficient native ATM protocol for resolution and management of multicast group addresses in a large ATM cloud. The CONGRESS service resolves multicast group addresses and maintains their membership for applications. The IMSS service [8] is supported over CONGRESS.
- Finally, reference [9] presents kStack, a new native-mode ATM transport layer in user space with support for QoS. This implementation is run on Unix, Windows-NT and other operating systems, and is based on and compatible with the original works of [2] Native-Mode ATM Stack, mentioned above.

For the past couple of decades there have been numerous and interesting attempts to design transport-layer protocol. Reference [12] presents a complete survey of issues in high-speed transport protocol design (TCP, TP2, TP3, TP4, X.25, FINE) as well as references to several other transport protocols. Reference [13] also presents the results of a survey of the literature on the characteristics of high-speed protocols, protocol architectures and implementation techniques. The literature in this field presents several transport protocols and architectures for high speed networks. Among those we surveyed, the following are the most important.

- Reference [2] present the design, implementation and performance of a native-mode ATM transport layer. This ATM stack consists of three main entities: the application entity and the signalling entity in user space; and the transport entity inside the kernel to achieve high performance.
- Paper [5] provides an excellent didactic architecture and protocol stack for multimedia applications in native-mode ATM. We have described this protocol architecture in the above section.
- Reference [14], SHiPP (Super High speed Protocol Processor), is a programmable architecture for protocol processing that increases speed by fine-grain parallel processing. In this paper SSCOP [15] (standardized as a signalling protocol for B-ISDN by ITU-T) is selected as a benchmark protocol for SHiPP. The paper also describes how to implement SSCOP protocol on SHiPP.
- Article [16] addresses the problem of supporting network-based parallel computing (High Performance Distributed Computing) over ATM networks and comes to the conclusion that the introduction of cell-based retransmission mechanisms does contribute to enhancing the performance of ATM network-based parallel computing. The authors suggest two cell-based transport mechanisms based on SSCOP.
- Reference [17] presents an adaptive network layer protocol for VBR video transport. This protocol minimizes buffer requirement, end-to-end delay and jitter of frames. The authors demonstrate the adaptability of their protocol and present a fair buffer/bandwidth allocation algorithm.

- Paper [18] deserves special attention since it describes the architecture, design, simulation, implementation and experiences of the Tenet Real-Time protocol suite, a connection-oriented internetworking set of protocols based upon resource reservation. Tenet is a set of network protocols capable of transferring real-time streams in heterogeneous packet-switching internetworks with guaranteed quality, and can coexist with the Internet protocols. Reference [19] outlines an efficiency comparison of these and other real-time transport protocol.
- Finally, we should note that network protocols have normally been implemented inside the kernel or in a trusted user-level server. Reference[20] describes the design and implementation of transport protocols as user-level libraries whose goal is to explore alternatives to a traditionally monolithic structure and outside the kernel.

3.- MULTIPOINT PROTOCOLS

Reference [21] is a current paper that surveys multicast transport protocols for the Internet such as MTP-2, XTP, RTP, SRM, RAMP, RMTP, MFTP, STORM, etc. The IETF and the IRTF (such as the ITU-T and the ATM Forum) also have been subject to active research in this field, and reference [21] reviews several existing kinds of multicast transport and classifies them according to the taxonomy of several features (data propagation, reliability mechanisms, retransmission, flow and congestion control, group management, etc.).
In a multicasting environment, there are several important considerations. First, as the number of receivers increases, scalability of the protocol becomes a problem. Feedback implosion results if each receiver acknowledges receipt of each packet and the number of acknowledgements routed to the sender becomes unmanageably large. Furthermore, the retransmission of lost packets would waste bandwidth. This and other problems are addressed in [22] which presents several policies for multicast applications. Currently there are not many proposals in this important topic for ATM, but we shall survey some of them.

- SMART (shared many-to-many ATM reservations) [23] is a protocol to control a shared ATM multicast tree supporting many-to-many communications. This proposal has important features such as: it reside entirely in the ATM layer and need not require any server; it should support one or several VCCs (and also VPCs) whose number is freely configured and independent of the number of endpoints; it should use the concept of data blocks as in ABT capability [24] and also allow VCCs of the CBR,VBR or UBR.
- SEAM (Scalable and Efficient ATM multicast) [25] proposes a scalable and efficient mp-mp multicast architecture for ATM networks, which uses a single VC for a multicast group consisting of multiple senders and receivers without changes in the AAL5 of the ATM. This scheme uses a single shared spanning tree for all senders and receivers. Each multicast group has an associated “core”, which is used as the focal point for routing signalling messages for the group.
- We conclude this section by presenting the Multiparty Conference Management Protocol (MCMP) [26], which, although not specifically intended for ATM, consists of an end-to-end distributed session/transport level protocol developed for group management of desktop conferencing applications.

4.- IP-ATM INTEGRATION

In the literature there is a variety of research on how to implement the IP protocol over ATM networks such as: classical IP over ATM, LANEmulation, IP switching, Tag switching, Address resolution (NARP) and MPOA. In the following section we shall revise these proposals. The main problem in integrating IP and ATM is to exploit the high speed and throughput of switching technology and also the scalability and flexibility of (connectionless) IP. Moreover, the differences already mentioned cause duplicated functionality (IP and ATM require their own routing protocols as well as management and control functions).

- The RFC 1577 “Classical IP over ATM” is an approach for running TCP/IP over ATM using the ATM switching environment as data links for IP [27]. There is a problem, however while IP-over-ATM provides a platform of data communications over heterogeneous networks, the IP applications cannot enjoy the ATM QoS because IP-over-ATM hides the layers underneath the ATM.
- IMSS (IP Multicast Shortcut Service) [8] presents a novel solution for IP multicast shortcut routing over a large ATM cloud. The great problem is to scale well to a large ATM environment and IMSS

overcomes scalability problems by deploying a dynamic mixture of multicast servers and full meshes of direct connections.

- NHRP (Next Hop Resolution Protocol) was developed as a means of facilitating inter-LIS (Logical IP Subnets) VCs in order to utilize the potential benefits of ATM which are lost with the classical model. NHRP is an inter-LIS address resolution mechanism that maps a destination's IP address to the destination's ATM address in cases where the destination resides within the same ATM cloud as the source. Although NHRP unquestionably overcomes some of the weaknesses of the classical IP over ATM models, it is not without its own limitations such as its inability to directly support multicast [28].
- IP switching (ATM under IP) is an alternative to obviate the end-to-end ATM connection and to integrate directly over ATM hardware while holding the connectionless IP model. IP switching supports multicast IP. An IP-switched router is equal to an ATM switch, without any modification hardware, but completely removes the software resident in the control processor above AAL5 (signalling, routing protocol, address resolution, etc.). IP switching is a connectionless approach to integrate IP with fast ATM switching hardware, and combines the simplicity and robustness of IP with the speed and capacity of ATM [29].
- CSR (Cell Switch Router), like IP switching, is based on hybrid ATM switch/IP router designs which allow coexistence of hop-by-hop IP forwarding with direct VC cut-through modes of service. This switch/router contains all the usual functionality of conventional IP routers and thus is capable of providing a connectionless IP forwarding service [28].
- On the other hand, the proposal Tag switching consists of a control component and a forwarding component. The control component is responsible for creating and maintaining a Tag Information Base (TIB) among a group of interconnected Tag-switched routers. The forwarding component uses the inputs in TIB and the tag of each packet and forwards them to their corresponding routers. The TDP protocol (Tag Distribution Protocol) is responsible for distributing the information into Tag-switched routers. There are three schemes for allocating a tag to a route. They are the downstream allocation scheme, the downstream-on-demand allocation scheme and the upstream allocation scheme [30].
- ARIS (Aggregated Route-Based IP Switching) [28], like Tag switching, is an approach to IP-over-ATM in which VC association is completely topology-driven. Labels are allocated based upon information available from the routing protocol, and virtual connections are established in advance of traffic being received. ARIS introduces the concept of "egress identifier" type to define granularity. For each value of "egress identifier" the ARIS protocol establishes an mp-p tree.
- Besides the technical IP switching already cited there is the official proposal of the ATM Forum, the MPOA (Multiprotocol Over ATM) based on other technologies such as LANE (which provide bridging at level 2) and NHRP (routing level 3). With routing and bridging, MPOA support non-routing and routing protocols (IP, IPX, DECnet, Appletalk) and that provides the multiprotocol adjective at MPOA. Besides not providing QoS directly, this is offered for LANE, and also the multicast support. Finally we note that, while the IETF proposes the support of IP over all technologies in layers (such as ATM), the ATM Forum proposes that all protocols of level 3 (as IP) run over ATM.
- There is another set of solutions that provides on ATM buffer management scheme to improve throughput and fairness while minimizing delay of TCP data traffic over the ATM-UBR class of service. These solutions provide fair, throughput and delay control. EPD (Early Packet Discard) and FBA (Fair Buffer Allocation) are two schemes of ATM buffers management to provide high performance and fairness. EPD is a technique to maintain packet integrity during overload in ATM switches. It is an ATM buffer management mechanism designed to ensure high end-to-end throughputs for bursty data applications during overload periods. EPD is one of the mechanisms proposed for congestion management in ATM networks. Reference [31] presents a study of throughput of EPD with several buffer sizes to find the balance between this size and the performance of EPD. On the other hand, PPD (Partial Packet Discard) is another scheme of congestion control for ATM-UBR. PPD discards the ATM cells that overflow the buffer. The difference from EPD is that PPD discards partial packets. Paper [32] shows how PPD alleviates the effect of packet fragmentation, and also shows a variant of EPD that provides better throughput and fairness.
- RED (Random Early Detection), like EPD and FBA, is another ATM buffer management scheme to improve throughput and fairness while minimizing delay of TCP data traffic over the ATM-UBR class of service. This mechanism tries to keep the average queue size of gateways as low as possible while

allowing occasional bursts. RED monitors the average queue size and hence avoids packet drops when the network load changes [33].

- The AREQUIPA (Application REQUested IP over ATM) protocol [34], is a mechanisms that allows IP applications to request SVCs with guaranteed QoS. The RFC2170 describes this protocol as a mechanism to establish end-to-end ATM connections.
- Finally, we cite another proposal for IP and ATM integration. The resource ReSerVation Protocol (RSVP) [35] provides QoS to IP flows or IPQoS. IP provides best effort datagram delivery that is sufficient for most of the conventional applications (E-mail, ftp, WWW and news).
- Another open issue is the side-by-side integration of ATM and Internet protocols when we use native ATM applications, however there is no work on that at present.

5.- NEW TRENDS

Active, open and programable networks is a new technical area to explore ways in which networks elements may be dynamically reprogrammed by network managers, network operators or general users to accomplish the required QoS and other features as customized services. This offers attractive advantages, but also important challenges in aspects as performance, security or reliability. Hence, this is an open issue to researchs and developments in customized routings and protocols to move the service code, placed outside the transport network, to the network's switching nodes.

- The literature in this field studies several mechanisms to obtain advantage from active nodes. Paper [36] is an excellent review of this new research field. This work discusses two expositions to build active networks: the idea of programmable switches and the concept of capsules. It also presents some of the most interesting architectures for active networks such as ANTS, ARM, SRM, Switchware, Active Bridge, etc. A network is active if in its multicast distribution trees there are active nodes with the capacity to execute the user's programs, and also if it implements mechanisms of code propagation. Many of the advantages of active protocols are achieved by installing active nodes at strategic points.
- Reference [37] demonstrates how to improve the performance of distributed applications by using active networks. This paper describes and analyses several active protocols that provide novel network services. Its principal goal is to demonstrate that there are network services that involve processing at intermediate nodes and the use of such services can lead to better end-to-end performance.
- Articles [38-40] are other very interesting references in active networks, and [41] presents an approach for building and dynamically deploying network protocols. The ANTS (Active Network Transfer System) protocol architecture is an active network toolkit, in which new protocols are automatically deployed at both intermediate nodes and the end system by using mobile code, demand loading and caching techniques. Paper [42] compares two active network architectures: ANTS and the Messenger System (M0). This technical report also presents a robust audio multicast protocol and a layered video multicast protocol with the two active network systems, ANTS and M0.

  [43] shows how to build an active node into IPv6, which incorpores ANTS in its architecture. The report describes the design and implementation the network node as active network capsule based model.
- Paper [44] shows as mobile software agents offer a way of controlling distributed systems with robustness and simplicity. The article [45] proposes the application of Mobile Agent Technology (MAT) to the telecommunication service of Intelligent Network architecture. This work concentrates on the discrete approach of active networking, where service deployment is performed separately (i.e., outband) from service processing, in contrast to the integrated approach of active network research, where the transmitted packets, or capsules, contain -in addition to the data- program fragments responsible for processing the data at the programmable switches. Also, [46,47] are a complete study on intelligent agents and mobile software agents as an emerging technology for telecommunications managent.
- Another novel topic is presented in [48] as a methodology for protocol design. Protocol boosters are a new contribution to programmable or active networks. An advantage of boosters is that they can easily be injected into today's systems without a wholesale change in the network infrastructure. On the other hand, [49] proposes the agent communication concept for multimedia communications services in wide area networks. This paper introduces an agent-oriented software architecture and proposes the concept of agent communication for multimedia communication service.

- The above concepts such as active networks, protocol boosters or software agent are proposed and developed for IP networks, however the proposals are insufficient for ATM networks and reference [50] is an example of this recent researche in ATM. The paper shows mobile software agents used to implement robust operation and maintenance functions in ATM networks. The agents have a role similar to that of OAM cells in the ATM standards, they are transmitted between control entities at regular intervals using predefined resources. The difference between the mobile agents and the OAM cells is that they can contain code as well as state information. Reference [51] proposes also Tempest how a way to partition switch resources on behalf of multiple control entities but also maintain the network operator's control of overall resource utilization.

  Previously, the authors of [52] proposed ATM flow control schemes through a semiautonomous multi-agent system and showed how using a high-performance agent may improve the performance of the network by a factor of 10%. Also, the agent scheme may be a valuable strategy for ATM traffic management, and the article [53] proposes and explotes a multi-agent scheme which integrates the advantages of the existing strategies for ATM traffic management.

  The ATM performance management is one of the more challenging network management problems, and the article [54] describes the application of software agent technology to this problem and proposes a new architecture and supporting technology for network management. For exemple, this work describes how the network may be partitioned so that each agent is responsible for managing VPCs on a single link. In congestioned networks the agents then all locally redistribute the capacity as appropiate.

  Also, a delegated agent may be used to execute tests that diagnose a problem and then reconfigures the device to recover from it. For some problems, the recovery routines may involve coordination and even delegation of additional agents. Papers [55,56] describe some aspects in distributed management by delegation, an also, severals delegated agents to management functions to the network elements in order to automate the monitoring, analysis, and control of these devices.

  The QoS adaptation is another field of ATM technology which the agents can offer attractives features. The paper [57] suggests the use of QoS monitoring agents in the ATM switches as well as in the end systems. This interesting article reviews the service classes ATM, the traffic parameters and the QoS parameters and proposes agents for QoS adaptation and monitoring, in a way that allows automatic recovering, if possible, from all the QoS violation.
- The IEEE P1520 reference model [58] is the standard IEEE for programmable network interfaces, which is being applied to ATM, IP and SS7-based networks.

We have shown how the field of programable and intelligent networks is a hot technical area and to conclude we note, for exemple, that the European research program ACTS sponsored several important projects dedicated to explore the usage of agent technologies in the area of telecommunications [59].

6.- CONCLUSIONS AND FUTURE WORK

We have seen how ATM is already an emerging technology with new proposals and protocols to support new applications which require a guaranteed network performance and QoS (throughput, delay, delay jitter and reliability). The ATM classes of service have been gradually redifined to support new and classical applications. The native ATM protocols developed to support the native ATM classes of service are of special importance. We are aware of the importance of protocols at the transport layer; the necessity to support multi-party real-time communications (including multicast) and the scalability features provided by ATM technology. We should be realistic, however, and consider the importance of the proposal to create protocols that offer a real-time service in an integrated-services heterogeneous internetwork. Equally important is the proposal that protocols should coexist with the Internet protocols. The use of active techniques in ATM networks is an important and new mechanism in order to build a programmable network.

We have briefly (an extended version of this document is located as technical report at http://www.ac.upc.es/recerca/reports/DAC/1999/UPC-DAC-1999-9.ps.Z) revised and classified a set of protocols described in the literature and from them we have acquired an important background and learned interesting lessons that we are making use of the proposal and evaluation of a new scalable and native protocol adapted to the ATM classes of service. Future work will include our new protocol.

References

[1] ____ , "Native ATM Service: Semantic Description Version 1," *ATM Forum Technical Committee, ATM Forum Document af-saa-0048.000*, (Feb. 1996).

[2] R. Ahuja, S. Keshav and H. Saran, "Design, Implementation, and Performance Measurement of a Native-Mode ATM Transport Layer (Extended Version)," *IEEE/ACM Transact. on Networking*, Vol 4, Nº 4, (August 1996).

[3] T. Zahariadis, J. Sanchez-P, C. Georgopoulos, V. Nellas, T. Arvanitis, D. Economou, and G. Stassinopoulos, "Native ATM Protocol Stack for Internet Applications in Residential Broadband Networks," *Multimedia Applications Services and Techniques ECMAST'98, Springer*, (May 1998).

[4] ____ , "ATM Name System Specification", Version 1.0, *ATM Forum*, (Nov. 1996).

[5] D. Kandlur, D. Saha and W. Willebeck, "Protocol Architecture for multimedia Application over ATM Networks," *IEEE Journal Selected and Communications Vol. 14, Nº 7*, pp. 1.349-1.359, (Sep. 1996).

[6] R. Karabek, "A Native ATM Protocol Architecture Design and Performance Evaluation," *IEEE Proceedings 22nd Annual Conference on Local Computer Networks*, pp. 204-210, (1997).

[7] T. Anker, D. Breitgand, D. Dolev, and Z. Levy, "Congress: CONnection-oriented Group-address RESolution Service," *P. of SPIE'97* vol. 3233 on Broadband Networking Technol, (Nov.97), *http://www.cs.huji.sc.il/transis/*

[8] T. Anker, D. Breitgand, D. Dolev, and Z. Levy, "IMSS: IP Multicast Shortcut Service," *Infocom*, (1998).

[9] Jean_François Huard, "kStack: A User Space Native-Mode ATM Transport Layer with QOS Support," Technical Report CU/CTR TR 463-96-29 *kStack http://comet.columbia.edu/software/kStack (1996).*

[10] R. Bagwell, J. McDearman and D. Marlow, "A Comparison of Native ATM-Multicast to IP-Multicast With Emphasis On Mapping Between the Two," *IEEE, Proceedings of the Twenty-Seventh Southeastern Symposium on System Theory*, (1995).

[11] Saran, "The IDLInet Native Mode ATM Protocol Stack," *Indian Institute Technology, Delhi, http://cell-relay.indiana.edu/cell-relay/publications/software/IDLInet.*

[12] D. C. Feldmeier "A framework of architectural concepts for high-speed communications systems," *IEEE J. Select. Areas Commun.*, Vol. 11, Nº 4, (May 1993).

[13] T. La Porta and M. Schwartz, "Architectures, Features, and Implementation of High-Speed Transport Protocols," *IEEE Network Magazine*, pp. 14-22, (May. 1991).

[14] T. Matsuda, K. Matsuda, "A new protocol processing architecure for high-speed networks," pp. 798-803 (1996).

[15] ____ , "B-ISDN, ATM Adaptation Layer Service. Specific Connection Oriented Protocol (SSCOP) Q.2110," *ITU-T*, (10-Mar. 1994).

[16] J. Solé-Pareta, J. Vila-Sallent, "Network-based paralell computing over ATM using improved SSCOP protocol," *Computer Communications* 19 pp. 915-926, (1996).

[17] P. Goyal, Vin, H., Shen, C., Shenoy, P., "A reliable, Adaptive Network Protocol for Video Transport", *INFOCOM'96*, Vol 3, pp. 1080-1090, (1996).

[18] Anindo Banerjea, Domenico Ferrari, Bruce A. Mah, Mark Moran, Dinesh C. Verma and Hui Zhang, "The Tenet Real-Time Protocol Suite: Design, Implementation, and Experiences," *Technical Report TR-94-059 http://www.icsi.berkeley.edu/* (1994)

[19] Pasquale Di Genova and Giorgio Ventre, "Efficiency Comparison of Real-Time Transport Protocols," *Technical Reports TR-95-004, http://www.icsi.berkeley.edu/* (1995).

[20] Chandramohan A. Thekkath, Thu D. Nguyen, Evelyn Moy, and Edwards D. Lazowska, "Implementing Network Protocols at User Level," *IEEE/ACM Transactions on Networking, Vol. 1, Nº 5, pp. 554-565*, (October 1993).

[21] K. Obraczka, "Multicast Transport Protocols: A survey and Taxonomy," *IEEE Commun. Magazine*, (Jan. 1998).

[22] John W. Byers, "Maximizing Throughput of Reliable Bulk Network Transmissions," *TR-98-2, http://www.icsi.edu/techreports/* (1998).

[23] E. Gauthier, J. Le Boudec and P. Oechslin, "SMART: A many-to-many Multicast protocol for ATM," *IEEE Journal on Selected Areas in Communications. Vol. Nº 3* (April 1997).

[24] Woo-Seop Rhee, Yoon-Young An, Hwa-Suk Kim, Hong-Shik, "Interoperability Mechanism of ABR/ABT Capability in ATM Public Networks," *IEEE ICC'97 Montreal, Towards the Knowledge Millenium. 1997 IEEE International Conference on Communications* Volume 3 pp. 745-749, (1997).

[25] Matthias Grossglauser and K.K. Ramakrishnan, "SEAM: Scalable and Efficient ATM Multicast" *Infocom'97, Proceedings IEEE* pp. 867-875, (1997).

[26] M. Nguyen, and M. Schwartz, "MCMP: A Transport/session level Distributed Protocol for Desktop Conference Setup," *IEEE Journal Selected and comunications*, Vol. 14 Nº 7, pp. 1404-1421, (Sept. 1996)

[27] G. Armitage, "IP Multicast over UNI 3.0 based ATM Networks," *IETF IP over ATM W. Group Draft*, (Oct 94).

[28] Paul Patrick White, "ATM Switching and IP Routing Integration: The Next Stage in Internet Evolution," *IEEE Communications Magazine, April 1.998, pp. 79-83* (1998).
Infocom'97 Proceedings IEEE , pp. 669-675 (1997).

[29] Peter Newman, Greg Minshall and Thomas L. Lyon, "IP Switching-ATM Under IP," *IEEE/ACM Transactions on networking, Vol. 6 Nº 2, April 1.998 pp. 117-129* (1998).

[30] Xipeng Xiao, Lionel M. Ni amd Vibhavasu Vuppala, "An overview of IP Switching and Tag Switching,"

[31] Maurizio Casoni and Jonathan S. Turner, "On the Performance of Early Packet Discard," *IEEE Journal On Selected Areas in Communications, Vol. 15, Nº 5, June 1997, pp. 892-902*, (1997).

[32] Kangsik Cheon and Shivendra S. Panwar, "Early Selective Packet Discard for Alternating Resource Access of TCP over ATM-UBR," *Local Computer Networks, Proceedings 22nd Conference on*, Pp. 306-316, (1997).

[33] Omar Elloumi and Hossam Afifi, " RED Algorithm in ATM Networks," *IEEE ATM Workshop Proceedings*, pp. 312-319, (1997).

[34] Almesberger, J. Le Boudec and Ph. Oechslin, "Arequipa: TCP/IP over ATM with QoS for impatient," *http://lrcwww.epfl.ch/WebOverATM/about_woa/arequipa.html*

[35] L. Zhang, S. Deering, D. Strin, S. Shenker, D. Zappela, "RSVP: A New Resource ReSerVation Protocol," *IEEE Network*, pp. 8-18, (Sep. 1993).

[36] D. Tennenhouse et al., "A Survey of Active Network Research," *IEEE Communications Magazine*, (1997).

[37] U. Legedza, D. Wetherall and J. Guttag, "Improving the performance of Distributed Applications Using Active Networks," *Infocom'98*, pp. 590-599, (1998).

[38] D. Tennenhouse, D. Wetherall, "Towards an active network architecture," *Multimedia Computing and Networking 96*, San Jose, CA, (Jan 1996).

[39] Li-wei H. Lehman, Stephen J. Garland and David L. Tennenhouse, "Active Reliable Multicast," *Infocom'98 pp. 581-589*, (1998).

[40] Rosen Sharma, S. Keshav, Michael Wu and Linda Wu, "Environmets for Active Networks," *Network and Operating System Support for Digital audio and video, Proceedings IEEE*, pp. 77-84, (1997).

[41] David J. Wetherall, John V. Guttag and David L. Tennenhouse, "ANTS: A Toolkit for Building and Dynamically Deploying Network Protocols," *Open Architectures and Network Programming, IEEE*, pp. 117-129, (1998).

[42] Albert Banchs, Wolfgang Effelsberg, Christian Tschudin, and Vollker Turau, "Multicasting Multimedia Streams with Active Networks", *TR-97-050 http://www.icsi.berkeley.edu/techreports*/ (1997).

[43] David M. Murphy, "Building an Active Node on the Internet, " (May 1997).

[44] Simon Steward and Steve Appleby, "Mobile Software Agents for Control of Distributed Systems Based on Principles of Social Insect Behaviour," *ICCS 94* pp. 549-553 (1994).

[45] Markus Breugst and Thomas Magedanz, "Mobile Agents - Enabling Technology for Active Intelligent Network Implementation," IEEE Network pp. 53-60 (May/June 1998).

[46] T. Magedanz, K. Rothermel, and S. Krause, "Intelligent Agents: An Emerging Technology for Next Generation Telecommunications ?," *INFOCOM'96, Proceedings IEEE*, Volume 2, pp. 464-472, (1996).

[47] T. Magedanz, and T. Eckardt, "Mobile Software Agents: A new Paradigm for Telecommunications Managemet," *Network Operations and management symposiom, IEEE*, Volume 2 pp. 360-369, (1996).

[48] David C. Feldmeier, Anthony J. McAuley. Jonathan M. Smith, Deborah S. Bakin, William S. Marcus and Thomas M. Releigh, "Protocol Boosters," *IEEE JSAC Vol. 16, Nº 3, pp. 437-443*, (April 1998).

[49] R. Kishimoto, "Agent communication system for multimedia communication services," *INFOCOM'96. Fifteenth Annual Joint Conference of the IEEE Computer and Communications Societies. Networking the Next Generation., Proceedings IEEE Vol. 1*, pp. 10-17, (1996).

[50] David A. Halls and Sean G. Rooney, "Controlling the Tempest: Adaptive Management in Advanced ATM Control Architecture," *IEEE JSAC Vol. 16, Nº 3*, pp. 414-423, (April 1998).

[51] Sean Rooney, Jacobus E. van der Merwe, Simon A. Crosby and Ian M. Leslie, "The Tempest: A Framework for Safe, Resource-Assured, Programmable Networks," *IEEE Commu Magazine*, Vol. 36 10 pp. 42-53 (Oct. 98).

[52] G. Pujolle and D. Gaïti, "ATM Flow Control Schemes Through a Multi-Agent System," *International conference on information Engineering'93, proceeding of IEEE*, Volume 1, pp. 455-459. (1993).

[53] Jiann-Liang Chen, Ying-Ping Yu, and Shinfeng Lin, "Exploiting Multi-Agent Scheme for Traffic Management in ATM Networks," *Intelligent Control (ISIC), proceedings, IEEE*. pp. 594-599 (September 1998).

[54] Jim Hardwicke and Rob Davison, "Software Agents for ATM Performance Management," *Networks operations and management simposium NOMS 98, IEEE*, Volume 2, pp. 313-321 (1998).

[55] German Goldszmidt, and Yechiam Yemini, "Delegated Agents for Network Management," *IEEE Communications Magazine*, Volume 36 3, pp. 66-70 (March 1998).

[56] G. Goldszmidt, and Yechiam Yemini, "Distributed Management by Delegation," *IEEE*, pp. 333-340 (1995).

[57] F. Nait-Abdesselam, N. Agoulmine, and A. Kasiolas, "Agents Based Approach for QoS Adaptation In Distributed Multimedia Applications over ATM Networks," *IEEE International Conference on ATM, ACATM-98*, pp. 319-326 (1998).

[58] P1520 - Proposed IEEE Standard for Application Programming Interfaces for Networks, *http://www.iss.nus.sg/IEEEPIN/* .

[59] Projects Advanced Communication Technologies and Services (ACTS), *http://www.fokus.gmd.de/* .