

TECHNICAL RESEARCH REPORT

ATM in Hybrid Networks

by John S. Baras

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ATM in Hybrid Networks

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Abstract

A discussion of the extensions or modifications required to integrate ATM into hybrid networks, i.e. seamlessly interconnected terrestrial and space, wireline and wireless networks will be presented. In this context, the discussion will include: interoperability problems and issues, asymmetric channels, and various data rates. Several issues with proposed standards will also be addressed.

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Current Activities

John Baras is the Director of the Center for Satellite and Hybrid Communication Networks at the University of Maryland and Professor of Electrical Engineering. He holds the Lockheed Martin Chair in Systems Engineering. He directs multidisciplinary research in integrated network management of hybrid networks (seamless interconnected terrestrial and satellite networks). Among his current research projects are Hybrid Internet Access Configuration management, Performance management, Fault management and interoperability of heterogeneous networks. He is also working on the development of middleware for the efficient integration of network management systems and heterogeneous databases.


Author Background

John Baras received the BS in Electrical Engineering from the National Technical University of Athens, and the MS and PhD degrees in Applied Mathematics from Harvard University. Since 1973 he has been on the faculty of the Electrical Engineering Department of the University of Maryland at College Park. From 1985 until 1991 he was the founding director of the Institute for Systems Research. He has performed extensive research on many aspects of control, communication and related computer systems. His current research interests include hybrid communication network modeling and simulation, network management, telemedicine systems, intelligent control systems, virtual manufacturing and integrated product-process design, speech and image compression and recognition, hybrid distributed databases for network management and control. He has received many research awards and distinctions and he is an IEEE Fellow. He has consulted extensively with many industry and government organizations.

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In this presentation we will describe hybrid networks and their role in the NII/GII. We will place particular emphasis on ATM as a promising link among the many heterogeneous networks comprising a hybrid network. However many services will be better implemented with asymmetric links and will involve paths, with wireless, wireline, and satellite networks in addition to fiber links. These transport media and the asymmetry pose challenges for the establishment of ATM as the ubiquitous transport mechanism of choice. We will discuss these challenges and point some possible solutions.

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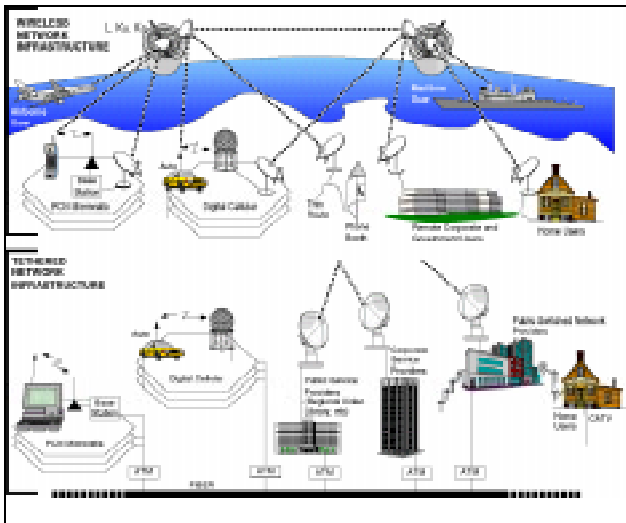
Hybrid communication networks, as the term is used in this paper, mean complementary, seamless and interoperable terrestrial, satellite and wireless networks. They provide an economically feasible and technologically efficient means to implement the global information infrastructure (GII). This claim is based on the proposition that certain industry forces are driving the convergence of satellite and terrestrial communications technologies and industries just as over the past decade we witnessed the convergence of computers and communications. And similar to the convergence of computers and communications, it is projected that the convergence of satellite and terrestrial telecommunication technologies will be a phenomenon of immense proportions.

Furthermore the information infrastructure must bring Information Age services to everyone and be affordable. Terrestrial fiber networks cannot alone create the needed infrastructure.

Hybrid networks have been identified as the unique infrastructure that can achieve this vision.

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The Center for Satellite and Hybrid Communication Networks, a consortium of telecommunication companies, Universities and Government agencies and Laboratories is working on key elements of this hybrid infrastructure along the following principles:

- Seamless interconnection of high data rate terrestrial, satellite and wireless terrestrial networks.
- Mass-access to the resulting hybrid information infrastructure induces mass-markets which in turn finance its development and deployment.
- Higher technologies are needed to make the increased complexity of the infrastructure transparent to the user. Otherwise the information infrastructure benefits only a small information “elite”.

The concept of the hybrid network as used here goes well beyond the traditional application of interconnecting a satellite hop with a terrestrial gateway. As opposed to the “fiber to the home” concept of a single fiber providing the full array of transmission services to the customer, the hybrid network implies diversity of media and consumer choices. It implies a cost effective, balanced migration to a market-demand-driven GII. It also implies a new industry structure built around diversity and no longer constrained by the old barriers to entry. Control of the ubiquitous copper pair will no longer define control of the market. In a

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Hybrid Networks and Information Infrastructure Deployment

- **Mass-Market Access to the Global Information Infrastructure**

Hybrid networks represent the most economically feasible plan to bring the GII to the mass consumer markets which in turn will finance its development and deployment

- **Information for the masses, not an information elite**

Higher technologies are needed to make the increased complexity of the information infrastructure transparent to the user. Otherwise the information highway benefits only a small information elite

very real sense the architecture of the network will reflect the structure of the industry which itself is on the verge of a major redefinition. Current legislation in the Congress is proposing to rewrite the Communications ACT of 1934. The result will create a new set of dynamics for the industry with the fundamental impact of introducing competition into the provision of local loop services. Ironically, as the telephone companies advertise a future of a single fiber supporting all services new legislation is being written that implies diversity in the local loop. This diversity will include hybrid satellite-terrestrial transport services.

In this context it becomes apparent that a key component for the cost efficient deployment of the GII will be the integration of satellite technology into traditional and developing terrestrial networks. Satellite technology can support the full complement of network services offered today and projected for the future. But in all major markets integration with other modes: existing analog plant of the public switched network, ISDN, cellular mobile, PCS, Internet, private networks, etc. is essential to the viable business case. The underlying theme is the migration of satellite services into the mainstream of mass market consumer network services. And that migration must take the form of integration with terrestrial modes. A very good recent example of the results of these forces has been the explosive growth of Direct Broadcast Satellite (DBS) services.

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Hybrid Networks and Information Infrastructure Deployment

- Create the Global Information Infrastructure by creating its components
- Hybrid Networks: complementary, seamless and interoperable integration of terrestrial, satellite and wireless networks
- Hybrid networks best solution to the "Market Development Paradox"
 - Market Establishment vs. Massive Capital Deployment
- Gradually introduce advanced networks built on a migration strategy of mass-market consumer products

A rapid and feasible (both technologically and financially) development of the NII and GII will follow the following scenario. We can capitalize on the existing installed base of the vast entertainment network (including cable and satellite delivery) and enhance it at no additional cost with many value-added services allowing information browsing and interactivity by the utilization of asymmetric channels. Then modify the end-user devices and service provision with small additional cost, so that the bandwidth differences in the asymmetric channel (and thus the asymmetry) can be variable and modifiable. Then we can let the market and services (to be developed) to determine the actual connectivity requirements on the basis of individual user needs. The rest is traffic engineering in the network. This scenario has gained wide spread support recently. For instance, several such products have been offered as the one being tested involving either cable or satellite entertainment and Internet type services.

The variety of applications in telecommunications during this development will increase significantly. The recognizable trends toward new network services, broadband multimedia and advanced mobile communications call for demand-oriented and cost-effective network capabilities. General purpose, modular, and layered concepts based on standardized network and service building blocks and suitable platforms will provide the universal and economic solutions required.

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Key Concepts

- Hybrid Networks
- Asymmetric Links
- Interoperability
- Mass access

These concepts will be supported by the uniform and bit-rate independent asynchronous transfer mode (ATM), with its flexibility concerning connections, bit rates, and qualities on demand. ATM networks are being introduced internationally, both in the private and public areas, to support fixed and mobile, narrowband and broadband communications in several steps.

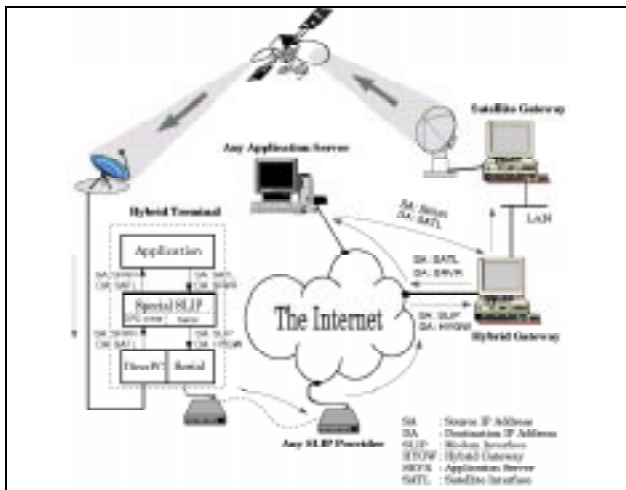
Broadband and multimedia communications applications are typical examples of the growing qualitative and quantitative requirements placed on telecommunication networks and services. In the future, there will be fewer and fewer applications using only one single information type. Instead, applications with mixes of different information types, service components and services will play a growing role. ATM can meet these challenges as well as the requirements of advanced personal mobility.

To reach this vision ATM must be extended, and modified so that it can be used over wireless terrestrial and satellite links, over hybrid networks with asymmetric links, and a variety of bit rates (from low 4.8 Kbps to very high 1 Gbps).

The Center for Satellite and Hybrid Communication Networks with industry partners such as Hughes Network Systems has been working to develop inexpensive hybrid (satellite and terrestrial) terminals that can provide a variety of services to the user and to foster hybrid communications as the most promising path to the Global Information Infrastructure.

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Many multi-media applications will include both real-time (delay sensitive) communications as well as less sensitive but massive data transfer. Digital image database browsing is such a typical application. Many of these applications are asymmetric in nature; that is the bandwidth requirements are different when sending from when receiving information. It is precisely in this area that explosive growth of services in the GII is expected. Many Internet services can benefit from low-cost asymmetric communications. These include high bandwidth file transfer, World Wide Web and the MBONE. In a joint effort with Hughes Network Systems we have developed and currently extending a Hybrid Internet Access scheme: Turbo Internet. In the current implementation of the DirecPC Turbo Internet we have achieved return bandwidth from the satellite portion at 400 Kbps.

The primary motivation for such hybrid services is that Internet access is either too slow or too expensive for individual users or small enterprises, especially at high bandwidths.

Our solution is what we have called Hybrid Internet Access. Using hybrid networking, the hybrid terminal merges two connections, a bi-directional terrestrial link using a modem, and a receive-only satellite link, so that the TCP/IP software above the device driver sees only one virtual device.

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Hybrid Asymmetric Multimedia

- Hybrid Internet access
- MBONE and Hybrid Internet multicast
- Hybrid Broadcast news
- TCP/IP over ATM over satellite and wireless terrestrial links

This design exploits three concepts:

- Satellites are able to offer high bandwidth services to a large geographical area.
 - A receive-only VSAT is cheap to manufacture and easier to install than one which can also transmit.
 - Most computer users, especially those in a home environment, will want to consume much more data than they will generate (asymmetric computer use).

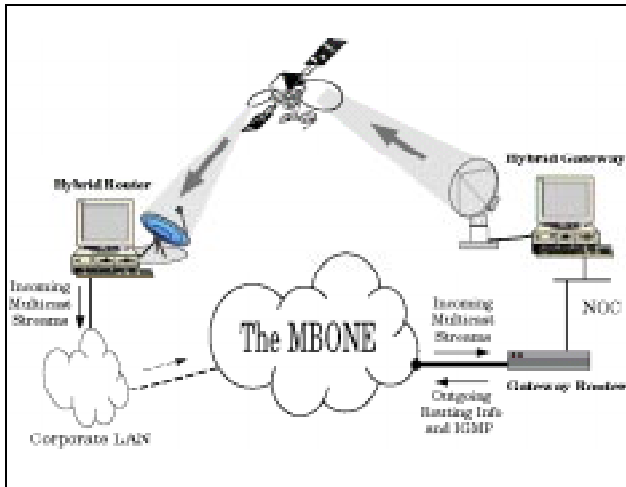
In order for this hybrid TCP/IP network to be commercially deployable, it must seamlessly interoperate with existing TCP/IP networks.

Such hybrid internet accesses can be designed also with telephone and cable systems, as well as with terrestrial wireless and satellite systems. ATM is an attractive transport mode for such applications which with its flexibility will ease management and enhance interoperability. It will exercise all advantages such as variable rate and asynchrony. As a result extensions and modifications of ATM over satellite and terrestrial links are needed as well as extensions and modifications of TCP/IP over ATM over such links.

In the age of distributed systems and cooperative workplace, group communication is an integral part of any computer and communication network. In a TCP/IP network, group communication is accomplished via a suite of protocols associated with IP multicast. The overlay multicast network in the Internet is called the MBONE, the Multicast Backbone. Examples of applications which drive the development of the MBONE are teleconferencing and information

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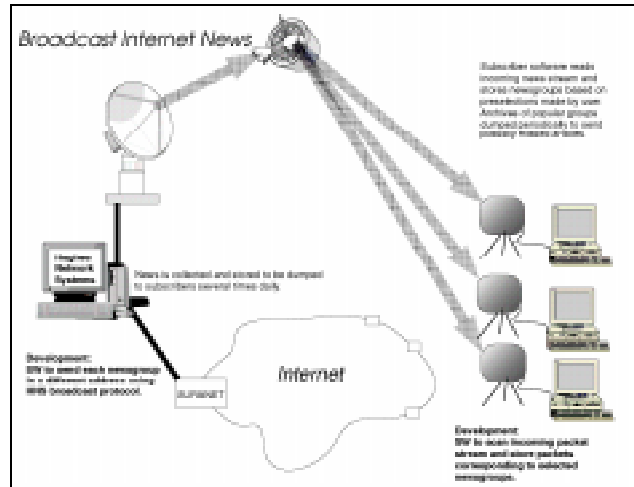
distribution. In the case of teleconferencing where the connections are of type multipoint-to-multipoint, because of the multiple large amount of data transferred, congestion could occur in the terrestrial backbone. The broadcast nature of satellite communication makes it an efficient way to deliver high-bandwidth multicast traffic to end users. By using an inexpensive hybrid terminal for incoming multiple IP multicast streams, the corporate Internet gateway bandwidth can be preserved for other out-going traffic. Because the satellite footprint covers the whole U.S. continent, it can even be used to off-load multimedia multicast streams from the Internet backbone.

In the figure we show an initial architecture of IP multicast in a hybrid environment. At the uplink, multicast traffic from the MBONE is transmitted over the satellite to remote DirecPC™ terminals. There is a multicast capable router as the gateway to the MBONE. At the downlink end, a hybrid router takes the multicast traffic received over the satellite and sends it out to the local area network. To systematically approach the problems, we split the project into two stages. Initially, we assume that the remote LAN does not already have access to the MBONE. The second stage is when the remote LAN already has another connection to the MBONE.

There are many issues associated with extending IP multicast over the hybrid network. These are some of the issues we are investigating:

- How does a remote hybrid terminal subscribe to a particular multicast group in the MBONE? The solution lies in how we can direct the “join” messages to the uplink site. We are working on extending the Internet Group

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Membership Protocol (IGMP) to solve this problem.

- How is a multicast tree constructed at a remote LAN? The problem is when there is another path into the Internet. The multicast tree has to be constructed so that all out-going multicast traffic from the remote LAN is directed toward the Internet gateway while the incoming multicast traffic comes through the satellite link. This requires an asymmetric multicast routing mechanism. We are looking into enhancing existing multicast routing protocols such as MOSPF, DVMRP, CBT and PIM to the hybrid environment.

- How is a data retransmission done in the multicast environment especially when the long delay in the satellite is involved? Issues relating to reliable multicast transport protocol over the hybrid network will be explored.

When, as is expected, ATM becomes the ubiquitous transfer mode over all such hybrid media, these questions must be reexamined in order to take maximum advantage of ATM over hybrid networks and asymmetric channels. Unfortunately current standard work is neglecting these issues which will affect the majority of the user markets; especially the asymmetric ones.

Another important application of multimedia communications employing a hybrid network is the on-demand distribution of news, bulky documents, images, software, etc.. In this service the user needs a low bit rate channel to request the information and a broadband channel to receive it. In addition the service can distribute the documents and information periodically via

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Ubiquitous ATM infrastructure

- ATM flexibility
- Services, operating environments, administrative domain interconnection
- Dynamic bandwidth variation

satellite broadcast and local filters at the user site can filter and keep only the information that matches the user's needs and interests via a profile. At the Center for Satellite and Hybrid Communication Networks we have developed such a service jointly with Hughes Network Systems: Hybrid Broadcast News.

These are but two examples of the plethora of multimedia services, that can be offered at low cost taking advantage of the efficiency of hybrid networks and asymmetric channels. ATM is the preferred transport mechanism for variable rate multimedia services.

The acceptance of asynchronous transfer mode (ATM) for use in the public wide area networks in the form of B-ISDN, coupled with the emergence of ATM as a local area networking technology, offers the possibility of a unifying communication paradigm. This unification goes beyond simply providing the same data service for LANs and WANs to allow straightforward internetworking of data transfer. There are three dimensions along which ATM facilitates unification: services, operation environments, and administrative domain interconnection.

Services -- A wide range of upper-layer services is supported by a single transfer mechanism. This allows not only integrated data transfer, but also novel integrated applications.

Operating environments -- ATM can span a range of bandwidths and localities (for example from the desktop to the wide area); it can be used in wired or wireless environments, and in both public and private networks.

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Ubiquitous ATM infrastructure

- Virtual service model
- Rate adaptation
- Appropriate for asymmetric multimedia

Administrative domain interconnection -- ATM separates the basic transfer mechanism (that is, cell relaying) from the policies governing routing, quality of service, security, and so forth. This separation facilitates the efficient interconnection of administrative domains. It is important to note that the boundaries between operating environments and administrative domains are not necessarily congruent. The consideration of wireless and portables leads to management domains that may even involve unconnected subcomponents.

In this paper, and in our longer-term work, we focus on some of the challenges that need to be met in order to achieve a ubiquitous ATM infrastructure. The promise of ATM can be inferred from the CCITT definition of ATM: "A transfer mode in which information is organized into cells; it is asynchronous in the sense that the recurrence of cells containing information from an individual user is not necessarily periodic."

This virtual service model, where the supported logical channels are separated from the underlying physical channels (although it is familiar within the data communications world), represents a radical departure from the traditional telephony model of a single, serially reusable, fixed bandwidth channel.

Important aspects of this model include:

- Simultaneous connectivity to a variable and potentially large number of peer users (or at least the appearance thereof).
- Dynamic variation in the bandwidth assigned to concurrently active channels.
- Rate adaptation (i.e., temporal decoupling) between peer users.

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Effects of satellite delay

- Robust feedback needed
- Special modifications
- effects on reliable data transport

With ATM via satellite, relatively large propagation delays can significantly increase the latency of feedback mechanisms essential for congestion control. The result is that, unless a robust feedback mechanism is designed, the ATM mechanism may become ineffective at a certain point. The second area where satellite delay plays an important role is concerned with reliable data transport via an ATM satellite link. Error correction for reliable data transfer is generally performed through coding or a retransmission protocol. For data connections using ATM, existing protocols such as TCP can be encapsulated into ATM cells, but this approach is limited by two factors scalability and error robustness, which are encountered in the high-speed, or stressed (high error-rate), environment. Another option is to use the SSCOP, which has been standardized for BISDN signaling, but which is also applicable to high-speed data transfer. Its principal function is to ensure data delivery, for high-bandwidth/delay connections. It offers an efficient error recovery mechanism, network delay insensitivity and flow control, and is suitable for high-speed implementations.

The performance of retransmission protocols depends on the bandwidth and delay of connections, as well as the underlying error rate. It is expected that SSCOP will be more resilient to degraded broadband environments than other protocols.

The burst errors on a coded satellite link affect the operation of both ATM and AAL protocols and their transportation in the SDH/PDH frames. ATM cell performance parameters include cell

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Effects on ATM transmission errors

- Bursty errors
- ATM link enhancement
- Extensions to higher rates

acquisition time, cell in-synch time and cell discard probability.

ATM performance is dependent upon the transmission channel bit error ratio (BER) and also on the nature of transmission bit errors. In the case of a satellite transmission channel, ATM cell performance parameters can only be quantified if the nature of transmission bit errors is first characterized. Here, bit errors are likely to occur in bursts due to the presence of encoding and decoding. The major performance objective for BISDN links is specified in terms of acceptable ATM cell discard probability (defined as the ratio of the number of ATM cells that are discarded because of uncorrectable errors to the total number of cells received). The stringent performance requirements being defined are driven by the characteristics of optical fiber, which can provide for BERs that are better than 10^{-10} . Moreover, the single bit error correcting ATM header error correction (HEC) code is capable of correcting most errors encountered, given the random distribution of errors, over fiber links.

Satellite links that operate at such high rates (BISDN at 1.55 Mb/s, as well as the 45 Mb/s) employ error correction schemes for providing acceptable link BER (10^{-7} or better). The burst error characteristics generated as a result of using these error correction schemes have been studied extensively. The burst errors cannot be corrected by the ATM HEC since it is capable of correcting only single-bit errors. The ATM cell discard probability over such links is therefore orders of magnitude higher than over links with random errors.

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Effects on ATM of transmission errors

- ALE interleaving
- Effects on AAL
- Broadband satellite constellations

To make ATM service feasible over satellites at the same quality level as fiber, COMSAT Labs have developed a proprietary ATM link enhancement (ALE) technique that is capable of providing significant improvements in cell discard probability.

The ALE incorporates a selective interleaving technique which does not impose additional overheads, allowing it to be transparently introduced into the satellite transmission link. The selective interleaving also takes into account the constraints imposed by the error detection and correction mode of operation specified in International Telecommunications Union (ITU-T) Recommendation 1.432.2. Hardware that implements the ALE functionality can be transparently introduced into a satellite transmission path. The ALE, which includes an interleaver and deinterleaver module, is inserted in the transmit and receive data between the ATM switch and the satellite modem.

The ALE was tested both in the laboratory and over the satellite to calibrate the ALE performance versus expected performance. Testing was performed using an HP ATM analyzer as the cell source. The ALE was successfully demonstrated to reduce ATM cell loss significantly on a satellite link.

Bursty errors also affect the AAL in ATM. Undetected errors can cause artificial loss conditions for example, and affect the synchronization mechanisms. Appropriate modifications have been developed and tested by COMSAT Labs for satellite links at 45 Mbps.

Different and more complex modifications will be needed at 165 Mbps and 622 Mbps. These

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ATM congestion control with satellites

- EFCI
- Backward ECN
- Efficient feedback and multiple priorities

are under investigation at the Center for Satellite and Hybrid Communication Networks, at COMSAT Labs and elsewhere. The increasing appearances of high-bandwidth satellites in all configurations (LEO, MEO or GEO) and the large number of systems, being proposed for the K_a band necessitate further study and development of the required ATM modifications.

Feedback is also frequently used for congestion control. The goal of feedback is to provide the traffic sources causing congestion with information about the congestion event so that the sources can take appropriate action to temporarily reduce the traffic load. Therefore, two main mechanisms are needed to accomplish this goal:

- The network element must incorporate a mechanism to determine when it is congested.
- A mechanism is needed to convey such information back to the source.

Typically, the first mechanism has not been subject to standardization, the reason being that such mechanisms are implementation dependent. However, some type of semantic is needed for such a mechanism so that responders (traffic terminals) can properly interpret the message. Currently, one mechanism (explicit forward congestion indication, or EFCI) for conveying congestion notification back to the source has been partially defined. This indication is the basic mechanism of what is known as forward explicit congestion notification (FECN). EFCI is carried through the use of a payload type coding in the ATM cell header. If a network element determines that it is "congested", it may set the EFCI bit in the ATM header on each cell of

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Local wireless ATM

- Wireless multimedia
- Lower bit rates
- Framing and interoperability

particular virtual paths or virtual channels contributing to or causing the congestion (Note: if a particular queue is congested, all virtual paths or virtual channels through the queue may have the EFCI set). At the destination end-system, this indication is sent to the higher protocol layer, which is instructed to notify its peer protocol entity to reduce its traffic load. The higher layer might need to filter the indications before reacting to them, depending on how the EFCI is set by the switch.

As it is currently defined, EFCI is inadequate for effective reactive congestion control. First of all, no semantic has been specified for EFCI; as a result, an end-system receiving this notification cannot be sure of the true state of congestion in the network. Second, no current user protocol can make use of this indication, although some types of future protocols (such as SSCOP within the AAL) may incorporate this function. Third, EFCI is unenforceable; no mechanism exists for the ATM layer to act on this indication and regulate the flow. Finally, and most critical for satellites, EFCI, and any other type of FECN mechanism, necessarily incurs at least a one-way propagation delay in notifying the source. Therefore, the effectiveness of various detection and reaction algorithms is limited by the propagation delay.

For these reasons, COMSAT Labs and other organizations have been advocating a faster mechanism, called backward explicit congestion notification (BECN). In the BECN proposed scheme, a congested network element would send a notification in the reverse direction of the congested path. This notification could either be a performance/management type cell or another

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Wireless and Mobile ATM

- Service independent ATM
- Transmission errors
- Mobility management

new type of cell. A network element, if it determined that it was "congested", would send a cell on the reverse path. The destination end system could act upon this notification by directing the source to reduce its traffic rate, and by enforcing the rate reduction at the ingress to the ATM network.

The effectiveness of BECN could be significantly better as compared to FECN if satellite links are involved and if users can quickly respond to notification. However, for a robust algorithm, consideration must be made of network configurations in which the congestion occurs on the destination side of a satellite link or other long propagation delay trunk. The comparative utility of FECN and BECN will vary depending on the network configuration and the source traffic characteristics. If a worst case environment for BECN needs to be designed for, FECN may have comparable performance and may be simpler to implement. Satellite ATM networks require a high degree of network efficiency with resulting minimal cell loss, and the control algorithms to achieve this efficiency must be relatively insensitive to delay. Currently, however, traffic management specifications do not adequately address the problem.

Local wireless ATM is becoming critical because an area of increasing importance in digital communications is the use of wireless networks. Continued advances in VLSI component density, packaging technology, and power consumption indicate that computers will reduce in size and increase in performance, functionality, and durability. How long before we have current workstation processing power and memory size in the form of a wriststation?

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Wireless ATM

- Variety of interference patterns
- Hierarchy of geographical cells
- Footprints, cell duplication and resequencing

Such devices will require the ability to interact with their environment; they require communications both with peer mobiles and resources attached to fixed networks. Although such fixed resources will certainly include computer systems offering traditional distributed services such as filing and printing, mobiles also will wish to communicate with even more basic device resources.

For some applications, the bandwidth and service characteristics required by such devices can be seen to be not substantially different from those that are considered as necessary for multimedia workstations in the next few years. Perhaps the bandwidth required is even greater in instances where a mobile uses the wireless network as an I/O bus.

The arguments supporting compatibility between the local and wide area networks also suggest a compatibility between the local fixed and local wireless networks. If we believe that mobiles will handle multiservice traffic, then it is natural to consider ATM in the local wireless network.

The consideration of wireless ATM networks highlights the requirement to consider and specify ATM service in a manner that is not based on a particular implementation.

All the shared media solutions that have been built for ATM switching, described previously, use the transmission system to delineate cells and have further used the cell as the unit of media access. Efficient solutions for wireless ATM networks share many of the same problems, including problems associated with features of the particular underlying transmission systems, and

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Challenges and the Future

- Hybrid networks, asymmetric access to the GI and ATM can provide low cost services for many
- Extensions and modifications of ATM over satellite and wireless links essential
Asymmetric operation
- Extensions of TCP/IP and other protocols over ATM in hybrid networks

Imperative that standards organizations address these challenging problems

hence will have similar solutions. Currently popular wireless transmission systems are infrared and GHz radio; these have radically different multipath and interference properties that are again different from the properties in an ATM network based on point-to-point fiber links. The solution to some of these problems commonly adopted in wireless communications is to add forward error correction; for an ATM wireless network this implies FEC over the entire cell.

One aspect of future wireless digital networks that can be clearly predicted from current experience with cellular phone networks is that in area of high-density communications, it is desirable to reduce the distance between base stations. In other words, reduce the size of the geographic cell. Within a building this could lead to very small geographic cells, perhaps one per office.

This provides the benefit that the reliability of the wireless transmission link can be increased by explicit per cell acknowledgments from base stations due to the small round-trip delay, but leads to the complication that if the network is based on an explicit handover when a mobile is passed from one geographic cell to another, the majority of network traffic will be due to signaling.

Approaches based on footprints that allow a mobile to range throughout a set of geographic cells without explicit handovers and change of channel identifiers reduces the signaling overhead, but introduces the possibility of multiple base stations receiving a cell. Hence the problem of cell duplication and resequencing is introduced. A sensible solution to this problem is

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to detect and remove duplicates and reorder cells within the network that interconnects the base stations before injection into a local or wide area network. A wireless network that aims to provide an ATM service must provide a solution to the duplication and sequencing problem just below the ATM level. In particular, an extended cell header (as compared to that defined for B-ISDN) must be used to include sufficient sequencing information.

The consideration of wireless ATM networks provides a clear example of the importance of distinguishing the ATM service interface from a particular implementation based on technology and engineering decisions. Hence, although a wireless ATM service is possible, the underlying cell structure that is transmitted must be considerably different from that defined for point-to-point links.

In conclusion, hybrid information infrastructures with asymmetric channels provide an extremely rich set of opportunities for massive applications over the resulting GII. ATM provides the flexibility necessary to become the ubiquitous transport mode for such networks and applications. Substantial extensions and modifications are needed for the realization of this vision. Unfortunately standards bodies are not devoting adequate attention and effort to these critical issues.

Acknowledgement

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