Future telecommunication networks

Citation for published version (APA):
Kazovsky, L. G., Khoe, G. D., & van Deventer, M. O. (1998). Future telecommunication networks: major trend projections. *IEEE Communications Magazine*, *36*(11), 122-127. https://doi.org/10.1109/35.733486

DOI:
10.1109/35.733486

Document status and date:
Published: 01/11/1998

Document Version:
Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
- The final author version and the galley proof are versions of the publication after peer review.
- The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy
If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.

Download date: 04. Oct. 2023

Future Telecommunication Networks: Major Trend Projections

Leonid G. Kazovsky, Stanford University

Giok-Djan Khoe, Technical University Eindhoven

M. Oskar van Deventer, KPN Research Leidschendam

ABSTRACT Integrating synergistically the issues of traffic types, technologies, and competition, we create a view of the future of telecommunications that appears to be probable and review the technologies likely to be implemented in the future.

Telecommunications is undergoing unprecedented changes. New competitive companies are offering lower costs and driving the introduction of new services. New technologies are emerging, government regulations are being reduced, and the industry is rapidly globalizing, even companies that have traditionally operated in national environments. The efficient transport of information is becoming a key element in today's society. This transport is supported by a complex communications infrastructure that, if properly implemented and operated, is invisible to end users. These end users seem primarily interested in services and costs only.

As new services evolve and the needs of users change, the industry must adapt by modifying existing infrastructures or implementing new ones. Telecommunications experts are therefore challenged to produce roadmaps toward future infrastructures. This is a difficult task because of incomplete knowledge of trends in users' demands and how technology will evolve.

The purpose of this article is to provide one view of the future based on traffic types, technologies, and competition. Also, a review of technologies that are likely to be implemented in the future is given. The study is primarily based on the situation in a compact country with a high population density, such as the Netherlands. The following characteristics apply to the Netherlands:

- Country size: 42,000 km^2
- Population: 15.2 million
- Population density
  - –Average: 450 persons/km^2
  - –Peak: 10 times average
- Backbone node spacing: 70 km

The boundary conditions of our study can be applied to many other regions as well. For example, the population of the Netherlands is quite similar to the population of California. The strategy used to support the arguments in this article can also be applied to regions or countries that are not similar to the above example, when details are properly adapted.

Another boundary condition is the projections' timescale, which is set for 10–15 years. Developments happening within two or three years are not of interest here, and issues that will emerge 50 years from now will not be speculated on.

We begin by outlining four possible hypotheses of future traffic growth, and discuss attributes and requirements of these four types of traffic.

Next, we review key electronic and optical technologies. We map the key features of the technologies and show that success or failure of a technology depends on the particular type of traffic. Furthermore, we discuss the impact of competition on the future of telecommunications. We show that the combined impact of open competition and rapid technological progress will force telecom companies to adopt service packages, in addition to the conventional means of better service and lower cost. We review some main strategies that telecommunications companies may adopt to cope with this trend.

Then we integrate synergistically the issues considered in developing a view of the future that appears to be probable and review the technologies that have a good chance of being implemented. Finally, we discuss possible factors which may influence the course of trends as predicted.

FUTURE TRAFFIC DEMANDS

We consider four hypotheses of future traffic growth. The first hypothesis is *conventional growth*. According to this hypothesis, telephone traffic will continue to dominate the telecom network. Figure 1 illustrates the expected growth rates under this hypothesis. Growth rates of about 10 percent for telephone traffic and about 30 percent for Internet traffic are assumed. In this situation, even though the absolute volume of telephone traffic will continue to grow at a *modest rate*, the absolute volume of telephone traffic is still much larger than what can be expected from Internet and digital video traffic. Basically, it would be possible to design networks for telephone traffic conditions and subsequently to accommodate all the other traffic in the network.

The precise numbers taken for growth are rather irrelevant. The importance of this picture is the ratio between telephone traffic and the rest. As long as the vast majority of the traffic (e.g., 95 percent) is telephone traffic, the basic philosophy and technological setup of the network will be oriented to telephone traffic, and the rest will be accommodated with lower priority. The point made here is that the network will not be designed around a tiny fraction of non-voice traffic.

The second hypothesis views the *Internet age*. It is assumed in this case that the IP traffic between computers and servers will grow so dramatically that it will become the dominant force and maybe the main force in telecommunications. Hence, most of the traffic in the future will consist of Internet traffic. It is shown in Fig. 2 that a huge growth is assumed in the Internet network, about 60 percent/year. Then by the year 2012 Internet traffic will actually become comparable to telephone traffic. Since it is certainly possible to transmit telephone traffic over the Internet and vice versa, these two traffic types are not really mutually exclusive, and the Internet dominance may be amplified even further by assuming that most resources will be devoted to Internet traffic.

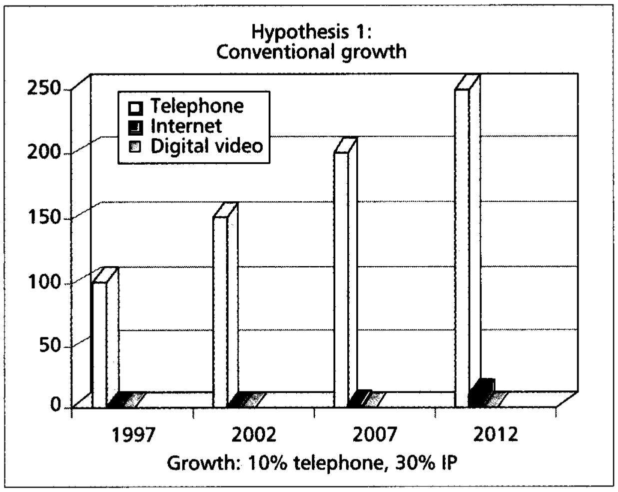
0163-6804/98/$10.00 © 1998 IEEE

The Internet domination can be caused by a number of issues. A new software release may and does cause a sudden increase in the number of providers and users. When Microsoft released the latest version of Windows with Internet Explorer, the number of Internet providers increased by a factor of 3. Hence, if such events are repeated the volume will certainly be driven up. Another issue that will drive up the volume is new applications such as multimedia. If users start to play multimedia games and multimedia movies, and take part in action movies themselves, all those will create additional traffic volume. There are signs that this is actually happening. Driven by the need to have more bandwidth, integrated services digital network (ISDN) lines are becoming very popular in the United States. It took about 10 years for such a trend to happen, but it is now taking off at an incredible rate. The rest of the world will probably follow this trend soon. Thus, many observers believe that the hypothesis is materializing right now.

For the third and fourth hypotheses the assumption is made that a *digital video age* is coming, so digital video will dominate all other kinds of traffic. At the moment digital video is not even in the same category as telephone traffic; it is merely in the noise level in terms of traffic flow. However, in the digital video age hypothesis illustrated in Fig. 3, digital video grows at an incredible rate: it doubles every year and overcomes the rest of the traffic by 2012.

Video and the Internet may be interdependent because it is technically possible to send video traffic over the Internet and vice versa. However, if the dominant kind of traffic is Internet, it is very likely that the entire network will be optimized for the Internet, and basically all other kinds of traffic will be adapted to fit into the Internet network. By the same token, if the dominant kind of traffic is video, the network will be optimized for video, and somehow all other traffic will be adapted to fit into that optimized video network.

Two different kinds of digital video traffic may develop. One is digital *video distribution*, basically entertainment video and possibly pay TV which is completely digitized. To provide high-quality digital video distribution, a high-bandwidth downstream is required. The precise bandwidth required may vary between a few megabits per second to maybe 100 Mb/s, depending on the compression used or the particular type of TV or high-definition TV (HDTV) format used.

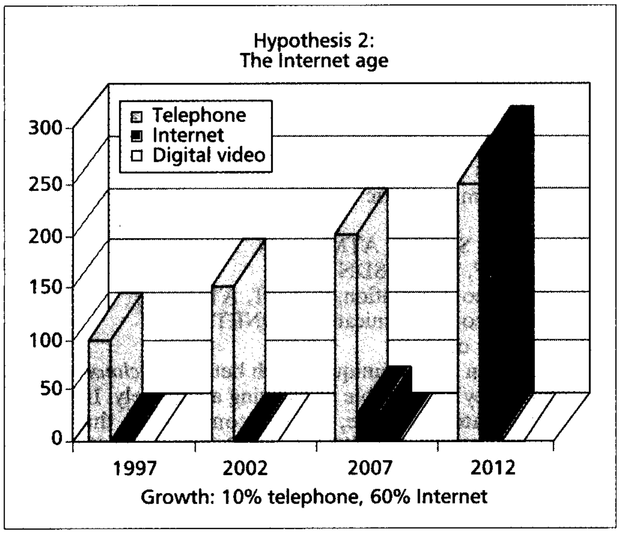


■ **Figure 1.** *Expected traffic growth rates assuming conventional growth.*

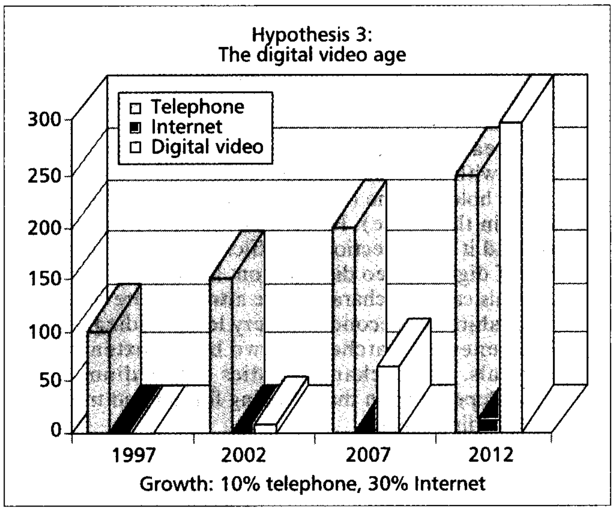
Some upstream and control transport must be provided, but most traffic will be transported from servers downstream to the subscribers. Latency, which is an important subject in the case of video communication to be discussed next, is not an issue here.

A second situation that may occur in the digital video age is the dominance of video communications, which has completely different implications. The traffic type is video, but it is typically communications by means of video, similar to videophones where one can place a video call to another user. Even though both fall within the category of digital video, the attributes of video communications are completely different. The bit rate requirements and quality needed in general will be much lower than needed for entertainment video. Usually, it is agreed that digital video sessions at 100 or 200 kb/s are quite acceptable. *Latency* requirements, on the other hand, are extremely stringent in this case. Typically users want to have pictures synchronized with voice.

Latency requirements for video communications are thus rather different from video distribution, where it is quite acceptable for users to order a movie and subsequently have it



■ **Figure 2.** *Expected traffic growth rates in the Internet age.*



■ **Figure 3.** *Expected traffic growth rates assuming that digital video will dominate all other traffic.*

	Latency	Bit rate	Holding time	Burstiness	Directionality
Telephony	Senstive	64 kb/s	Minutes–hours	Low	Bidirectional
Internet	Not sensitive	56 kb/s and up	One hour	High	Highly directional
Digital video distribution	Not sensitive	Several Mb/s	Hours	Medium/high	Highly directional
Digital video communications	Sensitive	100 kb/s-1 Mb/s	Minutes–hours	Medium/high	Bidirectional

Table 1. *Traffic attributes.*

delivered a few seconds later. Video distribution and video communications thus represent two very different issues. In one case large bandwidths are needed, but very long delays can be tolerated. In the other case, the bandwidths needed are moderate but the latency requirements are quite stringent. Latency may become a serious problem if asynchronous transfer mode (ATM) is used. By the time the transported data hops through several ATM switches, timing disturbances may become intolerable.

The development of digital video in the United States is of particular interest at the moment. After many years of efforts to develop analog enhanced television in the United States, it was subsequently decided to adopt a digital standard for the future. One reason for that decision may be that Japan developed analog technologies, which may have been a good reason for the United States to adopt digital technology instead. For a long while, however, that decision was not taken seriously, and it was consistently said at any time that digital technology would develop within a few years. That attitude has changed recently.

One factor influencing recent interest in digital video in the United States is the policy adopted by the Federal Communications Commission (FCC). The FCC recently approved rules that give broadcasters free licenses to provide digital HDTV. The FCC rules call for 30 percent of households to receive broadcast of at least three digital TV stations by May 1, 1999. However, many stations in the top 10 market have committed to start service within 18 months. It may thus be expected that very soon some markets in the United States will develop HDTV broadcast. It is not clear what the situation in the rest of the world will be. Sometimes, technologies developed in the United States emerge within a few years in Europe.

The next issue to consider is the traffic attributes. Table 1 lists the traffic attributes for the four hypotheses just discussed and formulated: telephony, Internet, digital video distribution, and digital video communications. The attributes listed are latency, bit rate, holding time, burstiness, and directionality. It is clear that these attributes are vastly different for each type of traffic. For example, telephony is associated with sensitive latency, very modest bit rate, and a reasonable holding time (depending on whether the user has teenagers in the house). For telephone, burstiness is fairly modest, and it is bidirectional traffic. On the other hand, in the case of digital video distribution, latency is not an issue at all. In this case the characteristic attributes are bit rates of many megabits per second and very long holding times. A movie is generally watched for two hours, extended with commercials. Other characteristics are medium to high burstiness depending on the encoding format and traffic that is almost unidirectional.

Table 1 clearly illustrates that the four kinds of traffic are quite different from each other. If the network is optimized for one particular type of traffic, it will be a rather poor network for another type, and vice versa. At this point we can discuss the technologies emerging today.

KEY TECHNOLOGIES

In this section we will review technologies and what four attributes these technologies possess. Then it will be outlined how they connect to the four hypotheses. Basically, we attempt to connect a particular growth hypothesis with the best technologies to use. First, each kind of traffic will be discussed separately, and then an attempt will be made to mix them together. Key technologies can be separated into electronic and optical technologies. Examples of electronic technologies are synchronous optical network (SONET), ATM, Internet, switched multimegabit data service (SMDS), frame relay, ISDN, broadband ISDN (B-ISDN), analog (TV), and wireless. Optical technologies include wavelength-division multiplexed (WDM) point-to-point, orthogonal time-division multiplexing (OTDM), solitons, WDM static networking (add-drop and cross-connect), and WDM dynamic networking.

WDM point-to-point basically uses different wavelengths to carry information from one switch to another. All processing within these switches is performed electronically. WDM static networking means that the information is carried from one point to another using different wavelengths. In addition, it is also possible to drop one (or more) of those wavelengths at the node so that a certain conductivity is provided between the nodes on this particular wavelength. However, the network is not reconfigurable. In dynamic network configurations, it is possible to rearrange the add-drop wavelengths.

In Table 2 some of the technologies discussed earlier are listed along with their traffic attributes such as bit rate, latency, and burstiness. The list shows that some of these technologies are clearly matched to some of the traffic types considered. The match between telephony and SONET is not really surprising: SONET was designed explicitly to carry telephone traffic, so it has a properly controlled latency and can accommodate high bit rates when required. It is probably not suitable for bursty traffic because it was not designed to be so.

In the case of the Internet, it is possible to have a huge latency, and it is ideally suitable for bursty traffic. Hence, if future networks are dominated by Internet traffic, it will be desirable to construct them entirely from IP routers, interconnected by (possibly SONET) links. On the other hand, if the future traffic is dominated by voice, it is not desirable to have IP routers switch the traffic because of the latency requirements. Table 2 therefore indicates that each technology works well with a specific kind of traffic. An attempt to explicitly map traffic to technology produces the following list:

- Telephone: SONET, ATM, ISDN
- Internet: IP, ATM, ISDN
- Digital video distribution: SONET, ATM, IP
- Digital video communication: SONET, ATM
- Backbones: optics

There is an almost unique match between *technologies* and the *traffic* they are capable of carrying adequately. If the traffic is dominated by voice, the key components that will be needed in the network will be SONET, ATM, and ISDN. The other technologies will probably be less important.

If the future network is dominated by *Internet* traffic, it may become essential to have IP switches instead of SONET add-drop multiplexers. ATM may or may not be needed, but

ISDN is not really necessary, although it may be used as well.

If the future view is pointing toward *digital video* networks, narrowband ISDN is probably not part of the picture because it does not satisfy broadband needs. In that case it should be anticipated that the upgrade from ISDN to B-ISDN will take place very soon. If, however, it is assumed that digital telephony will dominate future traffic, ISDN will probably be implemented for a long time, along with SONET and ATM. *Backbones* in all these cases will be optical.

Let's consider now the interrelationship between ATM, IP, SONET, and WDM. ATM and IP compete directly with SONET in switching, but not in transmission. It is possible to implement add-drop multiplexing (ADM) functions in ATM, IP, or WDM. In fact, if a completely new network has to be constructed today there is no real need to use SONET ADM networking. However, it can be assumed that SONET transmission will be used for a long time. For switching, however, it is possible to use ATM switches or IP routers. On the other side of the technology spectrum, WDM static networking also squeezes SONET networking because it is also possible to implement ADM functions in the WDM domain. SONET networking is thus being challenged from both sides by WDM, IP, and ATM.

Thus, the future network might develop as follows. ATM switches and IP routers are implemented, and all users are connected to ATM switches or IP routers. The ATM switches and IP routers are further interconnected with each other by SONET links without any SONET networking. WDM can be used to add more links as needed and also to provide ADM. This scenario will provide good flexibility and cost effectiveness.

As our studies are focused on a compact country or region, we can remark at this point that technologies which are driven by very long distances, such as soliton or optical time-division multiplexing (TDM), are not very likely to become important. For that reason, it would not be desirable for a company focusing on compact countries or regions to invest much in those technologies.

Technology	Latency	Bit rate	Suitable for bursty traffic
SONET	Controlled	High	No
ATM	Variable, small	N/A	Yes
IP	Variable, large	N/A	Yes
ISDN	Low	Low	Yes
Optics	Lowest	Highest	No

Table 2. *Feature mapping.*

THE IMPACT OF COMPETITION

Competition is traditionally perceived as a purely economic issue that has little relevance to technology, but this view has to be challenged. Clearly there are traditional competition tools like *better services*. An example is the presence of somebody at the telephone company who answers the phone and knows what happened to the bills. Another factor considered important by users is initial *costs*. The company can certainly get more appreciation for *high bit rate*, but it is much more important to offer what we call *service bundles*. A typical example of a service bundle is when a cable company providing cable TV also offers an additional box for telephone service. Similar situations are beginning to happen with the Internet. A user connected to the Internet can also obtain telephone service through the same connection. Hence, in the future it will be impossible to be a pure telephone company because the competitor who is going to provide cable or Internet access will offer to its customers telephone service for just a little more money. To be able to compete with others, each company has to provide more services. In the next section we will argue that service bundles are strongly influenced by technology. Examples of possible service bundles are:

- Internet over a voice network
- Voice over the Internet
- Video over the Internet
- Video over a wireless network

Technology developments have opened up the possibility of providing not only Internet over a voice network, which has been done for a long while, but also the other bundles listed above. Basically, the important issue is no longer different services but different bits. Telephone over the Internet used to be an unusual combination, but an announcement in early 1997 from Lucent Technologies seems to break that picture. Users of the Lucent Internet Telephone Server do not need any fancy equipment. We expect more combinations like this to be offered in the future.

A question to be asked at this point is how companies can adequately adapt to the expected trend. Basically, two different options are possible. One option is to build a heterogeneous network: one network is used for voice, another for Internet access, and yet another for video. In that case, users will perhaps have three or four different wall sockets. However, it may be possible to physically combine the different networks using WDM. Alternatively, it may be possible to build one integrated network, using IP or ATM, that carries all traffic over the same network. The network is not physically transparent but user-transparent. The two options are quite different from each other, and one can detect both approaches today.

An example of the first option is the Sprint/Stanford WDM Ring Research Testbed. The idea behind the Sprint/Stanford WDM ring testbed is to provide a backbone network around the San Francisco Bay area; telephone traffic can be carried over one wavelength, video over another wavelength, and so on. Hence, WDM is used here not only as a multiplier of bit rates but also as a service integrator. Another approach is Pacific Bell's superhighway configuration. The approach essentially starts with an existing telephone server, which is then combined electronically with a video server in a digital host. The combined signals are transported to a remote node and subsequently distributed by coaxial cable to individual subscriber homes.

Both options are therefore possible, and different companies are pursuing different configurations. It is not easy to predict at the moment which option or options will finally be adopted. We can now attempt to combine all the above considerations and attempt to develop a vision of the future.

SYNERGY: FUTURE PROJECTIONS

We first consider *general projections* which concern topology and technology. As far as the topology is concerned, rings are probably suited for backbones. For distribution purposes stars and double stars are considered better options, not only for telephone but also for video. Technologically, backbones are clearly the domain for optical technologies; interest in wireless technologies for distribution is currently increasing. Copper is therefore challenged on two sides and clearly becomes less important. Obviously there are examples, such as the Pacific Bell configuration shown earlier, where the use of copper is maintained. A more precise technological projection depends on the particular assumptions made for traffic development, as summarized earlier in this article. Below we review technologies' projections for each of the four hypotheses made.

If *conventional growth* takes place, the technology will be dominated by SONET/SDH. Other technologies like IP will remain marginal. ISDN will also grow, but if most of the traffic is in the voice domain, ISDN is not going to be comparable to voice technologies. SMDS is not likely to develop, since there is no reason to use SMDS if the only issue is to carry voice as adequately as possible. In addition, companies need to offer a mixture of services because of competitive pressure. That need is likely to lead to service mixers, which can be either electronic like ATM or optical like WDM. Service mixing in this case is not just bit multiplexing, but multiplexing of different services.

If, however, the *Internet age* develops, explosive growth in IP routers can be expected, and subsequently all other types of traffic will start gravitating toward the IP domain. Transmission of voice conversations through the Internet will grow. As a consequence, some drop in conventional technologies can be expected in favor of IP switches and IP technologies in general. In this case IP technology will compete directly with SONET ADMs. SONET networking will decline rapidly, but SONET transmission will remain. WDM will become important, mainly for transmission. This scenario, with IP and WDM squeezing out SONET and ATM, is currently very popular.

If the *digital video age* is expected, traffic will develop along the video distribution route or video communication route as outlined earlier. Technology will then develop either along voice or IP developments. ATM will become important because it is a very powerful service mixer. ISDN will become marginal, and B-ISDN must develop much sooner because the volume of traffic will be too large for conventional ISDN to handle.

Optical technologies will develop along with the growth of traffic. Link rates and related multiplexing and demultiplexing technologies will develop at 20 Gb/s and become commercially important. Subsequently 40 Gb/s will follow, but it is difficult to foresee the technology going beyond 40 Gb/s per wavelength, because it is easier at the moment to handle aggregate bit rate above 40 Gb/s in the WDM domain than in the TDM domain. WDM is already being implemented in many point-to-point links in the United States. On the other hand, substantial efforts are being made in Japan to reach 40 Gb/s in the time domain. The Femtosecond Association is an example of how Japanese efforts in that domain are being supported by the industry.

WDM point-to-point links are being rapidly implemented, and we can expect WDM static networking, with add-drop capabilities, to follow. The future of other optical technologies such as solitons and dynamic networking is more difficult to predict. In a compact region there is less need to use such optical technologies. Certainly technologies such as optical memory and optical switches are not at all an issue for countries like the Netherlands, at least over the horizon at which we are looking.

SUMMARY AND CONCLUSIONS

In the authors' opinion, none of the hypotheses discussed in this article are likely to materialize in their pure form. It is not likely that a situation will occur where the entire telecom network in the entire world will really consist of just IP switches and that all traffic will go through them, at least not in the timeframe considered. The picture will thus become much more complex. Many different kinds of traffic will still need to be carried, and therefore a rather incoherent mixture of technologies will remain. It can be expected that fiber technologies and wireless will grow tremendously. It is also clear that successful companies, wishing to survive, will have to offer all four service categories mentioned above, and probably many more.

Wireless technologies are likely to squeeze copper from the distribution plant, especially in new installations. In many countries where they do not have a good infrastructure at the moment, the last mile is not even installed; thus, the use of wireless is considered. Another likely development is the tremendous impact of ATM and IP on telephone companies. SONET will remain important for point-to-point transmission, but SONET networking is likely to be squeezed out since many of its functions will be taken over by ATM and WDM.

One can thus speculate about the following roadmap to the future. We envision a rapid growth in the use of IP routers and ATM switches interconnected by SONET links. Subsequently, when capacity becomes a bottleneck in the SONET links, WDM is implemented. SONET ADMs will probably not be used much. Service mixers are probably an issue which is underestimated. This requires more research effort, because it is not clear how to squeeze heterogeneous traffic into the same network.

Some form of advanced high-speed distribution, perhaps xDSL or SMDS, is likely to emerge and become very important in some market segments, such as high-tech areas (Silicon Valley or similar areas in other countries) where there are a lot of professionals urgently needing very fast connections. Links at 20 and 40 Gb/s are likely to emerge. The use of other optical technologies is not as obvious. It is clear that point-to-point WDM links will continue to grow. Past experience has shown that there will be a continuous dispute between higher bit rates and WDM. It has been said many times in the past that the next upgrade in the time domain will be very difficult, but bit rates have been steadily increasing and will probably do so to 40 Gb/s.

WDM static networking will be implemented within the next few years. WDM dynamic networking is quite different. To install dynamic networking, a way has to be found to integrate it with software and to find an appropriate control mechanism. It is not clear at the moment whether this is possible, and this is therefore an interesting challenge.

BIBLIOGRAPHY

[1] M. Hopkins *et al.*, "A Multi-Faceted Approach to Forecasting Broadband Demand and Traffic," *IEEE Commun. Mag.*, vol. 33, no. 2, Feb. 1995, pp. 36–42.

[2] H. Armbuster, "The Flexibility of ATM: Supporting Future Multimedia and Mobile Communications," *IEEE Commun. Mag.*, vol. 33, no. 2, Feb. 1995, pp. 76–84.

[3] Announcement of PacBell on a roadmap toward a superhighway configuration, *San Jose Mercury News*, July 1995.

[4] W. Pugh and G. Boyer, "Broadband Access: Comparing Alternatives," *IEEE Commun. Mag.*, vol. 33, no. 8, Aug. 1995, pp. 34–47.

[5] A. Jain, W. Fischer, and P-Y. Sibille, "An Evolvable ATM-Based Video Network Design Supporting Multiple Access Network," *IEEE Commun. Mag.*, vol. 33, no. 11, Nov. 1995, pp. 58–62.

[6] H. D'Hooge, "The Communicating PC," *IEEE Commun. Mag.*, vol. 34, no. 4, Apr. 1996, pp. 36–42.

[7] K. P. Davies, "HDTV Evolves for the Digital Era," *IEEE Commun. Mag.*, vol. 34, no. 6, June 1996, pp. 110–13.

[8] M. Figueroa and S. Hansen, "Technology Interworking for SMDS: From the DXISNI to the ATM UNI," *IEEE Commun. Mag.*, vol. 34, no. 6, June 1996, pp. 102–8.

[9] R. T. Hofmeister *et al.*, "Project LEARN — Light Exchangeable, Add/Drop Ring Network," *Proc. OFC '97*, Feb. 16–21, Dallas, TX, 1997, pp. PD25.1–PD25.4.

[10] R. S. Vodhanel *et al.*, "National-Scale WDM Networking Demonstration by the MONET Consortium," *Proc. OFC '97*, Feb. 16-21, Dallas, TX, 1997, Ppp. PD27.1–PD27.4.

[11] C.-J. van Driel *et al.*, "The (R)evolution of Access Networks for the Information Superhighway," *IEEE Commun. Mag.*, vol. 35, June 1997, pp. 104–12.

[12] Y.-D. Lin, Y.-T. Lin, P.-N. Chen, and M. M. Choy, "Broadband Service Creation and Operations," *IEEE Commun. Mag.*, vol. 35, no. 12, Dec. 1997, pp. 116–24.

BIOGRAPIES

LEONID G. KAZOVSKY [F] (leonid@ee.stanford.edu) is a professor of electrical engineering at Stanford University. He received his M.Sc. (summa cum laude) and Ph.D. degrees from the Leningrad Electrotechnical Institute of Communications, USSR, in 1969 and 1972, respectively, both in electrical engineering. He moved to Israel in 1973. From 1974 to 1984, he taught and carried out research at Israeli and U.S. universities. From 1984 to 1990 he was with Bellcore, Red Bank, New Jersey, doing research on coherent and high-speed WDM optical fiber communication systems. In 1990, he joined Stanford University as professor of electrical engineering. He has published in the areas of optical communications, high-speed networks, applied optics, and signal processing. He has acted as a reviewer for various IEEE and IEE transactions, proceedings, and journals, as well as for funding agencies and publishers. He serves or has served on technical program committees of OFC, CLEO, SPIE and GLOBECOM, and is an associate editor of *IEEE Transactions on Communications*, *IEEE Photonics Technology Letters*, and *Wireless Networks*. He is a fellow of the OSA.

GIOK-DJAN KHOE [F] (g.d.khoe@ele.tue.nl) received a Elektrotechnisch Ingenieur degree cum laude from Eindhoven University of Technology, The Netherlands, in 1971. He worked at the FOM Institute of Plasma Physics, Rijnhuizen, The Netherlands, on laser diagnostics of plasmas from 1971 to 1972. In 1973 he joined Philips Research Laboratories and in addition, was part-time professor at Eindhoven University of Technology from 1983 to 1994, when he became a full-time professor there. His work has been devoted to single-mode fiber systems and components. He has more than 40 United States patents, and has authored and coauthored more than 70 papers, invited papers, and books. His professional activities include many conferences, where he has served on technical committees, management committees, and advisory committees as a member or chairman. He has numerous involvements in journal activities, as associate editor or member of the advisory board. In Europe, he is closely involved in European Community research programs and Dutch national research programs, as participant, evaluator, auditor, and program committee member. He is one of the founders of the Dutch COBRA University Research Institute, and is currently a member of the board. He was European Representative at the IEEE/LEOS Board of Governors, and is currently VP of Membership and Region 8 Activities and a member of the Executive Section Committee of the IEEE Benelux Section.

M. OSKAR VAN DEVENTER studied electrical engineering at Eindhoven University of Technology from 1983 until 1987. He graduated cum laude on monopulse satellite tracking. Since 1987 he has been working at KPN Research on coherent optical communication, polarization effects, influence of reflections, and bidirectional communication. He worked for COST215, COST241, and RACE-COBRA. He collaborated in a high-optical-power transmission field trial for Telia Research, Sweden (Unisource collaboration) for half a year in 1994. In December 1994 he obtained a Ph.D. degree at Eindhoven University of Technology on the subject of bidirectional optical transmission. He has been working for the European ACTS project PLANET on high-splitting-ratio passive optical networks and as task leader for EURESCOM P615 on the evolution toward an optical network layer. Recently, he started working on asynchronous transfer mode and network control. He is (co)author of more than 50 publications and one book on optical communication.