A View of Telecommunications Network Evolution

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ABSTRACT

While deployment of new network technologies has not been steady over the years, it is useful to take a long-term view of how major new telecommunications infrastructures evolve. Since the beginning of this decade, we have witnessed the emergence of new generations of three major communication networks. This article addresses the market conditions, technology innovations, and services driving the need for intelligent all-optical, 3G wireless, and QoS-based packet networks. Market forces such as traffic and subscriber growth, equipment cost reduction, and new technology penetration have a deep impact on network buildouts. Technology innovations abound, especially in the optical domain. For example, Raman amplification, pure optical switches, and tunable lasers have had a major impact on the architecture of optical networks. Many key services, such as streaming audio and high-quality image transfer, were not possible using wireless access because of its limited bandwidth and performance. With 3G wireless technology, a true mobile Internet will become a reality. Businesses have shied away from the use of the public Internet because of service quality. Thanks to advances in MPLS and service intelligence, this is expected to change. For each type of network, we will survey the key factors shaping its evolution and implications on network architectures.

INTRODUCTION

In the history of network evolution, three different forces have consistently driven the architecture and evolution of telecommunications networks: *traffic growth*, development of *new services*, and *advances in technology*. These forces are not independent of each other, but each shapes the evolution in a different way. For example, competition among equipment vendors and technological advances result in cost reductions, which, in turn, stimulate traffic growth and encourage the development of new services.

Telecommunication traffic has been growing at a high and steady rate since the early 1980s. Even though the high end of traffic forecasts that were predicted in the late 1990s never materialized and the glut in backbone capacity is causing a downturn in the industry, one should not lose sight of the fact that the trend toward office automation, remote access, online transactions, and so on has been steady and will continue at the same historical rate we saw in the 1990s. Recent Internet traffic measurements indicate that in the last couple of years traffic continued to grow at 60–80 percent annually.[1] Furthermore, broadband and wireless subscribers grew at an average rate of 60 and 25 percent, respectively.[2]

The net effect of these driving forces is a set of new requirements that are placed on the major telecommunications networks. These requirements result in the emergence of a new generation of network architectures (optical, wireless, and data) roughly every decade (Fig. 1). For example in the 1980s, optical technology became a reality with the deployment of synchronous optical network/synchronous digital hierarchy (SONET/SDH) networks all over the world; analog wireless networks started its commercial debut; and data networks based on the X.25 standard and IBM protocols became widespread. In the 1990s, we saw the development of dense wave division multiplexing optical products, the deployment of 2G wireless, and the use of the Internet for commercial applications.

It is worthwhile to note that the evolution of the three types of networks is interdependent. For example, optical networks are used to carry data and wireless services in addition to carrying optical services. Likewise, wireless networks carry voice calls and data services in addition to wireless services (e.g., location services).

In the next sections, we delve deeper into each of the next-generation networks.

TELECOMMUNICATIONS NETWORKS

THE INTELLIGENT OPTICAL NETWORK

During the last two decades optical networks were viewed merely as *transmission pipes* that can carry a huge amount of traffic. With advances in optical technologies, that paradigm is shifting and optical networks are now capable of providing network flexibility, new services, and operational efficiencies. This is the notion behind the intelligent optical network. In addi-

[1] *Source: IDC, January 2002*

[2] *Sources: UBS Warburg, February 2002; Cahners In-Stat, December 2001.*

tion to the increase in data and wireless traffic volumes, new optical services have become possible due to recent advances in optical technology. Some examples of the new services include:

Intelligent ultra high bandwidth: Until recently, the only services business customers and service providers could order from an optical network provider were private line services at 155 Mb/s, 622 Mb/s, and, to a much lesser extent, 2.5 Gb/s speeds. Provisioning intervals were long and the services static in terms of bit rate, protection options, and routing. With this new breed of optical services, customers can order lines at 2.5 Gb, 10 Gb, or 40 Gb, and the service can be provisioned using signaling from the customer's equipment (e.g., router) or from a centralized network operations center in a matter of seconds. In addition to traditional 1+1 protection, other less costly protection schemes such as 1:1, 1:*N*, and shared mesh can now be offered.

Dynamic trunking: This service allows customer equipment (e.g., router or ATM switch) to set up and disconnect optical channels between equipment on an as-needed basis based on bandwidth desired, time of day, or destination. A good application for this service would be in storage area networks (SANs) where very high bandwidth connections, typically around 1 Gb/s, need to be set up between storage systems and servers for a few hours or even a few minutes at a time.

Gigabit Ethernet: Ethernet networking is now being extended to the wide area network (WAN). In addition to 10/100 Mb/s Ethernet, enterprise customers will soon be able to order 1 Gb/s Ethernet services (point-to-point or multipoint). The Ethernet signal can be carried directly over a 2.5 Gb/s wavelength or possibly multiplexed with other 1 Gb/s Ethernet lines. Protection is handled, in this case, in the optical domain. 10 Gb/s Ethernet is expected in the near future.

On the technology side, several breakthroughs are enabling new services. For example, *micro electromechanical system* (MEMS) [1, 2] technology has become an integral part of intelligent all-optical switches that can switch wavelength-level traffic without converting it first to an electrical signal. The intelligence allows the dynamic setup of wavelength services. *Solitons* [3] and *Raman amplification* [4] enable dense wavelength-division multiplexing (DWDM) systems to carry optical signals very long distances without the need for regeneration. By reducing the number of regeneration nodes, major cost savings can be accomplished.

Optical add/drop multiplexers (OADMs) can be used to drop, optically, some wavelengths from a fiber that carries 100 or more wavelengths. This will eliminate the need for hundreds or thousands of optical transponders (OTs) typically used today to terminate the traffic on a fiber at each node where traffic needs to be added or dropped. Since OTs account for a large fraction of network cost (sometimes over 50 percent), OADMs are expected to have a major impact on network cost reduction. Furthermore, *tunable lasers* promise to revolutionize the economics of optical systems. For example, instead of using 100 types of OTs to terminate 100 wavelengths at a node, only one type needs to be installed and remotely configured to the appropriate frequency.

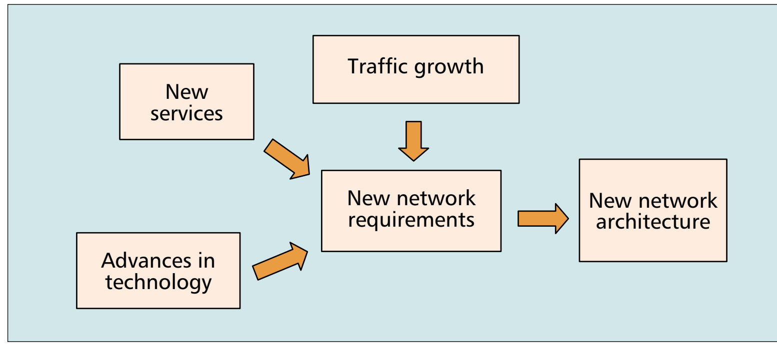

Figure 1. *Network architecture evolution.*

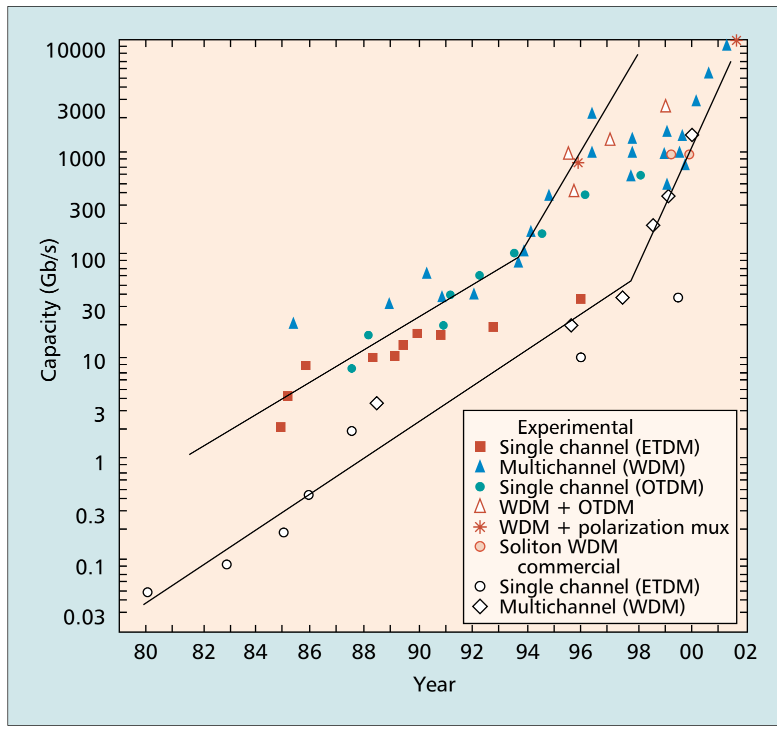

Figure 2. *Optical fiber capacity.*

All of the above breakthroughs, in addition to advances in optical fiber technology, have contributed to the impressive increase in optical fiber capacity, as illustrated in Fig. 2.

The implications of the new services and technologies are so profound that an entirely new network architecture is needed to meet customers' and service providers' needs. More specifically, the new intelligent optical network architecture has the following framework (Fig. 3).

A *transport plane* enables the transmission of traffic in a robust, scalable, and cost effective manner. The transport plane will have some key elements. One of them is a meshed optical core that consists of all-optical switches that can support various optical protection schemes such as 1+1, 1:1, 1:*N*, shared mesh, unprotected, and preemptable. It will also include a DWDM transmission system that can handle long-haul spans, ultra-long-haul spans, and wavelengths at 2.5 Gb/s, 10 Gb/s, and 40 Gb/s simultaneously. This is needed since there are different regions in a typical network, each proving-in a different transmission system reach and/or speed. Another element

Mobile Internet services not only aim to provide good performance over a wireless connection but to also do so when the user is mobile, an important requirement given the drastic impairment that mobility could have on performance.

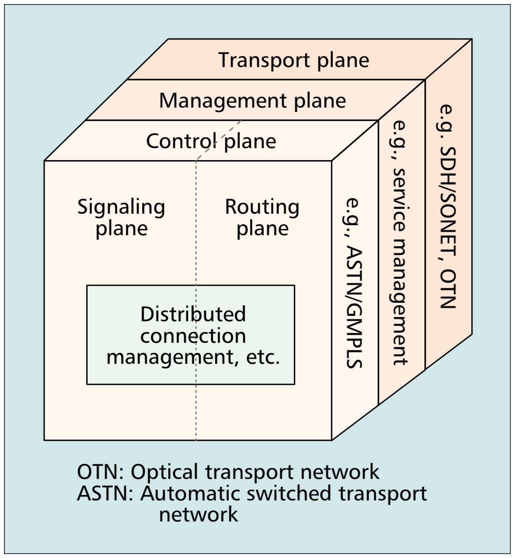

Figure 3. *Intelligent optical network framework.*

needed is a remotely programmable OADM to add or drop wavelengths at nodes along a span without the use of end terminals, which frequently require optical-electrical-optical (OEO) conversion in the form of expensive OTs.

A *distributed control plane* provides the intelligence to set up optical paths and is based on existing and new data protocols. The control plane is expected to support the stringent requirements of the transport plane. To do so, it needs to be as reliable as the transport network it is controlling and should support the new service capabilities. In addition, it has to meet several levels of performance that correspond to different types of signaling messages (e.g., alarms, setup, discovery).

A *management plane* facilitates the deployment of the new infrastructure. Because of the introduction of new optical services, new management functions will be needed to collect usage measurements for the new dynamic services, maintain customer profiles, and manage dynamic provisioning policies.

Evolution to the Next-Generation Optical Network Architecture — The evolution to this new architecture starting from today's networks will probably take place in several steps. The sequence of those steps will vary from one network to another. But in general, one can expect the following:

- Long-haul and ultra-long-haul DWDM systems are used to replace long spans in the core of the backbone to reduce the number of regeneration nodes.
- OADMs can be installed at major nodes where entire wavelengths need to be dropped/added. Multiplexing OTs can also be used to multiplex lower-speed wavelengths (e.g., 2.5 Gb/s) into a higher-speed one (e.g., 10 Gb/s or 40 Gb/s). They can also be used to groom wavelengths to efficiently pack them.
- All-optical switches are then deployed in the backbone nodes to switch high-speed wavelengths given their economic advantage at high traffic volumes.

As traffic and its granularity increase, the reach of the intelligent core will extend further to cover more of the backbone nodes and encompass the metro network. The intelligent metro architecture will provide wavelength services directly from customers' locations over fiber. One can envision a business or residential customer signaling to the network the need to set up, say, a 155 Mb/s or 622 Mb/s optical channel. This signaling will then propagate to the remote end in the same metro area or another one. Interoperability with the intelligent backbone is an essential ingredient to set up this end-to-end connection.

THE 3G WIRELESS NETWORK

Wireless traffic continues to increase at a steady rate. For example, 1.3 billion subscribers are expected worldwide by the end of 2003 and 1.8 billion by the end of 2007.[3] Such a trend will continue as wireless services shift from voice to packet data, and users become more accustomed to conducting wireless business and financial transactions. This course of evolution will be similar to what happened to the Internet: from a limited application environment to an integral part of the average person's life.

The future of wireless networks is not just in voice and financial transactions, but also in the integration of voice, data, and multimedia. Mobile Internet services not only aim to provide good performance over a wireless connection but to also do so when the user is mobile, an important requirement given the drastic impairment mobility could cause in performance.

With that backdrop, new wireless services are maturing, stimulated by advances in air interface technology, smaller and more powerful mobile terminals, and a slew of new protocols for subscriber services, quality of service (QoS), and mobility management. These services include:

High-speed wireless data services: Although wireless Internet access is not new, the high speeds resulting from the deployment of 3G wireless networks are new. As Fig. 4 illustrates, current wireless technologies including 2.5G can only support voice and basic data services. Even though burst rates for an individual user can reach 100–200 kb/s, the average throughput a user will experience, especially during busy hours, will probably be in the range of 30–40 kb/s.

With 3G[4] technology, one can expect the average user throughput to be in the 100–150 kb/s range, which provides adequate bandwidth for most applications such as Internet access, image transfer, content delivery, and data VPN. An exception to that will be in quality video applications that require bandwidths upward of 1–2 Mb/s. In addition to these higher throughputs, 3G systems are more spectrally efficient. This enables access to these data rates at a reasonable cost.

Location-based services: This is a new set of emerging services that make use of location-based technologies such as network-assisted Global Positioning System (GPS), cell-of-origin (COO), enhanced signal strength (ESS), and location fingerprinting. They support a wide array of applications that include emergency services and roadside assistance, tracking services for navigation and truck fleet management, information services for

[3] *Source: Baskerville Strategic Research, "Global Mobile Forecasts to 2010," April 2002.*

[4] *For the purpose of this article, 3G is defined as UMTS Release 99/Release 4/Release 5 and CDMA 3G-EVDO/3G-EVDV. 3G+ is defined as UMTS [5] or CDMA [6] releases beyond that timeframe. However, many technologies will be available in the 3G timeframe, but will become much more powerful in the 3G+ timeframe. Hence, their classification as 3G vs. 3G+ is somewhat arbitrary.*

traffic status and directory queries, and location-based advertising for proximity marketing.

M-commerce: M-commerce allows the wireless user to perform a monetary transaction securely from a wireless device with some form of browser. The user will be charged for the transaction itself and the merchandise or service via prepaid, postpaid, direct financial institution money transfer, or some combination. Many of the traditional e-commerce applications such as stock trading, online shopping, mobile banking, check-in services, and entertainment ticketing apply to M-commerce as well. There are also other wireless-specific applications such as vending machine purchasing and parking fee payment.

Finally, we should say a few words about mobile terminals and users in a mobile Internet. They can be categorized into three main segments:

- *Traditional users* with new handsets equipped with larger screens, and Wireless Application Protocol (WAP) type micro browsers that allow subscribers to access limited databases without the need for additional computing devices. Key applications include Web access, email, still images, and moderate audio.
- *Handheld users* with powerful devices (modified PDAs, palmtops) and a compact operating system that can do many laptop functions in a small form factor. They will be able to play MP3 audio, advanced games, and download small files. Screens with very low power consumption will be a key feature.
- *Laptop users* who perform the same functions as they do at their desktop, except they can now be mobile. They will be able to download large files, play hi-fi audio, and view good quality video.

As in the case of optical networks, several key advances in wireless technology have also taken place in the last few years. Three areas are of particular relevance.

Air interface: As is always the case, a limited critical resource tends to be the target of intensive research and continuous technological improvement. Many activities focused on improvements in the spectral efficiency of the radio access network (RAN) of code-division multiple access (CDMA2000) and Universal Mobile Telecommunications System (UMTS) (see [7] for a general overview). For example, *dynamic modulation*, which adjusts the constellation size in quadrature phase shift keying (QPSK) and 8-PSK depending on the state of the wireless link, has resulted in higher spectral efficiencies than static modulation. This scheme has already been adopted for UMTS. Higher order modulation schemes such as 16QAM and 64QAM may also be adopted in the future.

Advances in *digital signal processing* produced higher chip rates and faster power control (thus saving the mobile terminal's battery life), and improved the ability of the equipment to extract relevant data at lower signal-to-noise ratios, and perform payload compression/decompression and encryption/decryption functions at a much faster speed.

Newer *vocoding techniques* such as discontinuous transmission (DTX), which saves transmission bandwidth in the absence of voice activity, and variable bit rate (VBR) coding, which increases network capacity and improves coverage at the edge of a cell, could reduce the bandwidth requirement for voice by more than 50 percent.

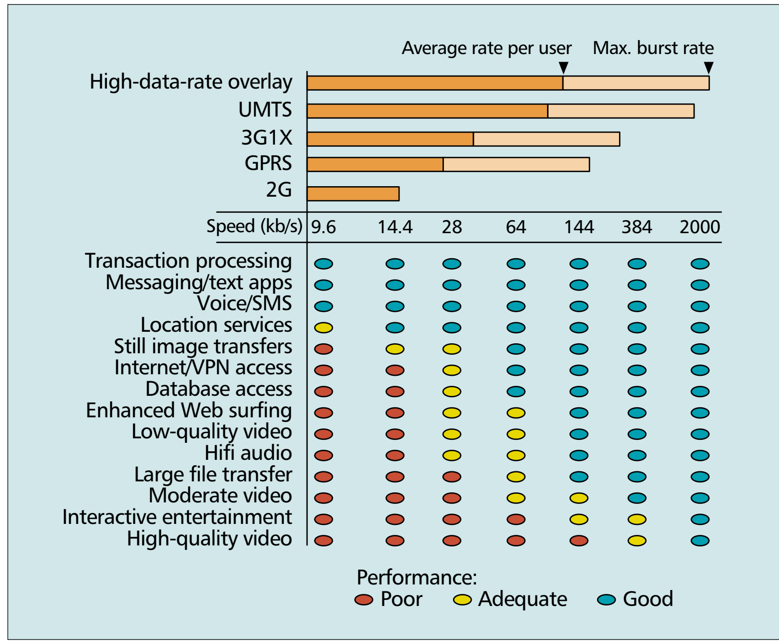

Figure 4. *Wireless services vs. throughput rates.*

A combination of these and other factors will allow 3G networks to offer peak data speeds up to 2.4 Mb/s per 1.23 MHz channel or about 600–700 kb/s of average throughput. Since 2.5G wireless technologies such as CDMA 3G1X and General Packet Radio Service (GPRS) can have average throughputs of 100–120 kb/s, one should expect the number of users for a given bandwidth of spectrum to increase by a factor of 5–6 and the mobile Internet to become a reality.

Access and backbone network: Beyond the air interface, several architectural changes to the wireless network will take place, the most important (Fig. 5) as follows:

All-IP converged network: All traffic leaving the future base stations will eventually be IP based and will be carried on an IP network that replaces the traditional ATM backhaul and backbone networks. This IP network will connect the session handling systems, to authenticate and manage both the IP sessions and voice over IP (VoIP) calls. VoIP calls destined to the public switched telephone network (PSTN) are transcoded at the edge of the IP network. Legacy circuit-switched voice traffic will be converted to packet at the legacy mobile switching centers (MSCs) to IP and then carried over the IP network At the link layer, multiprotocol label switching (MPLS) [8] will most likely be used as a convergence layer. Ethernet private lines, where available, present an economical alternative to MPLS.

QoS differentiation: Given the variety of services expected to be carried over the air interface, the wireline network, including the portion of the RAN that connects the base stations to the backbone, will need to support QoS mechanisms to provide some minimum performance guarantees. Network performance levels are characterized by combinations of delay, delay jitter, error rate, and throughput levels. Packets leaving the base

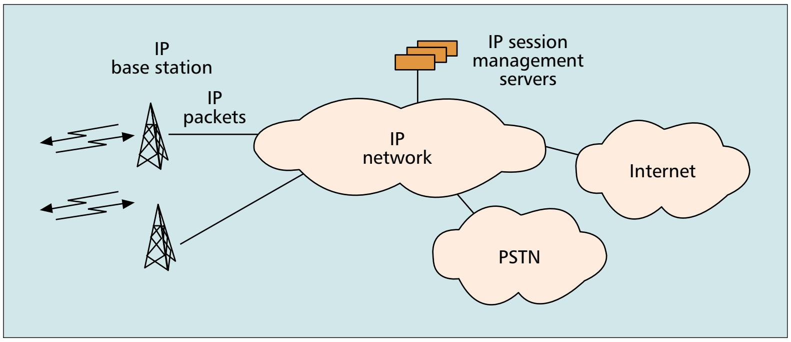

Figure 5. *Next-generation wireless network architecture.*

station may need to be marked (e.g., using *differentiated services*, DiffServ [9]) to indicate the service class associated with the application. Then the packets can be mapped into MPLS tunnels at the edge of the IP network. Each tunnel will be configured with the appropriate QoS parameters to ensure that end-to-end QoS requirements for the IP flow will be maintained.

802.11/3G Integration: Wireless users will expect to move seamlessly back and forth between public wireless LANs and cellular networks. This will require a handoff mechanism between the two technologies, and a common customer profile database and authentication method. In addition to advances in 802.11b [10] and 3G technologies, work on seamless mobility between the two types of networks has been progressing, especially in the areas of real-time handoffs, common user profile, and authentication database.

Wireless service providers are likely to incorporate 802.11 service as a complement to their cellular data offers, subject to the resolution of some technical issues such as unified billing and over-the-air security. This new combined service will increase the voice capacity of a 3G network by offloading some of the data traffic to the 802.11 network in some locations. This is expected to occur in localized areas where mobility is limited and required data rates are high. In the near future, the 802.11g standard will allow wireless LANs to support data speeds of 20–54 Mb/s and is backward compatible with 802.11b products.

Unified mobility management is needed to authenticate and manage profiles and Internet addresses for mobile users and enable secure roaming between networks of different technologies, such as CDMA, GPRS, UMTS, and 802.11. A new generation of home location register (HLR) is needed to integrate traditional HLR functions (user location management, authentication, etc.) with IP sessions' management functions such as authentication, authorization, and accounting (AAA) [11]. It will also allow the network to address users, not just terminals, and support the notion of *multiple terminals per user*.

Beyond the 3G timeframe (3G+), additional technologies will continue to shape the wireless network architecture. Two areas are of interest:

On the **air interface**, work on spectral efficiency will continue to provide even higher speeds per unit of bandwidth. This is needed to support the most demanding data applications and increase the subscriber density in a cell, improve call quality, and extend cell area coverage. Some of the promising technologies include *multiple-in-multiple-out* (MIMO) [12], which is a technology that exploits the scattering characteristics of the propagation environment, specifically multipath fading. By including multi-element antennas at both transmitter and receiver, transmission rates can be achieved far in excess of those possible with single antenna transmit and receive systems.

Smart antenna systems [13] combine multiple antenna elements with intelligent and powerful signal processing hardware and software to optimize their radiation/reception pattern in response to the propagation characteristics of the environment. There are several technologies associated with smart antenna systems such as spatial processing, phased arrays, adaptive arrays, and digital beamforming.

On the other hand, *high-speed downlink packet access* (HSDPA) [14] uses all available signal power, and dynamically adapts modulation and code rate based on channel quality estimates, thus resulting in greater bandwidth and power efficiency. HSDPA will eventually become part of the UMTS standard.

Other technologies such as orthogonal frequency-division multiplexing (OFDM) [15] and

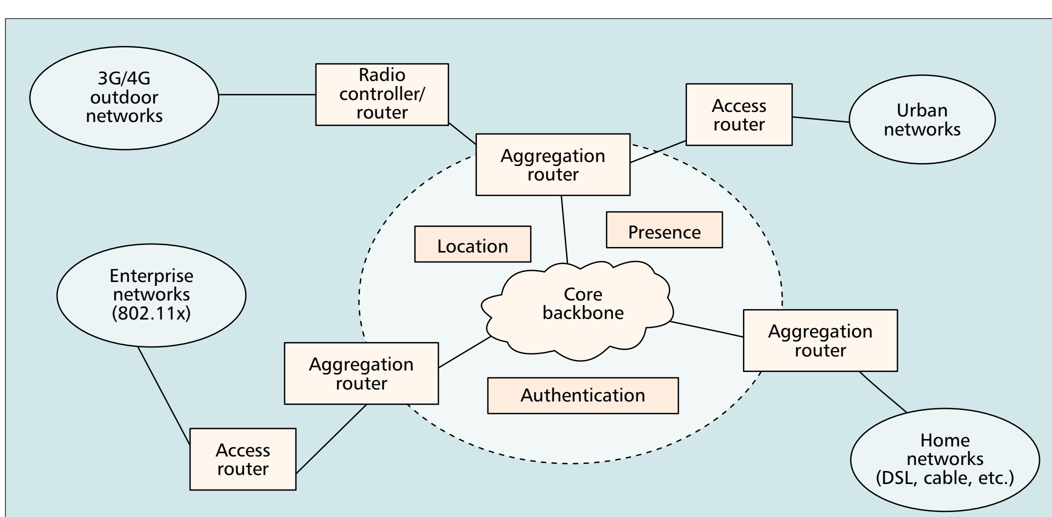

Figure 6. *A combined wireless/wireline network.*

software-defined radio (SDR) [16] will also play important roles in this timeframe.

The **network architecture** will be distributed, instead of hierarchical, to enable true peer-to-peer wireless communication. Such architecture will consist of one combined wireless/wireline packet network with common mobility management and control, a common transport infrastructure, and common session control. In this network, multiple wireless access technologies such as 802.11, HSDPA, and OFDM will coexist. Network intelligence is expected to move to the edge, closer to the base station, in order to reduce transport bandwidth requirements (Fig. 6).

At the user level, one should expect to see one common service for handling customer profiles, AAA functions, user *location* data, and *presence* status information as a result of unified mobility management and other developments. A subscriber will attach to the network in the same way, irrespective of the nature of the connection device. Hence, a customer dialing in using a wireline modem will be prompted to enter the same information as someone using a PDA equipped with a cell phone. Different billing models (e.g., holding time, content, and bytes) will be supported on the same network as well as real-time control of services to enable pay-as-you-go services and premium handling of a particular call. See also [17] for several articles on future wireless networks.

QoS-Based Packet Network

For many years, business data services such as IP virtual private network (VPN), multimedia services, e-commerce, and multicast have been discussed in depth. Most of these services have been offered on public frame relay or asynchronous transfer mode (ATM) networks contained within a small number of administrative domains, in addition to well managed IP networks. However, each one of these alternatives lacks in terms of one or more of the following key business requirements: good overall performance and reliability, flexibility of provisioning and routing, QoS support per application, and extensive connectivity (peering) with other networks.

The future growth of business services will be enabled by a higher-quality IP network with rich connectivity and QoS mechanisms. We refer to such a network as the *QoS-based packet network*.

This network infrastructure needs to build on assets that are already in place such as the optical core, traditional data networks, emerging broadband access, connections to the best-effort Internet, as well as assets that will be built out including metro optical and 3G wireless (Fig. 7).

Several key technical advances will enable such a QoS-based packet network. For example, many IP QoS mechanisms were standardized in the last few years to give corporations and service providers the ability to construct end-to-end QoS-based strategies for IP applications. In the enterprise network, 802.1d [18] will be used to prioritize Ethernet frames on the LAN, while DiffServ can be used at the edge of the enterprise to mark the IP packets belonging to a particular session with the appropriate QoS treatment. At the edge of the service provider network, packets are mapped to a specific MPLS tunnel based on the DiffServ marking.

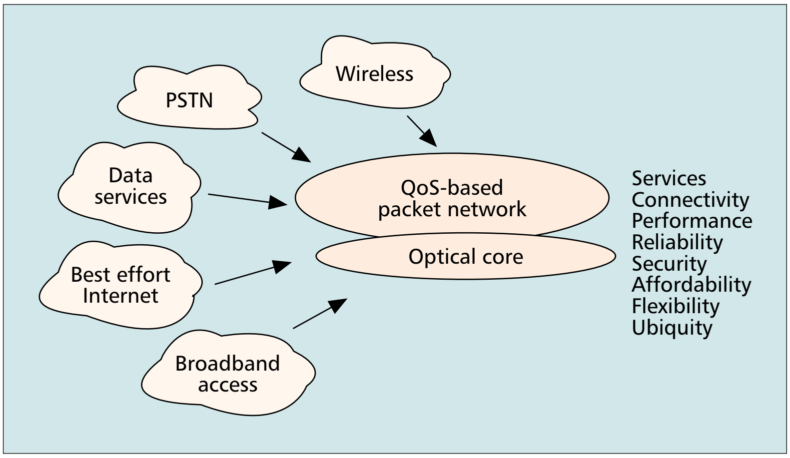

Figure 7. *A QoS-based packet network.*

MPLS combines the flexibility of IP networking with the QoS benefits of other data protocols such as frame relay and ATM. With the maturity of MPLS standards, several critical service provider functions that are necessary to maintain the overall service quality will be possible in an IP network. Such functions include setting up fixed paths for traffic engineering, load balancing, and fast rerouting under failure in addition to supporting different QoS parameters on separate tunnels across the network. The evolution from an existing IP or ATM network will require the use of a new generation of MPLS-based packet switches to interface with the legacy ATM switches and IP routers [19].

The QoS-based packet network will consist of the following architectural building blocks.

Service Intelligence — The intelligence layer recognizes users and their applications, understands their individual service needs, and mediates on their behalf to deliver the services and do all this regardless of when, where, or how they arrive on the network.

This allows customers to become part of the service provisioning process, thus drastically reducing operations cost for the service provider.

This intelligence layer is made up of several functional elements (Fig. 8). The key one is a *customer service portal and intelligent gateway*, which is needed to enable flowthrough self-provisioning. Users will be able to "turn up" or change certain services themselves via active Web pages and in accordance to the policy associated with their profile. Based on the requested services, the new network elements' configurations are downloaded and activated within each network element involved in providing the service. Users' profiles and policies are stored in a customer database (C-DB).

Another key element is the *network resource manager* (NRM) to maintain the QoS guarantees within the MPLS tunnels. This manager is needed to monitor the utilization on an end-to-end or a link-by-link basis. Based on the measurements and tunnel routing information, a determination is made if a particular tunnel has reached its capacity and hence no more traffic (e.g., a new

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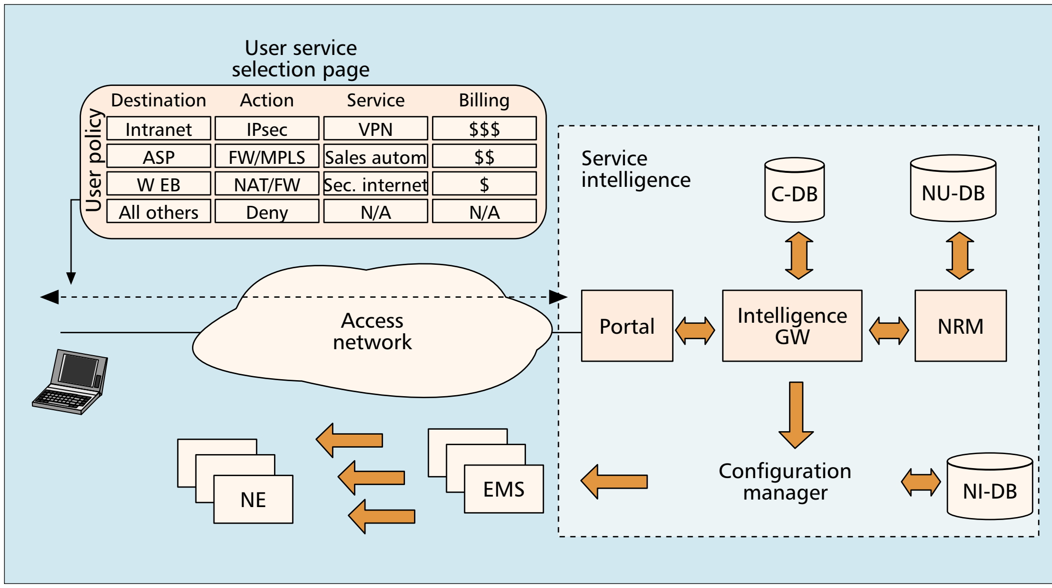


■ **Figure 8.** *Service intelligence architecture.*

video session) can be placed into that tunnel at the edge of the network. The network utilization and tunnel routing information are maintained in a network utilization database (NU-DB).

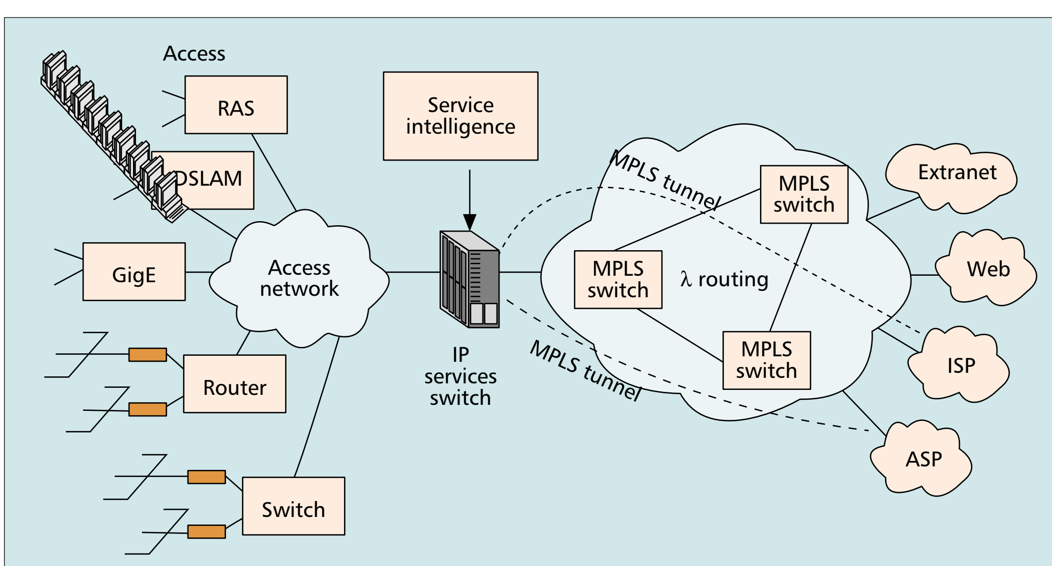
Finally, a *configuration manager* (CM) function is used to disseminate the new network configuration information to the network elements. The configuration manager interfaces to a network inventory database (NI-DB) and the element management system (EMS) for each of the network elements (NEs). And in order to insure that individual customers are protected, a *virtual routing* function is used to provide segregated VPN communities within a single network. Each customer will be able to use his/her own VPN routing table, and users' policies [20].

MPLS Transport — The MPLS infrastructure will create dynamic connections in the network for customized service delivery, driven by service intelligence.

Tunnels will be setup between IP service switches at the network edges to deliver QoS-based services at the request of service intelligence. Enterprise networks will use DiffServ to relay the QoS requirements for a new data session. Based on its DiffServ marking and destination address, each packet is then mapped to the appropriate MPLS tunnel. The service intelligence could also use existing tunnels assuming they meet the basic requirements (QoS level and endpoint addresses) and sufficient bandwidth is still available.

Broadband access technologies such as Gigabit Ethernet, cable, DSL, and 3G wireless will integrate seamlessly into the edge MPLS switches. In the backbone, with the large amount of traffic expected, core MPLS switches will eventually have direct DWDM interfaces. IP traffic can be mapped directly into individual wavelengths and switched within the optical core using all-optical switches as described earlier (Fig. 9).

Bandwidth requests from the MPLS layer to the optical core will be made using a user–net-



■ **Figure 9.** *An MPLS-based QoS network.*

work interface (UNI) [21]. Such a UNI will allow a client (i.e., MPLS switch) to create, modify, or delete an optical channel across the optical network. The request could specify several key parameters such as type of protection, maximum number of nodes traversed, and cost constraints.

Service providers can evolve into that vision from their existing frame relay or ATM network. For example, the legacy frame relay/ATM switches can continue to interface to the existing customers to maintain the current revenue-generating frame relay and ATM services. In such a role, they become edge network elements instead of core network elements. The new MPLS-based network is then introduced in the core to interconnect the FR/ATM switches. This can be done by mapping the FR or ATM virtual circuits into MPLS tunnels within the MPLS core network to provide the end-to-end QoS paths. As for the IP services, they can be connected directly to the MPLS core network via the IP services switch as described above. Over time, the IP services will become dominant, and the FR/ATM edge infrastructure can be gradually decommissioned.

Broadband access technologies such as Gigabit Ethernet, Cable, DSL and 3G wireless will integrate seamlessly into the edge MPLS switches. In the backbone, with the large amount of traffic that is expected, core MPLS switches will eventually have direct DWDM interfaces.

SUMMARY

The three new network architectures discussed in this article will lead the way for the rest of this decade. 3G wireless access will be capable of handling all applications with the appropriate QoS and will push the mobile Internet closer to reality. An optical core will move the bits economically and transparently. A QoS-based packet network will deliver on the promise of business packet services on a cost effective infrastructure.

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