PREFACE

When ADSL hit the market in the late 90s, the residential broadband market started to really heat up. Dial-up Internet access, while being a well-understood and reliable service, could not keep pace with the demands of having homes connected at broadband speeds. Cable networks, with their hybrid fiber and coax networks, were also competing for similar customers as traditional Telcos. Thanks to cable operators, triple-play services had already gained a foothold in the customer conscience as a service bundle that can be provided by a single company. This eased the way for Telcos to also deliver their own triple-play service bundles over a single copper pair—the same copper pair that was used for many years as a simple telephone line.

A triple-play package is a bundle of an Internet, video, and VoIP service. Video services almost always have two components: a Video on Demand, and an IP Television (IPTV). IPTV takes traditional terrestrial and satellite channels and delivers them over an IP network to the customer premises. Multi-play services are an extension of this concept and divide Internet access into more sophisticated services with specialized Quality of Service handling.

Until the early to mid part of this decade, apart from some early-adopters, service providers were not given to broadening their residential data portfolio past Internet access. This mindset is rapidly changing, and the market is diverging into two segments. The first segment is the commodity ISPs, who provide a cheap and fast Internet service. The cost-barrier to entry is lower due to the lower service overhead; the competition here is fierce. The second segment is to whom this book is aimed—those providers in, or looking at, getting into the triple- and multi-play service market.

Several reasons drive the diversification. From a political perspective, many Telcos with wired access are finding their traditional revenues being eroded due to regulatory pressures. Triple- and multi-service bundles are an ideal way to maintain some service margin in an increasingly competitive market. For access seekers, regulatory intervention is a much cheaper way to expand network coverage compared to an expensive copper or fiber access network rollout. For both wholesalers and access seekers, there was a major drawback to video service deployment: ADSL does not have much bandwidth to play with. ADSL2+ pushes up the downstream limit to over 24Mbps, giving ample headroom for high-definition IPTV channels, while not making a severe impact on Internet performance.

This book is the perfect companion for anyone in the networking industry. If you are a journalist or analyst who wants more inside, in-depth information about next-generation broadband access networks, you will find it here. Or if you work at a vendor or service provider, the architectures and configurations enhance your technical understanding with practical applications of protocols and hardware.

ATM-based DSL networks are well understood and have been in the marketplace for many years. There are already one or two books on these broadband networks. However, this book fills the gap in the market for a leading-edge architecture guide of next-generation, Ethernet-based DSL networks and triple- and multi-play services. Because this book is more about architectures than focusing exclusively on technology, this book appeals to a wider audience than just technicians. Planners, financial controllers, managers, and network architects will also find useful information. The designs and techniques described in this book apply to many markets around the world.

The intent of this book is to inform the reader of best practices in the industry, and where there is still contention, the pros and cons of each alternative are laid out. For example, North American providers generally choose to go with a customer-specific VLAN architecture, whereas European providers prefer to use a service VLAN. Explanations of these terms and the advantages and disadvantages of each are two examples of the flexible approach that this book attempts to provide.

Many readers already in the industry will be familiar with the topics in each chapter, but the concepts in the latter parts of each chapter are not intended for beginners. For example, many of the MPLS concepts in Chapter 3, "Designing a Triple-Play Backbone," are not intended for those whose exposure to MPLS is for the first time. The description for each of the 12 chapters listed in the next section tells the reader the intended technical level, along with any recommended reading titles.

What You Will Learn

After reading this book, the reader will have enough knowledge to work through the issues and challenges involved with designing and deploying a triple- and multi-play network. There may be times where there is not enough detail in a particular section. The intention has been to cover at least the basics, so the reader at least knows what issues are involved if they need to do more research. Most of the IETF RFC-based technologies have been referenced by URL for further investigation. Although Wikipedia might not be 100% accurate, for technical information it is a reliable and useful resource for unfamiliar topics. As of January 2007, PDFs of in-force ITU-T specifications are freely downloadable. These are quite specific in nature and are good when needing to delve deep into specific aspects of a DSL modulation, for example. Also included at the end of the book are two glossaries: a comprehensive glossary of terms, and a list of packet diagrams for many of the protocols described in this book.

MULTI-VENDOR ROUTING

We have tried throughout this book to give an independent rendering of broadband network architectures. Because all of us currently are employed by Juniper Networks, the reader may see some emphasis given to Juniper's routing technologies and protocols as opposed to Cisco Systems. This is not intentional but merely a fact of life that we all live and breathe one routing set of equipment.

Where appropriate, we have posted listings throughout the book that show both Juniper and Cisco configurations whenever they differ large enough to draw attention to themselves.

Because the focus of this book is on architectures, the basic principles do not change depending on what vendor supplies your routing equipment. Often one vendor will be stronger in one area over another. For example, their system might be better at handling DHCP over PPP, or might have a limited VLAN capacity, so prefers the N:1 over the 1:1 approach. Therefore, vendors differ in their recommendations for broadband network architectures; this is normal. This book has tried to present neutral, but smart network choices; and where there is still contention in the marketplace, to present as much information as possible. So, armed with the right information, the reader can make the best choices for their network.

PLAYERS IN THE STANDARDS WORLD

IETF

The development of the Internet has been accomplished through the cooperation among various commercial entities, government agencies, and educational institutions spanning multiple countries, all working toward the common goal of improving communications. Although this development happens through a larger network of cooperation, a central administrative authority is required to produce protocol specifications, operational guidelines, address assignment, and other standards. The Internet Engineering Task Force (IETF) is the body that oversees the Internet standards process.

The Internet began as a U.S. Department of Defense (DoD) project as an experiment in the use of packet switching technology. This network, called ARPANET, started as only 4 nodes in 1969, spanned the continental United States by 1975, and had reached beyond the North American continent by the end of the 1970s. To coordinate this growth, in 1979 the Internet Control and Configuration Board (ICCB) was formed to oversee the design and implementation of protocols on the Internet. Renamed the IAB (Internet Activities Board) in 1983, then reorganized again in 1986 into the Internet Research Task Force (IRTF), the Internet Engineering Task Force (IETF) was also formed to concentrate on short to medium term Internet engineering issues.

The IETF produces standards and documents, which are not submitted to "traditional" standards bodies. The IETF develops "Internet-Draft" documents in open forums known as Working Groups (WG), which can be submitted initially by anyone and have a lifetime of six months. These documents can later be published as archival documents known as an "RFC" (Request For Comments), but cannot be changed after they are published. The IETF Working Group process is described in RFC2418. The IETF's mission includes (and is documented in RFC3935):

- Identifying and proposing solutions to operational and technical issues in the Internet
- Specifying development and usage of protocols and near-term architecture to solve technical problems for the Internet
- Providing a forum for information exchange within the greater Internet community, including vendors, users, researchers, agency contractors and network managers

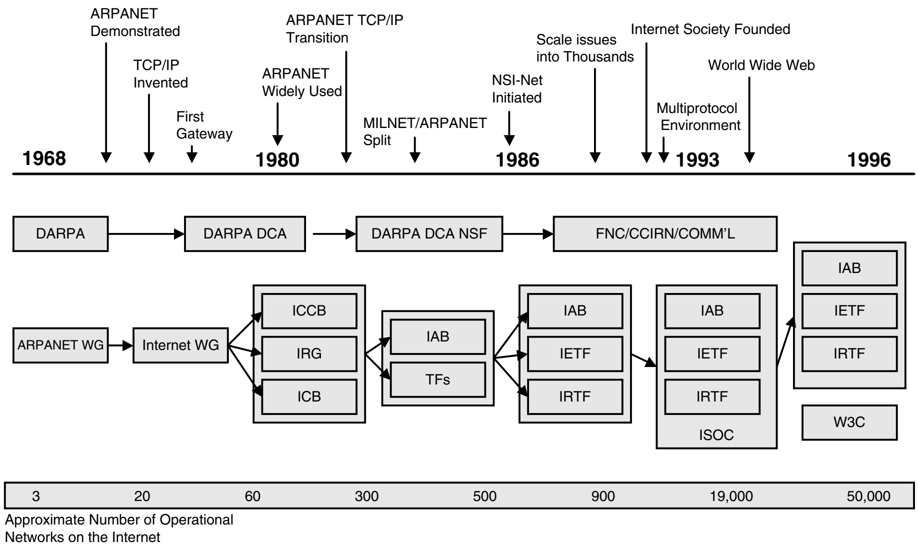

Figure I Evolution of the IETF

Over time, through various IETF working groups, the protocols and specifications that today's broadband networks consist of have been developed. The IETF standards include the fundamental protocols used today; from the Internet Protocol (IP), Transmission Control Protocol (TCP), User Datagram Protocol (UDP), routing protocols such as OSPF, RIP, ISIS & BGP, through access control protocols such as TACACS & Radius, Quality of Service, various Layer 2 control protocols, and other essential components in today's broadband networks. The following is a partial list of IETF working groups (WG) that have contributed to the protocols seen in today's Broadband networks, including ones described within this book:

- ANCP (Access Node Control Protocol)
- AAA (Authentication, Authorization and Accounting)
- ADSLMIB (ADSL MIB WG)
- AVT (Audio Video Transport)
- CCAMP (Common Control and Measurement Plane)
- DHC (Dynamic Host Configuration)

- DIME (Diameter Maintenance and Extension)
- DNA (Detecting Network Attachment)
- DNSEXT (DNS Extensions)
- DNSOP (DNS Operations)
- FECFRAME (Forward Error Correction Framework)
- IDR (Inter-Domain Routing)
- IPCDN (IP over Cable Data Networks)
- IPDVB (IP over Digital Video Broadcast)
- IPTEL (IP Telephony)
- IPv6 (IPv6 WG)
- L2TPEXT (Layer 2 Tunneling Protocol Extensions)
- L2VPN (Layer 2 Virtual Private Networks)
- L3VPN (Layer 3 Virtual Private Networks)
- MAGMA (Multicast & Anycast Group Membership)
- MIP4/MIP6 (Mobility for IP v4/6)
- MPLS (Multiprotocol Label Switching)
- PWE3 (Pseudowire Emulation Edge to Edge)
- RADEXT (Radius Extensions)
- SIGTRAN (Signaling Transport)
- SIP (Session Initial Protocol)

The IETF meets three times a year, in various locations around the world. Working Groups are divided into seven broad areas: Applications, General, Internet, Operations & Management, Real-time Applications and Infrastructure, Routing, and Security & Transport. The IETF consists of volunteers; there is no membership, and anyone can register for and attend any IETF meeting. See RFC4677 for a more detailed introduction to the IETF.

DSL FORUM

The genesis of DSL can be traced back to a number of key technical trials that were conducted around the late 1980s. Perhaps the most significant of those early efforts was conducted by Joseph Lechleider at Bellcore, who in 1989 was able to demonstrate the possibility of sending broadband signals and then followed this up with the astute observation that their application would be best served in an asymmetrical environment. Soon after this, John Cioffi pioneered discrete multi-tone(DMT), which enabled the separation of the signal into a number of frequency bands.

Telephony operators on both sides of the Atlantic, who at the time were grappling with the need for new services above and beyond traditional voice, were quick to take an interest. In a short space of time, a number of operators were deep into their own trials, many focusing on the possibility of using the new technology to deliver Video On Demand. While this particular application was a false start, it soon became clear that DSL would have a major role to play as enabling high-speed access to the Internet. When the Telecommunications Act was passed in the USA in 1996, the final piece fell into place and the technology had a truly viable future, both commercially and technically.

The momentum had been gathering pace for a while, and it was clear to key players in the DSL space that an official body was needed to bring the strands together. Following a meeting in New York, Debbie Sallee (Motorola) and David Greggains (Gorham & Partners) were instrumental in preparing people for what was to be the first official meeting of the ADSL Forum. That first meeting took place on October 7, 1994 at Church House in central London—54 people attended representing 43 organizations and 14 countries. The format and early goals were quickly established, and an interim steering group was appointed at the first meeting. A glance down the names appointed to that group shows many who would continue to play a major role in the Forum for many years to come:

Kim Maxwell, Independent Editions; Chairman David Greggains, Gorham & Partners; Secretary Dawn Diflumeri-Kelly, AT&T; Timothy Kreps, Amati; Mark Handzel, Orckit; Earl Langenberg, US West; Bill Rodey, Westell; Debbie Sallee, Motorola; Kamran Sistanizadeh, Bell Atlantic; Tom Starr, Ameritech; Alan Stewart, Network Interface Corp; Greg Whelan, Analog Devices; Gavin Young, BT; Federico Vagliani, Italtel.

The immediate goals of the DSL Forum can be seen as a microcosm of everything they have continued to achieve since inception in 1994. As the field trials continued to expand, so of course did the standards in use. The Forum was quick to recognize that in order for the technology to become "mass-deployable," it had to provide a base for the creation of a complete set of standards from the user to the network and everything above, below, and between. Second, and perhaps just as important, was a drive to promote the technology. In 1993/1994, many industry commentators and analysts were not convinced on the long-term future. And so began the Technical Committee and the Marketing Committee of the DSL Forum. Alongside these two key strands was a commitment by all original members to ensure that the Forum retained and promoted as much as possible an international focus.

Along the way a number of key milestones have shaped the importance of the Forum. In 1998, the ITU-T approved the ADSL Recommendation, and in 1999 the Forum officially changed its name from ADSL Forum to DSL Forum. Other key technical milestones are too numerous to mention; however, the approach has always been the same and is clear in its goals: Focus on the work most needed by the industry, converge on a single agreed-upon solution, and standardize this with Technical Reports that are voted on by a membership ballot.

The Forum currently has more than 200 members who meet four times a year at week-long meetings. These meetings continue to be invaluable as telecos, service providers, and equipment vendors thrash out best practices and architectures that enable rollout of new networks and services that are scalable, timely, and economical for all.

ITU

On May 17th, 1865, the International Telegraph Union was established—just over 20 years after Samuel Morse sent his first public message between Washington and Baltimore over a Telegraph line. The original 20 founders of the International Telegraph Convention initially set out to create a framework agreement that covered issues around international interconnection. In parallel, a common set of rules were developed to standardize the equipment used for international interconnectivity. This standardization was essential, because previous to this, international Telegraph communications required a laborious process to hand messages across international borders, as each nation typically had it's own systems and implementations.

After the telephone was patented in 1876, the ITU proceeded to develop international legislation for governing telephony. In 1906, with the introduction of the wireless telegraph and other early forms of radio communications, the International Radiotelegraph Convention was signed, which established the study of international regulations for radio telegraph communications. The 1920s saw the establishment of the International Radio Consultative Committee (CCIR), the International Telephone Consultative Committee (CCIF), and the International Telegraph Consultative Committee (CCIT). In 1932, the Union decided to combine the International Telegraph Convention and International Radiotelegraph Convention into a single entity—the International Telecommunications Union, which by this point covered both Wireless and Wireline communications.

Following World War II, the ITU formed an agreement with the United Nations (UN) to develop and modernize the organization, becoming a UN specialized agency. In parallel, the International Frequency Registration Board (IFRB) was established to coordinate the use of frequency spectrum. Then in 1956, the CCIT and CCIF merged into a single entity—the International Telephone and Telegraph Consultative Committee (CCITT). The 1950s and 1960s also saw the beginnings of space-based communications systems, with the launch of Sputnik-1 in 1957. The CCIR established a group responsible for the study of space-based radio communications in 1959. 1963 saw the allocation of frequencies to the various space services, and the beginnings of governance and regulation of radio frequency spectrum by satellites. In 1992, spectrum was identified for use in IMT-2000, the ITU developed global standard for digital mobile technology.

IMT-2000 was developed as a way to harmonize interoperability between the incompatible mobile telecommunication systems used around the world, by providing a technical foundation for new high-speed wireless broadband systems and devices capable of handling voice and data services. The 1990s also saw the ITU streamline into three distinct Sectors: the ITU-T for Telecommunication Standards, ITU-R for Radio communications, and the ITU-D for Telecommunication Development. A regular schedule of conferences was also established at this time.

With the strategic plan developed by the ITU in 1994 in Kyoto, a forum was established for the discussion of global telecommunications policy and strategies, known as the World Telecommunication Policy Forum (WTPF). The WTPF forum has hosted discussions on themes such as global mobile personal communications, telecommunications trade issues, and topics such as the Internet Protocol (IP).

CHAPTERS IN THIS BOOK

Chapter 1, "A History of Broadband Networks," describes the beginnings of broadband access networks, starting with the advent of the DSL family of technologies—CAP and DMT—and how this had an effect on deployment throughout the world. This tells the story of technology development from vendors and deployment milestones by service providers. There are also discussions of broadband access devices, access protocols, and the most common authentication and accounting protocol—RADIUS. The technical knowledge needed to understand this chapter is low.

Chapter 2, "Next-Generation Triple-Play Services," is an introduction to what triple- and multi-play services really mean. What does a video service actually entail? What are the components of a triple-play network, from a high-level perspective? How is VoIP integrated into the network? These questions are answered in this chapter. There is also a section on business connectivity, describing how services such as Layer 3 and Layer 2 VPNs are being deployed with DSL access. The technical knowledge in this section is medium due to heavy use of jargon and some of the more complex topics in each subsection.

Chapter 3, "Designing a Triple-Play Backbone," looks at how operators are implementing backbones that can carry triple-play services. The chapter begins with an overview of the most popular type of protocol on provider backbones—Multi-Protocol Label Switching (MPLS). The discussion quickly moves to describing a common service that providers have implemented—Layer 3 VPNs. MPLS networks are also used for their traffic engineering properties, and may not use any Layer 3 VPNs except for business services. Included are many examples of how IP multicast services can be integrated into these networks. The discussion starts from a common example of multicast and Protocol Independent

Multicast (PIM) and how traffic and protocols flow. There are many optimizations and enhancements possible with this model, such as using source-specific multicast and redundant rendezvous points, which are described here. An efficient way to transport multicast on an MPLS network using point-to-multipoint LSPs is explained here. Also included is a look to the future of next-generation backbone IPTV delivery using VPLS with point-to-multipoint trees.

The Broadband Network Gateway (BNG), often called a Broadband Remote Access Server (B-RAS), is an important point for service definition. The focus moves to integrating BNGs in to the network for triple-play services. This covers multicast protocols on the BNG, such as IGMP and additional features for PIM. Finally, implementing a highly available core network is a hallmark of any service provider, so there are protocols and strategies, such as BFD fast-reroute, that can be added to a network for added robustness.

The technical knowledge required for this chapter is medium to advanced because many of the principles described assume some prior experience with MPLS networks and multicast protocols.

Chapter 4, "Designing a Triple-Play Access Network," covers one of the most important aspects of a next-generation DSL network—the access network. There are two major components to this critical piece of infrastructure: the DSLAM, and the network between the DSLAM and the BNG, also called the aggregation network. DSLAM deployment architectures such as hub-and-spoke, daisy-chained are shown here. Designing the aggregation network is an important task. Examples described in Chapter 4 are using an MPLS network to transport customer traffic from DSLAMs to the BNG. Layer 2 tunneling technologies, such as VPLS, Martini or Kompella VPNs are also covered. Extensive deployment scenarios of these technologies is also shown as more traditional transport, such as CWDM, DWDM, or dark fiber.

The second part of Chapter 4 is the lively discussion as to the type of VLAN architecture to run between the DSLAM and the BNG: Should it be a 1:1, VLAN-per-customer model, or a service-per-VLAN model? The type of model chosen has important implications and should be designed correctly from the start. This chapter contains important information to enable the reader to make an informed decision for their VLAN architecture. Medium-level technical knowledge of MPLS protocols is also recommended for this chapter.

Chapter 5, "Choosing the Right Access Protocol," covers an equally lively debate in the industry—whether to use PPP or DHCP as the protocol between the BNG and the customer. Jargon and protocols, and deployment scenarios are explained here. As with any architectural choice in this book that does not have a clear answer, there are pros and cons to both approaches. Despite being quite narrow in focus, a low to medium level technical knowledge of PPP and DHCP is needed for this chapter.

Chapter 6, "Evolutions in Last-Mile Broadband Access," is a chapter for those who like to get deep into technical details on transport networks. This chapter takes a tour of the evolution of DSL networks, from the first ADSL deployments using Carrierless Amplitude/Phase Modulation to the standard Discrete Multi-Tone (DMT) in use today. Topics commonly associated with DSL lines—spectrum usage, cross-talk, special protocol features, and data rates—are explained in detail in this chapter. Line-level protocols covered include ADSL, ADSL2, ADSL2+, VDSL, VDSL2, and SHDSL. This chapter is appropriate for anyone with medium-level knowledge of transport protocols.

Chapter 7, "Wholesale Broadband Networks," covers what wholesale providers and access seekers need to know when working in a wholesale, unbundled environment. An unbundled environment is one where a local authority has mandated that an incumbent provide access to customers connected to the local loop. Types of unbundled services range from a simple Layer 3 IP wholesale service to a full unbundled copper service, which are two such examples that are covered. Some additional attributes and protocols associated with L2TP, such as tunnel fragmentation and proxy LCP, are also covered here. Low to medium level knowledge of L2TP and prior reading of Chapter 4 are sufficient for this chapter.

Chapter 8, "Deploying Quality of Service." Not a day goes by in discussions of next-generation DSL services without mentioning Quality of Service. This substantial topic is all about how to effectively deliver multiple services in a bandwidth-constrained environment. This covers the history of QoS in an IP environment, showing how IP precedence and Differentiated Services have had an important impact in helping to define a prioritization architecture. Uses of these mechanisms with QoS features, such as rate-limiting, shaping, RED and W-RED, and strict priority scheduling are a few of the features explained in this chapter. The concepts in this chapter do not require much prior knowledge and a low to medium level of understanding of access architectures in Chapter 4.

Chapter 9, "The Future of Wireless Broadband," presents a survey of the wireless technologies that complement today's traditionally wireline-based multi-service networks. With advances in 3G wireless technologies, such as growing data rates, advanced in service control, security and quality of service, it's becoming possible to deliver comparable services wirelessly as it is over wireline triple- and quad-play architectures. This chapter covers the history of wireless data, from the ETSI GSM and early CDMA days, through Wideband CDMA and UMTS, through today's evolving wireless broadband architectures, such as IMS, SIP, and non-SIP based fixed mobile convergence and wireless video. The chapter contains a survey of the different technologies, network architectures behind them, and evolving wireless broadband standards.

Chapter 10, "Managing IP Addressing," takes a look at one of the simpler tasks of a BNG—assigning an IP address. This chapter explains all the options available to a network operator, for both PPP- and DHCP-based networks. Whether this involves simple static address assigned via RADIUS or a more complex approach using dynamically signaled on-demand address pools (ODAP), many common approaches are described in this chapter. Keeping with the forward thinking trend of this book, there is also a section on the implications of IP address management in an IPv6 access network. The concepts in this chapter are of a low to medium technical complexity.

Chapter 11, "Dynamic User Session Control," is an overview of subscriber session management. It describes the important platforms that work behind the scenes to manage things like billing, provisioning, RADIUS, and the user database. This chapter also describes how advanced dynamic service provisioning can reduce the opex overhead of subscriber management, with such techniques as customer self-care web portals and automated service provisioning engines.

Chapter 12, "Security in Broadband Networks," presents some of the concerns carriers face when operating broadband subscriber networks. Subtopics include Denial of Service against infrastructure, and security of VoIP. The basic premise of the chapter is to present ideas around demarcation of levels of trust, and to discuss the problems that can occur when resources are exhausted or anomalous packets are received by systems. The reader should have a basic understanding of VoIP technologies when reading through the security concepts pertaining to VoIP. The majority of the chapter is of a low to medium technical nature.

Appendix A, "Glossary of Acronyms and Key Terms," is a comprehensive glossary of terms that are used throughout the book. Most technical terms and acronyms that are used throughout this book are expanded and explained in this section.

Appendix B, "Glossary of Packet Diagrams," contains packet headers and structures of common protocols that are used throughout the book. For example, if you find the concept of L2TP protocol difficult to conceptualize, there is an example showing how the protocols are layered on top of each other.