NEXT GENERATION TRANSPORT NETWORKS

Data, Management, and Control Planes

NEXT GENERATION TRANSPORT NETWORKS
Data, Management, and Control Planes

Manohar Naidu Ellanti
Steven Scott Gorshe
Lakshmi G Raman
Wayne D Grover

Springer

Manohar Naidu Ellanti
Lakshmi G. Raman

Steven Scott Gorshe
Wayne D. Grover

Next Generation Transport Networks
Data, Management, and Control Planes

Library of Congress Cataloging-in-Publication Data

A C.I.P. Catalogue record for this book is available
from the Library of Congress.

ISBN 0-387-24067-5 e-ISBN 0-387-24068-3 Printed on acid-free paper.

Printed in the United States of America.

9 8 7 6 5 4 3 2 1 SPIN 11054764

springeronline.com

Contents

Preface ix

Acknowledgements xiii

1. INTRODUCTION TO TRANSPORT NETWORKS 1

  1.1. General Introduction 1

  1.2. What is a Transport Network? 3

  1.3. Summary of the Chapter Contents 21

  1.4. What's Happening with Transport Networks? 25

  1.5. Conclusions 37

2. SWITCHING 39

  2.1. Introduction 39

  2.2. Taxonomy 40

  2.3. Space Division Switching 42

  2.4. Time Division Switching 59

2.5. Packet Switching 73

2.6. Interconnection Networks 80

2.7. Centralized and Distributed Switching 91

2.8. Fault Tolerance of Switching Networks 94

2.9. Conclusions 98

3. SONET and SDH 101

3.1. Introduction 101

3.2. SONET/SDH Layering Principles 107

3.3. SONET/SDH Frame Format 112

3.4. SONET Overhead Definitions 125

3.5. OAM&P Functions and Capabilities 135

3.6. Payload Mapping 146

3.7. Pointers and Justification 164

3.8. Synchronization 170

3.9. Sub-STS-Interfaces 172

3.10. In-band Forward Error Correction 176

3.11. Conclusions 177

4. NEXT GENERATION TRANSPORT TECHNOLOGIES 181

4.1. Introduction 181

4.2. Virtual Concatenation (VCAT) and the Link Capacity Adjustment Scheme (LCAS) 182

4.3. Generic Framing Procedure (GFP) 198

4.4. Resilient Packet Ring (RPR) 214

4.5. Optical Transport Networks (OTN) 230

4.6. General Conclusions 262

5. MANAGEMENT ARCHITECTURES 267

5.1. Introduction 267

5.2. What and Why of TMN 268

5.3. Architectures of TMN 273

5.4. Relationship Between TMN Architectures 299

5.5. Relationship Between Control and Management Planes 300

5.6. TMN Reality Check: What has Gone Wrong with TMN? 302

5.7. Conclusions 304

6. MANAGEMENT INFORMATION MODELS 307

6.1. Introduction 307

6.2. Transport Architecture 313

6.3. Generic Information models 318

6.4. SDH Information Models 321

6.5. Conclusions 375

7. MANAGEMENT TECHNOLOGIES 377

7.1. Introduction 377

7.2. Management Protocols/Languages Galore 379

7.3. Information Specification Languages 380

7.4. Information Access and Transport Protocols 420

7.5 Conclusions 480

8. TRANSPORT NETWORK SURVIVABILITY 485

8.1. Introduction 485

8.2. Automatic Protection Switching (APS) 489

8.3. Mesh-Based Network Survivability 515

8.4. Approaches for Control of Mesh Protection and Restoration 528

8.5. p-Cycles: Bridging the Ring-Mesh Dichotomy 559

8.6. Other Aspects OF NEXT-Generation Transport 566

8.7. Conclusions 579

9. CONTROL PLANE 587

9.1. Introduction 587

9.2. Why Signaling? 588

9.3. PSTN Control Plane (SS7) 592

9.4. ATM Control Plane 617

9.5. Optical Control PLANE 656

9.6. PSTN, ATM, and Optical Control Plane Signaling Features 681

9.7. Conclusions 682

Glossary 687

Author Biographies 697

Index 701

Preface

Are transport networks important? To society? To communications engineering as a field? What about the "fiber glut"? Isn't bandwidth already essentially abundant and free? Despite these and other popular misconceptions, metropolitan, national and international fiber-optic based transport networks are actually one of the engineering marvels of 20th century and have become fundamental infrastructure, crucial to current and future economies and societies. Like many basic civil infrastructures, such as water, roads, power, public health, such engineered systems are almost invisible to the layperson, especially when they work nearly perfectly. But major and unexpectedly severe economic, personal, and societal impacts arise if these systems are removed even temporarily. Like these other basic infrastructures, the fiber optic transport network is now of fundamental importance to our economy, lifestyles, education, entertainment, finance and so on. Advances in computing, wireless, mobility, multi-media, HDTV, the Internet, all come to a halt if it were not for the capabilities of the underlying transport network on which they all ride. The public sometimes asks "What about wireless and cell phones, with them we don't need fiber," but this is based only on technical unawareness that every cell-phone call relies on fiber optic transport for trunking between switches and base stations to complete the calls. Similarly, every DSL and cable modem user of high speed Internet access is also a user of the fiber transport backbone. These "access" technologies, to which we can add phone and bank ATM machines, are best known to us all as users because it is these systems that are "in our face." But all of them rely on a single, ubiquitous, relatively unseen transport network operating behind the scenes.

But there are also important ways in which the transport network differs from the older utility infrastructures mentioned above. Intelligence, survivability, and flexibility is one set of features, but the potential for productivity and wealth impact is an enormous differentiator. In a recent report by the Allen Consulting Group [1], it was estimated that achieving the goal of "true broadband" networking (over 10 Mbps to every home and office) can result in national productivity growth of 10-12%. They comment that this is the fundamental reason why governments should make investment in research networks, ICT, and competitive telecom their number one priority. In their view no other technology, even nanotechnology or bio-informatics is seen as having such a direct and measurable impact on national and global productivity. This means jobs. This means wealth creation. This means a plethora of still unimagined new educational, business, research, recreational, and entertainment possibilities. Transport networks are thus of fundamental importance to a society that wants to reach high and grasp this "prize."

There are many different ways to approach the topic of transport networks. Books typically focus on either the transport (data) plane or the control and management planes, depending the authors' expertise. In order to reduce overhead costs and increase the speed and flexibility of offering new services, however, carriers continually look to automate their operations, administration, maintenance, and provisioning (OAM&P) tasks. The result is an increasingly closer linkage between the transport, management, and control plane technologies. New transport plane technologies are unlikely to be adopted unless they offer OAM&P savings, and new OAM&P tools are unlikely to be adopted unless they can work with the current transport plane infrastructure. One of the objectives of this book is to provide a comprehensive, balanced overview of the transport, management, and control plane technologies. The book is organized with one section devoted to each of these three planes.

Another objective of this book is to provide a useful tutorial and reference information for current and next generation telecommunications network technologies. Since it is not practical for carriers to replace their existing infrastructure, even new equipment and network deployments will need to be compatible with the existing technologies such as SONET/SDH. Both the boom and bust in the telecommunications industry spawned a number of new technologies that are expected to become important in the coming years. Many of these technologies are not covered in existing books. This book provides a detailed tutorial overview of these new technologies, seeking to put them into the proper context with respect to interworking with existing networks and technologies. Examples include the Generic Framing Procedure (GFP), the Link Capacity Adjustment Scheme (LCAS), the

Resilient Packet Ring (RPR) protocol, Automatic Switched Optical Network (ASON), and XML/SOAP (Simple Object Access Protocol) based management technologies. Since TL1 and OSMINE are important for many North American carriers and vendors, a brief discussion of both is included in the management section. Also, discussion of multi-stage switching used in modern digital cross-connects and other switching equipment can be found in Chapter 2 as part of transport technologies. The critical, related topic of network protection is also covered extensively in Chapter 8 to round the book.

What do the four of us especially have to offer on the topic? The authors that Manohar assembled for this book have each been recognized by their peers for their contributions in their respective areas. Each of us has more than 20 years of experience in telecommunications research, product development, and/or standards. Steve and Lakshmi are both recipients of the Committee T1 Alvin Lai Outstanding Achievement Award for their standards contributions. Wayne is an IEEE Fellow for his contributions to survivable and self-organizing broadband transport networks. (More complete biographies of each author appear near the end of the book prior to the Index.) We divided the chapter responsibilities as follows: Manohar – Chapters 2, 7 and 9; Steve – Chapters 1, 3, and 4 (and contributing to 8); Lakshmi – Chapters 5 and 6; and Wayne – Chapter 8.

Due to the multiple authors, the book may have some inconsistencies in style, despite our best efforts to harmonize. If our readers identify any editorial or other types of errors that escaped us, please bring them to our attention - we will update our companion website with corrections to typographical or technical errors as soon as we discover them. This being a very detailed book - we are bound to have some errors and the companion website should be helpful for those looking for corrections. For any questions related to this book, please email Steve Gorshe (sgorshe@ieee.org).

Manohar N Ellanti
Fremont, California

Steven S. Gorshe
Beaverton, Oregon

Lakshmi Raman
Albany, Oregon

Wayne D. Grover
Edmundton, Canada

January 2005

[1] Allen Consulting Group, "True Broadband: Exploring the economic impacts," An Ericsson contribution to public policy debate, September 2003, available online: http://www.ericsson.com.au/broadband/true_broadband.asp

Acknowledgements

Manohar would like to thank his wife, Sumati, and children, Mounika, Vivek for letting him spend time working on this book- numerous versions and revisions of chapters, book proposals and correspondence related to this project. Manohar also likes to thank his co-authors for coming together on this project

Steve would like to primarily thank his wife Bonnie, and boys Alex and Ian for their patience as I worked on the book for many an evening. I would also like to thank Vern Little and Stacy Nichols at PMC-Sierra for their support in allowing me to combine some of my work on the book with my writing of white papers for PMC-Sierra.

The authors would like to express their thanks to the following individuals for their review and input to the material in this book. Thomas Alexander, Tim Armstrong, Richard Cam, Robert Crestani, Huub van Helvoort, Patrice Plante, Winston Mok, Anthony Sack, and Trevor Wilson, Harinder Singh, Rao Lingampalli, Manish Vichare, Mahesh Subramanian, Chiradeep Vittal, Steve Langlois. Manohar would particularly like to mention and thank Jackie Orr in helping with review and contribution to section on OSMINE, a very rarely covered material in other books. Special thanks to Lyndon Ong, who is involved in ITU, OIF and other standards bodies related to control plane, in helping with review of Control Plane chapter and contributing to parts of this chapter. Authors would like to thank Melissa Guasch at Kluwer/Springer for helping with reviews and general correspondence related to this project. Special thanks to Alex Green, the editor at Kluwer/Springer for providing support and encouragement.

Chapter 1

INTRODUCTION TO TRANSPORT NETWORKS

1.1. GENERAL INTRODUCTION

Telecommunications transport networks are the largely unseen infrastructure that provides local, regional, and international connections for voice, data, and even video signals. In fact, most "private" networks are implemented by leased connections through the public transport network infrastructure. Transport networks in telecommunications and data communications networks are changing rapidly with the introduction of new technologies that address the need for new value-added services, high availability, and integration. There has been a considerable amount of effort from equipment vendors and network providers to bridge and unify previously dedicated networks to serve the data and telecommunications market. This effort is reflected in the output of several standards bodies and industry groups and the field trials of new equipment and services.

In the midst of this change, there are two trends that have made transport networks more visible to end-users. The first is the desire for higher bandwidth multi-media enterprise network connections. The enterprise network administrators building the networks have to take into account the various capabilities of the transport networks, including whether they can provide an integration of voice and data services or whether each must be carried on a separate sub-network. The second trend is the increasing deregulation and/or privatization of national telephone carriers. For example, U.S. long distance carriers such as AT&T, Sprint, and MCI can now bypass the local telephone companies, effectively providing direct access for enterprise customers into their transport networks.

Who should care about transport networks, and why? As indicated above, those who construct or administer enterprise networks are often constrained by the capabilities of the public transport networks. Familiarity with transport network technology will allow them to make appropriate decisions regarding WAN connectivity. Service providers working to increase revenues with the introduction of value added services would benefit from understanding how to best utilize the capabilities of the new technologies. There is still a substantial market for transport network equipment, and clearly anyone involved in developing these products needs to be familiar with the existing and emerging technologies. Policy makers should also be familiar with the transport network technologies and their potential impact on policy decisions. Those in academic circles who use or do research related to telecommunications networks also need a thorough understanding of their technology, and the practical constraints on introducing new technologies.

The motivation for this book is to offer, in a single source, information that allows readers with differing requirements to gain a complete picture of the different dimensions of transport networks along with practical perspectives. With the large number of industry standards specifications associated with various aspects of transport networks, it is often difficult to get the big picture view of what will be deployed in the future and how it will facilitate a service provider to meet their business objectives. By bringing together in one place various topics that are spread across multiple specifications, the book enables readers with different goals not only to understand the complete picture but also to access details. The authors also attempt to provide insights on not only what the existing technologies are, but also how they evolved and the constraints and drivers for the future directions. The style of the book is to begin chapters and sections with tutorial background for readers that are new to the subjects. The chapters then move to a more detailed treatment that can be used as a reference for readers more familiar with the subjects. As such, the book is aimed at readers with different levels of prior knowledge, from the student to the network professional.

This introductory chapter begins with a description of transport networks, first from a historical perspective and then from two different taxonomy viewpoints. This discussion also includes a brief introduction to access networks in the context of how they relate to transport networks. With these descriptions in mind, the chapter then summarizes the contents of the remaining chapters of the book. The chapter concludes with a look at some of the current and anticipated future trends in transport networks.

1.2. WHAT IS A TRANSPORT NETWORK?

In the broadest sense, a transport network can be regarded as the set of facilities and equipment that carry data between the network elements (NEs) that switch or route the customer data into the transport network. These switching NEs use the transport network to carry the customer data to the proper destination, with the transport network being responsible for reliably delivering that data. (Perhaps the simplest definition of a transport network is Simila's Rule "a bit goes in and the bit comes out, no more, no less" regarding the preservation and delivery of the data through the network.[1]). Of course, this definition is somewhat simplistic. As transport networks grow in geographical size and capacity, it becomes increasingly important to have Operations, Administration, Maintenance, and Provisioning (OAM&P) systems associated with the transport networks. Otherwise, it would be impossible to set up and run a transport network with any degree of reliability or cost-effectiveness. As an example, the current lack of adequate OAM&P capabilities has prevented Ethernet from becoming a viable transport network technology except within in networks of very limited scope.

In this section, we examine transport networks from two different viewpoints. In the first approach, transport networks can be broken down according to their geographical or functional scope. The second approach, which provides the outline for the remaining chapters in this book, is to decompose transport networks into the three logical planes; transport, management, and control. To begin the section, however, it is useful to have a brief historical review of the evolution of transport networks to set the discussions in their proper context.

---

[1] A favorite saying of Ray Simila, former manager of U.S. West's transmission equipment evaluation laboratory who is still very active in the telecommunications field.

Table 1-1. Historical milestone summary of the public telecommunications network

Analog Era	Year	Description	Area
	1876	Telephone Invented	Access
	1878	First Switched Service	Switching
	1879	First Automatic Switch	Switching
	1892	Step-by-step Strowger automatic switch	Switching
	1917	A Carrier (4 voice circuits)	Transmission
	1938	Bell AT&T Crossbar switch	Switching
	1940's	TD carrier microwave (600 voice circuits + video)	Transmission
	1950'	TD carrier microwave	Transmission
Digital Era	1962	T1 digital trunk (24 voice circuits)	Transmission
	1965	1ESS, Computer Controlled Switch	Switching
	1972	Fully Digital Switches, Nortel	Switching
	1976	4ESS Computer Controlled Switch, CCS	Switching, Network Control
	1984	SSN, ISDN	Access, Network Control/Control Plane
Fiber Optic Era	70's-	Kao's paper on the possibility of optical transmission loss of <20db loss per Km, laser, Corning's invention of optical fiber, ubiquitous deployment of fiber, SONET/SDH standardization	Transmission
	1988	First SONET/SDH systems deployed	Transmission
	late 1990s	DWDM systems see significant deployment	Transmission
Policy/Regulation	1984	US Network divided into 160 LATAs	Regulatory
	1996	US Telecom Regulation Act	Regulatory
Mobile era	1985 forward	Introduction of cellular telephone technology made mobile phones practical and attractive.	Access
Internet Era	1975	Vincent Cerf invents TCP/IP protocol	Layer 3 Protocol
	1990's	Netscape, Internet	Applications
Stock Market	Late 1990s	Enthusiasm over the rapidly increasing bandwidth requirements of the Internet cause an unprecedented boom in investment new and existing telephone carriers, and system and component manufacturers.	Market Forces
	2000 -	Bandwidth Glut, Downturn in Telecom and market shakeout.	Market Forces
FR, ATM/QoS	1990s	Deployment of FR/ATM to carry data traffic	Data
OC-192 IP Routers	Late 90's	Juniper's First OC-192 IP router	Data

1.2.1 Historical perspective

The history and milestones of the telecommunications networks is summarized in Table 1-1. The earliest transport network were point-to-point copper cables with separate wires dedicated to each voice channel. (The switching nodes were operators with manual patch panels.) Since this was clearly an unscalable approach, it become important to introduce multiplexing so that multiple voice channels could be carried over the same set of wires. Until the 1960s, when the first digital transmission systems were introduced, the voice channels were transmitted as analog signals. The first multiplexing technology was Frequency Division Multiplexing (FDM) since this was the most appropriate for carrying analog signals. Carrying these analog FDM signals for long distances over copper wires was unattractive since it required running cables through very difficult terrain and required frequent amplification to restore the signal level. Microwave radio transmission provided the answer for many years in the long distance transport networks.

When digital transmission technology was introduced in the early 1960s, it proved to be revolutionary. As those familiar with communications systems are aware, a digital signal can be regenerated such that if there are no bit errors, there will be no degradation to the signal regardless of how many time the signal is regenerated[2]. In contrast, analog signals suffer a decrease in signal-to-noise ratio and some distortion at each point where the signal is amplified. Also, the integrated circuit technology that was also introduced in the 1960s proved much amenable to building low-cost digital circuits than analog circuits. With the introduction of digital transmission technology, the most appropriate multiplexing technology was Time Division Multiplexing (TDM). Digital TDM was used both on copper cable systems and on microwave radio.

In North America, the digital hierarchy was defined by AT&T and referred to as Digital Signal of level *n* in the hierarchy (DS*n*). The DS1 signal carried 24 voice channels at a rate of 1.544 Mbit/s, the DS2 multiplexed four DS1s at a rate of 6.312 Mbit/s, and the DS3 multiplexed seven DS2s at a rate of 44.736 Mbit/s. The DS*n* hierarchy was commonly referred to as the asynchronous hierarchy. In other parts of the world, the hierarchy defined by the CCITT[3] was adopted and referred to as the

---

[2] This, of course, assumes that the signal doesn't accumulate too much jitter at each regenerator.

[3] CCITT stands for International Telegraph and Telephone Consultative Committee. The CCITT changed its name during the 1990s to International Telecommunications Union – Telecommunications Standardization Sector (ITU-T).

plesiochronous digital hierarchy. The PDH signals are the 2.048 Mbit/s signal that carries 30 voice channels, the 8.488 Mbit/s signal that multiplexes four 2.048 Mbit/s signals, the 34.368 Mbit/s signal that multiplexes four 8.488 Mbit/s signals, and the 139.264 Mbit/s signal that multiplexes four 34.368 Mbit/s signals[4].

The only integrated OAM&P capability with analog FDM systems was the inclusion of an orderwire channel in some of the signals. An orderwire is a dedicated, point-to-point voice channel that the crafts people at each of the orderwire channel could use for communications when they configured or maintained that facility or equipment at either end of the channel. One of the characteristics of the DS*n* and PDH hierarchies is that they had very limited integrated OAM&P capability. The DS1 time-shared its framing bit to derive a CRC and its advanced implementations provide a 2 kbit/s OAM&P message channel. The 2.048 Mbit/s channel similarly time-shared its framing byte to derive OAM&P channels. The higher rate signals typically only included some type of error detection bits in the frame. The result was that OAM&P of the network tended to be somewhat labor intensive, and it was difficult to quantify the quality of service being provided to different subscribers (users). In the mid-1980s, it was estimated that over 70% of a telephone companies costs went to OAM&P with less than 10% going to new equipment. Clearly, reducing OAM&P costs was a high priority.

It was also true that providing new services typically took a long time. The long lead times included putting the infrastructure in place to enable those services, but even with the infrastructure in place it would sometimes take weeks or even months before a service could be turned up for a new customer. Long provisioning times and lack of network flexibility thus limited the carriers' ability to bring in new revenue.

Another key historical factor relating to OAM&P was the break-up of the Bell System (AT&T). Now, a typical business connection would involve three different carriers; namely the two local exchange carriers (LEC) and the long distance interexchange carrier (IEC). If a problem existed on a multi-carrier connection, it became extremely important (under the threat of law suits from business customers who were losing revenue) for the carriers to determine whether or not the problem occurred in their network. This situation was a major driver toward more better, more accurate, and faster

---

[4] These PDH signals are often referred to as E1-E4, respectively. The relatively new ITU-T designation for the DSn and PDH signals are P11 = DS1, P12 = E1, P21 = DS2, P22 = E2, etc. In this book, the more familiar DS*n* and E*n* designations are typically used. Both the DSn and PDH hierarchies have a level higher than the one shown here, but since these saw limited deployment they are omitted.

methods for tracking the performance of connections and facilities, and better fault location and identification. A similar situation occurred in other countries as the government owned carriers were privatized.

Around the same time as the Bell System break-up, fiber optic cables were being deployed in transport networks. Fiber offered huge improvements in capacity and signal quality relative to copper cable systems, and it was often easier to find right-of-way for the cables due to the much smaller size of the optical cables. As the technology improved, it became feasible to begin replacing the microwave radios in the long distance network with optical fibers[5].

Fiber brought some new challenges, but it also offered some critical new opportunities. The early fiber optic systems were built on the existing DS*n*/PDH multiplexing approach, with each vendor typically using its own proprietary multiplexing frame format for the higher rate signals. Hence, there was little economy of scale and almost no cases where different vendors' equipment could interwork. This meant that at a carrier-to-carrier interface, both carriers would have to agree to a common equipment vendor if they wanted an optical interconnection. The desire for a standard hierarchy for fiber optic signals was one of the primary drivers for the development of the SONET and SDH standards. Since this was a new standard, one of the opportunities was to define a standard that was compatible between North America and the PDH users. As seen in Chapter 3, this objective was largely achieved. The other opportunity derived from the much higher bandwidth capabilities of the optical fiber. With optical transmission, it was now feasible to add a considerable amount of overhead bandwidth that could be used to greatly reduce the cost and improved the capabilities of networks' OAM&P. The combination of the SONET/SDH OAM&P overhead capabilities and the growing availability of computer resources has revolutionized network management and opened the possibility of more automated control of the network.

At this point in history, SONET/SDH forms the backbone of most of the world's transport networks with computer-based network management systems being common. As discussed in the appropriate sections throughout this book, a number of potential future directions are being explored for next generation telecommunications networks. One future direction will be an increasing amount of wavelength-division multiplexing (WDM). WDM is already seeing extensive deployment, and interestingly, is essentially a return to an FDM technology (i.e., a wavelength can be regarded as a carrier frequency). Another direction for transport networks is an increasing capability for efficient, flexible data transport rather than just being

---

[5] Sprint was the first major long distance carrier to convert to an all-fiber long haul network.

optimized for voice traffic. At this time, the focus has been on adding transport capabilities. Some carriers are promoting a migration to carrying and switching all traffic as data traffic rather than using TDM. Multi-Protocol Label Switching (MPLS) is expected to be the core technology in these packet based networks. Voice signals can be packetized and carried as Voice over Internet Protocol (VoIP).

Another important future direction is and an increase in the ability for automated or near-real-time control of the transport network through the introduction of a control plane on top of the management plane as discussed in section 1.2.3. The control plane has the potential to allow much faster and more flexible initiation of new services and modification of services as they are being used. Chapter 9 contains extensive discussion of control plane related aspects.

A historical aspect that can't be overlooked is the increased capability of transport networks to recover from failures in the network. When individual facilities carried relatively few channels, it was not cost-effective to provide a redundant facility or bandwidth to carry the traffic in the event of a failure along the working path. As more channels are multiplexed onto higher-rate signals, it becomes increasingly important not to let a failure disrupt all of these channels. Some of the data traffic that is carried in modern networks is also critical to protect (e.g., communications among air-traffic controllers, and corporate and military data traffic). SONET/SDH integrates some very powerful automatic protection switching capabilities. A number of other protection and restoration options have become feasible due to the increased computing capabilities of network nodes. Chapter 8 is devoted to this topic.

1.2.2 Classification by geography

One traditional approach to classifying transport networks is in relation to their geographic scope. These classifications are illustrated in Figure 1-1. The access network is that portion of the network that connects the end users (subscribers) to the edge switching elements in the network. The metropolitan (metro) transport network is the network that interconnects central offices (COs) within an urban/suburban region. COs within a metro network are typically directly connected to both access networks and core long distance networks. These metro COs are typically owned by the same carrier, and in many cases either allow the carrier to centralize specialized services (e.g., ISDN or Ethernet routing) in just one CO, or to use different COs for back-up redundancy for each other (e.g., to take over switching functions in the event of a failure of the primary CO for that subscriber). The span lengths between metro COs are typically relatively short. The long distance core transport network provides the interconnection between metro networks, smaller community COs, service providers (e.g., Internet), and regional or international gateways.

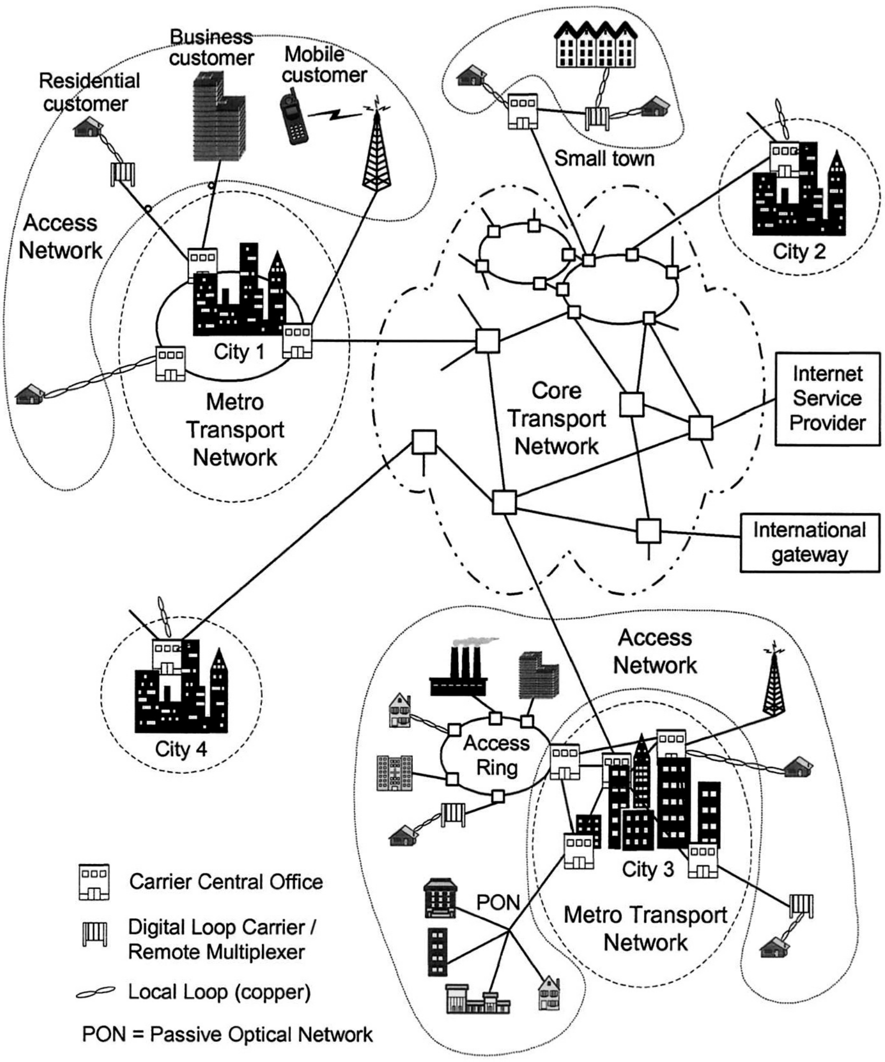


Figure 1-1. Illustration of a telecommunications network

Higher bandwidth technology typically sees its first deployment in the core network since the longer facility lengths necessitate more efficient utilization of the facilities. The technology used in the core networks, however, typically eventually finds its way into the metro network as the cost of the technology decreases and the bandwidth needs of the metro networks increase. From the management, craft training, and equipment inventory perspectives, it is desirable to have as much commonality as possible between the core and metro networks when they exist within the same carrier. LECs typically have both metro networks and core networks to provide interconnection within their region. IECs also typically have both metro and core networks since they often deploy metro networks in order to more efficiently reach their business/corporate subscribers.

Referring again to Figure 1-1, it can be seen that both metro and core transport networks can consist of ring and mesh topologies. Rings have become increasingly popular since they provide inherent route diversity that can be exploited for protection switching. (See City 1 and upper portion of the core network.) Rings have also become increasingly popular in access networks (e.g., City 3). Traffic routing on rings is also more straightforward than in arbitrary mesh networks. Ring topologies are not always convenient, however, due to such constraints as geography or having to use pre-existing right of ways[6]. Arbitrary mesh networks are constructed in order to use convenient cable routings or, in some cases, allow more bandwidth-efficient protection schemes. (See Chapter 8.) Transport networks often consist of a mix of ring and mesh subnetworks, including interconnected rings.

Traditionally, a sharp distinction was drawn between transmission and switching equipment. For the purposes of this book, however, transmission and switching are both considered as part of the transport network. The switches provide the automatic routing of voice (or data) traffic, while the transmission equipment handled the multiplexing and facility connections to carry the traffic between the switches. For example, a voice switch is the equipment to which a subscriber's telephone is connected that does the digit collection when the subscriber dials, and routes the call according to the number that was dialed. Typical transmission equipment includes SONET/SDH terminals. The distinction between transmission and switching has continued to blur over the past 20 years. Transmission networks have increasingly deployed digital crossconnect systems (DCSs) that perform the switching of subscribers' traffic between the various DCS interfaces according to a provisioned route. (See Chapter 2 for a full discussion on switching and crossconnect technology.) DCS-type

---

[6] Of course, a ring can be laid out such that the fibers from different inter-node connections share the same physical right of way or even the same cable. Such rings are called collapsed rings. Collapsed rings don't provide diverse fiber outing in the collapsed portion, and are hence vulnerable to a cable failure (e.g., due to a backhoe) in that region.

crossconnect capability has increasingly been integrated into add-drop multiplexers (ADMs). As illustrated in Figure 1-2, an ADM has two high-speed multiplexed interfaces, each to a different NE. Lower-rate traffic (tributaries) can be added/removed to/from the data transiting the ADM in either direction. ADMs are also typically capable of directly interconnecting two tributaries without that data appearing on one of the high-speed interfaces.[7] A network with switches, DCSs, and ADMs is illustrated in Figure 1-3. Rings nodes are typically ADMs, although they can also be DCSs, while mesh networks are typically constructed of DCSs.

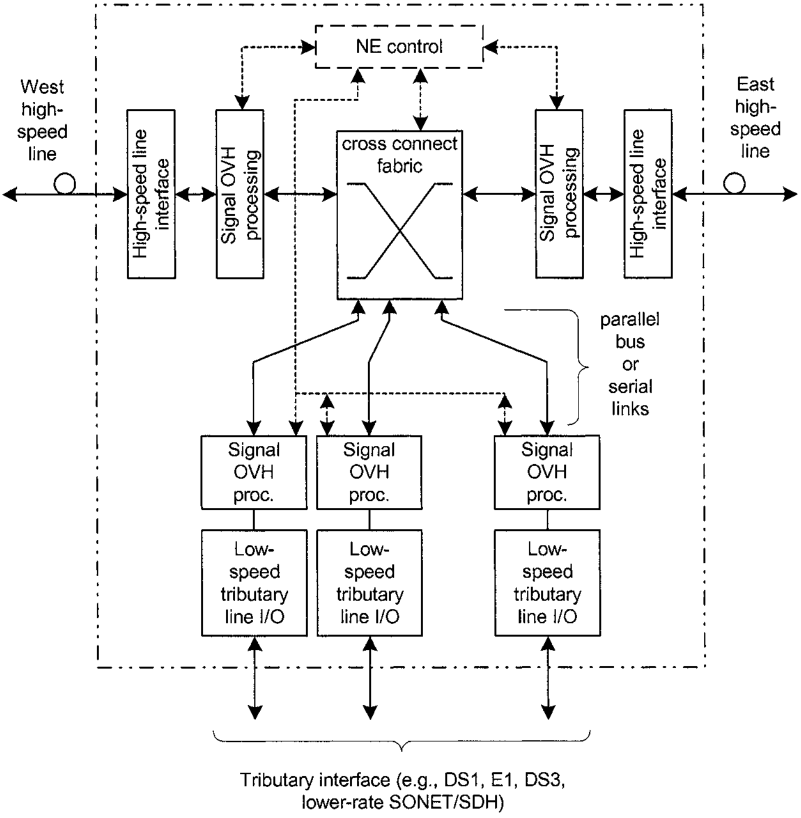
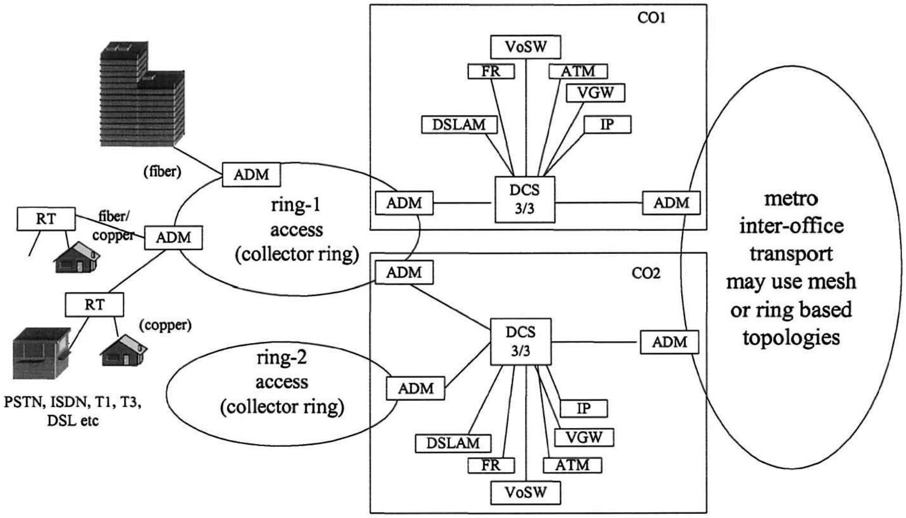


Figure 1-2. Illustration of an Add-Drop Multiplexer (ADM)

---

[7] This figure illustrates the main general functional blocks in an ADM. Different implementations have used a wide variety of approaches with respect to partitioning these functions among the different printed circuit boards and the interconnections between the functional units.

The distinction between a switch and a DCS/ADM has become a matter of how they are controlled rather than by their switching functions. Switches communicate with each other through a control plane in order to provide the customer-requested connection. (Control planes are introduced in the next section and are discussed in detail in Chapter 9.) DCSs and ADMs rely on provisioning from the network management system (i.e., the management plane that is introduced in the next section and discussed in detail in Chapters 5-7). Switches are very dynamic while crossconnects are relatively static. This distinction is beginning to blur even further, however, as protocols are being developed to allow dynamic re-provisioning of DCSs and ADMs through the control plane. (Again, see Chapter 9.)



ADM = Add-Drop Mulitplexer
DCS = Digital Cross connect System
DSLAM = Digital Subscriber Loop Access Multiplexer
FR = Frame Relay processing equipment
IP = Internet Protocol processing equpment
ISDN = Integrated Services Digital Network
PSTN = Public Switched Telephone Network
RT = Remote Terminal
VoSW = Voice Switch
VGW = Voice Gateway

Figure 1-3. Illustration transmission and switching equipment

1.2.3 Classification by Logical Layers (planes)

In order to address the complexity associated with transport networks, the well-known methodology of separation into three planes has been introduced. The term logical layers has been used in a couple of contexts and thus it is necessary to understand the difference between them.

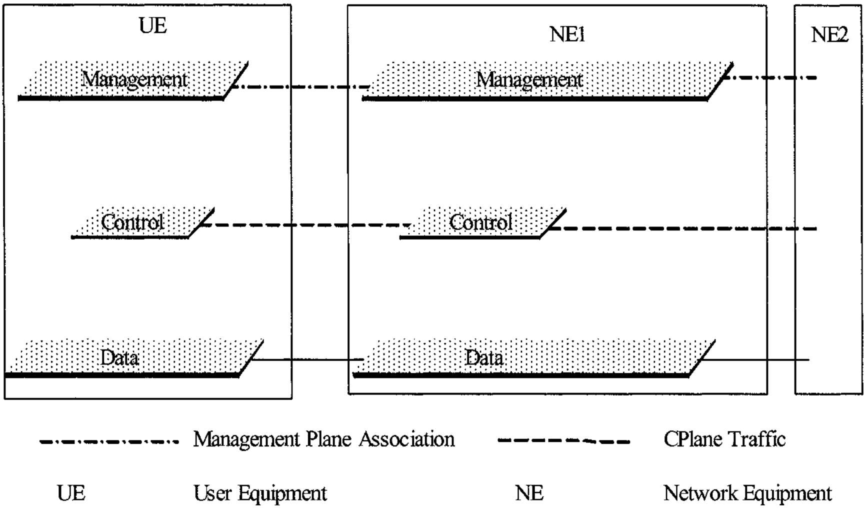


Figure 1-4. Illustration of the three planes[8]

In the first context all the functions associated with providing end-to-end services using the telecommunications networks is divided into three levels of abstraction. These are referred to as data or transport, control, and management planes. Note that in some cases where data and telecommunications merge, new terms such as service plane have emerged and the management plane functions are regarded as part of the control plane. In this book however, the terms are used in the conventional telecommunications sense, as illustrated in Figure 1-4, because of the following logic. A service plane is addressing services offered by the network. To offer a service, the user data is carried in the data plane with the control and management being necessary for enabling and maintaining the service according to the promised quality of service requirements. The need for rapid service introduction has introduced functions such as softswitching to meet the near real time requirements in the control plane compared to the traditional telecommunications practice of setting up a circuit through off-line provisioning, which is part of the management plane. In this context of logical layers, the network elements discussed include data and management plane functions. In some cases they may also include

---

[8] The details of this figure are spread between Chapter 5, 6 and 9 and is presented here as a visual aid. Management and control plane traffic in support of the associations usually flow in the embedded data channels supported by the data plane. However, other options exist, as will be explained in Chapter 9.

control plane features discussed in G.771x series explained in Chapter 9. There are also control plane elements such as signaling control point, signaling switching point network elements that perform only these activities (e.g., setting up a call using an SS 7 network). The management plane functions reside in the network elements and operations support systems discussed below.

The second context in which logical layers is used in the book is in discussing the management architecture in Chapter 5. The management plane functions are separated into different logical layers to provide different views of the management information. Depending on the management function and resources managed, different layers come into play.

1.2.4 Access networks and their relationship to transport networks

Although a full treatment of access networks is beyond the scope of this book, it is worthwhile commenting on several aspects of access networks here that have a bearing on transport networks.

A very large portion of each LEC's capital investment is in the copper wires that connect to the subscribers through the access network. In order to reduce the amount (and length) of access network cable and reduce cable maintenance, carriers increasingly deploy digital loop carrier (DLC) or remote multiplexing (RM) equipment. DLC and RM equipment connect to a number of subscribers over relatively short copper connections and multiplex their signals onto a shared facility (either copper or fiber) back to the CO. A DLC is effectively a remote extension of the voice switch in the CO. RMs include remote digital subscriber line access multiplexers (DSLAMs) that provide DSL service to subscribers. The use of RMs is often necessary in order to reduce the length of the copper connections to the subscribers to a range that will support high-speed data services such as DSL. DLCs and RMs also have the advantage of placing performance monitoring capabilities closer to the customer, which is often very valuable when subscribers use services with a guaranteed service level. The further downstream the network reaches to end subscribers, however, the fewer the number of subscribers that can share that facility or equipment. Due to this reduced sharing, the access facilities and equipment are very cost sensitive.

Access networks typically use transport equipment for connecting to DLCs, RMs and wireless network base stations, and also for dedicated connections to larger business subscribers. For example, many DLCs are connected to SONET multiplexers in the same remote enclosure. Another example is providing DS1, DS3, or SONET interfaces to subscribers from a business campus node with a SONET multiplexer providing the link back to the CO. In many cases, the access networks are deployed with a SONET/SDH ring topology in order to protect against facility or equipment failures. Chapter 8 discusses such protection switching. In a recent development, the IEEE 802.17 Resilient Packet Ring (RPR) technology allows a convenient method for multiple subscribers (typically businesses) to have efficient, flexible data access to SONET/SDH ring networks. RPR is one of the topics covered in Chapter 4. Carriers will typically try to use transport equipment in their access networks whenever the equipment costs allow it, since this commonality can reduce their overall cost of training and equipment inventory. SONET is a prime example of a transport technology that continues to migrate from the transport network to the access network.

One aspect in which the U.S. access network affects the transport network has to do with federal government regulation. In order to encourage competition for local access, the Federal Communications Commission (FCC) requires the incumbent LECs (ILECs) to lease portions of their access network to competitive LECs (CLECs) at a discounted rate. The discounted rate allows the CLEC to provide the same services as the ILEC at a competitive rate. The services, equipment, and facilities that the ILEC must make available to the CLEC are referred to as being unbundled. The nature of the unbundling regulations changes over time. The current regulations include the requirement for the ILEC to provide DS*n* access to subscribers regardless of whether they are carried over copper cable or are derived from a fiber optic multiplex system (e.g., carried over SONET through the access network). This gives DS1 and DS3 access connections an artificially lower cost for CLECs than equivalent SONET connections[9]. As noted in Chapter 4, this situation can be especially important for the IECs and service providers leasing access to their business subscribers through the ILECs.

Another aspect of the relationship between the access and transport networks is that the access network is often the primary bandwidth bottleneck in the overall network. The amount of traffic carried in the access networks determines the bandwidth needs of the transport networks. For larger business customers, it is usually cost-effective to deploy a dedicated high-speed fiber or copper facility from a CO or a remote fiber node to the business office. The traffic from these connections can often be multiplexed with other traffic in the access network as shown in the City 3 access ring of Figure 1-1. For residential customers, however, it is very expensive to upgrade or replace the copper cables[10] that connect them to the telephone network in order to support broadband service. Meanwhile, there has been

---

[9] ILECs are not required to unbundle their fiber-based interfaces and associated services.

[10] The copper wire connection to a subscriber is typically an unshielded twisted pair of wires. This wire pair is often referred to as a loop (subscriber loop or local loop).

no driving application that motivates subscribers to pay high enough rates to justify the network upgrade. Current technology such as DSL provides adequate speeds for today's applications such as Internet access and telecommuting. So, while this bottleneck is gradually being removed for residential and small business subscribers, it may take many years.

This bottleneck situation has led many in the telecommunications industry to hunt for more cost-effective ways of providing higher bandwidth to residential and small business subscribers. The alternatives fall into four broad categories:

- Higher rates over the existing local subscriber loop
- High-speed data connections through the cable TV network
- Direct fiber connections to the home or near to the home (I.e., FTTx – Fiber to the "x" where x can be a home, curb, business, building, or equipment cabinet.)
- Wireless links

Achieving higher rates over the local loop means deploying remote multiplexers (RMs) much closer to the subscribers in order to keep the loop lengths short enough to allow the higher rates. Very high speed DSL (VDSL) promises rates high enough for video delivery over loops a few hundred to a few thousand feet long. The main cost benefit to this approach is that it re-uses the copper loops. It is still expensive, however, to deploy all the RMs to get close enough to the subscribers. The RMs are connected to the CO through an optical fiber, which means that the each of the RMs needs a local connection for power.

The other existing infrastructure is the cable TV network. Originally, this network was developed for the downstream broadcast of analog video signals. In order to support data services, it is being upgraded to provide an upstream as well as downstream data channels. The connection to the subscriber homes is through a shared coaxial cable with cable modems used by the subscribers for the data connection to the network. Since the coax cable segments are shared by multiple subscribers, the data rate available to each subscriber depends on how many subscribers are using that segment. There may be up to 2000 homes connected to the same segment. The Data Over Cable System Interface Specifications (DOCSIS^{TM}) protocol is used to control the medium access for the data. The coax segments are connected to fiber nodes (FNs) that are in turn connected to hub nodes. The hubs are ultimately connected to a head-end for their video signals or to service provider networks for Internet connections. Due to this mix of coax segments and fiber, these networks are commonly revered to as hybrid fiber/coax (HFC) networks. The FNs are analogous to the RMs and the hubs are analogous to either ADMs or DCSs in the telephone network. The main cost advantage of cable modems is the sharing of the coax segments and the inherently higher bandwidth capabilities of coax cable. The cost is similar to the RM/VDSL telephone network approach. Higher rates per subscriber require fewer subscribers per segment, which means more FNs. While this architecture is very good for residential subscriber connections, it is typically not very good for business subscribers who prefer dedicated bandwidth and prefer a non-shared access medium for security reasons. (Also, few businesses have pre-existing connections to the cable TV network.)

The ultimate scenario for telephone and cable TV network providers is to have a fiber optic connection to each subscriber. The fibers can offer virtually unlimited bandwidth to the subscribers. The main cost to fiber connections is the components and circuitry to connect to the fibers. Consequently, passive optical networks (PONs) have been a focus of considerable interest. In a PON, there is a single fiber connection at an optical line terminal (OLT) in the CO, and that fiber branches out to multiple subscriber-end optical network terminal units (ONUs) through a network of passive optical splitters. A time division multiple access (TDMA) protocol is typically used to multiplex data on the fiber tree.

There are two groups actively pursuing PON standards. The first is the Full Services Access Network (FSAN) forum. FSAN has developed a standard referred to as Broadband PON (BPON) that is based on ATM technology[11]. The BPON rates are 155 or 622 Mbit/s downstream (i.e., to the subscriber) and 155 Mbit/s upstream. FSAN recently completed work on a Gigabit PON (GPON) that is based on a GFP-like format. (See Chapter 4 for a full description of GFP. GPON uses modified header information relative to a normal GFP frame and allows fragmentation.) The GPON rates are 2.4 or 1.2 Gbit/s downstream and 155 or 622 Mbit/s upstream. FSAN has brought its work to the ITU-T for publication with G.983 covering BPPON and G.984 covering GPON. The other standards body working on PONS is the IEEE 802.3ah. Not surprisingly, these PONs are based on Ethernet and are referred to as EPONs. EPONs support rates of 10 – 1000 Mbit/s in both the upstream and downstream directions. BPON, GPON, and EPON each have their advantages and disadvantages. While North American carriers have chosen the PONs from FSAN, there is considerable interest in other regions in EPON (e.g., Japan and Korea) where for regulatory competitive reasons carriers need to make a clear distinction between the POTS and data service access networks.

PONs can be very attractive for business customers since they provide a lower cost network for broadband services than point-to-point fibers and

---

[11] An ATM-based PON is commonly referred to as an APON.

they allow the ability to burst data at higher rates (i.e., approach the full PON bandwidth) when the network is lightly loaded. Apart from the cost issues, PONs have one technical issue that has been a major impediment. A major feature of the current telephone network is that the LEC provides power over the local loop to subscribers' phones. Since this telephone company provided power insures that the phones will still operate during power company outages, it is often referred to as lifeline phone service. Clearly this is not possible over an all-fiber network, so the telephone company must either provide an alternative, battery-backed power source, which is very expensive[12], or the subscribers must take responsibility for their own power and maintain their own batteries. Perhaps the growing prevalence of mobile phones will make this a viable option at some point as subscribers become accustomed to idea of being responsible for their own phone batteries. As discussed further below, a number of carriers are counting on this.

The fourth alternative for broadband subscriber access had long been considered the wildcard, but is now looking very promising. That alternative is wireless access. Previously, broadband wireless access required a point-to-point microwave radio link from the subscriber to a base station, with many of these systems requiring a line-of-sight clear path between to two antennas. Here, each subscriber has its own radio channel. One common early system was the Local Multipoint Distribution System (LMDS). These systems were somewhat difficult to engineer and were somewhat costly for many areas. Their main value was for business customers. The Multi-channel Multipoint Distribution Systems (MMDS) addressed some of these shortcomings, but was still expensive for large-scale deployment. The radio technology that appears to be changing the whole situation is IEEE 802.11. With 802.11, multiple subscribers can share a single broadband radio channel. The statistical channel sharing means that subscribers will typically see very high throughput rates. The widespread use of 802.11 technology in LAN applications has driven the cost down to a very attractive point. The IEEE 802.16 technology extends some of the 802.11 concepts to a metropolitan area. The main initial application for 802.16 has been the backhaul of traffic from 802.11 base station sites to central switching sites (e.g., a CO), thus providing metropolitan area network (MAN) connectivity between the 802.11 sites. Some business

---

[12] The cost of maintaining batteries at each subscriber's home makes it a prohibitive option for the LECs. There have been some attempts to solve the problem be having a common power pedestal in the neighborhood that provides a battery-backed power feed to multiple homes. While this is better, it still means a large number of batteries that need routine maintenance and still requires maintaining a copper infrastructure.