TELECOMMUNICATION NETWORKING

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Summary

Toady's telecommunication network serves as an essential platform in our society for exchange of information in its various possible forms, viz., voice, data and video, and thus helps us in living the life of this modern era. Networking practices have evolved almost over two centuries with an unbelievable range of technologies, services and standards, calling for accommodation of heterogeneous networking equipments and transmission media of different times, regions and standards. In this chapter, we make an attempt to provide an overview of the various concepts and technologies used for the realization of today's networking setup, followed up by some interesting real-life networking scenarios. However, considering the wide span of the subject, the outline of the chapter has been conceived with the assumption that the readers would have some basic knowledge of communications systems and networking, which is expected to get supplemented by the broad overview and the practical networking examples presented herein.

1. Introduction

The basic purpose of a telecommunication network is to provide a setup for communication between two or more spatially-separated users by electronic means, wherein the users might send/receive a broad variety of information in the form of voice, video or data. Since the end of the 19th century, the various concepts and technologies used for telecommunication networking have matured through numerous innovations and developments, starting from the telegraphy demonstrated in 1875 by Samuel Morse.

Thereafter, the twentieth century, following the invention of telephony by Graham Bell in 1886, witnessed phenomenal progress in science and technology, leading to the unprecedented developments in the field of telecommunications. The synergy of electronics with telecommunications and computing brought in novel networking technologies offering wide range of services for the common people and the corporate sectors as well. Today, the needs of information-hungry society, driven by the potential of this synergy, are being ceaselessly served by the ever-increasing variety of telecommunication technologies all over the world. In particular, the arrival of Internet with its unprecedented penetration, the wireless connectivity to the users in the last mile of a mobile communication network, the vast footprints of satellites and, the enormous wired-bandwidth of optical fibers in long-haul backbone networks have significantly changed the ways one can communicate in our society and live one's life today both in personal as well as professional fronts.

Before discussing the enabling technologies behind the above developments, it would be instructive to have a look at the typical ways a networking infrastructure is utilized in today's society, in particular from the user end. To start with, consider a residential subscriber having a traditional wired or landline telephone connection using a twisted copper wire-pair, or simply twisted wire-pair (TWP). He can talk over the phone concurrently while accessing Internet from his desktop computer at the residence through the same TWP by using a broadband modem. Be it telephone connection or Internet access, both are routed through the TWP from the residence to the local telephone exchange, i.e., the central office (CO), also referred to as end office in some countries, wherefrom the voice and data services embark on their respective paths through the appropriate routes and infrastructure of backbone networks. This is an example of a voice-centric network (i.e., originally designed for voice traffic only), wherein the service of data connectivity between computers was introduced later as an overlay. On the other hand, an office employee working on his desktop computer in the office (while having a possible traditional telephone also on his desk) can access organizational documents/resources stored in some central computer (server) and exchange files with other coworkers in the office using a local (intra-office) computer network (usually called local area network or LAN). He can also access Internet and other remote LANs through appropriate connectivity to the backbone network, typically by using some leased connection through the nearest CO premise. These computer users can also access voice service from their LANs by using appropriate overlay technologies, e.g., Internet protocol (IP) telephony using voice-over-IP or the popular services, such as, Google talk, Skype using voice-over-instant-message. Residential cable-TV users can also have similar services as the telephone subscribers in respect of Internet access by using a cable modem, along with the voice service by using the cable-telephony technology. Furthermore, the LAN-based intra-office networking can be extended to realize enterprise networking for an organization having its offices spread over a wide geographical area (maybe a country or across the globe). Such organizations usually have their LANs at all the needed locations, which would be interconnected through national/international backbones using appropriate technologies of wide-area networking (WAN). Typical examples of such enterprise networking are banks, government organizations, airlines/railways and their agents' offices, large national and multinational companies etc., each of them running its offices/services at many places, usually with main server(s) located at some convenient centralized location(s). Another interesting form of enterprise networking, however with

more complexity, is used in e-commerce-based business transactions carried out by credit-card issuing associations/organizations, e.g., visa card. These organizations operate for their card holders and the respective sellers or merchants through the respective bankers of both parties (buyer and seller) through network-aided on-line transactions. In such networking scenario, the buyer (credit-card holder) approaches the seller with his card, which is used to charge the card-holder's bank from the seller's bank, mediated through the credit-card association (e.g., visa card). The seller usually sets up online connection with its bank using telephone line, which in turn executes the rest of the transactions through appropriate networking support, after the buyer's card is slid through on-the-counter machine of the seller.

In this chapter, we make an attempt to describe in brief how the wide variety of concepts and technologies have been put together to realize the complex form of today's telecommunication networks. It may be worthwhile to indicate that, the outline of the present chapter has been based on the assumption that the readers would have some basic knowledge of communications systems and networking, which is expected to get supplemented by the broad overview and the examples of practical network settings presented herein. The rest of the chapter is organized as follows. First, in Section 2 we describe the chronological milestones in this area and cast them into a simple hierarchical abstraction for comprehensive understanding of the evolving technologies. Sections 3 and 4 present the two fundamental constituents of any telecommunication network, viz., transmission systems and switching/broadcasting schemes, respectively. Thereafter, in Section 5, we present some basic networking setups used in practice. In Section 6, we present some real-life networking examples which are formed using mix-and-match of the basic setups as discussed in Section 5 Finally in Section 7, we conclude the chapter.

2. How it evolved

With the foregoing introduction to telecommunication networks, let us now look into the chronology of technological milestones in this area. Historically, as mentioned before, the earliest form of telecommunications, viz., telegraphy, was demonstrated by Samuel Morse by using variable-length binary codes, wherein English alphabet were represented by sequences of dots and dashes with letters occurring less frequently having longer code words. Thereafter, following the success of telegraphy, basic telephony was demonstrated by Graham Bell, and voice communication through telephone network using both wired and wireless media gained momentum. Telephone networking gradually evolved with a hierarchical connectivity, wherein the last-mile segment grew around a telephone exchange (i.e., CO), connected to its telephone subscribers using TWPs. These COs were, in turn, interconnected to appropriate backbone networks using higher-level switching nodes communicating between themselves using suitable combinations of various transmission media, such as, copper cables, terrestrial microwave links, satellite links, optical fibers etc. The long-haul inter-city transmission in the backbones for early terrestrial communication systems adopted suitable schemes of analog modulation of carriers and frequency-division multiplexing (FDM) over copper cables and microwave (radio) links. The backbone networking grew in dimension from metropolitan, regional, national to international coverage. Subsequently, with the advent of voice digitization schemes, computer-controlled switching nodes, digital modulation schemes and optical fiber systems, the erstwhile analog telephone networks (controlled and managed by

analog electro-mechanical switching nodes) gradually went through evolutionary developments, eventually leading to the modern telephone networks using digital telephony [1]. These developments led to easier multiplexing of voice channels and improved signaling schemes, better signal regeneration at intermediate nodes, efficient performance monitoring, accommodation of diverse services, and so on. However, utilization of these benefits became more visible at the backbone level, while the last-mile segments continued to operate in analog domain for economic reasons. With digitized voice waveforms and computer-controlled switching nodes, aided by digital modulation techniques, it became easier to integrate the signaling/switching operations (which are by nature digital) and transmission of digitized voice at baseband level in a seamless manner, making the network control and management much easier and intelligent as well. Today's wired telephone networks permitting a subscriber to make a telephone call using a calling card from anywhere in the world is a fallout of such intelligent networking.

While voice communication through telephone networks kept maturing with the emerging digital transmission and switching technologies, digital computers gradually became cheaper and smaller, and hence available at affordable prices for more users/organizations. These developments relaxed the necessity for mainframe computers with time and, generated an increased demand for information exchange between several of computers, thereby generating a need for communications between computers with appropriate networking infrastructure. Thus, computer communication ushered in as a different class of telecommunication leading to computer networks, also called as data networks [2]-[5]. While interconnecting such localized organizational networks, more popularly known as local-area networks (LANs), either separate backbone networks were set up, or fractional bandwidth from the existing telephone backbones were taken on lease. Thus, digitized voice and computer-generated data, both being available in the same binary form, were soon found being integrated together and transmitted over the same backbone network, albeit with different service requirements. For example, voice service between two subscribers had to be delay-sensitive with symmetric traffic (bandwidth requirement) in either direction, while data exchanges between two computers could have more relaxed constraints on delay-sensitivity and bidirectional traffic symmetry but needed to ensure for the correctness of the data, unlike the voice waveforms received by more-tolerant human ears.

Having gone through the abovementioned developments, a new era started with the arrival of Internet and the phenomenon of telecom deregulation. Success of Internet created the need for access to data network anywhere and anytime in the society, so much so that the residential users desired to get Internet access from home, going beyond the erstwhile LANs within organizational premises. Around the same time, telecom market was deregulated in USA by breaking the monopoly of the erstwhile network providers [1]. This evolved gradually as a global phenomenon, with a voice-centric telephone network coming up with offers for Internet access from traditional telephones at residential as well as office premises using dial-up modems. In such data communication mode over a landline telephone setup, the computer-generated data for the typical applications (e.g., web through http, file transfer through ftp, remote login through telnet) are transmitted from the subscriber end by modulating sinusoidal carriers (within the telephone bandwidth) using a modem to send data from a residence to the respective CO in the locality. The CO in turn digitizes the modulated carrier waveforms received from the

subscriber end by converting the received modulated carrier waveforms from the subscriber's modem into a pulse-code modulated (PCM) bit stream (by sampling an A/D conversion). Thereafter, the CO forwards this digitized modulated-carrier waveform over its digital-telephone backbone network through a pre-provisioned path and channel, usually by assigning appropriate time slots in time-multiplexed PCM streams over long-haul digital links along the desired route. Elsewhere, in the backbone network, this digital signal lands up into the desired subscriber's premise and first goes through D/A conversion (for being converted back to the modulated carrier from the PCM form), subsequently followed up by an appropriate demodulation to convert eventually the modulated carrier back to the original data streams. With similar objective, the video-centric cable-TV networks also came up to provide cable modem and cable telephony services and so on. In a response to this transformation process, eventually the data-centric LANs were also engineered to offer the voice-over-IP service, thereby bringing in an all-out blurring of boundaries between data, voice and video services to the users. Thus, a voice-centric telephone network extended its functionality to offer data service, video-distribution networks offered data as well as voice services and the data-centric LANs also joined this process with voice-over-IP to offer telephone service. All these disjoint segments started necessarily communicating with each other in the interest of wining their own markets from the respective users, ushering in an era of competition and cooperation between the various segments of the telecom service providers. Thus, administratively-disjoint last-mile access networking setups with different traditional services (e.g., PSTN for telephony, LAN for data, cable TV for video) started interoperating with each other, smearing the erstwhile rigid network boundaries, be it physical, logical or administrative.

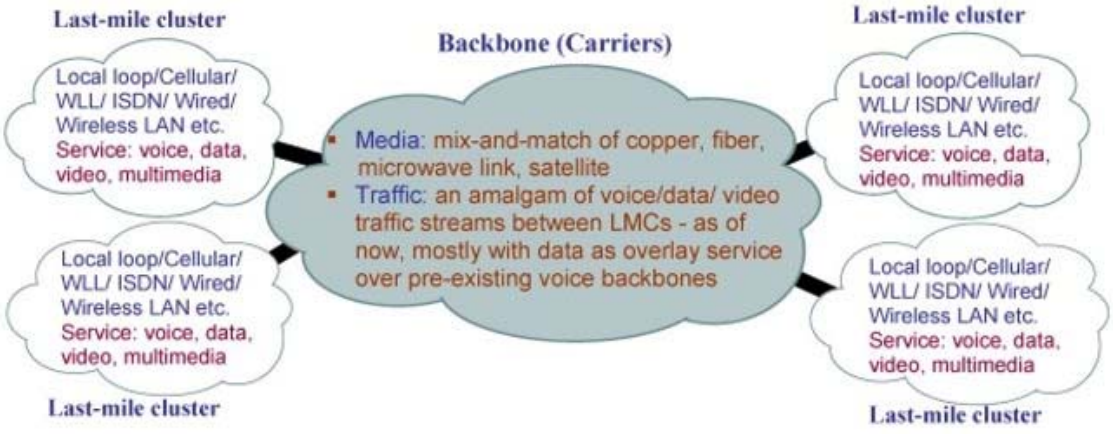

Figure 1. A hierarchical abstraction of today's telecommunication networks

The potpourri of the telecom networking, as discussed above, keeps changing with time and would perhaps evolve even beyond our anticipation in years to come, thanks to the ongoing developments in microelectronics and VLSI engineering, digital signal processing, and wireless as well as optical transmission techniques. However, it may be worthwhile to make an attempt to visualize this emerging heterogeneous, hierarchical (however, with increasingly-diffused boundaries as time moves on) and unpredictable telecom networking scenario, as shown in Figure1. As discussed earlier, in Figure1 we conceive the existing telecom networking potpourri as a hierarchical abstraction of two

generic segments at two different levels, viz., the last-mile clusters (LMCs) that provide network access to a user and the backbone (usually formed by multiple carriers) that interconnects all possible LMCs using appropriate networking technologies.

One possible form of an LMC can be visualized as the voice-centric access network, with its wired or landline telephone subscribers forming the local subscriber loop (or, simply local loop) around a telephone exchange (i.e., a CO), which would in turn be connected to the backbone of the respective public-switched telephone network (PSTN). Such access clusters have traditionally offered during pre-deregulation era the plain old telephone service (POTS), without any provision for data service, such as Internet access. However, as indicated earlier, in today's version of PSTN, a subscriber can access Internet along with the existing POTS by using a modem, at the residence. Wireless version of such an LMC can be a group of cellular-phone users functioning through respective base stations and switching offices. The cellular wireless systems was also primarily designed for voice, with some limited data services, viz., short-message service (SMS), and eventually its successors arrived in the market with provisions for various other services, such as, e-mail, Internet access etc. However, traffic for both types of LMCs may propagate over the same backbone at times, and both may need to communicate with each other for end-to-end connectivity between users belonging to different LMCs. It may be noted that both of these two categories of LMCs have been basically voice-centric access networks, accommodating data access as add-on features. Furthermore, over the same wired subscriber loop using TWP, one could also realize always-on broadband data services as well as integrated-services digital network (ISDN), offering a wide range of services, such as, voice, video conferencing, data etc. On the other hand, an organizational LAN using wired connectivity in an office building or campus can be visualized as a data-centric version of an LMC, wherein a user would primarily be interested to get data-oriented services, such as, remote login (telnet), file transfer (ftp), Internet access (http) etc. However, one can also avail voice service (IP telephony) through voice-over-IP from a computer connected in a LAN and have telephone conversation with other computer users within the same LAN or with the computer users in other LANs interconnected through WANs. Wireless version of the same setup is realized as wireless LAN, wherein one can get access to the same types of services without any wiring overhead, however usually with lesser bandwidth as compared to wired LANs.

The two basic constituents that have played the key roles towards the developments of today's complex telecommunication networks are (i) transmission systems and (ii) switching and broadcasting schemes. While transmission (through wired or wireless media) was the most significant step to make telecommunication viable between two remote users, switching as well as broadcasting techniques became important when multiple users had to communicate between themselves through a set of physically interconnected users using the available transmission media. In this chapter, we make an attempt to address various issues of this ever-evolving telecom networking scenario with an introduction to the basic concepts and technologies of transmission and switching/broadcasting techniques, which have evolved over the decades to provide services for voice, video and data communication. Thereafter, we present several examples of typical telecom networking practices in use, followed up by some examples of real-life networking scenarios.

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Biographical Sketch

Debasish Datta received his BTech degree in 1973 from Institute of Radiophysics and Electronics, Calcutta University, India, and MTech and PhD degrees from IIT Kharagpur, India, in 1976 and 1986, respectively. He has been engaged in teaching and research at IIT Kharagpur for the last twenty-eight years, wherein he served as Head in the Department of Electronics and Electrical Communication Engineering during 2007-2008 and, as Chairman in G.S. Sanyal School of Telecommunications during 1999-2002. In the early phase of his career, he worked for Transmission R&D Division in Indian Telephone Industries,

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Prof. Datta received Sir J. C. Bose Award in 1985 from IERE, UK, for a paper on Optical Receiver in the Journal of IERE. He served as Guest Editor for IEEE JSAC for January-2002 Special Issue on WDM-based Network Architectures, and presently he serves as Editor for the Elsevier Journal of OSN. He also serves regularly in the technical program committees of various national as well as international conferences in the area of optical communications and networking. His current research interests include wavelength-routed optical backbones, WDM-PONs, link adaptation schemes and MAC protocols for wireless networks.