ROUTLEDGE COMPANIONS

The Routledge Companion to Network Industries

Edited by Matthias Finger and Christian Jaag

This is a time of critical transformation for infrastructure industries with profound implications for relevant networks and underlying market design. This book provides a rare and systematic overview about the recent evolution of the different network industries and includes case studies, insights about perspectives – a treasure for all those concerned by the future of our infrastructure networks.

Christoph Frei, Secretary General, World Energy Council, UK

Network industries constitute the physical presence of past development. They provide the contemporary infrastructure for future value creation. Modern technology and global economics lump together former vastly different industrial sectors in the emergence of new service systems and innovative enterprises. This book provides a unique and comprehensive overview. It pairs functional development to underlying principles, crossovers and dynamics. It asks what is to be done about it in terms of policy, management and regulation. This book constitutes a standard and indispensable reference for understanding the complexities of modern strategic infrastructure development.

Theo Toonen, Dean, Faculty of Behavioral, Management and Social Science and Professor, University of Twente, the Netherlands

All over the world, network industries have undergone profound transformations as a result of their liberalization since the late 1980s. This unique publication documents this transformation in the nine main infrastructure sectors. In the process, it analyzes the details of the changes at the industry, policy and firm level in quite a pedagogical way. It is probably the most systematic, self-contained and up-to-date overview of network industry transformation currently available.

Antonio Estache, Professor, Université Libre de Bruxelles, Belgium

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The Routledge Companion to Network Industries

In recent decades, network industries around the world have gone through periods of de- and re-regulation. With vast amounts of sometimes conflicting research carried out into specific network industries, the time has come for a critical over-arching assessment of this entire industry in order to provide a platform of understanding to aid future research and practice.

This comprehensive resource provides an orientation for academics, policy makers and managers as to the main economic, regulatory and commercial challenges in the network industries. The book is split into sections covering market, policy, regulation and management perspectives, whilst all of the key network industries are covered, including energy, transport, water and telecommunications.

Overseen by world-class editors and experts in the field, this inter-disciplinary resource is essential reading for students and researchers in international business, industrial economics and the network industries.

Matthias Finger holds the Swiss Post Chair in Management of Network Industries at EPFL, Switzerland. He is also the Director of the Florence School of Regulation's Transport Area in Florence, Italy.

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1

Introduction

Matthias Finger and Christian Jaag

Network industries have witnessed around 20 years of de- and re-regulation, as well as deep changes in their underlying technologies. It is time for a critical assessment and a look into the future. This book's ambition is to provide an orientation for academics, policymakers, and managers as to the main economic, regulatory, and commercial challenges – and potential solutions – in nine network industries: telecommunications, postal services, electricity, gas, maritime transport, railways, air transport, urban public transport, and water.

Network industries can be categorized into four domains (see Figure 1.1): communications, transport, energy, and water. While most industries clearly belong to one of these domains, the postal sector is somewhat hybrid in that it provides a means of communication (letter mail), but also transportation (parcel services).

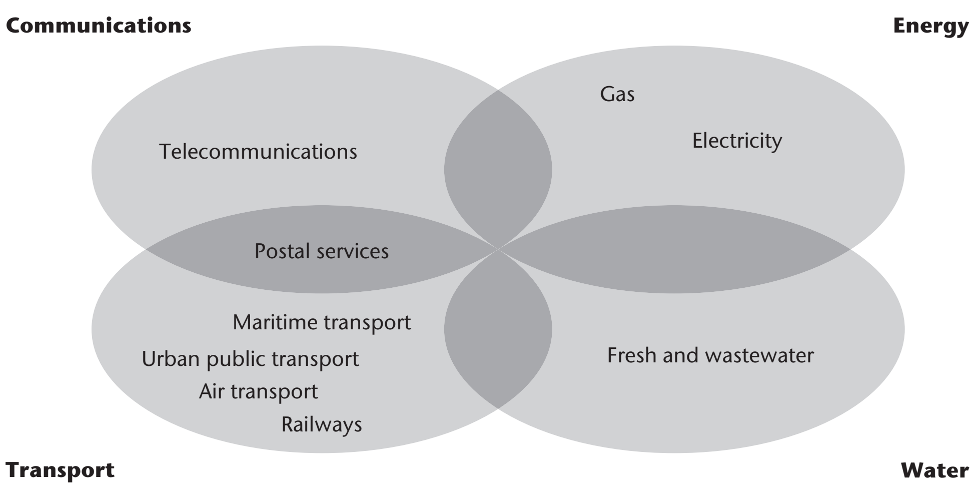

Figure 1.1 Network industries

Source: Authors' own elaboration

Network industries are interesting from an engineering, economics, and policy perspective for three main reasons:

- First, they share a common layered structure that determines their heterogeneous economic characteristics (see Table 1.1). The passive network-infrastructure layer comprises the physical infrastructure with a high fraction of irreversible fixed cost and strong economies of scale and/or bundling. This results in naturally monopolistic bottlenecks. The second layer (active infrastructure) is part of the infrastructure as well, but investment cycles are shorter and the cost may be reversible. The services layer uses the other layers to provide services to customers. The cost structure is more flexible and competition is easier to implement than in the infrastructure layers. This layered structure necessitates a differentiated (disaggregated) and well-targeted regulatory approach (see Knieps, 2000). A major organizational issue is the unbundling of the three different layers, since an integrated firm may have incentives to bar others from being active in the (potentially competitive) services layer. Hence, access to the infrastructure is an important issue, both commercially and from a regulatory perspective.
- Second, they exhibit network effects, also called network externalities (see Katz and Shapiro, 1985; Farrell and Saloner, 1985). This is the effect that a user of a service has on the value other people derive from that service. As a result, the value of a product or service is dependent on the number of others using it. The telephone is a classic example: the more people who own telephones, the more valuable the telephone is to each owner. The network effect may be present on all three layers of network industries. It creates commercial and regulatory challenges as well.
- Network industries also consist of, and provide platforms with, two- or multi-sided markets. This means that they serve two or several distinct user groups that provide each other with network benefits (Rochet and Tirole, 2006). Multi-sided platforms produce value for all users or parties that are interconnected through it by playing an intermediary role, and therefore those parties may all be considered customers (unlike in the traditional seller–buyer dichotomy). This creates a potential for pricing issues and a strong tendency towards concentration, and therefore motivates regulatory oversight.

In order to capture all these aspects and provide a unified view, the book approaches the network industries from three main perspectives:

- The **industry perspective,** with a focus on current market developments and dynamics.
- The **policy perspective,** discussing the rationales and aspects of sector-specific regulation.
- The **management perspective,** focusing on the strategic challenges resulting from regulatory and technological change.

The three perspectives depend on each other and are strongly interrelated (see Figure 1.1). The industry perspective observes the market outcome and its development over time. It captures the entry and exit of market participants, as well as their behavior and market position. The behavior of the market participants is expressed by their business models, their product range offered, and their pricing strategy. These strongly depend on the legal and regulatory framework that prohibits, enables or incentivizes certain business models and may determine the market structure and the organizational structure of the market participants.

Table 1.1 Layered structure of network industries

	Layer 1: Passive infrastructure	*Layer 2: Active infrastructure*	*Layer 3: Services*
Economic characteristics	Mainly irreversible fixed cost Long-term investment cycle	Mixed cost structure Medium-term investment cycle	Mainly reversible cost Short-term investment cycle
Market structure	Naturally monopolistic bottlenecks	Actual and potential competition	Actual and potential competition
Telecommunications	Ducts, cables	Routers, switches	Voice and data services
Postal services	Streets, buildings	Post offices, sorting centers	Letter and parcels conveyance services
Electricity	Transmission and distribution networks	Power plants (nuclear, hydro, coal, oil, gas), pump storage, batteries	Energy services, metering services, balancing services
Gas	Pipelines, liquefied natural gas converting facilities	Refinement	Energy services
Maritime transport	Channels	Harbors, ships	Transportation services, harbor-related services
Railways	Tracks, on-track signaling systems	Train stations, on-train signaling systems, rolling stock	Transportation services
Air transport	Air traffic control infrastructures	Airports	Air transport, airport-related services
Urban public transport	Streets, tracks, tunnels	Rolling stock	Transportation services
Water and wastewater	Water distribution and wastewater pipes	Water and wastewater treatment plants	Water services

Recent developments in the legal framework of the network industries can be structured in terms of regulation, liberalization, and privatization:

- Regulation refers to the entirety of legal constraints on economic activity in the sector. Network industries are characterized by a dense regulatory framework (see Figure 1.1). Economic regulations may be concerned with fair competition, and be symmetrically targeted to all operators in the sector (market regulation). Additionally, regulations may focus on correcting market failures by providing a socially desired level of service quality or redistribution, or fostering environmental protection. This second kind of intervention (provision regulation, such as universal service obligations [USOs]) is often asymmetric and costly, which has long been the main motivation for establishing state monopolies. Such monopolies have necessitated further regulations to deal with market dominance.

  In addition to economic regulation, in network industries there are safety regulations (in energy, railways, and air transport), data protection (in telecommunications and postal services) and security of supply and national independence (in energy).

- Liberalization is the abolishment of reserved areas and the opening of markets for new operators. In recent years, most network industries have become liberalized in many countries. In addition, technological change - which is mostly driven by information and communication technologies - is substantial in some of the network industries and often goes in parallel with market dynamics. As a result, sectors have converged, stimulating indirect competition between different industries (for example, postal services and telecommunications).
- Privatization is the process of transferring ownership of a network operator from the public sector (government-owned) to the private sector. The precursor to privatization is corporatization, which transforms government agencies into corporations. Privatization often takes place in parallel with liberalization (or prior to it) in order to ensure a level playing field for all firms in the sector.

In parallel with liberalization and increased competition, sector-specific regulation in the different network industries has become a widely discussed topic among academics, policy makers, industry economists and regulators themselves. The focus of these debates has usually been on whether such regulation is necessary, and, if so, what its optimal design should be. Some argue for deregulation (that is, the abolishment of price regulation or USOs), whereas others propose re-regulation, which involves the replacement of pre-existing (monopoly-related) regulations with new regulations that aim to safeguard service levels and competition. The resulting compromise is often somewhere in between de- and re-regulation. The current and future challenges in network industries mainly pertain to the dynamics in the industries' regulatory frameworks. Therefore, regulation is one of the main focal areas of this book.

From an economics perspective, the principal rationale for regulation is to remedy market failure; that is, the deviation of the market outcome from an efficient allocation. Markets can fail (in theory and in practice) for four major reasons (see, e.g., Viscusi *et al.*, 2005; Armstrong *et al.*, 1994; Laffont and Tirole, 1993):

1 Market power: If one firm or several firms (oligopoly or a cartel) can profitably raise their price above the competitive level, then the market is not efficient as the price exceeds the marginal opportunity-cost of production. A monopoly may naturally develop due to high fixed and irreversible cost to build infrastructure. Remedies for the abuse of market power are primarily price and access regulation, sometimes combined with quality of service standards.
2 Externalities: Economic activities may impose losses or benefits on third parties that the market participants do not take into account. Since their choices do not consider the social cost and benefit, their actions are distorted. This implies that the externality-creating activities are under- or over-provided relative to the efficient level. Pollution and congestion are examples in which the social cost is higher than the private cost. Typical remedies for externalities are taxation, production quota, or, more recently, cap-and-trade mechanisms.
3 Public goods: The consumption of a public good is neither rivalrous nor excludable. A competitive market fails to provide an efficient level of a public good due to freeriding and the inability of the suppliers to appropriate an adequate return. Security of energy supply and load balancing is an example of a public good. Spectrum for mobile telecommunication services has been made a private good by first defining and allocating corresponding property rights.
4 Asymmetric information: Imperfect information gives rise to two problems – adverse selection and moral hazard. These issues arise often in situations in which risk is involved.

In addition to economic regulation as a remedy of market failure, a further rationale is distributive concerns. Redistribution is often implemented in the form of price control, cross-subsidies or USOs.

In practice, not only markets but also regulation may fail due to its being costly and creating its own distortions (see, e.g., Coase, 1960). This has resulted in the development of a framework of government failure (Wolf, 1988; Demsetz, 1969) and later the New Institutional Economics approach (Williamson, 1985).

The market outcome in network industries is primarily determined by regulatory policies in two domains: first (on the left-hand side of Figure 1.2) market regulation aims to ensure fair competition. It governs market access (for example, through a reserved area or a licensing regime) and network access to monopolistic bottlenecks (especially to the passive infrastructure). It also regulates interconnection (provisions related to numbers and addresses, for example in telecommunications, see Laffont and Tirole [1996], or in postal services). Flanking measures may pertain to the regulation of labor conditions in labor-intensive industries such as postal services. Second (on the right-hand side of Figure 1.2), provision regulation intends to remedy the under- or over-provision of certain goods or their quality. In telecommunications or postal services, this is ensured through USOs concerning the provision of quality services to the entire population in all regions of a country. Conversely, regulations may be concerned with environmental pollution or energy efficiency. After the identification of an under- or over-provision, the first aspect to be governed is the concrete definition of obligations. In a second step, one or several operators have to be designated if the market does not spontaneously provide the desired level of service quality. If the (asymmetric) regulatory intervention constitutes a binding economic constraint and a relevant burden on the designated operator(s), a financing mechanism is needed for compensation.

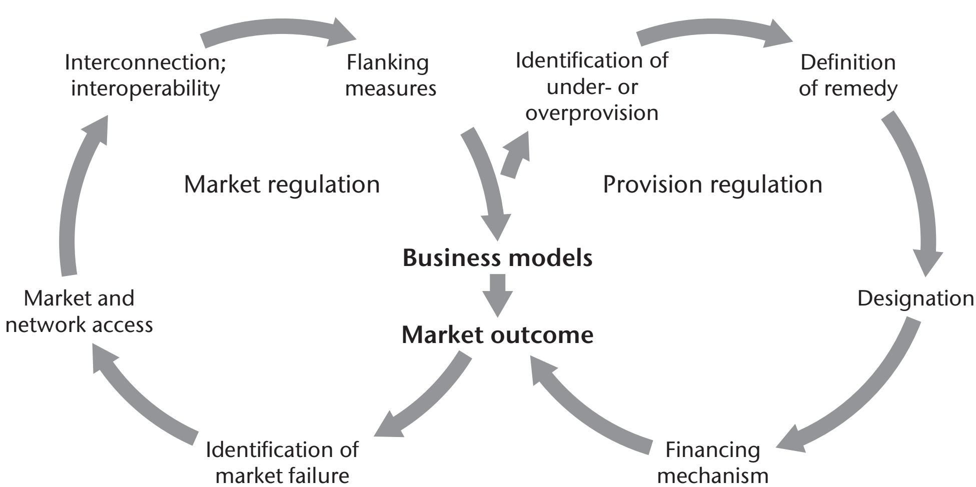

Figure 1.2 Illustration of interactions

Source: Based on Jaag and Trinkner (2011)

This book covers the main institutional levels of policy and regulation; namely, the global level (airlines, maritime transport, and telecommunications), the regional level, especially Europe (railways, air traffic control, electricity and gas), the national level (postal services, and road transport), as well as the local level (water and wastewater, urban public transport and airports). The remaining chapters discuss the concrete interactions between regulation, technology and market forces in each industry sector in detail. For each of the nine network industries, a separate chapter gives a view from a sector/market perspective, the policy/regulation perspective, and a management/strategy perspective.

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Part I

The market and industry perspective

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2

Telecommunication networks

Technology and market development

Wolter Lemstra and William H. Melody

Introduction

Telecommunication is widely considered an important contributing factor to economic productivity and growth, as reflected in a strong correlation between gross domestic product (GDP) per capita and teledensity. With the emergence of the Internet, the role of the telecoms industry has become even more important, as economic and social activity is increasingly electronically mediated and transacted online.

In the OECD, business and private spending on telecommunications moved from a plateau of just above 2 percent of GDP in the period 1985–1995, to a peak of 3.5 percent in 2001; this slowly declined to a level just below three percent from 2011 onward. This is linked to an underlying increase in the proportion of household expenditure on telecommunication; from an index of 100 in 1990, it increased to approximately 130 in 2003 and remained relatively flat in later years (OECD, 2003; 2005; 2007; 2011; 2013).

As the industry has evolved from connecting homes to connecting people, and more recently to connecting devices, it has become increasingly global. This applies in particular to the supply industries that provide infrastructure equipment. With the emergence of the Internet, the content conveyed is becoming increasingly important and, hence, so is the relationship with the computer and media industries. This has both global and very local policy dimensions.

This chapter is structured as follows: first the historical developments of the telecommunications industry are captured. The development trajectories in both fixed and mobile communications are summarized, as well as the convergence between these. The way in which the Internet is subsuming the role of traditional telecoms receives special attention. Subsequently, the development of broadband markets, from the year 2000 onward, is discussed. This is followed by a discussion of the challenges in the transition to ultra-fast next-generation access networks and concluding remarks close the chapter.

This chapter should be read in conjunction with Chapter 11 on Electronic communications policy and regulation in Europe, and Chapter 20 on Innovative and disruptive effects of the Internet on strategy in the communications and media markets.[1]

Overview of major developments – technologies and markets

Telecommunications development has been linked to the application of new network technologies for the provision of specific services; for example, telegraph, telephone, video, mobile voice and data. Improvements in technologies led to the expanded capability of these networks to provide additional services, thereby creating a degree of overlap and competition for the provision of some services. It has now reached the point where infrastructure networks are increasingly capable of providing most, if not all, telecommunication services. The range and variety of services are also expanding rapidly as they are applied innovatively in all sectors of the economy, including the other network industries. One of the main challenges today is to ensure that next-generation networks (NGN) will have the capacity and quality to support the anticipated rapid growth in new applications of telecommunications services.

Telephone network

The telecommunications industry originated in the invention of the electrical telegraph in 1832, and the telephone in 1876. Telephone services started through private entrepreneurship; however, following the expiry of the Bell patent in 1893, many competing networks were built in US cities and towns. AT&T maintained its market dominance primarily by refusing to interconnect with new competitors. Under the threat of being charged with violation of US competition laws, AT&T lobbied the federal government to establish a regulation that would sanction its monopoly. In return AT&T agreed to enable universal service, meaning it would interconnect with other operators serving neighboring areas (Falk, 1984; ITU, 1965; Mueller, 1997).

In Europe in the early 1900s, most private and municipal telephone networks transitioned to central government ownership, whereby public administrations (PTTs) became responsible for the national telephone infrastructure and service provision. These developments resulted in a private monopoly under regulatory supervision operating in the US, Canada, the Philippines, and a few other countries, and national public monopolies operating in Europe and most other countries. The infrastructure equipment supply was also largely a national affair. Hence, a vertically integrated industry structure resulted, according to the model of 'one country – one operator – one (main) supplier' (Lemstra, 2006).

The AT&T monopoly was successfully challenged in the late 1960s by an independent terminal provider (Carterfone) and an alternative provider of long-distance communication using microwave transmission (MCI). This stimulated support for market liberalization throughout the 1970s from the electronics, satellite manufacturing, and computer industries. The latter wished to use telephone lines to connect computers and data terminals. The break-up of AT&T in 1984 for its violations of US competition laws, and a gradual erosion of the monopoly, changed the industry environment dramatically, culminating in full liberalization under the Telecommunications Act of 1996 (Falk, 1984; Melody, 1997).

In Europe, pressure for market liberalization caused the publication of a Green Paper by the European Commission on creating a harmonized market for telecommunications, and liberalization of the telecommunication services industry in 1987 (EC, 1987). January 1, 1998, was set as the target date for full liberalization of the telecom markets. In Japan, liberalization started in 1985 with the privatization of NTT, and regulations were eased gradually. South Korea began to open its telecom markets in the early 1990s (Mizutani, 2012; Oh and Larson, 2011).

A dedicated telephone network was developed, and optimized for transmission of the human voice. A two-way connection was set up for the duration of each call, known as circuit switching. Later, data was encoded for transmission within the voice band (300–3400 Hz); this enabled the development of facsimile and data communication at data rates up to 56 kbit/s. Higher data rates could be provided using leased lines. The local loop – the connection between the home and the central office – remained analogue until the Integrated Services Digital Network (ISDN) was introduced in the mid-1980s in the US, and in the early 1990s in Europe. ISDN offered two user connections at 64 kbit/s. Interconnection of networks was facilitated through standardization of the equipment interfaces at national, regional, and global level.

Mobile networks

Wireless communication using radio-based transmission was introduced around 1950 and used by telephone operators for intercity transmission of phone calls and relaying television signals. The introduction of cellular systems, using small cells with lower power and allowing the reuse of radio frequencies, occurred around 1980. NTT in Japan was the first to use such technology. These were the first-generation (1G) analogue systems for mobile phone service (using Frequency Division Multiple Access [FDMA]). Fully digital systems were introduced in the early 1990s. The European GSM system, using Time Division Multiple Access (TDMA) became the world's leading second-generation (2G) system (King and West, 2002; Manninen, 2002; Meurling and Jeans, 1994).

In the late 1980s, Qualcomm, in close cooperation with PacTel, demonstrated a Code Division Multiple Access (CDMA) prototype, which provided a tenfold capacity increase compared to TDMA systems. In the mid-1990s, the CDMA standard was ratified by the US Telecommunications Industry Association and adopted by PCS PrimeCo, Airtouch and Sprint. Other early adopters were Hutchison in Hong Kong and Korea Mobile Telecom (Mock, 2005).

In the late 1990s, Wireless Application Protocol (WAP) served as an early attempt to provide access to the Internet. The introduction of General Packet Radio Service (GPRS) provided for a packet-switched overlay with a data rate of up to 170 kbit/s. The capacity was extended through Enhanced Data for Global Evolution (EDGE) to rates of 200–700 kbit/s (GSM Association, 2009).

Initially, licenses allowing the use of the radio frequency spectrum for mobile telephony were granted by the national governments to the incumbent PTTs. During the early 1980s in the US, two licenses were granted in each market, one for the wire-line carrier and one for a non-wire-line carrier. Through the acquisition of local cellular operations, McCaw built the nation's largest cellular company, which was sold to AT&T in 1993 (Corr, 2000).

During the 1990s in Europe, second licenses were typically issued through a 'beauty contest'. This marked the start of competition, which was not controversial as the mobile market was booming. Vodafone was one of the first mobile operators to build a multinational presence, extending its operations from the UK to Europe, Japan and the US. In the late 1990s, additional licenses were auctioned. Over time, consolidation usually reduced the number of competitors to three to five. Competition has been enhanced through Mobile Virtual Network Operators (MVNOs), which lease infrastructure capacity from Mobile Network Operators (MNOs) to provide their services, typically targeting special user groups or leveraging a consumer brand.

In rural areas, mobile communication has become a substitute for a lack of fixed communication. This applies to many countries in Africa, South East Asia and Latin America, but also to countries in central and eastern Europe, where fixed penetration has peaked at a density of approximately 60 percent of households (Skouby and Williams, 2014).

The introduction of prepaid service in the early 1990s unlocked telecommunications for many users with irregular earning patterns at the 'bottom of the pyramid'. This also applied to the Grameen Village Phone program in Bangladesh, which brought phones to 45 percent of all villages using microfinance to turn mobile phones into payphones. The microtelcos in Latin America and the Caribbean also enabled mobile services to be used by the poor (Lirneasia, 2014; Mahan, 2005, Samarajiva and Zainudeen, 2008).

The Internet

The Internet had a different starting point and a totally different development trajectory compared to the telecom networks. In the mid-1960s in the US, the Advanced Research Projects Agency (ARPA) sponsored a study to be executed by universities and research centers on the cooperative network of time-sharing computers. The invention of packet switching in the mid 1960s in the US and the UK led to the ARPANET project, with the first research centers being connected through packet switching in 1970; this was the precursor of the Internet (Abbate, 2000).

In packet switching, a data message is split into a number of relatively short packets, to which an address is added to enable routing of the packet through the network. This method is much better suited for computer communication, which is very wide-ranging in terms of the volume of data to be transmitted; it is asymmetric, with most data being transmitted in one direction; and sometimes involves a short transmission time compared to the set-up time of a circuit switched connection.

In the 1980s, the Internet was so named and the 1000 host computers switched en masse to the use of the newly agreed protocols set for data transmission – transmission control protocol and Internet protocol (TCP/IP). International connections to universities and research institutes were established from the late 1980s onward. A spin-off of one of the regional research centers started to provide TCP/IP network services to business customers. In the early 1990s, a number of US-based Internet service providers (ISPs) created the non-profit organization Commercial Internet Exchange (CIX), to connect their networks through gateways. The operation was financed through a membership fee, and traffic from any other member network was handled free of charge (peering). A similar function was soon established in Europe (through RIPE) and other regions of the world (Abbate, 2000).

In hindsight, four major events can be identified as instrumental in the Internet's development towards its current-day popularity: (1) the creation of the TCP/IP protocol in 1972, under the leadership of Vint Cerf, to be used universally across the Internet for information exchange; (2) the creation of the World Wide Web using the principle of hypertext developed in 1989 by Tim Berners-Lee – the application (html) that would unlock information stored in computers on a worldwide basis; (3) the introduction of the first popular browser, Mosaic, by Marc Andreesen in 1993; and (4) the transition of the Internet in 1995 from a research domain to an open-network resource. Fundamental to the development of the Internet has also been the popularization of computing through the introduction of the PC, notably the Apple in 1977, followed by the IBM PC in 1981 and more recently the laptop and the tablet (Lemstra, 2006).

Cable TV networks

Another infrastructure development trajectory that is important in the context of broadband access to the Internet is the cable TV (CATV) network. CATV networks emerged for the distribution of radio and television (RTV) signals to apartment buildings, using a common antenna system. Through interconnection and consolidation, these systems typically evolved into municipal and regional systems using coax cables for signal distribution and fiber cables in the backbone network. To provide data communication services, these CATV networks had to be upgraded from one-way analogue RTV signal distribution to two-way digital communication.

These CATV networks were typically developed by private entrepreneurs in North America. In Europe, they were more often owned by housing corporations or municipalities, and at the time of liberalization transferred into private ownership or to a utility firm, such as the electricity provider. In most countries, a consolidation wave led to a number of large players operating in non-overlapping service areas, such as each being a monopoly provider in the area they served.

Convergence of networks

Leading up to the broadband era, which started around the year 2000 in most countries, three network development trajectories came together: those related to the two fixed networks, and to the mobile network. To this we must add the trajectory of the Internet. Figure 2.1 shows a stylized representation of the innovation avenues.

The coming together of the worlds of circuit switching and packet switching produced a clash between two engineering cultures and two different technology paradigms, represented on the one side by the 'Bell Heads' from the telecoms industry and on other by the 'Net Heads' from the computer industry (Dosi, 1982; Lemstra, 2006).

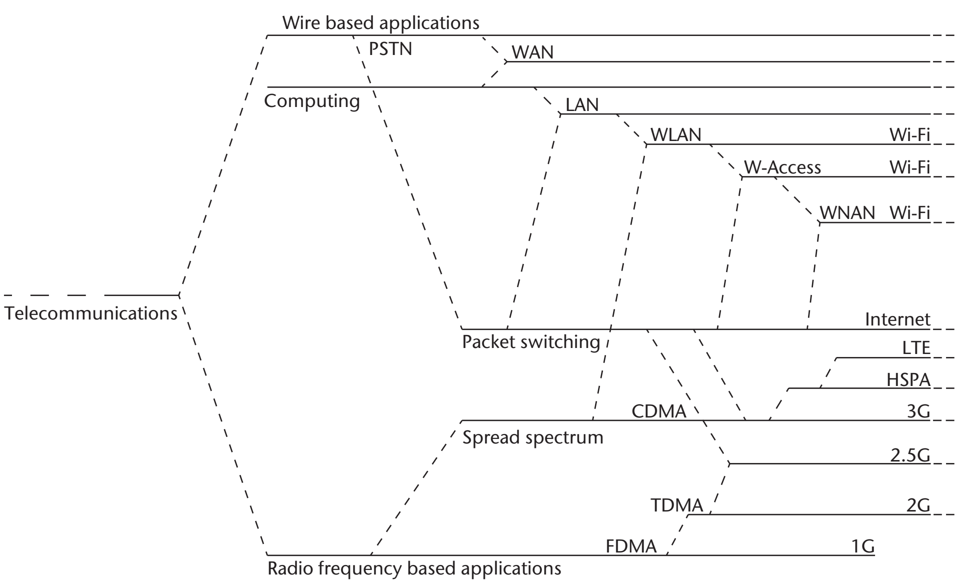

Figure 2.1 Wi-Fi and Internet innovation avenues re-combine

Legend: PSTN: 1–3G: first- through third-generation mobile; CDMA: Code Division Multiple Access; FDMA: Frequency Division Multiple Access; HSPA: High-Speed Packet Access; LAN: Local Area Network; LTE: Long-Term Evolution, 4G; PSTN: Public Switched Telephone Network; TDMA: Time Division Multiple Access; WAN: Wide Area Network; WLAN: Wireless LAN; WNAN: Wireless Neighborhood Area Network.

Source: Lemstra et al. (2010). Reprinted with permission from Cambridge University Press.

The early packet networks were inadequate for real-time applications, such as voice and video. Today, with higher data rates, the Internet is increasingly used for all types of services. Moreover, a difference in quality is often accepted, as the services are typically included 'free'; that is, as part of the subscription fee.

Broadband market dynamics

The final decennium of the twentieth century was a defining period for the telecommunications industry. It featured active implementation of market liberalization policies in many countries around the world. Varying degrees of competition were introduced, and in many countries the incumbent operator was privatized. The market dynamics were fueled by a strong interest from the financial industry, leading to a period of market euphoria. The period marks the beginning of the end of the era of traditional telephone systems based on circuit switching, and the start of the era of packet switching and the Internet. The ubiquitous use of TCP/IP enables an effective decoupling of the underlying transmission infrastructure from the services and applications provided over those networks. It marks the end of the era of dedicated networks and the beginning of over-the-top (OTT) services provisioning.

In the late 1990s, the exponential growth of Internet traffic led to a wave of investments in the construction of fiber backbone links. In the US, incumbents such as AT&T, MCI WorldCom, Sprint, and Qwest, and new entrants, such as Global Crossing, Williams Communications, Level 3, and Enron, deployed close to 900,000 route miles. In Europe, operators such as Telia, Interoute, KPNQwest, COLT, and Global Crossing built competing pan-European fiber networks. Competition in the backbone networks drove down prices for long-distance connections, directly impacting prices for leased lines and long-distance calling. Liberalization also provided more freedom and opportunities for the equipment suppliers who now had many new potential customers (Lemstra, 2006).

Following the collapse of the stock price bubble in 2000, the telecom services sector became subject to consolidation. Incumbent operators refocused on their core services and core markets (Lemstra, 2006). Many of the more recent market entrants had insufficient cash flows to survive. The OECD reported 142 filings for bankruptcy with a total default of US$183 billion, for the period 1999–2003. Infrastructure investments dropped to 30–50 percent of previous levels, which led to the bankruptcy of Nortel Networks, the merger between Alcatel and Lucent Technologies, and Siemens and Nokia merging their telecom networking activities (Lennin and Paltridge, 2003).

Despite this setback, Internet traffic continued to grow although at a slightly lower rate. As the leading supplier of Internet routers and switches, Cisco was least affected. Huawei and ZTE from China started to make important inroads as telecom equipment suppliers.

In the following sections we capture the developments, with a focus on broadband.

Infrastructure-based competition

With the inherently higher bandwidth of the coax cable, the CATV companies became drivers of the competition on speed. A series of upgrades of the DOCSIS modems (data over cable service interface specification – from version 1.0 through 3.0) allowed data rates of up to 120 Mbit/s to be provided. As in the cable network, a group of end users share the capacity of the final part of the access network, at higher data rates the degree of sharing needs to be reduced and fiber is deployed in the feeder network towards the street cabinet.

For access to the Internet using the public switched telephone network (PSTN), asymmetrical digital subscriber line (ADSL) equipment was introduced in the access part of the network, starting with a data rate of up to 2 Mbit/s downstream and 512 kbit/s upstream. ADSL uses a high-frequency band on the local loop and hence could be provided in addition to telephony and ISDN. Subsequent technological upgrades (ADSL2, ADSL2$^+$) allowed for data rates of up to 24 Mbit/s downstream and 1 Mbit/s upstream. As higher data rates required shorter copper loops, fiber was deployed in the access network up to the street cabinet, with very high data-rate DSL (VDSL) equipment used on the remaining part of the copper loop. Data rates per user were further increased to around 80 Mbit/s through bonding (using a double wire pair) and vectoring (active canceling of cross-talk in copper cables).

It should be noted that infrastructure-based competition is a result of the extent to which the legacy networks have been deployed. The PSTN has reached the highest penetration levels, with close to 100 percent of households in the most developed nations, approximately 60 percent in Central European countries, and much lower levels in, for instance, Central African countries. Cable TV networks have been built in urban areas only, and are completely absent in some countries. In Europe, the penetration is highly varied, with close to 100 percent in the Netherlands and Belgium, to being fully absent in Italy and Greece. In the US, the cable networks have a very high penetration level (Lemstra and Melody, 2015).

Competition also emerged based on the opening of the internal communication networks of utility firms; in particular, electricity companies have deployed fiber along the electricity grid. A typical example is KEPCO in South Korea (Oh and Larson, 2011).

Access-based competition

Infrastructure-based competition has been viewed by many analysts as more effective than access-based competition, whereby new entrants provide services competition, facilitated by access to the incumbent operator's infrastructure network. However, in the absence of a cable network, opening the PSTN was the only means to create fixed network competition. This required regulation in order to create a level playing field for entrants. Recent econometric analysis of developments in Europe shows that the combination of access-based and infrastructure-based competition provides the best possible outcome (Lemstra, Van Gorp and Voogt, 2015).

Access regulation became linked to the so-called ladder of investment concept. At the lowest rung of the ladder, the market entry barrier is also the lowest, and very little investment is required from the alternative operator to enter the market. Having established a customer base using a product such as resale or bitstream, the alternative operator would be enticed to decrease its dependency on the incumbent and the fees to be paid by investing more in its own infrastructure (Cave, 2006). As the alternative operators change from resale and bitstream to partial and full local loop unbundling (LLU), their investments per end user connected increases, as does their ability to innovate in the service provision. The progression on the ladder is illustrated in Figure 2.2, using France as an example.

Free/Iliad, an alternative operator in France, is a salient example of an operator having reached the highest rung of the ladder by deploying fiber in the major cities in France. This started with Paris, where the deployment was facilitated by the use of the sewer system and later by access to the duct systems of incumbent France Telecom/Orange (Lemstra and Van Gorp, 2013).

With the CATV network as the most important competitor to the PSTN, regulators refrained from applying access regulation. More recent attempts to open the CATV network show that this is difficult due to the different technologies and network architectures applied. In the US, with a broad deployment of CATV networks, access regulation was abolished in the mid-2000s, with the aim of improving the incentives for investment in fiber to the home.

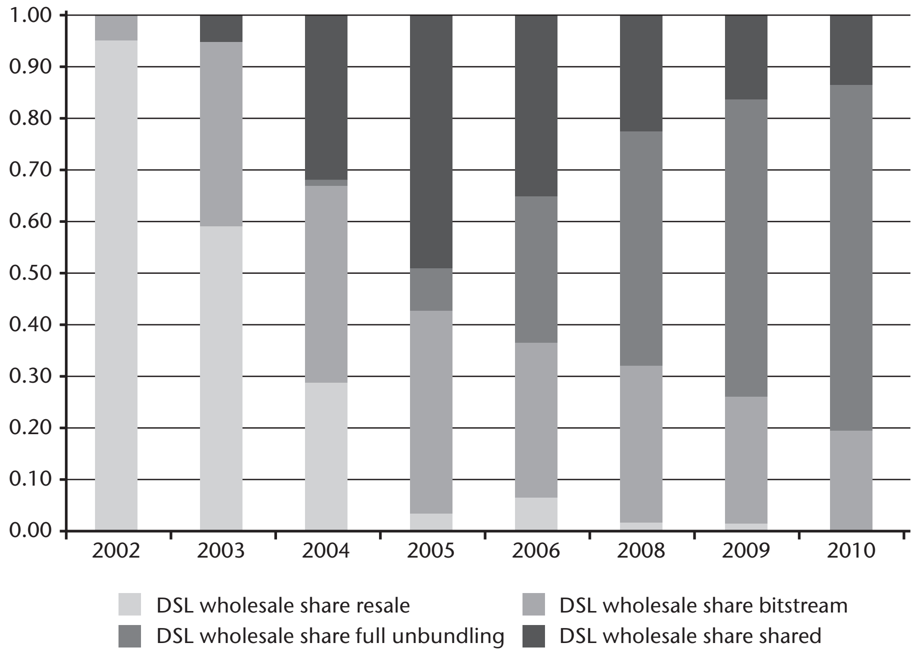

Figure 2.2 DSL share by wholesale type in France, 2002–2010

Source: Lemstra and Van Gorp (2013)

Competition from mobile

The unexpected success of text messaging, or Short Message Service (SMS), as part of 2G, indicated the potential of mobile cellular technology for providing data communication. The introduction of i-mode services by NTT DoCoMo in Japan in the late 1990s illustrates the point: within six months, one million subscribers had been achieved; after 18 months the 10 million mark was reached; and soon thereafter, one third of the user base (Natsuno, 2000).

The development of a standard for broadband communication with data-rate capacity in the range of Mbit/s started in the mid-1980s, gaining traction in the mid-1990s through the 3rd Generation Partnership Project (3GPP), which involved standards and industry organizations from Europe, the US, Japan, and Korea. In 1999, the dispute over intellectual property rights that had emerged in 1995 between Ericsson and Qualcomm was settled and a 3G standard could be concluded, with three modes to assure compatibility with each major 2G standard.

The success of 2G mobile voice technology, combined with the success of the Internet, raised high expectations for mobile broadband networks. This was reflected in the initial willingness by operators to pay very high prices at auction for 3G licenses. The first auction was held in the UK in 2000, with five licenses on offer. The gross proceeds amounted to US$33.3 billion, or US$650 per inhabitant. This auction coincided with the peak of the financial market euphoria (Lemstra, 2006; Melody, 2001).

Later in the year, SK Telecom in Korea introduced the first commercial 3G offering, based on the CDMA 1X standard. NTT DoCoMo of Japan followed a year later. In 2002, Verizon launched 3G services in the US. In the fall of 2007, 132 operators had deployed 3G with high-speed packet access (HSPA), with data rates between 1.8 and 7.2 Mbit/s on the downlink, and

56 operators were providing high data-rate uplinks of 1.4–5.7 Mbit/s. The setback after the period of financial euphoria and delays in providing a range of 3G terminals caused the introduction of 3G to take much longer than that of 2G.

In those countries where people have no or limited fixed services, mobile broadband is the preferred infrastructure for accessing the Internet. With increasing data rates, the number of mobile-only households in other countries is also increasing, reflecting a substitution of mobile for fixed services.

Market dynamics

Competition for access to the Internet has resulted in the quick convergence of prices and strong price competition. In recent years, the competition has become focused on offering higher data rates at relatively constant prices, with ADSL and DOCSIS providing 'always on' connections to the Internet for a flat subscription fee. For mobile access to the Internet, maximum limits were set for the amount of data that could be transferred without additional charges.

Competition in mobile telecommunication has become complex, with many different types of smartphone, applications platform providers and related stores (Apple and the Appstore; Google and Google Play), and service providers. While the BlackBerry was one of the first and most popular smartphones by the Canadian supplier Research in Motion, Taiwanese (such as HTC) and Korean (such as Samsung) suppliers have become market leaders, next to US-based Apple. In terms of the underlying technology, the competition is between the platform operating systems of Apple (iOS), Google (Android), and, to a lesser degree, Microsoft (Windows Mobile). Android is considered to be a more open platform, being built on open source software, while Apple and Microsoft use proprietary software.

Competition in fixed broadband is increasingly driven by bundles of services being offered. From the early combination of Internet plus telephony to triple-play and quadruple-play, the latter includes Internet, telephony, TV, and mobile.

At home, in businesses, in hotels, and at public places (hotspots) high data-rate wireless access to the Internet is provided using WLAN, known as Wi-Fi. Wi-Fi is considered to compete with mobile broadband, but is also a complement for offloading data traffic. Wi-Fi operates in the license-exempt 2-GHz and 5-GHz frequency bands, and has become popular as it is typically provided free of charge. Municipalities have taken up the deployment of Wi-Fi-based networks to improve their services to the public. The low barrier to the technology has allowed the creation of community Wi-Fi networks in underserved areas, such as the Nepal Himanchal network, the Dharamsala network in India, the Mérida network in Venezuela, and the Knysna and Mpumalanga networks in South Africa (Lemstra, Hayes and Groenewegen, 2010).

Over-the-top services and applications

Although not designed for data services, short message service (SMS) has become a very popular and profitable technology in this area. It was also the first service to be absorbed by the Internet in the form of instant messaging (IM), first among BlackBerry users, and later among iPhone users, and has become widely used through WhatsApp. As a result, SMS traffic has fallen by 30–50 percent in recent years.

Voice over the Internet protocol (VoIP) has become popular through Skype, which is a closed community network but is connected to the PSTN through an off-net calling feature.

Most PSTN operators, including incumbents, now provide IP-based telephony services as part of their All-IP strategy.

This also applies to IP-based TV. The PSTN operators have been able to gain a significant share of the RTV distribution from the CATV operators – up to 15–25 percent in some countries. Internet TV is watched mostly in delay mode, using video streaming, replacing the traditional recording of TV programs at home, or by using video-on-demand services, such as those provided by Netflix. In addition, music on demand, which uses platforms such as Apple's iTunes store, or radio-streaming services (including most of the traditional radio stations) provided by a multitude of companies can be received via the Internet.

The market structure

Infrastructure networks (both fixed and mobile broadband), and access to them are necessarily local and national in supply. Hence, competition is still largely influenced by national policies. Alliances have been created between operators, such as 'Concert' between AT&T and BT; Unisource between KPN, Swiss Telecom and Telia; and a joint purchasing agreement between France Telecom and Deutsche Telekom. However, they did not survive. The cross-border supply to multinational corporations, such as by AT&T and BT, consists largely of a combination of own and locally procured services.

More characteristic for the fixed market in 2015 is a combination of the incumbent operator(s), one or two major alternative operators, and a few (specialized) smaller players. In the mobile sector the structure is different, with many more cross-border activities and regional/global branding, such as by Vodafone, T-Mobile, Telefónica and Hutchison. Typically, three to five mobile operators compete in each territory, often with a large number of virtual network operators representing 5–15 percent of the market.

After liberalization, incumbents wishing to expand their business had to go abroad or expand vertically. Hence, the ownership of incumbent operators has become much more diversified and international. See Figure 2.3 for an illustration of the expansion of Telefónica in the 1990s; the figure reflects both geo-political and language preferences, in addition to the opportunity to invest.

Where ownership rules have been liberal, we can also observe private equity funds taking control of the PSTN incumbent, such as in Ireland and Denmark, and of many CATV operators. US-based Liberty Global has become a major player in cable in Europe (Melody, 2007; Lemstra and Groenewegen, 2009).

Through the application of the TCP/IP protocol, telecom services have become decoupled from the underlying infrastructure and can be supplied 'over the top' (OTT). Service provision is no longer bound by geographical borders, but only by language limitations or legal borders. This has emphasized the two-sided market characteristic of the telecoms network infrastructure. Network operators contend that as these OTT service providers (in particular providers of film and video that require very large bandwidth capacity) pay only access charges but not transport and delivery fees, the incentive to invest in access networks is reduced. A recent contract between Netflix and the US-based cable company Comcast suggests a further willingness to pay, as well as a possible move away from flat-fee subscriptions by Comcast. The willingness to invest by content providers is also shown in the deployment of content distribution networks (CDNs), which assure high-quality access close to ISPs.

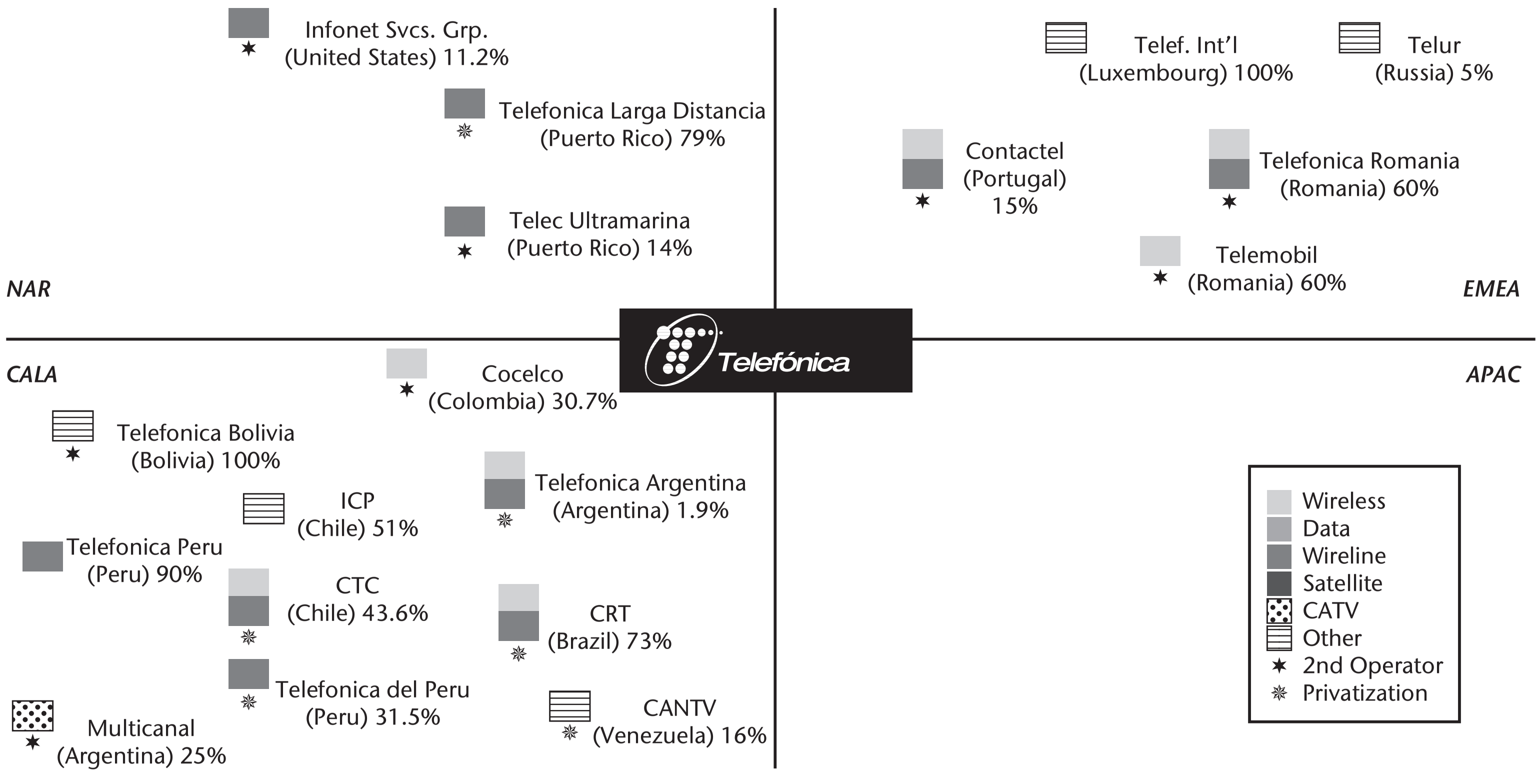

Figure 2.3 Expansion of Telefónica

Legend: APAC: Asia and Pacific; CALA: Caribbean and Latin America; EMEA: Europe, Middle East and Africa; NAR: North America Region.

Source: Courtesy Lucent Technologies.

Realizing next-generation access networks

The use of the Internet intensifies with more subscribers, more data-intense applications and more devices, in particular smartphones, tablets, and an increasing variety of communication-capable terminal devices and machines. This growth in demand drives the transition towards next-generation fixed and mobile networks. These transitions represent major investment challenges for the network operators, as data demand is growing while revenues remain flat.

Next-generation fixed – Fiber to the Home (FttH)

As the full replacement of copper by fiber requires major investment in trenching between the street cabinet and the customer's premises, Fiber to the Home (FttH) deployment has become a gradual process. Demand aggregation is important to reach a viable business case; an initial 20–30 percent take-up rate is typically required. Cost reductions in terms of using existing ducts and rights-of-way are also important, and collaboration in civil works among utility providers is being considered. The low-end offer on fiber is typically 100 Mbit/s symmetrical (that is, in the up- and downlink) and the offers extend into the gigabit range.

Different countries show different trajectories in the transition towards next generation fiber access. A few examples are provided below.

In Korea, a number of factors combine to explain the early take-up of fiber. From 1980 onwards, the Korean Electric Power Corporation built fiber-optic connections to most of the country's high-rise apartment buildings, which became accessible to ISPs through regulation. Around 2000, in the wake of the Asian crisis, the Korean government offered ISPs attractive loans to invest in broadband, which, for instance, Hanaro Telecom used to build optical cables to 4,700 high-rise apartment complexes. Moreover, the use of fiber was subject to exemption from unbundling after 2004, and in 2008 regulations allowed IP-TV providers to offer real-time broadcasting, thereby boosting demand (Kushida and Oh, 2006).

In the Netherlands in the early 2000s, because of the lack of fiber investment by established operators, municipalities declared a 'market failure'. In collaboration with housing corporations, providing demand aggregation and funding, many municipal FttH projects were initiated. This triggered a construction company to build passive open-access fiber networks in competition with the established operators (Lemstra and Melody, 2015).

In Sweden, a large country with low population density outside the major cities, 60 percent of the 290 municipalities are involved in fiber deployments. To ensure these networks are deployed on the basis of market principles, they are all open-access networks with service-level competition. The ownership and operation of the passive infrastructure is typically separated from the active network layer, whereby the operators are selected through a tendering process (Forzati and Mattson, 2015). See Figure 2.4 for the network layering and variety of business roles.

In the US, to facilitate the transition to fiber the regulator exempted it from unbundling in 2003. In 2005, the transition was further stimulated by the abolishment of local loop unbundling. However, investment by both incumbents has been significantly lower than originally anticipated.

In Japan, fierce competition in DSL stimulated the transition to fiber-based competition, which is facilitated by aerial deployments. The incumbents NTT-East and NTT-West, in which the government still has a large interest through a 50 percent share in the NTT Holding Company, lead fiber deployments. Fiber-based competition was stimulated by providing access to fiber, rolled out by the utility companies. By the first quarter of 2008, the number of FttH lines already exceeded the number of DSL lines (Mizutani, 2012).

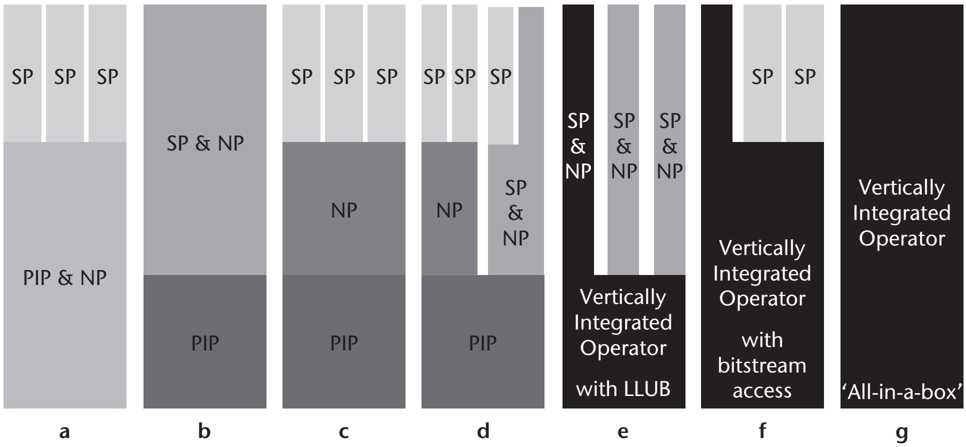

Figure 2.4 Access network business models

Legend: LLUB: Local Loop Unbundling; NP: Network Provider; PIP: Passive Infrastructure Provider; SP: Service Provider.

Source: Lemstra and Melody (2015). Reprinted with permission from Cambridge University Press.

In Australia, in 2008 the federal government opted for a National Broadband Network (NBN), which included the establishment of a new company to build and operate a national fiber network to reach 90 percent of homes, schools, and workplaces with 100 Mbit/s. As the NBN is being realized, the copper network was to be decommissioned. The 2013 NBN review process found that the plans were forecast to miss the intended completion date by three years, and to cost AU$73 billion rather than AU$48 billion. The government's response was a multi-technology approach that would reduce costs to AU$41 billion and facilitate completion by 2019 (Beltrán, 2013).

Next generation mobile – 4G and beyond

Smart mobile devices, such as tablets, and the use of video content and cloud-based applications, are driving data demand. The cumulative annual growth rate of 50 percent or more is expected to continue in the coming years. Hence, operators are being forced to upgrade the existing 3G systems through HSPA, HSPA$^+$ and HSPA Advanced, which accelerate the transition to the next generation of mobile technology (4G), also known as Long-Term Evolution (LTE).

LTE has become a misnomer as 4G follows on the heels of 3G in order to provide an All-IP solution to meet increasing data demand. To improve the system capacity and capacity per user, LTE uses a combination of techniques including Orthogonal Frequency Division Multiple Access, multiple send and multiple receive antennas, wider frequency channels of up to 20 MHz, the ability to combine frequency channels across different frequency bands, smart antennas with beam forming, and interference mitigation techniques to allow the combined operation of macro, pico, and femto cells, as well as Wi-Fi for offload. LTE provides typical user download rates of between 6 Mbit/s and 26 Mbit/s (Rysavy, 2013).

A typical LTE cell has an average of 42 Mbit/s of download traffic, and to reach its spectrum efficiency it needs to be able to ramp up to 100 Mbit/s instantaneously, which is why LTE typically requires fiber-optic links for connecting cell sites to the core network.

LTE was first used at the end of 2009 by Telia Sonera in Oslo and Stockholm using USB-based data modems. With the availability of LTE-compatible smartphones from Samsung and HTC, services were introduced in the US between 2010 and 2011. By the end of 2013, 256 networks were operational in 97 countries, with South Korea, Japan, and the US in the lead. The upgrade to LTE Advanced was first introduced in 2013, providing a cell capacity of 1.2 Gbit/s.

The performance objectives set for the next generation of mobile (5G) are radically higher data rates (two to three orders of magnitude relative to 2012), much lower round-trip delays (<1 ms), and very high dependability for critical applications, combined with a far lower energy footprint and reduction of exposure to electromagnetic radiation. Implementation will include software-defined networking and network function virtualization, based on 'cloud' computing.

Next generation Internet – Internet of Things

The next step in the evolution of the Internet is the interconnection of uniquely identifiable embedded computing-like devices using the Internet, denoted as the Internet of Things (IoT). IoT requires transition to IPv6, which has a much larger address space of up to 3.4×10^{38}, as well as low data rates with very low energy consumption.

IoT includes the earlier form of machine-to-machine (M2M) communication, which originated in the field of industrial instrumentation. The ubiquitous use of the Internet facilitates M2M communication and expands its range of applications, particularly in tracking and tracing. Previously, this was also denoted as telematics. Many mobile operators have departments dedicated to M2M services. A number of energy utility companies have recently outsourced the collection of smart-meter data to communication providers.

IoT is to include: environmental monitoring; energy management; remote health monitoring and notification; building and home automation, such as the smart city of Songdo in South Korea; smart vehicles; and more. The IoT is expected to encode 50 to 100 trillion objects and will be able to follow these objects (where human beings in urban environments are each surrounded by 1,000–5,000 traceable objects). This raises new issues around privacy and security, as well as of autonomy and control (Höller *et al.*, 2014).

Conclusion

Over the first 100 years of telecoms development, the end-user perception of the telephone service largely remained the same. This has fundamentally changed in the past 25 years through the introduction of mobile and the Internet.

A succession of fixed and wireless technologies has changed the user's experience in accessing the Internet for a host of applications. While increasing data rates on fixed networks have led those on wireless networks by a factor of 10, it is mobility and convenience that makes wireless services combined with smart devices so attractive.

In providing increasing data rates, wireless and wire line technologies are converging, as wireless traffic must be offloaded to the fixed network as quickly as possible. Fiber is the next step in increasing the Internet access capacity at home, and in increasing the backhaul capacity of wireless cells. Wi-Fi in the home is converging with femto cells, leading to the extension of the wireless network into apartment buildings and homes.

Although the liberalization of the industry introduced approximately 25 years ago removed the protected monopoly status of incumbent operators, the deep investment required to sustain the deployment of successive generations of infrastructure technologies has resulted in an oligopoly of private firms. While three to five nationally operating mobile infrastructure providers are still economically feasible, the transition towards next-generation fixed access, such as fiber to the home, suggests a return of the monopoly in fixed access networks. Based on the current trends in technological and market development, outside the main urban areas there will be no viable business case for infrastructure-based competition using fiber access. Hence, access regulation will be necessary in many regions to ensure that natural monopoly fiber networks remain open to competition at the services level.

Note

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