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5 The fixed Internet and mobile telecommunications sectoral system of innovation: equipment production, access provision and content provision

Charles Edquist[1]

1 Introduction

This chapter focuses upon the "new" parts of the telecommunications sectoral system of innovation. This means that we concentrate on analyzing innovation in fixed data communications (including the Internet) and mobile telecommunications (including the mobile Internet). We largely disregard, for example, traditional telecommunications – i.e. equipment for fixed telecommunications systems and fixed telecommunications voice services. Rather, we concentrate on what is emerging and growing – i.e. how the SSI is currently changing and how previously independent systems are converging.[2]

We address both equipment production (material goods) and the production (provision) of intangible service products. This is because innovations in manufacturing and in services are *complementary* – in both directions: service innovations are dependent upon manufacturing innovations *and* vice versa. It is hard to imagine a mobile phone call without a mobile handset, and vice versa. And the Internet is useless without content. Such a combined approach, addressing the production of goods and services alike, is unusual.

Equipment production includes routers and other kinds of exchanges for the Internet as well as base stations, exchanges and handsets for mobile telecommunications. It might be noted that such equipment is currently constituted not only by hardware but also by software, to a very large extent. Equipment producers such as Cisco and Ericsson employ

[1] The author wishes to thank Bent Dalum, Nicoletta Corrocher, Jeffrey Funk, Leif Hommen, Per Högselius, Michael Jensen, Martin Kenney and Gert Villumsen for their very useful comments on earlier drafts of this chapter.

[2] We return later to whether it is useful to talk about *one* system or *several* systems in this field.

thousands of software engineers and might therefore be labeled giant software firms.

The provision of Internet service products is often said to be accounted for by so-called Internet service providers (ISPs). However, with this term we normally mean provision of access to the Internet – which is certainly a service product. This means that firms that are normally called Internet service providers could better be named Internet access providers (IAPs). This will increasingly include providers of access to mobile telecommunications systems. However, for the Internet to be useful and in demand there must also be a content supplied in connection with it. Other kinds of service products constitute this content and firms other than the IAPs often supply it. A proper name for these would be Internet content providers (ICPs).[3] It is for these reasons that we talk about "equipment production, access provision and content provision" in the title of this chapter.

The ESSY project was described in the introduction to this book. It included the study of the fixed Internet and mobile telecommunications SSI reported in this chapter. However, this chapter is partly a summary of a much more comprehensive study. In addition to this synthesis chapter, the study resulted in a number of reports with the following titles and authors:

- "Fixed data communications: challenges for Europe," by Bent Dalum and Gert Villumsen (Dalum and Villumsen 2003);
- "The global system for mobile telecommunications (GSM): second generation," by Leif Hommen and Esa Manninen (Hommen and Manninen 2003);
- "The universal mobile telecommunications system (UMTS): third generation," by Leif Hommen (Hommen 2003);
- "Data communication: satellite and TV subsystems," by Bent Dalum (Dalum 2003);
- "The Internet services industry: sectoral dynamics of innovation and production," by Nicoletta Corrocher (Corrocher 2003a);
- "The Internet services industry: country-specific trends in the UK, Italy and Sweden," by Nicoletta Corrocher (Corrocher 2003b); and
- "Policy implications for the future of the sectoral system," by Charles Edquist.

All these reports are included in a recently published volume (Edquist, 2003).

Section 2 of this chapter deals with the Internet and mobile telecommunications. Section 3 draws out the policy implications of the analysis and

[3] Hence IAPs and ICPs constitute ISPs.

discusses the future of the SSI as well as the relations between Europe, the United States and Japan within it.

2 The fixed Internet and mobile telecommunications sectoral system of innovation

2.1 *Introduction*

Section 2 covers the important developments in the fields of mobile telecommunications and fixed data communications (Internet) in recent decades. It provides a synthesis of the other reports produced within the ESSY study of the fixed Internet and mobile telecommunications SSI, which are mentioned in the introduction to this chapter. It is heavily based on these reports, without always explicitly referring to them. This section also tries to "fill in the gaps," in the sense of covering some important issues that are not dealt with in the reports mentioned. This implies, for example, dealing with the birth of mobile telecommunications as triggered by the Nordic Mobile Telephone (NMT) standard, i.e. part of the institutional basis for the first generation of mobile telecommunications.

Section 2 relates to some of the key questions in the ESSY project, e.g. the knowledge base of the sectoral system, its organizations and institutions and the boundaries of the (data communications and mobile telecommunications) sectoral system. Public policy, the future of the sectoral system and comparisons with the United States and Japan are addressed in section 3.

Since the main elements of all systems of innovation – including sectoral ones – are *institutions* and *organizations*, we discuss these factors – and changes in them – with regard to data communications and mobile telecommunications. The relations between different kinds of organizations and between institutions and organizations is a central focus in what follows. Institutions are often created by organizations. At the same time, existing institutions influence organizations as well as the relations between them. We try to make a clear distinction between organizations (players or actors) and institutions (the rules of the game) in order to be able to discuss the relations between them as well.

In addition there is here a certain emphasis on the *functions* in SIs.[4] It is important to address these, and not only the elements of the systems. The main function in innovation systems is – of course – the carrying out of

[4] The elements (institutions and organizations) and functions in SIs – national, sectoral and regional – as well as the boundaries of such systems are addressed in a more systematic, profound and theoretical manner in the introductory chapter to Edquist (2003). Similar discussions are pursued in Edquist (1997), (2001b) and (2004).

innovations. However, the functions of the SIs also include activities leading up to innovations. These secondary functions, or sub-functions, influence the ability of firms (and other organizations) to carry out innovations. Examples of important functions are knowledge creation (through R&D and in other ways), collaboration in pursuing innovation processes, the provision of relevant education, the creation of standards, etc.

Section 2 is organized in the following way. Section 2.2 briefly addresses the main functions and organizations in the sectoral system(s). In section 2.3 the focus is on institutions and institutional changes, and on their consequences for organizations and functions. Different subsections will concentrate on the fixed Internet, mobile telecommunications, satellite communications and rate structures. Section 2.4 addresses the boundaries between subsystems and convergence between them.

2.2 *Functions and organizations in the system(s) and relations between them*

Organizations can be defined as *formal structures with an explicit purpose, which are consciously created* (Edquist and Johnson, 1997, p. 47). They may also be called agents, actors or players. Their purpose is to perform certain *functions* in the system(s). In the fixed Internet and mobile telecommunications sectoral system(s) of innovation some of the most important functions are:

1) The development of equipment (innovation in new equipment, hardware and software);
2) R&D relevant to the further development of the system(s);
3) The provision of relevant education and training;
4) The creation of standards and other regulations of importance to the systems(s);
5) The provision of access (e.g. Internet access or mobile telecommunications subscriptions);
6) The development of new content (introduction of new services, e.g. e-commerce); and
7) The provision of consulting services related to all of this.

The functions of an SSI may refer to the development and diffusion of innovations and how smooth and efficient these processes are. In turn, this may be a result of how good the SSI is in creating new knowledge or new combinations of existing (and new) knowledge, in providing education, in creating standards, etc. Other functions could also be mentioned. They might refer to how efficient the financing of product development is, how smoothly new firms are created, how inclined firms in the system are to diversify into new product areas, or how efficiently new markets are created for the new products (goods and services). On the whole, much more research needs to be carried out on the functions in systems of innovations. It should also be noted that this is quite similar to studying the determinants of innovation.

The functions are carried out by organizations (or, in some cases, by individuals). However, there is not always – or even often – a one-to-one relation between functions and organizations. A certain organization can carry out several functions and one function may be carried out by different kinds of organizations. Below I relate the functions listed above to some important organizations that carry them out.

- The development of equipment – which is increasingly of a software kind – is carried out by telecommunications and Internet equipment producing firms, such as Siemens, Ericsson, Cisco and Motorola.
- These firms also carry out a large part of the R&D needed for developing the new systems. Some R&D is also carried out by public universities and dedicated research organizations.
- Education is of great importance to the sectoral system of innovation, and it is largely carried out by publicly controlled and funded organizations. However, firms also sponsor further education and provide training. In addition, "learning by using" and "learning by doing" take place within organizations.
- There are organizations that create the standards and regulations that are important for decreasing the degree of uncertainty for equipment producers and for coordinating their relations with various other organizations in the Internet and mobile telecommunications SSI. They have often been of a public character, although private organizations have also been intensively involved in these activities. In addition, there are various industry organizations that have a quasi-public character, but no "official mandate" from government.
- Access is provided by the Internet access providers and mobile system operators. They own (or lease) the physical infrastructure (the network) and in this way provide the backbone of the Internet and mobile telecommunications. This category includes incumbent telecommunications operators, new entrant telecommunications operators, cable TV operators, alternative network providers and "pure" IAPs.[5]
- The access providers may also – and often do – provide (some) content to be transported by the systems, but there are also pure or specialized content providers that own the content (but do not provide access to the systems). There are general content providers, such as companies running portals, and specialized content providers, such as news and financial companies. We call these Internet content providers. They include

[5] For reasons presented in the introduction to this chapter, we have chosen not to call these organizations Internet service providers, even though they certainly do provide service products.

traditional media and publishing companies as well as new firms. Often they derive their revenues from advertising but they are increasingly trying to charge a fee for the provision of content. Their ability to do so increases if their content is highly specialized and/or customized. However, consumers tend to want content to be free of charge. Electronic commerce is offered by new firms working only over the Internet, such as Amazon.com, but, increasingly, old and established firms are also using the Internet as a new marketing outlet. This includes business-to-consumer as well as business-to-business e-commerce.

- Finally, there are consultancy firms – as in all knowledge-intensive sectors – that offer various services related to the Internet and mobile telecommunications. Examples are Web design, Web hosting, the development of platforms for electronic commerce, etc.

Over the last twenty years we have seen an increased "functional differentiation" and "organizational diversity" in the telecommunications SSI (in a wide sense). For example, in the past it was common that (monopolistic) access providers were also regulators. Now separate organizations have been created to perform the regulatory functions.

Digitization, or "digitalization," has provided the technological basis on which it is possible to separate telecommunications and Internet network operation (access provision) from content provision. It was therefore possible to make this kind of separation between "infrastructure" and "access" and "content services" with the emergence of the fixed Internet – and even earlier with the digitalization of fixed telecommunications. This separation was a very real possibility when the second generation of mobile telecommunications first appeared. Nevertheless, this separation was not fully implemented with the second-generation mobile standards such as GSM, despite the best efforts of the European Commission (see section 2.3.2.2). This will change with the third generation of mobile telecommunications (see section 2.3.2.3).

In telecommunications – in a wide sense – the set-up and character of organizations has changed very much during the most recent decades. For example:

- Publicly controlled telecommunications operators have been transformed into joint-stock companies and privatized; they are no longer public sector monopolies (with regulatory power).
- The relations between the most important organizations in the system have changed considerably.
- Formerly close ties between "national champions" in equipment production and monopolistic access providers have been progressively loosened.
- Important new organizations have emerged in the system, such as IAPs and ICPs.

- Similarly, new regulatory agencies have been created, concomitant with the privatization of public telephone operators (PTOs).

2.3 *Institutional changes and their consequences for organizations and functions*

Institutions can be defined as *sets of common habits, routines, established practices, rules or laws that regulate the relations and interactions between individuals, groups and organizations* (Edquist and Johnson, 1997, p. 46). Relevant examples in this context are laws concerning deregulation and liberalization, technical standards (particularly relevant for Internet and mobile telecommunications), access tariffs, rules with regard to intellectual property rights, etc. The institutions constitute the rules of the game, which influence the players – or organizations, e.g. firms – when they are trying to achieve their purposes. However, the relations between institutions and organizations are mutual. Institutions are formed and changed by the actions of (some) organizations. We now discuss the relations between institutions, organizations and functions in various parts of the sectoral system.

2.3.1 *The fixed Internet*

As we see in section 2.3.2, an institution – i.e. the NMT 450 mobile telecommunications standard – provided the cradle for the development of mobile telecommunications in Europe. But what provided the cradle for fixed data communications or the Internet?

Fixed telephone lines have existed for more than a century now. As mentioned in the introduction to this chapter, we do not deal with fixed voice telecommunications here (except occasionally for reasons of comparison). Instead we start our story when fixed telephone systems started to carry significant amounts of data in their cables, in addition to voice telecommunications. At the same time – or, rather, as a precondition for this – the fixed networks became digitized. There were two technological breakthroughs that made this digitalization possible: packet-switching technologies, and the Internet Protocol (IP).

In packet-switching technology "packets" of information share the network lines (bandwidth) with other packages, optimizing the use of the existing bandwidth. In packet-switched transmission protocols any type of information (voice, data, video, etc.) is broken down into packets, which are sent from one computer to another with no chronological order. A "header" on each single packet directs the routing from the sender to the receiver; the header contains information about the destination. The packages are sent individually and reassembled into a complete message at the receiving end.

By comparison, in the traditional circuit-switched networks an end-to-end communication path is established before the communication begins, and it stays open during the whole connection. With the conventional telecommunications network, each conversation uses a fixed amount of bandwidth for the duration of the call and the available bandwidth is dedicated to the call even if no information is transmitted (e.g. during silences in a voice conversation).

In 1968 the US Defense Advanced Research Projects Agency (DARPA) granted a contract to the engineering firm Bolt, Beranek and Newman, based in Cambridge, Massachusetts, to build the first packet switch (Mowery, 2001, p. 8). Hence this was a matter of *public technology procurement*; i.e. a public agency placed a contract with a firm ordering the development of a technology or an artifact that did not exist at the time of granting the contract, but which the partners believed could be developed (Edquist, Hommen and Tsipouri, 2000). The resulting switch was called an interface message processor (IMP), and linked several computers to each other. The result was ARPANET, which was the earliest forerunner of the Internet.

In 1973 two DARPA-funded engineers, Robert Khan and Vinton Cerf, developed an improved data networking communications protocol that simplified routing, eliminated the need for the IMP and allowed physically distinct networks to interconnect with one another. The idea of an open architecture that allowed network-to-network connectivity was a key intellectual advance in their design. Kahn and Cerf called the new protocol Transmission Control Protocol (TCP) and openly published the specification in 1974. Later it was split into two pieces and renamed TCP/IP (Transmission Control Protocol/Internet Protocol – Abbate, 2001, ch. 4; and Mowery, 2001, pp. 9–10). Hence the TCP/IP protocols, which were absolutely central to the development of the Internet, were also developed with the help of military research funds.

The TCP/IP is based on a distributed architecture, within which the IP and the TCP have separated functions: the TCP handles the transmission characteristics, while the IP manages the routing and network anomalies. The TCP/IP is embedded in distributed customer hosts that are located at the network periphery, therefore reducing the need for centralized control. The software is located with the servers and the user hosts, which makes possible Internet connectivity and integrated applications.

As a matter of fact, an increasing part of voice telecommunications is currently sent over IP networks; users may be unaware that a telephone call or a portion of a call is routed over an IP network. The transmission network is today (in part) common for Internet and voice telephone networks. This convergence has also, of course, influenced the telecommunications and Internet equipment industries.

TCP/IP was rapidly adopted. There were several reasons: it was highly reliable; it was an open standard; and it arrived just as the computing research community began to standardize on a common platform.[6] The TCP/IP protocols became an integral part of this standard platform. As a result TCP/IP became the dominant protocol for most networking applications in the early 1990s, and now it is virtually synonymous with the technical definition of the Internet (Mowery, 2001, p. 10).

One reason why TCP/IP became dominant was the decision by the National Science Foundation (NSF) in the United States to adopt it as the standard on its national university network. Beginning in 1985, any university receiving NSF funding for an Internet connection was required to provide access to all "qualified users" and use TCP/IP on its network (Kenney, 2001, pp. 12–13). Again, public action was crucial – this time for the early diffusion of TCP/IP.

Other government organizations in the United States were also important for the development of the Internet. In the late 1970s the NSF and DARPA founded a set of organizations to oversee the standardization of the backbone of TCP/IP. The Internet Configuration Control Board (ICCB) was established in 1979. In 1983, when ARPANET switched over to TCP/IP, the ICCB was reorganized and renamed the Internet Activities Board (IAB). The IAB had two primary sub-groups: the Internet Engineering Task Force (IETF), which managed the Internet's architecture and standard-setting processes (including editing and publishing), and the Internet Research Task Force, which focused on longer-term research (Mowery, 2001, pp. 12–13).

The Internet is not formally standardized as the public telecommunications network. There is no standardization body like the International Telecommunications Union (ITU), where all nations participate. The IETF is the closest equivalent to a standardization body. This voluntary organization updates standards, provides information about changes and controls the use of global addresses, but it is not an organization with formal power.

As opposed to the standard organizations involved in developing the mobile telecommunications standards, the IETF is mainly a voluntary organization, without any central management.[7] To the extent that the IETF has a management, it is embodied in the working group charters. These working groups are the main drivers in the development of Internet standards. The work is voluntary and, as such, often dominated by

[6] This platform was the Unix operating system, originally put forward by AT&T/Bell laboratories but gradually adopted by the main computer firms, and initially driven by some of the then newcomers in "network computing" and workstations, such as Sun Microsystems and later on the dominant incumbents of Hewlett Packard, IBM and DEC.

[7] Mobile standards are addressed in section 2.3.2.

large actors (telecommunication operators and manufacturing firms). As a consequence of the origin of the Internet in the United States, the protocol has been highly influenced by US actors via the IETF. In other words, US firms have dominated the standardization process related to the Internet.

The organizations that managed the establishment of Internet technical standards were quite informal, yet responsive. They managed to develop open standards and to adapt these standards rapidly to meet new technical and economic challenges, and this contributed powerfully to the rapid diffusion of the Internet (Mowery, 2001, p. 42).

An important institutional change that made the rapid diffusion of the fixed Internet possible was also the deregulation or liberalization of the telecommunications sector. Internet penetration came earlier and was more rapid in countries where liberalization occurred early (the United Kingdom: 1984; the United States: 1985; Sweden: 1993) than where it came late (Italy: 1998).

The early deregulation in the United Kingdom had a significant impact on the market structure. It also had an impact on the rate of technical change itself, since it allowed the entry of new companies and forced the incumbents to engage in the development of innovations. The liberalization of the telecommunications sector also had the consequence of substantially reducing the charges for telephone calls (Corrocher, 2003b).

Sweden has the highest Internet penetration in Europe and also the most advanced Internet service SSI. The telecommunications market in Sweden was liberalized in 1993 and Sweden now has the most liberalized telecommunications industry in the world. This has been a major driver for the development of alternative networks to that of the former incumbent operator (Telia). However, the unbundling of the local loop has not yet been achieved in reality since Telia is still charging too high a price for interconnection to allow others to compete on an equal basis (Corrocher, 2003b).

In contrast to what happened in the United Kingdom, one of the major obstacles to the development of the Internet in Italy has been the slow process of deregulating the telecommunications sector, which, in turn, has been caused by the lack of a clear policy for the implementation of an appropriate competition policy and of an independent regulatory authority. A telecommunications authority was established in 1997 and deregulation occurred in 1998. This delay has hindered not only the development of a competitive industry but also the diffusion of new technologies and applications (Corrocher, 2003b).

In the 1970s and 1980s the data transmitted via the Internet were primarily related to research activities and to the communications of

large firms with branches in different locations. However, in the 1990s, thanks to innovations made at the Conseil Européen pour la Recherche Nucléaire (CERN) in Switzerland, data traffic became increasingly demanded by final consumers. Tim Berners-Lee and Robert Cailliau at CERN released in 1991 a new document format called HyperText Markup Language (HTML) and a related document retrieval protocol called HyperText Transfer Protocol (HTTP). Together they turned the Internet into a vast cross-referenced collection of multimedia documents. Berners-Lee and Cailliau called their invention the "World Wide Web" (WWW). A US company – Netscape – that was listed on the stock exchange in 1995 commercialized these inventions. Hence, although the HTML and the HTTP were not invented in the United States, they were first commercialized – i.e. transformed into innovations – in that country.

There were prototype networks designed that constituted alternatives to the ARPANET, for example in the United Kingdom and France. "US dominance thus did not result from a first-mover advantage in the invention or even in the early development of a packet-switched network. The factor that does seem to separate ARPANET from these simultaneous projects was sizable public funding and flexibility in its deployment . . ." (Mowery, 2001, p. 9). This resulted in a network of a large (continental) scale that included different kinds of organizations: DARPA, universities, consulting firms, research institutes, etc. Its size and the inclusion of different kinds of organizations distinguished the ARPANET from its British and French counterparts (Mowery, 2001, p. 9).

Public funds were used to develop many of the early inventions that fueled the development of the Internet in the United States, and federal R&D spending played an important role in the creation of the entire complex of "new" post-war IT industries in that country. "The origins of the Internet can be traced back to these efforts" (Mowery, 2001, p. 24). Hence, public intervention was crucial.

However, the influence of public policies was not restricted to funding. Federal regulatory, antitrust and IPR policies were also important. According to Mowery, the overall effect of these policies was to encourage the rapid commercialization of Internet infrastructure, services and content by new, frequently small, firms (Mowery, 2001, p. 28). As a result there was an Internet explosion in the United States in the 1990s.

From the late 1980s onwards, US firms achieved a dominant position in the production of equipment for the Internet.[8] This occurred very much

[8] As we saw earlier, they also highly influenced the creation of standards in the Internet field.

because of their "head start" in serving the large – and early-developing – US domestic market, just as US-packaged computer software firms had benefited from the rapidly growing US domestic personal computer market during the 1980s. In the Internet field the firms that came to dominate were not large system vendors, such as IBM, DEC or Sun. Instead a group of smaller firms, most of which were founded in the late 1980s, became the most important ones. Examples are Cisco, Bay Networks and 3Com (Mowery, 2001, p. 16). Cisco is still a very dominant player on this market. And it is certainly not a small firm any longer.[9]

Currently there are, basically, five ways for consumers (and small business enterprises) to access the Internet (Dalum and Villumsen, 2003):

1) "Ordinary" modems (connected directly via the telephone line);
2) ISDN modems (connected directly via the telephone line);
3) xDSL, primarily Asymmetrical Digital Subscriber Line (ADSL – connected directly via the telephone line).
4) TV networks (via "cable modems" for cable TV or "set-top boxes" for satellite TV; and
5) Fixed wireless access (FWA).

The first three use the "twisted pair" of copper wires for the last mile to the consumer. They can all be installed as an integral part of an ordinary fixed-line telephone system, which in practical terms means that the incumbent telecommunications operators have a rather clear advantage in delivering these access modes. Competing companies will have to use the existing infrastructure on the last mile to reach the customers – i.e. they will have to make arrangements with the incumbent operators. This has preserved the powerful position of the latter, which appears to be a major inhibiting factor in the diffusion of high-speed Internet access in many countries.

Since a traditional subscriber line supports only analog transmission, a modem has to be used to transport data. The simple modem access (1), which converts analog to digital signals, does not require changes or enhancements in the network. The maximum speed is 56 kilobytes per second (KB/s). A first enhancement of the modem technology is ISDN (2), which runs at a higher speed (maximum 144 KB/s). In addition, ISDN makes possible parallel connections (data and voice).

As the demand for faster access methods increases, there are several digital subscriber line technologies that make possible higher speeds. Their common name is xDSL (3), where x indicates the specific variant. Since the demand for sending and downloading for most users is

[9] The role of venture capital for the rapid growth of these firms is strongly stressed by Kenney (2001).

asymmetrical, a technology where the bandwidth is higher for downloading is demanded. ADSL is thus currently the most common technology for high-speed "broadband" (above 2 megabytes per second – MB/s) access over a "twisted pair."

An alternative to the telecommunications cables is access via TV networks (4). This alternative has been growing very rapidly in some countries since many telecommunications operators (the previous state monopolies) have been slow to deliver high-speed access solutions. There has been an incentive problem since they have been able to charge huge amounts of revenue because the low speed simply generates high telephone bills.[10]

According to one source (*Financial Times*, 2001) – reporting data for broadband subscriber trends without specifying what exactly "broadband" is – there were over 40 million subscribers worldwide in 2001, divided into three shares of equal size: ADSL; digital set-top boxes; and cable modems (for cable TV). The US lead in the absolute amount of broadband subscribers is, however, concentrated on cable modems and set-top boxes. The TV-network-based broadband access share appeared to be around 80 percent in the United States in 2001. It has been mainly the alternatives to the incumbent telecommunications operators – i.e. the TV networks – that have been the "carriers" of broadband access in the United States.

A final access channel is FWA (5), which uses a wireless connection on the "last mile." Potentially very large amounts of data can be transmitted through the air at reasonably short distances. Several European countries have recently been through contests over FWA licenses, which have attracted much less attention than the UMTS auctions and/or "beauty contests" for mobile systems.[11]

2.3.2 *Mobile telecommunications*

2.3.2.1 The first generation – NMT The first standard for modern cellular telecommunications began to be specified in January 1970 and was called NMT 450 – i.e. the Nordic Mobile Telephone standard based on the 450 megahertz (MHz) bandwidth.[12] Important characteristics were that it was an analog standard, that it was fully automatic and that it

[10] Rate structures and levels are discussed in more detail in section 2.3.4.

[11] An emerging – and potentially very important – access method is via wireless local area networks (WLANs), which may become a core part of what is now considered to be fourth-generation (4G) communications systems, involving a true integration of mobile communications and the fixed Internet. See further in section 2.3.2.3.

[12] NMT is not covered in the other reports within this study of the fixed Internet and mobile telecommunications SSIs carried out within ESSY.

had a roaming function within the Nordic countries.[13] The development of the standard was initiated by the Nordic PTOs, which were state-owned monopolies at the time. A working group, its members drawn from the staff of the PTOs in Finland, Norway, Denmark and Sweden, designed the technical specifications. The Swedish PTO had a leading role in this work. In 1971 the NMT group gathered around forty national and international companies that were potential suppliers of equipment for NMT 450. They received preliminary specifications. The technical specifications were further developed in discussions within the group and were finalized between 1975 and 1978 (McKelvey, Texier and Alm, 1998, pp. 16 and 25).

In 1977/78 the implementation of the project started, and the Nordic post, telegraphs and telecommunications authorities (PTTs) started to look for suppliers of the different component technologies – namely radio base stations and switches. The NMT group opened the bidding for the supply of switches to a number of companies. This means that the mechanism of *public technology procurement* was used, as in this case, as an instrument to initiate the development of equipment. The bidding was international, but the Swedish firm Ericsson won the order to deliver switches to Sweden, Norway, Denmark and Finland. Ericsson's main competitor was the Japanese NEC. However, Ericsson first offered a computer-controlled switch with electromechanical switch elements, called AKE-13. Then Televerket (the Swedish PTO) wanted an adapted version of Ericsson's fully digital switch (AXE), and made it clear to Ericsson that they would choose the digital switch from NEC if Ericsson did not offer the AXE (McKelvey, Texier and Alm, 1998, p. 26).

The NMT 450 was very specific, which meant that network operators had the possibility of buying components from different producers and putting them together themselves. NMT 450 was implemented in Sweden in October 1980 and at the beginning of 1981 in Denmark, Finland and Norway. However, the first implementation occurred in Saudi Arabia in August 1980 (McKelvey, Texier and Alm 1998: 16).[14] In other words, it took as much as ten years to specify the standard and get it functioning.

The NMT 450 was much more successful than expected. It was initially forecast to have around 50,000 subscribers by 1990, whereas by 1992 it had approximately 250,000. Since more subscribers were joining than the standard could handle, the Nordic PTTs developed and added the NMT 900 (MHz) standard in 1986. The NMT 900 system was developed as an intermediary system, between the NMT 450 and the future European

[13] "Roaming" means locating the mobile phone handset of the person called.
[14] This turned out to be an important order for equipment producer Ericsson.

digital standard (which was later agreed to be GSM – McKelvey, Texier and Alm, 1998, p. 16).

The Nordic countries had the highest rates of penetration of mobile phones even before the advent of liberalization and before GSM – i.e. during the NMT era. It was about 7 percent in Sweden in 1992, thanks to the high quality of service provision and low tariffs. In 1990 market penetration in the United Kingdom was only 2 percent, despite much more extensive liberalization of the market for mobile (and fixed) telecommunications there.[15] The rapid penetration in Sweden was largely due to the consolidation of a strong market for mobile telecommunications via concerted action by the Nordic public telephone companies in defining the first-generation NMT standard and through low prices. Sweden's fixed subscription rates were much lower than in the United Kingdom, and call charges were only about half. The rapid subscriber penetration contributed to rapid market growth, which was important for the ability of equipment suppliers to benefit from economies of scale.

NMT 450 can be considered to be an institution – in the sense of a set of rules. This set of rules decreased the degree of uncertainty and risk for the equipment suppliers. The NMT standard was conceived primarily as a regional standard, though it later verged on becoming pan-European.

The institution of NMT 450 provided the cradle for the development of pan-European mobile telecommunications. It actually spurred the development of a whole new industry – or sectoral system – of very great economic significance. Public sector organizations dominated the development of the standard. The development was actually initiated and led by a few Nordic national PTOs.

In techno-economic development there has often been an institutional lag; i.e. institutions (rules and regulations) lag behind technical change (innovation) and constitute an obstacle to such change. This was, for example, the case with the diffusion of the fixed Internet in Italy – see section 2.3.1. However, in the case of NMT 450 the contrary happened. When this institution (NMT 450) was created it pushed – or, rather, pulled – the whole development process, for example by decreasing the uncertainty for equipment producers and operators. We might call this an "institutional push" (or "pull") instead of an "institutional lag."

The development and implementation of NMT was actually an example of the importance of user-producer relations in innovation processes, which is stressed so strongly in the systems of innovation approach. The public organizations provided a technical framework for and decreased the uncertainty of private equipment producers. The Nordic equipment

[15] As mentioned earlier, liberalization was initiated in the United Kingdom in 1984 and in Sweden in 1993.

producers/Ericsson and Nokia greatly benefited from this, and this is a very important factor behind their leading role in mobile telecommunications equipment production today.

However, NMT was not the only standard that was developed in the proto-period of mobile telecommunications. In the 1970s R&D on cellular systems gained momentum in parallel in a few countries (with the United States, the Nordic countries and Japan as forerunners).[16] This resulted in the introduction of as many as eight cellular standards between 1979 and 1985 (Lindmark and Granstrand, 1995, p. 386).[17]

AMPS (advanced mobile phone system) was developed by Illinois Bell Telephone, Bell Laboratories and Motorola, and the first AMPS system was launched in 1983 (as opposed to 1981 for NMT), delayed by arguments over access to radio frequencies and a complicated licensing procedure. NMT 450 was also the first standard to be adopted by multiple countries, and by the end of 1993 thirty-six countries had introduced the NMT 450 system (Funk, 2002, p. 41). AMPS was quite successful; it was diffused to a larger number of countries than NMT and had a larger number of subscribers worldwide (Funk, 2002, p. 40).[18] However, NMT in the Nordic countries showed the highest penetration rates in the world, constantly outstripping forecasts (Lindmark and Granstrand, 1995, pp. 386–388). In addition, NMT was the basis for the development of GSM, which became the globally dominant standard in second-generation mobile telecommunications – as we see in the next section.

2.3.2.2 The second generation – GSM

A Europe The GSM standard – introduced in 1992 – is an institution. It was conceived from the very start as a pan-European standard, and it was intended to cover many countries. And it certainly came to do so. In 1992 commercial GSM services were initiated in fifteen countries, but by 1996 GSM operated in 103 countries. It was possible to make phone calls between countries – even between continents – thanks to the fact that the national systems could be integrated in order to trace where a certain terminal was located (roaming).

16 The laboratories of Bell are usually credited with having invented the design concept of cellular mobile telecommunications (in 1947), the main idea being to overcome radio spectrum congestion by combining space division with radio spectrum division (Lindmark and Granstrand, 1995, p. 386).

17 The standards were: NAMTS, NMT, AMPS, TACS, C-450, RC-2000, RMTS and Comvik, although some experts argue that RC-2000, RTMS and Comvik were not fully functional cellular systems

18 This is explained not only by the size of the home market (the United States) but also by the diffusion to some large markets in the Asia-Pacific region and Canada (Lindmark and Granstrand, 1995, p. 392).

The above means that the development of the GSM standard was characterized by the involvement of a far greater number of organizations than the NMT standard(s) and by a far greater complexity in the relations among them. There were also other differences. Until the 1980s the public telecommunications companies in Europe often had monopolistic positions with regard to network operation and service provision. They also had the role of regulating the telecommunications sector. By the mid-1990s they were much more oriented toward network operation. Separate regulatory organizations had been created, and, in turn, these new organizations created new institutions.

In Sweden the National Telecommunications Council was created in 1990, followed by the National Telecommunications Agency in 1992. This ended the double role of Televerket (the former PTO) in the area of frequency management, and it also meant the creation of an independent telecommunications regulator capable of ensuring competition in the non-monopoly telecommunications sector, which now included the mobile sector. Televerket was also increasingly exposed to competition as a network operator from new entrants, domestic and foreign-based alike.

Just as in the case of NMT, public sector organizations were very important in the development of GSM; for instance, the national telecommunications firms were central in initiating and developing the new standard. However, the number of such organizations was now much larger. The development of GSM also occurred within the formal organizational framework (and not in an ad hoc consortium) provided by two European standard development organizations: the Conference on European Post and Telecommunications (CEPT) and the European Telecommunications Standards Institute (ETSI). CEPT was an association of European telecommunications organizations while ETSI – which gradually took over the role of standard creation – was a European Union organization.[19] In addition, equipment suppliers and public research organizations also participated actively in this work. This reflected the fact that the (former) public monopolies no longer had a monopoly of knowledge and expertise in the telecommunications field (Hommen and Manninen, 2003; and Glimstedt, 2001).

The Swedish former monopoly (Televerket) was very active in the GSM work, together with other Nordic operators and equipment production firms such as Ericsson and Nokia, which formed a "Nordic coalition." Televerket – which was later transformed from a public enterprise into a joint-stock, limited liability company, and in due course partly privatized

19 For an account of the role of the European Commission in the development of GSM, see Glimstedt, 2001.

in the form of Telia – effectively led the Nordic alliance. This consortium was based on the historically close collaboration between Nordic PTOs and Nordic equipment producers. In competition with a "Franco-German group" the Nordic proposal was selected, supported by thirteen of CEPT's voting members. In this way, GSM may be said to have developed "out of" NMT – i.e. along the same trajectory (Hommen and Manninen, 2003). ETSI adopted GSM without German and French support, but the two countries were still forced under EU law to use GSM as the basis for the public mobile telecommunications network (Glimstedt, 2001, p. 10).

Later, Ericsson, together with Televerket/Telia, developed and tested the first prototype of a full GSM system, thus consolidating its technological leadership, although Ericsson produced equipment for all three major international standards. Nokia also benefited – even more – from the GSM decision, since in fact it produced only base stations and switches to be used within GSM. This meant that Ericsson, Nokia and other Nordic equipment manufacturers were given a great advantage in relation to others. The way GSM developed increased the leadership they already had.

However, the Nordic proposal was based upon well-established technologies, to which a number of non-Swedish firms held the intellectual property rights; Motorola held many (50 percent) of the important patents, and it licensed them selectively to the main Nordic equipment manufacturers, Nokia and Ericsson. The second largest share (16 percent) was claimed by AT&T. Bull and Phillips claimed 8 percent each. Hence, at least 82 percent of the patents for the GSM standard were of non-Nordic origin. In this light, it is quite surprising that Nordic firms attained such a dominant position as GSM equipment producers. A relevant question is why Motorola did not (successfully) push its technology in the United States. Motorola sold licenses to Ericsson and Nokia and thereby benefited directly by collecting licensing fees. However, Motorola was not in a position to produce equipment for GSM to any large extent. A possible explanation for Motorola's behavior is that it felt that it would be unable to compete with European equipment producers in Europe, and perceived GSM as a European standard that would not necessarily develop into a world standard (Hommen and Manninen, 2003).[20]

In the first generation of mobile telecommunications, telephony and radio were combined. In the second generation, digital technology was fully implemented, creating possibilities for data transmission in addition

[20] Actually, none could, at the time, know that the result of the evolutionary development was that GSM would become the dominating standard in the world.

to voice transmission. In GSM, data transmission was first introduced through short messaging services (SMS). This is actually a two-way variant of the previously existing paging system. It has become unexpectedly popular. GSM can also provide Internet access though HTML compatibility, currently developed in the form of the wireless application protocol (WAP).

Finally, a remark on the role of deregulation for GSM. GSM was developed and implemented before large-scale liberalization in Europe, and hence the deregulation process did not play a major role for GSM. The relation was rather the reverse. GSM was actually used as a "spearhead" of the EU strategy for telecommunications deregulation in the 1990s; it was used as a tool to change the telecommunications sector in Europe.

B *The United States and Japan* In the United States, one of the responsible standardization agencies, the Cellular Telephone Industry Association (CTIA), chose a digital standard (D-AMPS) that was compatible with the existing first-generation (analog) systems. The idea was to facilitate a gradual shift between generations.[21]

Another relevant regulatory agency, the Federal Communications Commission (FCC), also decided that there would be no national digital standard for the United States as a whole, but that operators were free to adopt any standard. On this basis another digital standard also came into use, called code division multiple access (CDMA). It emerged later, but attracted more operators.[22] These two main standards were not directly compatible with each other; they were so only through the use of analog channels. This was the so-called "backward compatibility" insisted upon by the FCC (Hommen and Manninen, 2003).

Partly because of this, both the digital standards diffused relatively slowly in the United States. The United States had a mobile phone penetration rate of 20 percent in 1997, as opposed to 40–50 percent in the Nordic countries. In addition, 60 percent of these were subscriptions to the analog standard, while it was almost completely digital in Europe. The slower diffusion of digital systems in the United States was due to the presence of several standards and a weaker migration from the first generation to the second generation due to backward compatibility. In addition, the structure of tariffs on mobile services was different in

[21] This is in contrast to Europe, where the standard creators did not care about backward compatibility with a first-generation standard.

[22] CDMA was technically superior to D-AMPS, but it had limited availability of terminal equipment and was implemented differently by each operator.

Europe, and roaming and caller pay issues were resolved much earlier (Hommen and Manninen, 2003).[23]

The two main US digital standards diffused to Latin America and Asia only to a limited degree, and never became a serious international competitor to GSM. Foreign standards were used to a very small extent in the United States. Instead the most important US operators transferred to GSM. It started with AT&T Wireless in late 2001, and thereafter six additional mobile operators have decided to follow the example. Among the reasons were that GSM accounted for 60 percent of the world market even before this, and that economies of scale lead to lower prices. In addition, the transfer to 3G (W-CDMA) is being facilitated. GSM has, thereby, effectively become a world standard. The transfer has also strengthened the position of Ericsson and Nokia.

The US standard regulatory organizations seem to have wanted to secure competition between standards as well as between operators in the United States. In Europe competition took place only between operators.

In Japan the digital mobile telephone standard adopted was called personal digital cellular (PDC), and it never diffused outside Japan. It was incompatible with all other standards. The Japanese market remained closed to other (foreign) standards.

2.3.2.3 The third generation – UMTS/WLAN Unlike the NMT 900 and GSM standards, the development of the UMTS standard was not driven primarily by the need to accommodate unexpectedly rapid growth in the number of subscribers. Instead, improved functionality seems to have been the main driving force.

Although UMTS is a standard supported by ETSI (i.e. it is a European standard), it also has the official sanction of the ITU, an organization with truly worldwide coverage and authority. At the same time, ETSI actually chose NTT DoCoMo's W-CDMA technology in January1998 as the European third-generation standard (Funk, 2002, pp. 78–82 and 206–208).[24] The previous development within ETSI was pursued in very general terms, and when it came to an actual decision W-CDMA was chosen. ETSI chose W-CDMA because it believed that W-CDMA offered far greater capabilities than an enhanced version of GSM and because W-CDMA included the evolution of the GSM network interface (Funk, 2002, ch. 6). Hence UMTS can be seen as a further extension of GSM, and the two systems are intended to be compatible with one another.

[23] The tariff structure is discussed in section 2.3.4.
[24] NTT DoCoMo is the largest mobile phone operator in Japan. It is a spin-off of NTT, the former operator monopoly. NTT is still a majority equity holder in DoCoMo.

The choice of W-CDMA has been seen as a major victory for Japanese manufacturers and its two European supporters, Ericsson and Nokia. The ETSI and ITU decisions have also made W-CDMA a global standard. The "UMTS alliance" includes the European Union and some national operators, such as Japan's NTT DoCoMo. It also includes multinational telecommunications equipment manufacturing firms such as Ericsson and Nokia. The choice of W-CDMA was a blow to supporters of other standards, such as TDMS (telecommunications data management system) and cdma2000.

UMTS will be, in important respects, a significant departure from existing mobile telecommunication systems, and will constitute a "3G" system. It involves several important breaks with GSM:

1. the use of broadband, as opposed to narrow band, radio frequencies;
2. the full integration of voice and data communications;
3. the full integration of "fixed" and "mobile" telecommunications networks; and
4. the provision of "seamless" global roaming, in addition to high functionality.

However, a certain level of wireless data transmission is already possible within GSM. For example, the further development of GSM technology (and other second-generation counterparts) has proceeded for some time within a framework consistent with UMTS objectives. A case in point is the wireless application protocol, created in 1998. WAP constitutes an intermediate stage of development between existing GSM capabilities for wireless data transmission and the UMTS goal of making the "wireless Internet" a reality through an integration of fixed and mobile communications networks. WAP is HTML-compatible, since Internet material is in HTML format.[25] WAP allows a great advance in GSM wireless data transmission by enabling Internet information to be delivered on mobile devices that already support GSM-based SMS.[26] WAP was in operation by 2001 in many countries, but it had not become a success in terms of number of users by 2002.

Another "intermediate" solution – between 2G and 3G – is the general packet radio service (GPRS). It brings the IP into the GSM network and thus enables data to be sent in small packets, users to be charged for these packages as opposed to connection times, and data transmission speeds of up to 115 KB/s. GPRS also makes multimedia services possible (Funk,

[25] The HTML protocol is addressed in section 2.3.1.
[26] As mentioned before, SMS is data transmission of a "paging" character, but in both directions. Here there is a direct link between mobile phones and the fixed Internet; i.e. SMS can be sent to and from fixed computers as well as mobile phones.

2002, pp. 211–212). Many GSM operators introduced GPRS during 2001.

The first operator to put UMTS in operation was NTT DoCoMo in Japan, which initiated the service in October 2001.[27] DoCoMo was a natural first mover since the company has operated the i-mode mobile Internet system since February 1999. i-mode is, like WAP, somewhere in between second- and third-generation mobile telecommunications, and had 31 million subscribers by March 2002.[28] The fact that UMTS was first introduced in Japan might provide Japanese equipment manufacturers with an advantage over other manufacturers.

Reasons for the success of i-mode in Japan include the low usage of the fixed Internet and DoCoMo's effective strategy. The reasons why DoCoMo has the largest number of subscribers and content sites are its early release of compatible handsets, a packet service, a clearing house and its use of compact HTML. The packet service enables small packets of information to be sent inexpensively. In the clearing house, DoCoMo collects money for the content provider's fee-based services and takes a percentage (9 percent) of this as a handling charge. This organizational or managerial innovation is crucial since it makes it easy for content providers to earn money from their provision without actually being responsible for collecting the charges from the users themselves (Funk, 2002, ch. 6).

In Europe auctions for UMTS licenses were held in many countries during 2000 – and the operators in some cases agreed to pay enormous fees. This has created economic problems for some operators and will certainly be an obstacle to the diffusion of UMTS in Europe. Some people believe that short-sighted governments dreamt that they could finance the increasing costs of taking care of the growing numbers of old people by taxing the new economy agents, such as the mobile telecommunications operators, and that this may in turn hurt an important part of European hi-tech industry. In some countries – e.g. Sweden – the licenses were allocated by means of "beauty contests." The investments in 3G systems will be very large and started during 2002 and 2003 in Europe, although there are delays in the build-up of the infrastructure. The United States will also be a laggard with regard to UMTS, partly because other users, e.g. the military, tie up the relevant radio frequencies.

27 However, the system has suffered from a number of technical problems that have made many potential subscribers hesitate. Therefore, the 3G system had fewer than 55,000 subscribers in March 2002, which was well below DoCoMo's objective.

28 i-mode is a transitional system, based on narrow band frequencies and a development of the Japanese PDC standard. DoCoMo established i-mode also in the Netherlands, Germany and Belgium in early 2002.

Whether third-generation mobile telecommunications systems (including mobile Internet access) will diffuse rapidly or slowly will depend on:

- the quality and importance of the services provided (as evaluated by those who pay);
- the structure and rate of the tariffs; and
- the cost of accessing similar services in other ways.

If operators want to enhance the rapid diffusion of third-generation mobile telecommunications subscriptions they should ensure that the services are good and probably offer flat subscription rates of a limited size. In addition, cultural differences between countries may be important. So may the way everyday life is organized. For example, long commutes with public means of transportation – as in Tokyo – may contribute to the rapid diffusion of third-generation systems.

The European success in NMT and GSM will not necessarily be repeated in 3G mobile telecommunications because some of the conditions behind the success of the first and second generations no longer apply. In particular, liberalization has reduced the central role of monopolistic PTOs, so that the close interaction between them and equipment producers has been diminished. Consequently, producers may find that large domestic markets are more difficult to obtain from the start for new products.

There are also alternatives and supplements to the third generation. 3G systems will not provide users with the full range of broadband services available to fixed Internet users. 3G systems are based on rather low-speed data communications: 2 MB/s is at present the absolute maximum for UMTS, and speeds lower than 400 KB/s will be normal in the next couple of years at least. Much higher speeds will be provided by a complement to UMTS called WLAN. This began with the development of customer premises networks or wireless local area networks for professional users (firms). Recently WLANs also started to be installed in public areas. Public WLANs can cover only small geographical areas or "islands" – e.g. an office, an airport or an Internet café. In these "islands" a PC or a palmtop can be used to access the Internet at speeds of 10–50 MB/s.

Currently there are signs that WLAN will diffuse very rapidly in the near future. Already by April 2002 there were about 300 public locations covered by WLAN in Sweden (*Ny Teknik*, 2002). A 4G mobile telecommunications system may be considered as an integration of a 3G mobile telecommunications system and WLAN access to the "traditional" fixed Internet (and integrated with other wireless options such as GPRS, Bluetooth, etc.). The customer will be automatically connected to that network that has the highest capacity, and the same subscription is used for all of them. The standard now emerging as the winner within WLAN is the American Institute of Electrical and Electronic Engineers' 802.11a and b. The 802.11a operates in the 5 GHz band with a potential speed of 50 MB/s, while 802.11b operates with 10 MB/s in the 2.4 GHz band. The European ETSI standard HiperLAN 2 appears to be a loser in this standardization game.[29]

The frequencies used by WLAN are unlicensed – i.e. free – and they therefore encounter interference from other WLAN systems or from different applications. The 2.4 GHz band that is currently mainly used for WLANs is also used by – and can therefore get disturbed by – Bluetooth, microwave ovens and car parking sensors. The 5 GHz band, which is the frequency proposed for new WLAN systems, is free from interfering competitors and can allow many operators to coexist.

Currently the United States is probably most advanced in private and public WLAN installations. At the same time the third generation is delayed there since no radio spectrum has been allocated. For these reasons it is more probable that WLAN will become very important in relation to 3G here than in any other country (although WLAN can, of course, not cover large areas). In Europe 3G licenses have been awarded in most countries and will be installed fairly soon. However, operators that did not buy or get any 3G licenses may be pushing WLAN. The country most committed to 3G is Japan, where 3G is already operating and where there is very little discussion about WLAN (*Wireless Web*, 2002).

Within the mobile telecommunications sector the number of categories of actors as well as the number of actors in most categories will increase. Currently the dominant categories are suppliers of equipment and access providers (operators). The vendors of systems (base stations and switches) are not likely to be threatened, since economies of scale and barriers to entry are very large. For them the matter is to wait until the current crisis is over and the operators start investing again. On the handset side we are, however, likely to see additional producers, probably with niche strategies focusing on cheap mass-market phones or very advanced ones. This increased competition will mainly influence Nokia, Motorola, Siemens and Sony-Ericsson.

The number of access providers will increase in many markets in the near future. In Sweden, for example, two new large mobile operators planned to enter when the 3G networks start to operate during 2003 and

[29] HomeRF is yet another variant, while Bluetooth-based solutions basically operate only within 10 meters of distance and act more as substitutes for cables. See, e.g., Garber (2002); Mannings and Cosier (2001); and *Financial Times* (2002).

2004, but one of them has withdrawn. In addition those operators that own networks may start renting capacity to others – i.e. operators without networks will enter. Hence competition will increase in several ways.

A major obstacle to the breakthrough and growth of 3G is the supply of mobile Internet content. Just like the fixed Internet sector, content providers that are independent of the access providers will have to solve this problem to a large extent. We are here talking about content such as games, music, news, information, financial services, etc. Hence the division of labor between operators and independent content providers must be cleared up. How is the final customer to pay? Via the invoice from the access provider, via a bank account or via some other intermediate actor? Here there is a struggle between various interests.

An even more difficult issue to solve is how the cake should be divided between providers of access and of content. Currently the operators appropriate most of this cake, and it is probably necessary that more be handed over to content suppliers in order to create stronger incentives for the development of content for the mobile Internet! This conflict must be solved at the latest when handsets with larger displays in color (3G phones) emerge in large numbers, i.e. in 2003 and 2004. When discussing DoCoMo's i-mode it was stressed that organizational and managerial innovations are important in this field. 3G will not become successful without content that really attracts the final customers enough to make them willing to pay. And such content will not be developed if its providers cannot charge for it.

2.3.3 Satellite communications

Wireless access to the Internet and to telephone lines can also be achieved via satellite communications. A communications satellite is basically a microwave repeater revolving around the earth in a specified orbit. On earth the signals can either continue in cable or mobile systems or be transferred to private houses by means of small discs. The satellites are primarily used for TV and radio transmission. For example, the European EUTELSAT system was broadcasting 750 analog and digital TV channels and 450 radio channels by the end of 2000. However, in 1999 20 percent was used for a range of broadband services, including Internet "backbone" and access and corporate networks.

So called "set-top boxes" may facilitate high-speed Internet access in remote areas. They may also represent an alternative solution if incumbent telecommunications operators are too reluctant to make high-speed access available; and – finally – they make it easier for people without computer skills to reach the Internet through their TV screen. This obviously represents a convergence between TV broadcasting and Internet access. The potential importance of TV networks for data communication (other than TV and radio) – e.g. the Internet – is enormous (Dalum, 2003).

At the beginning of the 1990s four large consortia announced plans for mega-projects of satellite-based mobile telecommunications systems. Iridium, Globalstar and ICO are the best known. They were all built up, but in the first half of 1999 Iridium and ICO went bankrupt and the Globalstar plans were significantly adjusted. Operations were geographically focused on areas where there were no terrestrial mobile communications systems available, which decreased the number of customers as well as their purchasing power.

A significant underestimation of the success and vigorous growth of cellular mobile telecommunications caused the commercial failure of these enterprises to a large extent. At the beginning of the new millennium the huge ambitions of the global mobile satellite-based systems for voice and data transmission had to be drastically scaled down (Dalum, 2003).

With widespread 3G mobile communications – or WLANs – within reach in the next five to ten years, the satellite-based mobile phone systems will have the role of complementary systems in areas with weak coverage by terrestrial mobile communications networks. They will also play a role in maritime communications, and perhaps also for systems intended to be used by the airline industry.

2.3.4 *Rate structures and levels*

The structure and level of rates and tariffs may also be considered to be "rules of the game" – i.e. a form of institution. In this case, it is an institution created, to a large extent, by firms (i.e. at the micro-level), although the firms are also influenced by other institutions – e.g. regulations. The quality and value of a telecommunications or Internet service as perceived by the user influence the rate of diffusion of the service. The cost of the service also, obviously, influences the diffusion. This implies that the comparative prices of the different modes of accessing certain services are important. So are, of course, the comparative prices of the content provided over the networks.

In GSM there was agreement that calling charges were to be billed to the caller. However, when calls were placed to a mobile handset located in another country at the time of calling, the caller was charged the local rates and the cost for forwarding the call outside the home country was paid by the receiver.[30]

[30] This decision was taken because the caller would otherwise not know the cost of calling.

In the United States, however, the receiver has traditionally been charged. If a call is placed from a fixed telephone line to a mobile phone, only the receiver is charged (if the receiving handset is located in the vicinity). This is because there is normally no variable cost for local phone calls from fixed lines in the United States, but only a fixed subscription fee. For long-distance calls there is also a variable cost. If the receiver is located outside the local area, then both the caller and the receiver pay. If a call is placed between two mobile phones, both also pay a variable fee.

This posed an obstacle to the diffusion of mobile telecommunications in the United States as compared to Europe. It constituted a disincentive to subscribe to mobile services. It also created an incentive for users to switch off the handsets – which led to non-availability. There was also a disincentive to give out mobile numbers because of this.

The importance of the level of charges (related to the quality and value of the service provided as well as to the cost of the alternatives for getting access to the same or a similar service) can also be illustrated by the fact that mobile subscriptions diffused rapidly in Sweden (in comparison, with the United Kingdom), due to the low tariffs already in place during the analog era (see section 2.3.2.1).

The introduction of the prepaid card was also instrumental in increasing the diffusion in those countries where it became available. In Sweden these cards were first introduced in 1997 by Comviq – one of the three operators (now called Tele 2). The prepaid cards are, for example, used by people that are not able to subscribe, such as young people and those who are not creditworthy for other reasons.

The structure and level of costs for access to the fixed Internet also vary between countries and continents. In the United States only a flat rate is normally charged, which makes possible unlimited Internet access. Local dial-up is not metered.[31] In the United Kingdom, and also in Italy, Internet access has been provided to a large extent free of charge, although this phenomenon might be gradually disappearing in the near future. In Sweden most consumer Internet access has been mediated by a modem and a variable cost has been paid (in addition to the subscription fee). However, the US pricing structure is currently becoming increasingly common in Sweden. In Japan the cost structure is similar to that in Sweden – i.e. both a fixed and a variable cost are charged.

The rate structure is probably part of the explanation of the high penetration of Internet access in the United States – and the low ratio in Japan.

[31] Other OECD countries with unmetered local telecommunications services are Australia, Canada and New Zealand. In all these countries, and in the United States, there is a high penetration of Internet hosts (Mowery, 2001, p. 37).

However, the rapid diffusion in Sweden certainly cannot be explained by rates. Neither is the slow Internet penetration rate in Italy a consequence of the pricing structure, but, rather, of a lack of familiarity with ICT applications, of the inertia of Italian consumers and of the limited knowledge of English.

The low diffusion of the fixed Internet in Japan – together with the low density of home PCs – may, in turn, partly explain the rapid diffusion of the i-mode mobile Internet operated by NTT DoCoMo. Further, this may be a reason why DoCoMo was the first operator to install a full-scale third-generation mobile telephone system, in October 2001 – as discussed in section 2.3.2.3.

2.4 *Boundaries between systems and convergence between subsystems*

What is the sectoral system of innovation in the telecommunications field? Is there one sectoral system or are there several systems?

The telecommunications sector – in a wide sense – is growing rapidly and there is convergence between various parts or subsystems. It is possible to talk about convergence in several senses and respects.

First, we saw a convergence between IT and communication technologies into ICT, which occurred in the 1980s. There was also a convergence between ICT and the broadcasting/audio-visual technologies in the 1990s. This constituted the starting point of the so-called multimedia revolution.

The transfer to digitized mobile telecommunications systems in the 1990s implied a convergence of formerly separate technologies. The technological base had broadened to include innovations from outside the traditional telecommunications sector, mainly from computer and software firms. This actually meant that telecommunications equipment producers in essence became IT and software firms, although with a specialization toward telecommunications. It also meant that traditional telecommunications firms had to confront new entrants with a competency that had originated in other sectors. In addition, standard-setting organizations became important. There has also been considerable growth of publicly funded research in telecommunications in Europe during this past decade.

In the 1990s we also experienced a convergence between traditional telecommunications and the Internet. The emergence of the Internet meant that another subsystem entered the telecommunications sector. This also implied that new functions became important, and new kinds of organizations entered the sector – e.g. new IAPs (such as telecommunications operators and cable TV operators), ICPs (such as e-commerce companies) and software and Internet specialized consulting companies.

Further, we will see a convergence between the fixed Internet and mobile telecommunications in the near future with the emergence of third-generation mobile telecommunications. This kind of convergence has already started with SMS, WAP and GPRS (and with UMTS in Japan). What WLANs will mean in terms of convergence is still unclear.

We have also seen a convergence process with regard to receiving devices or customer premises equipment. For example, third-generation cellular phones offer Internet connection and narrow band services. Similarly, desktop computers can be used to make telephone calls or to watch a video, and set-top boxes are also starting to become an alternative device for Internet access. Organizers of the "palm pilot" kind may also be used for Internet access. There are also combinations of these devices. In 1994 Nokia introduced one of the first data interface products – a "PC" card that could be inserted into a portable computer connected to a mobile handset by means of a cable.

All this has meant that the knowledge base for the telecommunications sectoral system (in a wide sense) has become increasingly complex. Convergence also means that boundaries are changing and that sectoral systems may be moving targets, becoming larger and more complex. However, boundaries may also change in the opposite direction and sectoral systems may become more specialized and more isolated from other systems and subsystems because of increasing specialization, and they may become smaller. Therefore, both convergence and divergence might occur.

There is a certain degree of arbitrariness when it comes to the specification of sectoral boundaries. Therefore, we can consider data communications to be one sectoral system, and mobile telecommunications to be another. However, we could also see both of them as belonging to one combined system (particularly if they are converging). It is partly a matter of choice and convenience. Some minimum degree of coherence is nevertheless required to make it useful to talk about a sectoral system. We would not regard paper pulp and telecommunications to be the same sectoral system of innovation.

Here, we take a very pragmatic view of whether we are talking about one SSI or about several within telecommunications in a wide sense. Sometimes it may be useful to regard the whole field as one system. At other times it might be more fruitful to consider the Internet and mobile telecommunications to be separate SSIs. It depends on the context – e.g. on the purpose of the study to be carried out. In addition, equipment production, network operation (access provision) and content provision can be regarded as separate systems or as one common system.

However, *when* an empirical study is to be carried out it is absolutely necessary to identify the boundaries of the sectoral system that is to be scrutinized. The boundaries have to be specified in a sectoral as well as in a functional sense (and in a geographical sense, if the system is not global).

The functional boundaries of SIs are identifiable with the determinants of the relevant innovation processes. If we can identify the determinants of different kinds of innovations in the fixed Internet and mobile telecommunications, then we can say that these determinants constitute the functional boundaries of the relevant SSI. However, we do not know these determinants in detail, given the present state of the art.

3 Policies and strategies

Specific policy implications for the Internet and mobile telecommunications are discussed in this section. They are mainly based upon the analysis in section 2.

Institutional rules may be created, redesigned or abolished. Those institutions that can be influenced by public agencies are public policy instruments. Similarly, those institutions that are influenced by firms are firm strategy instruments. Further, organizations may be phased out, redesigned or created. If policy makers do this, these changes are also policy instruments. If firm managers do it, they are firm strategy instruments.

3.1 The fixed Internet

Although several of the important inventions that served as bases for the development of the Internet did not emerge in the United States – e.g. HTML and HTTP – it was there that the Internet developed commercially *first and most rapidly*. The Internet was commercialized and diffused on a large scale in the United States before anywhere else.

The US *state* was extremely important in the *very early stages* of the development of fixed data communications – i.e. in the period when the SSI of fixed data communication was fragile and not well established. Government agencies were very important as financiers of research developing fixed data communications; they initiated the public technology procurement of elements of the system. Other agencies required that organizations receiving public economic support had to use a certain data communications protocol. The state also injected increased dynamism into the telecommunications sector by pursuing deregulation.

State agencies were not strong leaders, however, in the creation of standards for the Internet in the United States. This was, instead, a rather spontaneous process where private firms had a large influence. The idea of "open standards" or the "compatibility of standards" appears to have been the characteristic US strategy.

The *relations* among various organizations were crucial for the development of innovations in the SSI. These included the relations between public and private organizations – as in public research funding and in public technology procurement. Relations among different private organizations were also important, both in terms of competition and in terms of collaboration.

The fact that the early development and diffusion of the Internet took place in the United States – with government support – gave a "head start" to US Internet equipment producers. This is an important explanatory factor behind the fact that US Internet equipment producing firms, such as Cisco, are still very dominant globally. It is obviously very important for firm competitiveness in high-tech areas to be *early movers* in the sector and to be close to customers in these early stages.

3.2 Mobile telecommunications

State-controlled organizations were very important in creating the first successful mobile telecommunications *standard* in Europe. Public telecommunications monopolies in the Nordic countries created the NMT 450 mobile telecommunications standard in collaboration with firms. The PTOs pushed the technical development of the standard and pulled national equipment producers along their trajectory. They placed orders to firms and partly used the instrument of public technology procurement to create incentives for firms to develop equipment for NMT 450. NMT 450 provided the cradle for the development of mobile telecommunications in Europe. *Deregulation* of the telecommunications sector was also important in some European countries, such as Sweden and the United Kingdom. However, liberalization was not a key factor in Sweden's success with NMT and GSM. At most it aided the diffusion process that was already under way at the time of deregulation (1993).

Relations among organizations were obviously important in this process. So were the relations between various kinds of institutions – such as NMT 450 – and the firms and other organizations involved. The relations between the operators – the main standard creators – and equipment producers were very important for the fact that European equipment producers became leaders at the global level. For firms such as Nokia and Ericsson it was also important that mobile telecommunications got a "head start" in the Nordic countries, and that they grew rapidly.

Most second-generation standards were developed with the potential to become de facto world standards through international adoption. The

European GSM standard – which developed out of the NMT standard – more than fulfilled the expectation of wide international diffusion. Initially conceived as a pan-European standard, it became a world standard. No other second-generation standard achieved this. Deregulated operators (such as Swedish Televerket/Telia) as well as firms (such as Ericsson and Nokia) were very active in the consortium that supported the development of the GSM standard. Hence, the close relations between users and producers continued. Over the longer term, however, these close relations gradually became more and more loose. The GSM success could not be ascribed only to the strategies of a few innovative organizations but also to the *collaborations* between a variety of different organizations: PTOs, standard-setting organizations and research organizations, as well as equipment producers.

The European Commission also had a leading role in the development of GSM. The European Union was pushing *one* standard and it was developed *ex ante*. This was also a standard that was technologically advanced and operated well, and – therefore – it diffused rapidly outside Europe. In contrast, the US digital standards diffused internationally only to a limited extent, and the single Japanese standard not at all. The European Commission pushed liberalization and competition in the (mobile) telecommunications sector.[32] But it did so within one single standard and did not care about letting standards compete – as in the US standards policy. The standard pushed by the European Union was secured to serve all EU members, while the US digital standards were not completely compatible with each other. What the European Union did over (originally) thirteen European countries the United States did not manage to do over one country (albeit large).

It proved to be a major policy mistake to have several standards in the United States. This can be considered a serious policy failure for the United States as well as a great policy success for the European Union. The reasons for this are that it led to a slower diffusion of mobile telecommunications in the United States than in Europe, and that the strongest equipment producers emerged in Europe.

The US policy was conscious and consistent. The FCC was against *ex ante* standardization – which was preferred by ETSI – and advocated an open network architecture.[33] The arguments were that the open architecture was very important for the creation of the Internet and that closing it could block further innovation. The FCC was passive in relation to the

[32] In 1996 the Commission decided that mobile services had to be competitive, with multiple GSM licenses in each member state.
[33] The FCC preferred market- and user-driven *ex post* standards.

European invitation to participate in *ex ante* standardization in wireless services. The FCC also later blocked the route toward 3G convergence in the form of W-CDMA as a global standard (supported by ETSI). This all happened in the latter half of the 1990s. One interpretation of this is that the FCC was tied by the fact that US participants in the 3G race represented different technological alternatives, and therefore the FCC remained "neutral" in the standardization process. At the same time there is a trend that "the regulation of the new information infrastructure has gravitated toward a clearer recognition of market-driven standards. As the world of mobile telecommunications and computer communication (the Internet) collide, the clear trend is for direct regulation to withdraw from the market" (Glimstedt, 2001, p. 22).

Firms such as Ericsson and Nokia are also moving away from their original idea of a single standard for the 3G services and toward the position that the new mobile telecommunications services should be based on several different but compatible standards – a "family of standards." This is similar to the idea of open architecture in relation to the Internet. This idea is that "network architecture should be as open as possible, allowing user-led innovation and new combinations of radical technologies" (Glimstedt, 2001, p. 22). At the same time, however, we saw that the most important US mobile telecommunications access providers have, during the first years of the new millennium, transferred to GSM. If a reason for this is that the transfer to W-CDMA will be facilitated, then *ex ante* standardization seems to be winning the game anyway. This may be because market sizes and economies of scale created by *ex ante* standardization lead actors into the dominant trajectory in the evolutionary process of standard creation.[34]

The promotion of one single standard was of great importance for the European dominance in the production of equipment for the mobile telecommunications industry; for example, economies of scale could be exploited. The fact that the relations between users and producers were close also proved very important, primarily for the producers. The way GSM developed increased the leadership position of Nokia and Ericsson. This is all the more notable in the light of the lack of European success – and US/Asian dominance – in most other ICT sectors. The mobile telecommunications market was growing rapidly and was a major job creator in Europe.

Europe has emerged as a clear leader in mobile telecommunications due to its success in defining good standards in mobile communications.

[34] In this chapter it is argued that there has been an evolutionary process from NMT 450 through GSM to W-CDMA.

Ericsson's and Nokia's dominance among equipment producers in mobile telecommunications is often traced to the early success of the NMT standard, and GSM is similarly regarded as the means by which early Nordic success was generalized to other European Union countries in the second generation of mobile communications.

One reason for the relatively poor international performance of US-based 2G mobile standards was the "division" of the market between standards, none of which could match the subscriber base of GSM. These developments are considered to account for the subsequent loss of market share by US equipment manufacturers to European rivals during the second generation of mobile telecommunications. The slower transfer from first- to second-generation standards in the United States was due to regulatory decisions that stressed the necessity of achieving "backward compatibility" with the existing analog standards, rather than compatible digital standards. Decisions with regard to charges were another factor contributing to the low subscriber penetration rates; often the receiver has to pay for all or part of a mobile phone call.

The crisis at Ericsson during 2001–03 – as well as with much of the mobile telecommunications equipment industry – is mainly caused by a drastic decrease in demand because of the slowdown in the international business cycle (and thereby in telecommunications system investments) as well as the slow development of 3G. It serves to conceal the fact that Ericsson is still dominant in base stations and switches, while Nokia strongly dominates global handset production.

In the 1990s we experienced a convergence between traditional telecommunications, the Internet and mobile telecommunications. This was also accompanied by a wave of mergers and acquisitions (and strategic alliances), both among equipment producers and among operators. A strategic decision for the equipment producers is whether they should select voice as their main business area and thus go for the growing mobile phone markets; whether they should concentrate on the rapidly growing Internet equipment market; or whether they should go for the mobile Internet.

3.3 *The future of the sectoral system and relations between Europe, the United States and Japan*

It is clear that Europe has, so far, had the initiative in mobile voice telephony. Whether this will continue during the third-generation UMTS standard is unclear. NTT DoCoMo's i-mode had 31 million subscribers in 2002, and DoCoMo was also the first operator to enter 3G in October 2001. This means that the locus of the center of experimentation may have moved from Europe to Japan. This can spur equipment producers

since user/producer interaction had proved to be important earlier. In the United States some operators have transferred to GSM, and they will be more standardized in 3G than they were in 2G. However, the United States is a slow starter in third-generation mobile telecommunications. Although Europe will probably enter 3G earlier than the United States, it is doing so at a slower pace than Japan. This might partly be because of the very high prices European operators had to pay in some countries for a 3G license – i.e. it might partly be a consequence of public policy.

Currently 3G is developing quite slowly. However, telecommunications operators' revenue was growing by 10 percent per year in 2001 and the immediately preceding years. This indicates that telecommunications operators were not subject to a structural crisis but were hit by the downturn of the business cycle during 2000 and 2001 – which is expected to take off again in 2004.

The most important obstacles to the diffusion of 3G are – in the short run – the availability of handsets and – in the longer run – the supply of attractive content suited to the mobile Internet. This points to the crucial role of demand in the emergence of new sectoral systems. As far as equipment is concerned, the demand-side policy instrument of public technology procurement was used both with regard to the Internet (the United States) and with regard to mobile telecommunications (Scandinavia). When it comes to content in the 3G mobile Internet, most of the demand has to be provided by final consumers – firms and individuals – outside the public sphere, to the largest extent. The success of i-mode in Japan seems to indicate that this will happen,[35] but access providers and content providers will have to be innovative not only with regard to access and content proper but also when it comes to charging systems and other innovations in the field of management and administration. It is also a matter of developing niche strategies adapted to the new medium: movies will never best be watched on a mobile phone!

Fixed Internet diffusion is proceeding. In 2002 about 70 percent of households had access in the United States. In other countries the degree of diffusion varies a lot. The dominance of US equipment producers, which was established early in the history of the fixed Internet, is likely to remain stable, at least in the medium term. At the same time, this sector may be entering a more mature stage of development, with slower growth and smaller profits.

If WLAN becomes a serious competitor or an alternative to third-generation mobile telecommunications – i.e. if the development jumps the 3G "step" and goes directly into 4G – this will probably benefit the United

[35] But the slow diffusion of WAP and GPRS in Europe and the United States points in the opposite direction.

States. The reasons for this are that 3G will not be implemented there in the near future, there are already a fair amount of WLAN installations, and because the United States is very strong in PCs and palmtops. There seems to be a possibility of leapfrogging here.

3.4 The three most important policy issues

Here follows a summary of the three most important policy issues with regard to the fixed Internet and mobile telecommunications. They are presented in abbreviated form, and in no particular order.

The role of institutions has been crucial for policy. Standards have played a major role in innovation and the success of European mobile telecommunications, both in terms of the diffusion of use and with regard to the success of equipment producing companies. Deregulation has also played a role in the diffusion of the Internet and mobile telecommunications. Other important institutions are the structure and level of tariffs. Some institutions are national, some are sectoral and others are firm-specific. An important firm strategy objective has been to influence institutions to the firm's benefit.

The relations between different organizations and between institutions and organizations are crucial for the functioning and performance of (sectoral) systems of innovation. Examples are the relations between private and public organizations in the form of research funding, standard setting or public technology procurement. Relations between different kinds of firms and other private organizations are also important – e.g. collaboration between users and producers. Organizations provoke institutional changes, and when the new institutions come into effect they may greatly influence the same or other organizations.

It is of crucial importance that public policy intervention occurs early in the development of the sectoral system. Public technology procurement was crucial for the very early development of the Internet in the United States and the formulation of standards was crucial for the very early development of mobile telecommunications in the Nordic countries. This proved to be very important also for equipment producers in these fields. It is in the very early stages in the development of an SSI that the uncertainty and risks are greatest, and private actors and markets therefore operate least efficiently and dynamically.[36] Therefore policy intervention in these very early stages often means the difference between success and failure.

[36] That public policy intervention in the field of innovation should be practiced only in situations where private firms and markets fail to achieve the wanted results spontaneously is argued in Edquist (2002, 2001a). This means that public policy action should not replace or duplicate markets and private actors.

Hence policy resources – which are always scarce – should mainly be allocated to the very early stages of the development of new SSIs or new product areas.

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6 The European software sectoral system of innovation

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1 Introduction

The global software industry is young, large and very dynamic (Mowery, 1996). Markets for software as a commodity independent of computer systems have been established for little more than three decades, while a vast amount of software continues to be produced by firms to meet their own specialized information processing requirements. Revenues from software sales to European companies and individuals amounted to approximately €47.9 billion in 2000 and are expected to continue to grow at double-digit percentage rates in the near future (European Information Technology Observatory [EITO], 2001). At least 2 million European workers (1.35 percent of the European Union labor force) are directly engaged in the production of software as part of their direct job responsibilities.[2]

Software is the collection of instructions that computers follow in executing the tasks of acquiring, storing and processing data and exchanging them with their human operators, as well as the guides and reference information that humans need to specify what can be, should be or is done in these processes. Like food, software can be pre-packaged, constructed from ingredients or served where it is consumed. When it is pre-packaged it is reasonable to think of it as a product, and when it is produced "to order" it may be thought of as a service. The nature of the market for software creation and exchange activities, and the technologies supporting these activities, are shaped by three fundamental issues: the nature of software as an economic commodity; the historical patterns of the division of labor involved in software creation; and distinctions in the design and use of software that define the nature of software markets.

[1] This chapter summarizes the key findings and policy implications of research conducted by SPRU and the WZB on the European software sectoral system of innovation. The research underlying this chapter was conducted by Luciana D'Adderio, Mark Lehrer and the author.
[2] See below for the derivation of this estimate.