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10

Vladislav V. Fomin

The Process of Standard Making

The Case of Cellular Mobile Telephony

UNIVERSITY OF JYVÄSKYLÄ

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UNIVERSITY OF JYVÄSKYLÄ

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ABSTRACT

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This thesis studies the evolution of standardization processes in connection with the development of mobile telephony from 1946 until the present day. It seeks to understand the pattern of such processes within the cellular mobile industry, and on a more general level provides insights into standardization processes within complex infrastructural information technologies and changes in the institutional regulation of technology.

The study examines the history and evolution of cellular technology and changes in its standardization processes and practices, using case studies, a literature review, and archival research. The history of the technological development of cellular phones, and the marketing and strategy policies of the main players are embraced. The standardization processes and the necessary technological development are analyzed through the prism of actor-network theory.

The specific objectives of the study are 1) to provide a comprehensive and systematic study of the history and evolution of the NMT and GSM standards, 2) to outline the development and transformation of the telecommunications industry, and the societal impacts this transformation imposes, 3) to reveal the factors for either success or failure of different cellular technologies (standards) and, 4) to develop a model of the standard making process.

This study is a result of two longitudinal case studies of standardization initiatives in the field of cellular mobile telephony. The methodology is motivated by a concern with both for process descriptions and theory building. The focus is on highly complex processes that take several years to unfold.

The findings offer insights into the evolution of cellular technologies and their standardization strategies and practices. Two most important contributions are those that 1) actor-network theory is found to be an appropriate tool for studying standards as socio-technical processes and addressing technology as an intangible artifact and, 2) the study suggests a model of standard making process which can be generalized and thus applied to the analysis of other complex infrastructural technologies.

Keywords: standardization, cellular mobile telephony, standard, actor-network theory, model

ACM Computing Review Categories

K.1	Computing Milieux: The computer industry: *Markets*, *Standards*
K.2	Computing Milieux: History of computing: *Hardware, People*, *Software*, *Systems*, *Theory*
K.4.1	Computing Milieux: Computers and society: Public Policy Issues: *Intellectual property rights, Regulation*
K.4.2	Computing Milieux: Computers and society: Social Issues
K.4.3	Computing Milieux: Computers and society: Organizational Impacts
K.6.0	Computing Milieux: Management of computing and information systems: General: *Economics*
K.6.1	Computing Milieux: Management of computing and information systems: Project and People Management: *Life cycle*, *Systems analysis and design*, *Management techniques*

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Jyväskylä, Finland.
August 2001

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1 The author was a member of a research project STAMINA (March 1997 to March 2001) funded by the Academy of Finland. For more information see http://www.cc.jyu.fi/~wlad/stamina.

To Him who makes all things possible

“Come, let us build ourselves a city, with a tower that reaches to the heavens, so that we may make a name for ourselves and not be scattered over the face of the whole earth” (Gen.11:4)[2].

2 Illustration by Laima Degutyte-Fomins

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LIST OF ORIGINAL ARTICLES

I Fomin, V. V., & Lyytinen, K. (2000). How to distribute a cake before cutting it into pieces: Alice in Wonderland or radio engineers' gang in the Nordic Countries? In K. Jakobs (Ed.), Information Technology Standards and Standardization: A Global Perspective. Hershey: Idea Group Publishing. pp. 222-239.

II West, J., & Fomin, V. V. (2001, Agust 5-6). When government inherently matters: National innovation systems in the mobile telephony industry, 1946-2000. Paper presented at the Academy of Management Conference, Washington, DC.

III Fomin, V. V. (2000, June 2-3). Equilibrium and Transformation in Standards Making Process. In the proceedings of the The Pacific Asia Conference on Information Systems (PACIS2000), Hong Kong. pp. 600-614

IV Fomin, V. V., & Keil, T. (2000, December 10-13). Standardization: Bridging the Gap Between Economic and Social Theory. In the proceedings of the The Twenty First International Conference on Information Systems (ICIS 2000), Brisbane, Australia. pp. 206-217

V Fomin, V. V., Keil, T., & Lyytinen, K. J. (2001). Standardization: towards integrating fragmented theory. Manuscript, Jyväskylä.

OVERVIEW AND SUMMARY

1 INTRODUCTION

> Now the whole earth had one language and few words. And as men migrated from the east, they found a plain in the land of Shinar and settled there. And they said to one another, "Come, let us make bricks and burn them thoroughly." …Then they said, "Come, let us build ourselves a city, and a tower with its top in the heavens, and let us make a name for ourselves, lest we be scattered abroad upon the face of the whole earth." And the Lord came down to see the city and the tower, which the sons of men had built. And the Lord said, "Behold, they are one people, and they have all one language; and this is only the beginning of what they will do; and nothing that they propose to do will now be impossible for them. Come, let us go down, and there confuse their language, that they may not understand one another's speech". (Gen.11:1-7.)

The biblical story of the Tower of Babel emphasized the importance of communication in everyday life and still has relevance in today's high-tech world[3]. When people are building contemporary Towers of Babel, for example, such as a Global Information Infrastructure (GII), they come with different objectives and pursue different goals. Even though they speak one language (or use translators to understand each other), very often *confusion* still arises. Therefore initially, a common sense of the discussion must be reached, a language *standardized* to the given context, images and concerns of one world must be translated to that of another (Star 1991). In the same way, Information Communication Technology (ICT) makes interpersonal communication between people possible, despite the fact that the "Lord scattered them abroad from there over the face of all the earth" (Gen.11:8). Should two *scattered over the face of the earth* agents wish to talk to each other, it is not enough that they must speak one language. In the first place, ICT must be deployed and a communication channel must be established between them. A communication channel is established when remote terminals are utilized by agents to "talk" to

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[3] Babel sounds like the Hebrew for confused.

each other in one language (protocols, signaling, coding, etc.), which in the IT domain is often referred to as a "standard"[4].

The use of ICT has transformed our understanding of time, space, and social organization (Edwards in press; Monteiro 1998), and necessitated us to rethink the traditional approaches which divide the phenomena of ICT into technical (development) and social (uses) spheres (Ciborra 1998). One way to grasp this phenomena as a whole is through learning more about the practical uses of technology in organizations and society (Ciborra 1998), and through the deployment of methodologies which allow for the non-separation of science from nature (technology from the social) (Ciborra 1998; Latour 1999; Monteiro 1998). "We need to go back to the world of practice to find the foundations of a new style of information systems teaching and research" (Ciborra 1998, p.5). In the light of the aforesaid, the aim of this research study is to develop *a model of the standard making process*, an intricate process where the technical and social, the natural and scientific are interwoven (as practice reveals), in order to extend our understanding of how complex infrastructural technologies come into being.

In this study the role of *socio-economic networks* in the *making of standards* and the role of *standards* in the diffusion of technology is examined. Standards are viewed as a means of aligning the interests of diverse social groups: government institutions (regulation, policy making), commercial/scientific institutions (technology development, production), and consumers. An alignment of interests is understood as a (successful) process "in which sets of relations between projects, interests, goals, and naturally occurring entities – objects which might otherwise be quite separate from one another – are proposed and brought into being" (Callon and Law 1989, pp.58-59).

The study further depicts the process of the standardization of mobile telephony in the Nordic Countries, and Europe. It will reveal that the alignment of interests of different social groups was needed, and crucial in the success of the technological innovation. The study will look at the dynamics of the socio-technical networks involved, and their increased dependency and size throughout the diffusion process. The different centers of alignment and power dependencies, which were crucial in the making of the cellular telephony standards for the Nordic Mobile Telephone (NMT) system and the Global System for Mobile communications (GSM) are identified and analyzed.

In the research, standardization is first viewed as a process of knowledge development and modification, stretching initially from R&D labs and governmental institutions to the wider market. As will be seen, several important processes took place within this knowledge creation community, which will be examined from the beginning of the development of the NMT standard.

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[4] Indeed, several standards may be needed for establishing a communication channel (what ever the media) between two remote terminals: one standard for coding, one for signaling, etc. According to Mähönen (2000), developing a single multimedia capable mobile terminal may require consulting 20 to 120 different standards.

Finally, the research focuses on the development and spread of mobile communications through the prism of actor-network theory and the diffusion of technology. The work develops a systematic and comprehensive account of those processes, and represents a description and systematization of the standardization processes in the IT domain based on two case studies: the development of the NMT and GSM cellular telephony standards.

2 MOTIVATION BEHIND THE STUDY

> This is the first time that this part of the world has had a lead in something that truly matters to the rest of the world. If we made the fastest paper machine in the world it was interesting, but no one really cared in Manhattan, Los Angeles or Tokyo.
>
> (Kai Karttunen, Evli Corporate Finance, Helsinki, Finland. In (Brown-Humes 2000))

2.1 Changing lifestyles

Have you ever taken a train from Helsinki, the capital of Finland towards the city of Jyväskylä situated 270 km to the north? The journey would normally take four hours. You take your seat, make yourself comfortable, relax, and perhaps think of taking a nap. However, even before the train has departed, you'll probably hear a cacophony of ringing cellular phones throughout the carriage. If you are a foreigner in Finland, and traveling there for the first time by train, you might get the impression that by accident you have found yourself in a special businesspersons carriage, in which the latter are busy arranging their affairs whilst away from the office. These suspicions may subside, when you notice that few people are talking in a low voice or trying to keep their conversations private. If you knew Finnish (most foreigners wouldn't) you'd learn that a young man three rows in front is making a date with his girlfriend, a lady a few rows behind is telling her husband what time he should expect her home, whilst another owner of a "handy"[5] tells her friend that she managed to catch the train on time. As this first wave of surprise passes, a secondary phenomenon may become apparent. You may notice that the owners of the mobile phones don't engage in prolonged conversations, but that nevertheless the mobile devices may still irritate you with their constant ringing, or their

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[5] One of the many names for a cellular phone.

signaling in Morse code "connecting people", whereupon the owner of the phone will pick it up, push several buttons, change her facial expression and push more buttons before putting the phone back where it was. These may have been calendar alarms or built-in games, but most likely these travelers were receiving and sending short messages (SMS[6]) using their mobile phones.

If all this is new to you, perhaps you haven't been following the headlines in the "Technology" sections of popular magazines and newspapers such as Business Week and the Financial Times. What all these stories have in common is that they describe how quickly the mobile phone in Europe, and particularly in the Nordic Countries has transformed peoples' lifestyles. People use cellular phones to pay bills, read the news, trace stock market prices, and even to buy a bottle of coca-cola from a vending machine. One story relates how a Finn didn't visit his bank a single time during the time he constructed his house, paying the hundreds of bills for purchases and from subcontractors by an Internet (read WWW) banking system from his home PC. Would it have been the present day, he could have well used his WAP[7]-enabled mobile phone instead of a PC. The journal, Scientific American, devoted a special issue to narrating the wonders of the cellular world. Fiona Harvey (2000) wrote: "imagine it's the year 2005, and you're in New York City on a business trip." The fiction that followed is an exciting adventure of a couple, whose date is mediated by uses of cellular devices. However, all the "hot & crazy" things that the actors of the story do in NYC in 2005 are already possible in the Nordic countries today.

The reader may say "well, business people can afford to have the newest time-saving technology at hand". My reply would be "Lets look at what is taking place in Finnish schools". While entering a classroom, the teacher collects cellphones from her pupils. She does not want to be disturbed by phones ringing during the class. Neither does she want pupils cheating by having the answers received as a short message on their phones. Some schools are reported to have even installed cellphone detectors at the school entrance. This is simply because virtually everyone from the age of 11 upwards owns a cellphone. One explanation for this phenomenon is that parents want to be able to know where their kids are at any given moment, and an easy way to do so is to give them a mobile phone. Their children will then use weekly pocket money to pay for the phone calls made and, in larger volumes, the short messages sent.

Receiving either a call or a message over the GSM cellular system in Europe is free of charge. Following the popularity of ICQ[8], GSM operators offer

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6 The Short Message System in the GSM standard allows the user to send up to 160 alphanumeric characters from one cellular phone to another. Some advanced models of cellular phones allow for the sending of up to 2000 characters at once, such as the Nokia 9110i.

7 Wireless Application Protocol – Internet protocol to enable Internet access from portable devices such as a cellular phone.

8 Popular online messaging system for Internet users. Based on the idea of IRC – Internet Relay Chat, a program originally developed for Unix users and later due to its popularity cloned to other operating systems. It is interesting to note, that IRC was developed in Finland and later witnessed world wide popularity. By the time when this thesis was being finalized, ICQ started to offer its users messaging to and from GSM phones (ICQ ver. 2000b).

their subscribers SMS-based chat rooms. Subscribe to a chat "channel" by sending a short message, and you'll receive messages from whoever subscribes to the same channel. Operators advertise this service by giving examples of "sensible" and "non-sense" conversations – it does not matter what you type in, just keep on sending. We could give tens of more examples of the uses of cellular phones, whether from strictly business applications to "non-sense" chats by teenagers. There is no doubt that the lifestyle of the European has changed since the introduction of the Global System for Mobile communications, or simply GSM.

2.2 The rising world of cellular

In April 1998 "Business Week" published an article by Elstrom, Reinhardt, Jackson, and Yang (1998) called "Telecom's New Trailblazers". The article described how incumbent operators are loosing business to start-up operators in the telecommunication business. The reason for the giant telcos to be worried about losing billions of dollars is twofold. First, using the traditional circuit switched networks, which incumbents run, it is difficult to meet the growing demand for voice calls (8% annually), due to the architectural and physical limitations of the telephone network. Second, the start-up operators offer voice telephony at lower tariffs due to the utilization of computer technologies, which convert the traditional voice conversation into a stream of data packets. These networks, called switched packet networks, allow for much higher efficiency and reduce traffic load, and as a result permit lower tariffs[9]. Moreover, as BW stresses, these lower prices "will seem insignificant compared with what's ahead" (Elstrom et al. 1998).

The utilization of packet switched networks means instant access to the huge infrastructure of the Internet, free data transfer, lower equipment prices, and "a whole new world of computer-industry inventors" (ibid.). Converged networks carry video, voice and data at high speeds and seamlessly swap information around the Net. AT&T's executive vice president called this coming trend "the paradigm switch" (Elstrom et al. 1998). Even in 1998, the authors of the article could not have known that the US, Europe and Japan were preparing for the coming of a new world wide cellular technology, 3G[10], which

9 BusinessWeek (BW) compares a telephone conversation over the traditional circuit switched network with that over a packet switched network. In the former case, in order to establish a telephone conversation, an entire telephone circuit is dedicated to a phone call between point A and point B. "This is like a driver reserving the whole lane of a highway for a trip from New York to Boston" BW writes. In the case of packet switched network, the sound of voice is broken into packets, which results in much higher efficiency, because at the same time the network can carry many packets – pieces of many simultaneous conversations, data- and fax calls. "It's similar to many cars traveling in the same lane between New York and Chicago". See Section 3.6 for a description of circuit switched and packet switched networks.

10 Third Generation Cellular Mobile Telephony. Also known as the Universal Mobile Telephone System (UMTS), Future Public Land Mobile Telephone System (FPLMTS), and IMT-2000 (International Mobile Telephony). The 1st generation cellular systems, e.g. NMT

will bring to customers access to converged networks: voice, high speed data, and video simultaneously.

The introduction of 3G cellular telephony in October 2001 in Japan and (presumably) 2003 in Europe will be a real challenge to wireline operators, providing vast resources of converged networks and high data transfer rates (up to 2 Mbits/s, compared to the 56 kbits/s or 128 kbits/s that users of traditional telephone lines or ISDN[11] lines respectively would normally have) to subscribers of the 3G network at affordable rates. Why would you need a fixed line telephone, if all the services offered by wireline operators were provided by a cellular telephone, but at a higher speed and with greater mobility? Initially rates will be higher, but as penetration increases, they will diminish, as in Finland, where high penetration rates and competition for equipment manufacturers (especially those of handset makers) brought down the prices for both cellular handsets and air access. Moreover, even though wireline operators have low rates for local calls, they now have to compete with cellular providers over long distance rates.

TABLE 1 Charges of Finnish wireline and wireless operators. All prices in FIM[12]

Operator	Charges										
	Connection fee	Monthly fee	Calls to local wireline			Calls to long distance wireline			Calls to mobile		
			Daytime	evening & weekends	night	daytime	evening & weekends	night	Daytime	evening & weekends	Night
Wireline	350-700	70-80	0.04	0.04	0.04	0.3	0.3	0.3	1.9	0.9	0.9
Wireless	50	20-30	0.5-2.0[13]	0.5-1.0	0.5-1.0	0.5-2.0	0.5-1.0	0.5-1.0	0.5-2.0	0.5-1.0	0.5-1.0

In Finland, with much lower connection rates and monthly fees (see table 1) cellular operators are slowly winning customers over when deciding what kind of phone they wish to buy. This trend will soon be followed in other European countries, especially as the number of cellular operators expands. The year 2000 for instance, witnessed the ending of the last monopoly in cellular telephony

and AMPS, used analogous voice transmission. The 2nd generation cellular systems, e.g. GSM and D-AMPS, use digital voice transmission and are capable of transmitting data. The principal difference of 3G cellular telephony is that the voice transmission function is not the major function anymore. Transmission of data (multimedia in particular) at high rates is the main function, and voice is seen as one of the instances of data transmission.

11 Integrated System for Digital Services. Technology developed in the 80s to offer digital services to wireline telephone subscribers. The first true ISDN network was indeed implemented within GSM – a cellular telephone system/standard launched in Europe in 1991/92.

12 $1 US is approximately 7 FIM in June 2001.

13 For GSM subscribers there is no difference a in local vs. long distance call. The same rate applies, as the subscriber may not know where the called person is at the moment when the call is made, assuming that the called person is also using a mobile telephone service.

within the OECD area (OECD 2000), whereas some countries, including Finland, already have up to four GSM operators.

Finland moreover, is the first country in the world where the number of mobile subscribers has exceeded that of fixed line subscribers, and approximately every fifth household in Finland uses *only* a mobile phone (Paltridge 2000). It is not however the only country with high penetration rates for cellular technology. For example, in Italy and Korea the number of mobile subscribers has surpassed the number of fixed access line users (see figure 1).

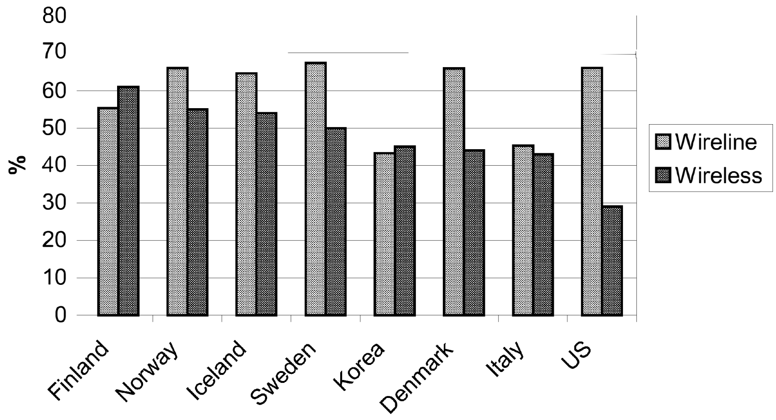

FIGURE 1 Mobile penetration in OECD area, June 1999. Mobile subscribers per 100 inhabitants. Source: wireless, (Paltridge 2000); wireline (for 1998): (ITU 1999)

Nordic countries are also ranked high in the manufacturing of IT products (mostly Sweden and Finland) and in providing IT services (Falch and Henten 2000, p.393). Harris (1999) states "If you want to see the future, look north. More precisely, look Nordic", and he continues, "That's long been true if you want to see where mobile telephony is taking us".

Finland doesn't only have vastly increased penetration rates for cellular telephony, it is also reported to be the only country in the world with greater Internet host density per head than the US, and the US is only marginally ahead of Iceland and Norway (Harris 1999)[14]. Furthermore, the Nordic countries boast Europe's biggest Internet bank in Nordea[15], which has offered GSM-banking for several years now; incredibly as much as 82 per cent of the Icelandic population is online, giving it the highest internet penetration rate anywhere (Brown-Humes 2000).

According to Harris, some analysts predict that cellular teledensity in the Nordic countries will peak at over 100%, this is, "because many people like to use different products [mobile phones] for business and for pleasure [for

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14 Referring to Next Generation Internet Associates: http://www.ngi.org/trends.htm.

15 http://www.merita.fi.

private purposes]" (Harris 1999). For instance, hundreds of thousands of people in Finland have more than one GSM subscription, and many people have more than one cellular phone.

The first GSM call took place in Finland in July 1991, and later, in March 1999 Finland became Europe's first country to license third-generation cellular operators. "Given Scandinavia's [read Nordic] near-universal love of both mobility and the Internet, then, it was inevitable that the two would, somehow, have to be combined" (Harris 1999). This anticipated convergence of Internet and mobile does not have to wait for the advent of third-generation cellular technology. You can already browse the web on WAP-enabled phones.

Once a leader in mobile technologies, Motorola of the US has lost it's position to it's Nordic rivals, namely Nokia Ltd of Finland and LM Ericsson Ltd of Sweden (see table 2). One reason for this could be the companies' different attitudes towards the customer. A key player in the NMT standardization, recalled the days when Nokia was a humble new entrant into the cellular business, whereas Motorola had been an established "champion" for decades: "In our meetings with industry representatives of Motorola they would always say: 'We know what the customer wants!' The Nokia guys [on the other hand] would say: 'We would like to get to know what the customer wants'" (Lyytinen, Manninen, and Fomin 1998).

TABLE 2 Communications equipment manufacturers as for 1998. Source: (Elstrom et al. 1998)

Company Name	Annual sales $ millions	Sales growth % 1-yr.	Net profits $ millions	Profit growth % 1-yr.	Market value $ millions	Total return % 1-yr.	Total Return % 3-yr.
Motorola, Inc	29794.00	6.5	118NA	2.3	33017.25	1.63	-0.20
Ericsson (LM)Tel	21227.00	15.2	1511.00	45.1	42523.76	36.27	48.21
Nokia Corp ADS	7723.00	-9.0	598.00	74.5	32214.22	69.04	41.63

This special attention to the needs of the customer has also been referred to as Scandinavian participatory design, an approach to software engineering, in which customers (end users in this case) participate in the design process. At the present time, after successfully "getting to know" what the customer wants, Nokia is busy supplying handsets and whole cellular infrastructures to the growing GSM market. The cellular handsets have been transformed from a businessperson's high end product into a commodity, "cool stuff", especially those with fancy covers which one can change according to one's mood (Malkani 2001). With this growing competition and subsequent advances in technology, the prices for mobiles have also fallen drastically. Initially from costing around 20'000 FIM in 1985, their price has steadily decreased to 3'000 FIM in 1995[16] and to most recently 650 FIM in 2000, with some models selling

16 Rudi Bekkers (2001, p.370), referring to Pan-European Mobile Communications, Issue 11, Autumn 1992, p.17, writes that at the time when handheld GSM terminals were introduced in the late 1992, the first Motorola International 3200 handheld was priced at

for only 300 FIM. Moreover, the phones have become smaller, lighter, and capable of more functions.

Cellular manufacturers have also had to keep pace with the increasing changes in the GSM market. As the telcos are expecting to see data use grow (compared to that of voice) from the 2% of today to 25% by 2002 (Harris 1999), new standards will have to be introduced on top of GSM's basic infrastructure. In the year 2000 for instance, Sonera of Finland (a former incumbent operator, but presently one of the four GSM operators in Finland) offered to its subscribers a GPRS[17] service, enabling data transfer rates which peak at around 50 kbits/s, compared to the 9.6 kbits/s of the "standard" GSM. This is a great leap forward, providing almost the same Internet access speed as ISDN, and a step towards "fixed-mobile convergence". As Harris (1999) states, "operators that can offer true fixed-mobile convergence will be able to offer their customers the best of both worlds: maximum mobility and flexibility when they need it, as well as the extra bandwidth they need for data-heavy applications." It is certain, that the Nordic telcos, "backed" by the world's leaders in cellular equipment, Nokia and Ericsson, are heading towards such a goal.

Another headline reads: "Nokia has consolidated its position as the world's biggest seller of handsets, while Ericsson remains a leader in the provision of mobile infrastructure" (Brown-Humes 2000). The story reveals that the extraordinary success of both companies has not only been a source of great pride to Sweden and Finland, but has also helped to make their shareholders rich. Nokia's share value for example, has grown tenfold since 1998, and the two companies are now among the 10 most highly-valued companies in Europe (Brown-Humes 2000). With respect to the issue of convergence, both Nokia and Ericsson see the mobile Internet as the immediate future. While Nokia has sold more than 1m of its 7110 WAP phones, Ericsson has been chosen as a supplier for 3G contracts awarded in Finland and Japan (Brown-Humes 2000).

The convergence of mobile telephony and the Internet is crucial to the development of the IT sector: "The emergence of this sector has been an extremely welcome development in Finland, not least because it has given the country an important third leg to balance its traditional dependence on pulp and paper and engineering" (Brown-Humes 2000). Companies like Ericsson and Nokia have provided something important for small Nordic countries, they have made sure that Sweden and Finland are known globally, for the impact that Nordic advances in the IT sector have had on a world scale has been considerable. Stockholm is now referred to as the "Internet capital of Europe", and as one journalist puts it, "It is extraordinary that this should be happening on the remote fringes of Europe in countries with sparse population and long winters, and societies better known for high taxes than entrepreneurship" (Brown-Humes 2000). The IT field is changing economies in the Nordic

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DM 2'500 (including VAT), and the first Nokia 1011 was priced at DM 2'490 (excluding VAT).

17 General Packet Radio Service – data transmission standard for GSM. Promising up to 384 kbit/s.

countries. Nokia for instance, accounts for about one-third of Finland's GDP growth (Brown-Humes 2000).

There are several reasons why Nordic has become a synonym for Internet-, mobile-, and advanced- technologies to name a few. High standards of education and low or negligible admission fees for university studies have had a significant impact on advances in the IT sector. The deep recession of the early 1990s forced Nordic countries "to restructure for the new economy much earlier than other European countries", according to Jorma Ollila, Nokia's CEO (Brown-Humes 2000). The massive R&D investments of Ericsson and Nokia have also helped to foster a wider e-competence (see table 3).

Since the focus of this thesis is the standardization process and standards in the wireless industry, in the next section we'll look at contemporary penetration rates in wireless telecommunications, and the role of the NMT and GSM standards in the transformation of the world's telecom industry.

TABLE 3 R&D investments in the ICT sector. Source: (OECD 2000). * 1995 for R&D to value added ratio (R&D intensity)

	R&D in ICT (million PPP USD)	R&D / value added for ICT (%)	R&D in total business sector (million PPP USD)	Share of ICT R&D in total business sector (%)
Finland	962	15.7	1'887	51.1
Norway*	324	6.3	1'111	29.2
Sweden	1'427	12.1	5'123	27.9
Iceland	11	N/A	49	21.8
Denmark	329	N/A	1'558	21.1
United States	59'916	10.3	157'539	38.0

2.3 Transforming the industry

As already mentioned above, in some countries the penetration of the GSM network has exceeded that of the fixed line network. Finland is such an example, where more than 70% of the country's population has at least one cellular phone per person, and at least one GSM or NMT subscription. Many people also have two subscriptions, one for business purposes, and one for private use. Nevertheless, from the beginning of the cellular era in the Nordic countries all estimates relating to network growth have *always* been *wildly inaccurate*, underestimating the anticipated number of network subscribers by at least several times. This is only one of the paradoxes continuously remembered by those involved in the development of the NMT and GSM standards. For instance, Hans Myhre, the former chairperson of the NMT group and nowadays a senior manager at Norwegian Telenor, recalls on this issue (Lyytinen, Manninen, and Fomin 1998):

> "This had happened in 1978. We settled down to make the first prognoses for NMT to make automatic mobile phones. We collected all available information on the

> market and based on that we made plans for the gradual development of the market. We expected approximately 10'000 subscribers by the end of 1983. Maybe it was a little bit over-realistic and optimistic. Our colleagues in other Nordic countries had opinion that we were much too optimistic. Although we were wrong all of us. The traffic was so enormous that no one had expected it. On 1st of January 1984 we had already 24'000 subscribers, when the prognosis was only 10'000".

These numbers tell us that the estimates that telecom representatives made in 1978 relating to subscriber take-up were 2.4 times lower than the actual growth six years later. The former chairperson of the GSM committee, Mr. Thomas Haug recalls in his interview conducted in March 2000 in Helsinki (Manninen et al. 2000):

> "I remember that once, when we introduced GSM for the first time to some of [what was then] the Eastern Block [countries] in October 1990, in Hungary, somebody said that GSM existed just on paper, which was of course true. Not a single piece of hardware existed at that time. But anyway, we described it. And I had to give the introductory address. I thought I was very optimistic [when] I said: "Perhaps by the end of the 20th century, mobile phones [are] becoming so popular, perhaps the world's total number of mobile phone subscribers, including AMPS will reach a hundred million. And they laughed! I think we have 250 million of GSM [subscribers] alone?".

By March 2000, the total number of GSM subscribers had indeed exceeded 290 million (table 4), or 2.5 times the "very optimistic" estimate of 1990! The subscriber statistics in table 4 demonstrate the numbers of people using GSM at different frequencies, and in different global regions. It demonstrates phenomenal customer growth, running at twice the industry's predicted level (figure 2).

This massive underestimation of customer growth is exemplified by the forecast of Finland's PTT in 1983, which estimated that the total number of mobile subscribers (ARP, NMT, and GSM) by the end of the 20th century would exceed 150'000. However, already by 1998 the number of connections was 20 times this forecast!

TABLE 4 Subscribers by Technology. Source: http://www.GSMWorld.com. Accessed 19.05.01. All figures are in Millions

	Oct 99	Jan 00	Apr 00	Jul 00	Oct 00	Nov 00	Dec 00	Jan 01	Feb 01	Mar 01	Apr 01
Total GSM	227.5	272.2	306.9	354.0	401.9	420.0	441.8	457.8	473.1	488.5	502.2
GSM 900	126.0	148.7	163.6	173.8	196.7	205.4	216.8	224.9	232.3	241.1	249.5
GSM 1800	24.9	34.1	40.2	47.2	56.4	59.9	63.8	66.9	69.8	71.8	73.6
GSM 1900	5.6	6.6	7.2	8.0	9.1	9.5	10.2	10.6	11.0	12.1	12.3
GSM 900/1800	70.9	82.8	95.9	124.9	138.4	145.2	151.0	155.4	160.0	163.3	166.8

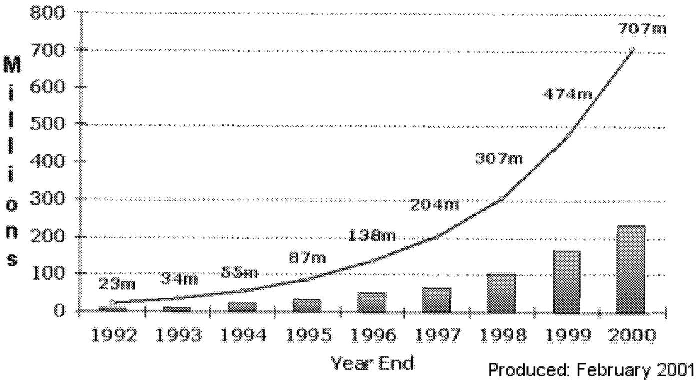

FIGURE 2 World Cellular Subscribers. Subscriber Growth & Estimate to Dec '00. Source: http://www.GSMWorld.com. Accessed: May 2001

The statistics given in table 6 demonstrate that the number of subscribers of GSM in Europe alone, surpasses the total number of subscribers in other parts of the world. While Nordic countries cannot compete with their European counterparts in the number of cellular users due to small population sizes, when taking cellular penetration rates as a criterion, they have always taken the lead (See table 7 through 10). Different reasons, some of which border on the mythical, have been used to account for this. For example, it has been claimed that Nordic people are shy when talking face to face, but much more talkative over the telephone. Others have argued, that these countries are so sparsely populated, that one needs a mobile phone to be able to keep in touch with others. However, surely none of these reasons, mythical or otherwise, can account for the phenomenal growth of cellular networks in the Nordic countries. Nonetheless, cultural factors without doubt have played a major role, even if it is not a simple task to identify these or inaccurate to claim the existence of a common "Scandinavian" culture.

In this thesis it will be attempted to unveil how the development of cellular technology in the different regions of the world took place. In the following sections we will show how the world of cellular emerged, despite the challenges the developers of the different standards faced when creating the cellular world of tomorrow, and, as the main thrust of the thesis, describe *how the process of standard making evolved.*

TABLE 5 Subscribers for Other Digital Technologies. Source: http://www.GSMWorld.com. Accessed 19.05.01. All figures are in Millions

	Apr 00	Jul 00	Oct 00	Nov 00	Dec 00	Jan 01	Feb 01	Mar 01
CDMA	64.5	68.8	76.2	79.2	81.9	84.6	87.7	89.7
PDC	47.0	48.3	49.7	50.1	50.8	51.2	51.6	52.7
US TDMA	46.0	50.6	59.2	61.7	64.3	66.6	70.3	72.2
Total Digital Subscribers	464.4	521.8	587.1	611.0	637.8	646.4	682.9	703.1
Total Analogue Subscribers	78.0	78.0	71.5	70.4	69.3	68.4	66.1	65.3

TABLE 6 Cellular Subscribers Regional Breakdown. Source: http://www.GSMWorld.com. Accessed 19.05.01. All figures are in Millions

	Dec 98	Dec 99	Mar 00	Jul 00	Oct 00	Nov 00	Dec 00	Jan 01	Feb 01	Mar 01	Apr 01
Total	138.4	259.0	294.8	354.0	401.9	420.0	440.7	456.7	473.1	488.5	502.2
Arab States	2.4	4.4	5.4	7.6	9.0	9.5	10.0	10.5	11.0	11.4	11.7
Asia Pacific	34.3	69.6	80.4	98.1	111.3	116.3	121.5	125.8	130.7	136.5	142.0
Africa	3.0	5.6	6.7	7.9	9.1	9.6	10.3	10.7	11.0	11.5	12.2
East Central Asia	0.56	1.0	1.3	1.6	1.8	1.9	2.0	2.0	2.2	2.3	2.7
Europe	93.7	170.0	191.6	226.8	256.5	267.8	281.1	291.2	300.6	307.6	314.0
Russia				1.3	1.8	2.0	2.2	2.3	2.4	2.5	2.7
India	1.1	1.6	1.9	2.3	2.8	2.9	3.1	3.2	3.4	3.6	3.7
North America	3.1	6.1	6.6	7.2	8.1	8.5	8.9	9.3	10.0	11.0	11.2
South America	0.18	0.71	0.90	1.2	1.4	1.5	1.6	1.7	1.8	1.9	2.0

TABLE 7 Nordic analog and digital cellular subscriber update. Source: Mobile Communications International (MCI)

Country/ Operator	Subscribers end June 00	% growth from end June 99	% penetration of population
Denmark	3’078’800	37.3	58.95
Finland	3’641’080	15.7	69.64
Iceland	191’540	41.3	67.59
Norway	2’993’250	22.4	67.50
Sweden	5’744’000	22.5	63.77
Total:	*15’648’670*	Avg.: *27.8*	Avg.: *65.49*

TABLE 8 European analog and digital cellular subscriber update for selected countries. Source: MCI

Country/ Operator	Subscribers end June 00	% growth from end June 99	% penetration of population
France	23’845’000	70.0	40.24
Germany	34’048’000	97.0	40.67
Ireland	1’844’960	72.1	51.23
Italy	35’150’000	44.5	61.50
Luxembourg	244’540	49.8	56.35
Netherlands	8’601’160	74.6	53.51
Spain	19’925’000	100.0	49.25
Switzerland	3’995’500	79.5	51.29
UK	30’603’800	82.2	51.79
Total:	*158’257’960*	Avg.: *74.4*	Avg.: *50.65*

TABLE 9 Asian & Pacific analog and digital cellular subscriber update for selected countries. Source: MCI

Country/ Operator	Subscribers end June 00	% growth from end June 99	% penetration of population
Australia	9'295'050	32.0	48.68
China	66'413'850	75.4	5.18
Hong Kong	4'912'450	37.3	69.18
Total:	*80'621'350*	Avg.: *48.2*	Avg.: *41.01*

TABLE 10 North American analog and digital cellular subscriber update. Source: MCI

Country/ Operator	Subscribers end June 00	% growth from end June 99	% penetration of population
USA	95'624'510	25.9	34.69
Canada	7'703'540	29.1	24.64
Total:	*82'859'770*	Avg.: *27.5*	Avg.: *29.67*

3 RESEARCH PROBLEM

> The seamless web character of technology and its pervasive socially constructed character indicate a multitude of opportunities to influence the development of technology (and society and so on) at all stages. But more studies of how this can be brought about are needed.
>
> (Bijker 1995, p.253.)

The first aim of this study is *to develop a model of the standard making process*. In the light of the complexity of IT phenomena, it would be inappropriate to begin such an endeavor without addressing the context in which the standardization processes that were studied took place. Hence, the second aim of the thesis is *to provide a rich socio-technical analysis of the evolution of cellular telephony*, from the early days of mobile radiotelephony through to the introduction of the global 3rd generation (often referred to as 3G) standard for wireless communications.

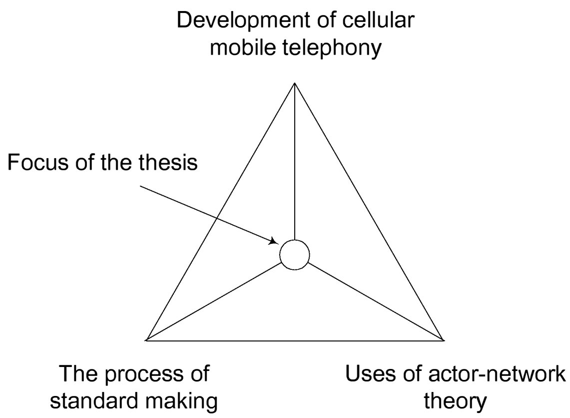

FIGURE 3 The scope and focus of the thesis

The socio-technical study of wireless communications and the development of a standard making model to a large extent will be based on actor-network theory. Indeed, *applying actor-network theory to the study of complex infrastructural* *technology* forms the third aim of the thesis. Thus, the scope of the study is prompted by the intersection of these three distinct problems: 1) The study of the process of standard making; 2) The study of the development of cellular mobile telephony; and 3) The applicability of actor-network theory in studies of complex infrastructural technologies (see figure 3).

The thesis then focuses on the interplay of the technical and institutional forces, that shaped the specific social and institutional network configurations, that enabled the development of highly successful cellular technologies in the Nordic countries, Europe and later throughout the world. Whilst placing emphasis on the socio-technical and socio-institutional aspects of the technological development of complex systems, the technical aspects of cellular telephony are not excluded from the analysis. On the contrary, we carefully trace how technology played either an enabling or disabling role in the systems' development.

Thus, in order to provide a rich description of the domain in which the standardization processes analyzed took place, a holistic view of cellular telephony's development will be taken, addressing amongst others the following issues:

a) the emergence of the cellular technology; and
b) the divergent paths of this technological development across three continents.

This will involve concentrating on:

i) Three geographical regions: Europe (the main thrust), US, and Japan (overview only).
ii) Two generations of technology: first generation (analog) and second generation (digital). The facets of deployment: technology and diffusion.

Based on, but not limited to the findings from these studies, theoretical elaborations will also be presented aimed at developing a model of the standard making process. These two phenomena, the development of cellular technology and the process of standard making, are intermingled in the study to the extent that they become almost inseparable. This was not done for reasons of complexity but because it is believed that presenting theoretical elaborations separated from their practical origins is inappropriate, theory and practice must go hand in hand.

3.1 Main objectives of the study

As mentioned above, one of the aims of this study is to propose a process model of standard making, in which *standardization* is considered as a process of creating a technical standard and diffusing it into the market place.

However, as we view theory and practice, science and reality as inseparable, our *first objective is to provide a comprehensive and systematic study of the history and evolution of the NMT and GSM standards*. This history and evolution of these cellular technologies will be presented in chapters II and III.

There have already been numerous attempts to study this phenomenon. Despite this, the focus of these studies was not necessarily on the NMT and GSM standards per se, nor on the impact of their standardization on society at large but on merely one or several specific aspects of the story of cellular telephony's development. A study of the development of complex networked technologies it is argued, cannot however be based on a single theory, rather a combination of several theoretical approaches is required to further an understanding of the processes constituting standard making. This issue of the theoretical approaches relevant to studying the standardization process will be addressed in Chapter V.

Northern Europe has maintained it's prominent position in the development and utilization of telephony technologies since the last century, when a telephone service was first introduced. Sweden and Finland have always had high penetration rates for fixed line networks, and were among the first in the world to introduce countrywide mobile radio- and telephone systems. In the previous section we described the position of Nordic countries in the ICT domain today, which suggests without doubt that they have not only preserved, but also significantly strengthened their role in the development and utilization of telephony services. This is a major reason for undertaking a study focusing on the Nordic region and its role in the development of wireless services.

It is suggested that earlier attempts to study the above phenomenon, no matter how professional, could not have fully succeeded if they were undertaken from outside Norway, Finland, or Sweden. The simplest reason for this is the necessity to be familiar with at least "Skandinavska" (a mélange of Swedish, Norwegian, and Danish), and preferably Finnish in order to make a comprehensive study of the development of NMT and GSM systems. Knowledge of these languages is needed for instance to read minutes of the meetings[18], and to conduct interviews with former participants of the development projects (even though most of them speak fluent English, use of the native language is always preferable). Even though the author conducted most of this study in English (he has an everyday knowledge of Finnish), as part of a team based at the University of Jyväskylä, he is indebted to his Finnish colleagues and especially Ari Manninen for material provided.

The role of culture cannot be understated when describing the need of a Nordic background to the study. There was something special about the telecommunications engineers of 1970s and 1980s in Scandinavia, called by

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18 During the last three years of the study work, our group has collected over 9000 pages of documentation on the development of NMT and GSM – minutes of the meetings, correspondence, directives, etc. A large part of the materials would be useless for an English-only reader, even if equipped with an automated translation engine, because hundreds of pages are handwritten in Swedish, Norwegian or Finnish.

Knuuttila (1997) "the radio engineers' gang", who were in charge of developing the necessary technical specifications. The spirit of co-operation, the long working hours without extra pay, and informal meetings, were all important in the making of the Big Bang. This cultural setting in which the NMT system developed and the cooperation between Nordic countries in creating it, will be addressed in the Original Article I.

A common trend in the Nordic countries is exemplified by the effort of the Danish government to transform Denmark from an information to a network society (Falch and Henten 2000), for instance, by educating people in IT and making the Internet accessible for everyone. If this "information-to-network" transformation is looked at from the point of view of telephony, then can't clear similarities be identified between it and the "wireline-to-wireless" transformation? This isn't exactly the case, as owning a mobile phone does not provide very many networking possibilities, except for being contactable and the ability to contact others at any moment. This may change if the much talked-about 3G system becomes operational, where "being connected all the time" (online) would be a radical change compared to the cellular systems of today. This is when society would suddenly become a global network, with everyone having access to the vast resources of the Internet, municipality services, and online shopping, and in which every car would have it's own IP[19] address. Already in 1996 an OECD[20] report (1996) stated:

> "In the decade to come, the prospects are even more exciting as digital technologies are introduced, standards are harmonized and as equipment and usage prices fall. There is the very real possibility that mobile communication services will do for the telecommunication industry in the 1990s what the personal computer did for the computer industry in the 1980s; namely, to bring about a revolutionary change in the way products and services are sold and used".

It is exactly this convergence of wireless and wireline that was discussed at the beginning of the thesis, and marks the transformation of wireless telecommunications from a supplementary service, as they were originally designed (Toivola 1992) to a dominant telecommunications service. "As other [than Scandinavian] national markets develop, it is likely that they too will soon shift from a situation in which mobile and PSTN operators complement each others' activities to one in which they compete for traffic; on price as well as on service availability" (OECD 1996). The statement above was made back in 1996. Nowadays, we can already see that the transformation of the telecommunications industry from wireline to wireless has taken place, evidence of which is that "approximately every fifth household in Finland uses only a mobile phone" (Paltridge 2000, p.453). In the light of the above, *the second objective of the study is to outline the development and transformation of the telecommunications industry, and the societal impact that this transformation has*

19 Internet Protocol. In order to have access to the Internet, each server and client terminal must obtain an IP address. Only through the use of IP addresses is it possible to find resources on the WWW, send emails, have Voice-Over-Internet communications, etc.

20 Organisation for Economic Co-operation and Development.

imposed. We addressed the issue of organizational and societal transformation in the section "Motivation behind the study". Issues related to the development and transformation of the telecommunications industry will be presented in the Original Article II.

Many researchers have attempted to identify the factors behind successful technological innovation. Scholars from different schools of technology and innovations studies have advocated different ideas on why and how certain technologies are a commercial success whilst others fail. This study aims to build on this tradition but further stressing the importance of context, institutional aspects, regulatory bodies, and social networks in the shaping of technology and society? Thus, *the third objective of the study is to reveal the factors, which contribute to either the success or failure of different cellular technologies (standards)*. We look into these factors with respect to standardization in the Original Articles I and the Original Article II. Earlier attempts by the author and others to identify these can be found in Fomin (1999), Fomin (2000) and Fomin (2000).

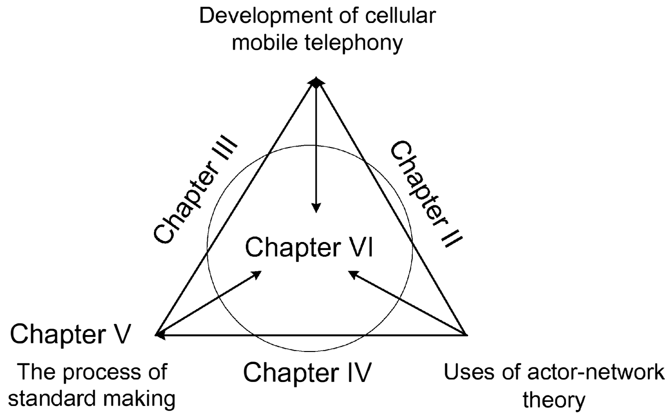

FIGURE 4 Research problem and the structure of the thesis

As the aforementioned objectives become apparent as the thesis evolves, we shall meet the *fourth and the most important objective of this study, to develop a model of the standard making process* based on a rich description of the NMT and GSM standardization processes and a sound theoretical framework. The first attempt to develop such a model is presented in the Original Article III and further elaborated on in the Original Article V.

An overview of the scope of the research and its main objectives is given in figure 4, and the correspondence of the structure of the thesis to these research objectives in table 11.

In order to fulfill our objectives and to answer the aforementioned questions, we will undertake an exploratory voyage back to the 1960s, when the development of the first commercial cellular systems was initiated. From the 1960s we'll return to the beginning of the 21st century, following the developmental paths of different cellular mobile telephone technologies across different continents as we go.

TABLE 11 Objectives of the study and the corresponding chapters of the thesis

Objective of the thesis	Original Article/ section
To provide a comprehensive and systematic study of the history and evolution of the NMT and GSM standards	I, II
To outline the development and transformation of the telecommunications industry, and the societal impacts this transformation imposes	II, Summary (section "Motivation for the study")
To reveal the factors of either success or failure of different cellular technologies (standards)	I, II
To develop a model of the standard making process	III, IV, V

3.2 Previous studies in the field

This work is not the first attempt to study either cellular mobile telephony or standardization processes, nor the applicability of actor-network theory. Numerous studies exist which have investigated these phenomena in isolation, for instance those related to the development of radio and wireless telephony. However, these earlier studies did not specifically focus on the standardization process within cellular telephony itself. In the following section those studies will be introduced that fall into the field delimited by the three apexes of the triangle in figure 4. The first group of works that will be briefly mentioned relates to studies on the development of cellular telephony.

3.2.1 Cellular mobile telephony

"Digital Cellular Radio" by Calhoun (1988) is a systematic, well-written, and respected source for those interested in the history of radio, the associated industry and regulation in the US. The study provides an excellent overview of the history of radio and its development into cellular telephony. Written in the 1980s, the story of cellular in Calhoun's view is more a story of radio than that of telephony. However, although the most important players at different historical "turns" are named, a comprehensive socio-technical analysis of this story is largely overlooked.

In "The Mobile Book", Meurling and Jeans (1994) describe the development of mobile communications as a success story of a single manufacturer, LM Ericsson of Sweden. Despite the obvious bias in awarding Ericsson the central role in the development of cellular mobile telephony, the book nonetheless is an interesting read, as it is on the whole based on a micro-analysis, describing the lives of those involved and narrating their achievements.

A similar story is written by Toivola (1992). The similarity is prompted by focusing on a single player, the Finnish teleoperator "Tele". Unlike the global perspective of "The Mobile Book" however, Toivola presents merely a history of the Finnish cellular industry.

Attempts to provide a comprehensive technical analysis of mobile communications have been made by for example, Bekkers and Smits (1998), Mehrotra (1994), and Paetsch (1993). With the exception of the work of Bekkers and Smits, these focus on the engineering aspects of the technology, thus leaving little or no place for an analysis of the social or political implications and setting of cellular development. The regulatory issues concerning mobile communications have been well covered in the works of Melody (1997) and Anders (1997; 1998). In a recent work, Bekkers (2001) assesses the success of the European Telecommunications standards, including the GSM and UMTS cellular mobile telephony standards. Bekkers (2001) provides a comprehensive empirical study of the policy implications, institutional and economic environments affecting and shaping the development of standards in the field of telecommunications in Europe.

Less comprehensive works have been published in conference proceedings and journals. These works have usually focused on some aspects of technological development in general, taking mobile communications as a case example. However, in the main, only a certain cellular technology would be reviewed, examples of such studies include; economic comparisons by geographic regions (Kano 2000), market regulation and selection mechanisms (Pogorel 1994), comparisons of technological evolution (West 2000), studies on societal and social aspects of certain technological developments (Knuuttila 1997), (Fomin and Lyytinen 2000), and the characteristics of standards required for their global diffusion (Funk 1998).

3.2.2 Standardization process

Particularly in the information and communication technology industries, technological standards play an important role. Some standards become global and give significant competitive advantage to their users through economies of scale; other standards either never take off or remain in the form of technical documentation only (Funk 1998). Some firms succeed in standardizing their innovations and gain control over an industry through patents and intellectual property rights (IPRs), other processes are blocked due to inability to resolve the IPR issue (Bekkers and Liotard 1999). How do these standards emerge? What is the process through which these standards are created? What factors govern their creation and more importantly their success or failure? These are the questions that have engaged scientific debate over the decades. Several theories have emerged that try to explain standardization from a variety of perspectives including for instance, economics, sociology, and management sciences.

In economics, the early literature analyzed standardization as a rational game between the actors involved (Besen and Farrell 1994). Based on game theoretic models, the choice of actors to create standards or to join standardization initiatives was analyzed and the welfare implications of different standardization modes considered (Farrell and Saloner 1988). A second class of economic models of standardization has been concerned more with the diffusion of technologies and the emergence of de facto standards (Funk 1998). These models often are based on notions of increasing returns (Arthur 1989). The basic mechanism that these models describe is that a technology gains an initial lead in the installed base of the technology.

Within management sciences, the nature of dominant design competition and bandwagon processes have mainly been studied (Tushman and Anderson 1986; Wade 1995). Comparably less attention has been given to the processes through which technology is standardized. Farrell and Saloner (1988), and a few others have focused on the selection of standardization mechanisms, distinguishing between market- and committee-based ones (Funk and Methe 2001; Vercoulen and Wegberg 1998), but not using game theoretic models.

Disconnected from the economic and management literature, a socio-technical network literature of standardization has emerged (Williams and Edge 1996; Williams 1997). This literature has modeled standardization as a process of social interaction within a network of actors. This socio-technical stream of literature analyzes "why" the process development has followed one particular trajectory or another (Mangematin and Callon 1995). For instance, actor-network theory posits that decisions are made after the alignment of interests of the involved actors takes place. This alignment of interests is one of the possible outcomes of the continuous negotiation process in which the actors are involved (Callon 1986; Callon and Law 1989; Latour 1991). Closest to the interests of this study, are works on the standardization of electronic data interchange (EDI) practices (Hanseth and Monteiro 1997; Hanseth, Monteiro, and Halting 1996). In these works the authors employed actor-network theory to analyze the creation of complex networked technologies. To summarize the socio-technical approach to standard making we can note, that while the socio-technical network literature complements it's economic counterpart, it does not provide a fully specified model of the standardization process.

Assuming a diversity of perspectives, there have also been attempts to develop an integrated theory of standard making, for example Schoechle (1999), but in the author's opinion with little success. By contrast, this thesis engages in an attempt to show that none of the existing theories address the complexity of the standardization process fully (Fomin and Keil 2000).

3.2.3 Actor-network theory

Actor-network theory (ANT) emerged in 1980s as a result of collaborative efforts of two principal theorists, Michael Callon and Bruno Latour from Center for the Sociology of Innovation (CSI) at L'Ecole Nationale Supérieure des Mines in Paris. In what they first called "the sociology of translation" (Callon, Latour, and Rip 1986; Latour 1987) they developed "a version of STS known as 'actor-network theory,' which promises nothing less than a complete makeover of the social sciences, specifically by defining 'networks' as the stuff out of which both individual identity and social organization are constructed" (Fuller 2000, p.12).

ANT was built on case studies of failures in developing and/or implementing complex large scale technologies in France: that of electric car (VEL) to be made publicly available (Callon 1993), the Minitel to become integrated into global computer networks, and a computer driven customized rail system to appeal to Parisian commuters (Latour 1996).

In each case the failure was found to be a result of an exaggerated confidence in what top-down management could accomplish without attending to the 'interests' of other actors whose cooperation would be required for the policy's implementation (Fuller 2000, p.14). These failure cases revealed that even 'weak' actors are able to block or enable major alignments of knowledge and power needed for technology's development and implementation (Fuller 2000, p.17).

Thus, in applying the theory to technological development, ANT traces the interactions between human and non-human actors and seeks to identify points in time, where technology could be designed in more than one way, and to explain the dominance of one choice over another. In this we find a parallel to the *path dependence*[21] view of evolutionary theory.

Since the advent of ANT, it has been applied to studies of different phenomena. Relevant to our study, Latour (1995) showed how ANT could be applied to studies of computerized work sites. Hanseth and Monteiro (1997) in their work used the theory to show how standards inscribe behaviors of different actors into the information infrastructures under development, and Lehoux et al. (1999) used ANT for an IS' evaluation.

To summarize, studies of technology based on ANT reveal the interplay between technology and society, and the role of technological artifacts in the formation of socio-technical networks. In the domain of IS and IT, ANT has been used to study the success and failure of complex technologies, but as yet no one has applied the theory to studies of cellular mobile telephony. What makes our study different is that we deploy ANT to study highly complex, infrastructural, and partially intangible technologies, such as protocols. In contrast to studies of, for example, the creation of the electric vehicle (Callon 1993), or the implementation of an information system (Lehoux, Sicotte, and Denis 1999), studies of the standardization of cellular mobile telephony must grasp a much broader scope due to the number and diversity of the actors and issues involved.

3.3 Literature review

As was shown in the previous section, a number of studies on wireless telephony exist. This can be partially understood as a result of the potential diversity of possibilities which can be covered, ranging from the purely technical, to the economic and societal. Another reason is due to the question of

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21 The definition of the path dependence is given on a page #37.

methodology. Many different methods and theories can be used to study the same phenomena and most researchers will choose those they are most familiar with. This is not problematic as far as such methods are appropriate for pursuing the objectives at hand. In a similar vein, as this study aims at delivering a comprehensive and reliable story of the development and standardization of mobile communications, the methodology used must be sound.

In the first part of this section the technical-economic and social theories are outlined whose focus has been on studies of technology. Subsequently, the methodological considerations for conducting the chosen type of research will be considered. In the remaining sections, on the basis of the collected data and literature, a rich historical, social, political, and organizational context is depicted in which the development of cellular mobile technology takes place.

3.3.1 Different approaches to studying technology

Our focus in studying technology is on innovation and standardization processes, with special reference to cellular mobile telephony. Primarily, we shall look at how the standardization of different cellular mobile telephony standards has evolved within the last three decades across Europe, North America, and Japan. As a reference point we shall first define what is meant by the terms "standard" or "standardization" and "technology".

The Oxford English Dictionary (Simpson and Weiner 1989) defines "technology" as (1) "a discourse or treatise on an art or arts; the scientific study of the practical or industrial arts," and (2) "a particular practical or industrial art." Bijker (1995), extends these definitions to incorporate a greater complexity of phenomena, he states "Technology will have at least three different layers of meaning: physical artifacts, human activities, and knowledge" (Bijker 1995, p.231).

The Oxford English Dictionary (Simpson and Weiner 1989) defines "standard" as (1) "the authorized exemplar of a unit of measure or weight," and (2.) "a definite level of excellence, attainment, wealth, or the like, or a definite degree of any quality, viewed as a prescribed object of endeavour or as the measure of what is adequate for same purpose," and (3) "something permanent; something that has lasted a long time." Scholars studying standard making have re-framed this definition of "standard" for use in the IT domain. For example, David (1990) provides the following definition: "A 'standard' is to be understood, for the present purposes, as a set of technical specifications adhered to by a producer, either tacitly or as a result of a formal agreement" (David and Shane 1990, p.4). In our context the words "standard" and "technology" can be often seen as synonyms. Since we defined technology as having multiple layers, the definition of standard must be amended also to match that of technology. Correspondingly a "standard", incorporating the definition given by David, will be defined as *"the set of technical specifications, regulatory rules, and knowledge of uses, adhered to a specific technology"*.

By providing a broad definition of what is meant by a standard and a technology, the aim is to emphasize the complexity of the technology under investigation. Cellular mobile telephony technology is not a "single product" type. It is highly complex and networked, characterized by network externalities and economies of scale (Lyytinen and Damsgaard 1998). Studying complex networked technology can't be achieved by focusing solely on physical artifacts. For this reason, Bijker's (1995) definition of what technology is, is regarded as appropriate, for besides hardware there are human activities and knowledge involved in an innovation process, in making a new technology.

Technological evolution and the standard making process can be studied from a number of perspectives. Due to the importance technologies and technological artifacts play in our lives, there has emerged a vast stream of literature on technology studies, often using not simply different, but mutually eliminating approaches and methodologies. The differences between the methodologies pursued pertain to the different understanding of what a technology and it's environment is. Traditionally, three prominent approaches can be distinguished, technological, social determinist, and socio-constructivist. Depending on the approach each of these schools advocates, the focus of analysis will be for example, either the influence of technology on society, the social settings of technology, or technological inflictions. The way different schools model technological development determines the methodological approach.

3.3.1.1 Materialist models of technology studies

This class of model focuses on the technology itself as its explanatory basis. These models are either *technology determinist*, that is, they assume that societal development is determined by technology, or *contingent*, stressing that technological development has a contingent rather than unilinear logic (Bijker 1995, p.239). What unites these two groups, is that they are *evolutionary models*. Typically, an evolutionary model would, first, highlight the variations generated by engineers and others, and then focus on the process by which some of these variations are selected (Bijker 1995, p.239). The selection process would be explained in economic terms.

The perspective of *neoclassical economics* can be associated with materialist models. Economists consider technology to be important but it is taken for granted that technological innovations are always unproblematically available, "off the shelf" (Bijker 1995). Bijker stresses, that neoclassical economic models try to capture the influence of specific labor, capital, and technical changes on economic growth. Technology itself stays outside of the analysis as an exogenous variable (Bijker 1995, p.235). As a result, the analysis of technology development from this perspective does not reflect the influence that society exerts on technology.

Schumpeter (see e.g., Schumpeter 1934/1980) has been the most influential economist to have analyzed the role of technology, and has shown that radically new innovations can create completely new industries and thus lead to new economic and societal directions. This economic pattern was called "the waves of creative destruction", meaning that novel technologies would destroy the obsolete ones. Relevant to our study, Mowery and Nelson (1999) in their study on national systems of innovation observed however, that the creative destruction of established firms and their replacement with new ones is largely an American phenomena - they have occurred less frequently in postwar Europe and Japan (Mowery and Nelson 1999, p.12).

3.3.1.2 Cognitive models of technology studies

This class consists of evolutionary and rationalistic models. Cognitive evolutionary models differ from the aforementioned economic evolutionary models by "taking technological *knowledge as the key characteristic* for modeling technology" (Bijker 1995, p.237). These models stress the role of problem solving.

As discussed in the previous section, the *economics of evolutionary change* posit that standardization is a result of market competition, where market selection mechanisms assure that the superior technology is selected (Levinthal 1998; Nelson and Winter 1982). This viewpoint however, is contradicted by the well-known examples of the Betacam vs. VHS video recording formats, and the QWERTY vs. Dvorak keyboard layouts standardization processes, which showed that superior technologies are not necessarily selected as *dominant designs* among rival technologies (Choh 1999; Gould 1997). This "phenomenon" can be explained by Arthur's notion of *path dependence*, a brilliant explanation of how a *"lock-in by historical events"* creates market situations, where a superior technology doesn't necessarily become a dominant design (Arthur 1989). Arthur finds that path inefficiency is possible where there are increasing returns, as long as the information regarding payoffs is available to relevant decision-makers (Liebowitz and Margolis 2000). In the case of complex technological innovations however, the free availability of the relevant information for decision makers is unlikely.

Information gathering is costly and "the users select how much they are gathering information against the expected value of innovation" (Heikkilä 1995, p.142). The probability of adoption can therefore change unpredictably, depending on the availability of relevant information. Relevant to our work is that of Farrell and his colleagues (Farrell, Monroe, and Saloner 1994), who use game theoretic models to analyze the formation of standardization alliances. In these models, players make choices based on calculated anticipations of some rational concerns. Uncertainty however, regarding the technological choices available, puts the usefulness of game theoretic models in question. It is argued that such models make an important contribution to analyses of standard selection, and are well suited for standard selection processes when the decision makers are well informed on the possible choices of other market players (Farrell and Saloner 1988).

3.3.1.3 Social models of technology studies

Choh (1999) summarizes the findings of researchers from the evolutionary domain (see e.g., Levinthal 1998; Nelson and Winter 1982; Oliva 1994) by noting that industrial standard-making is contingent on the socio-historical context. Since the logic embedded in the market does not guarantee the best technological trajectory for standardization, and the market is embedded in a socio-institutional context, diverse social forces could be recognized to operate in the process of technological development and standardization (Choh 1999, p.170).

Social models focus on the social shaping of technology. Scholars advocating these models reject assumptions that technology is driven by either its own momentum, or a sort of economic rationale (Bijker 1995, p.241). There are rather numerous social factors which affect the decision making process under conditions of environmental complexity and uncertainty. Opportunism, bounded rationality and information asymmetry, make economic actors act "to further their personal interests even at the cost of harming those with whom they are supposed to have collaborative and mutually beneficial dealings" (Kumar, Dissel, and Bielli 1998, p.203).

3.3.1.4 Summary of the models of technological development – which one to choose?

To summarize the models listed above, their limitations in turn shall be considered.

Economic (or materialistic) models assume that technologies are always available "off the shelf" as market demand arises. These models utilize economic factors to analyze the development of technology, but fail to open the black box of technology, limiting the analysis to the environment in which it develops. In doing so, these models assume a one-way influence, from the technology to society, rather than vice versa (see figure 5).

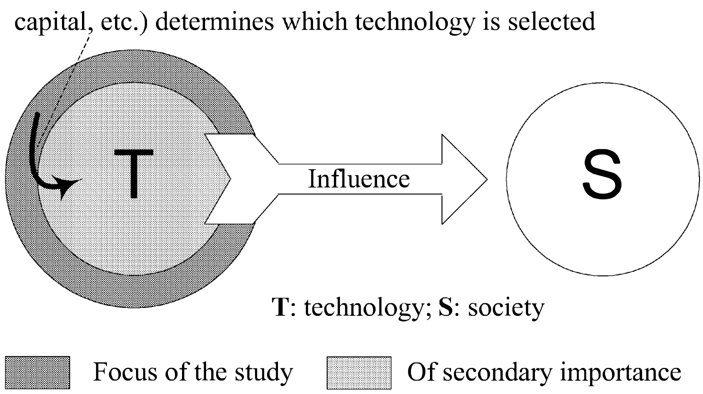

FIGURE 5 Materialistic models

Cognitive models differ from materialist ones in that they explain choice as a knowledge-based process, rather than as one of market selection (see figure 6). Cognitive models help us to explain why technically superior technologies do not always become dominant. However, a limitation for this class of model, is its reliance on the availability of the relevant information needed for the decision making process. When dealing with highly complex technologies, decision makers will more likely face uncertainty than a ready "package" with comprehensive information.

A further step away from technological determinism is taken by the social models. These attempt to account for the problems associated with uncertainty through the workings of social behavior. Unfortunately, it is not uncommon for social models to take another extreme position, advocating the social determinism of technology. Economic factors according to this view do not count anymore, everything is dependent on the social context in which the technology develops (see figure 7).

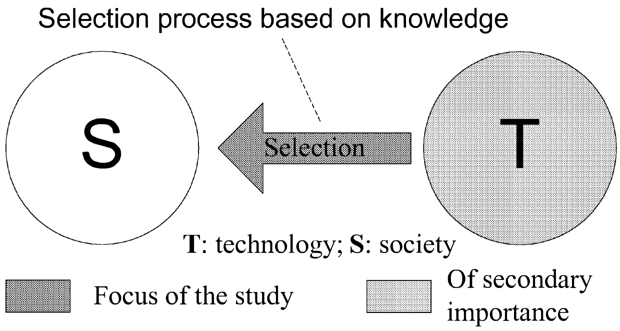

FIGURE 6 Cognitivist models

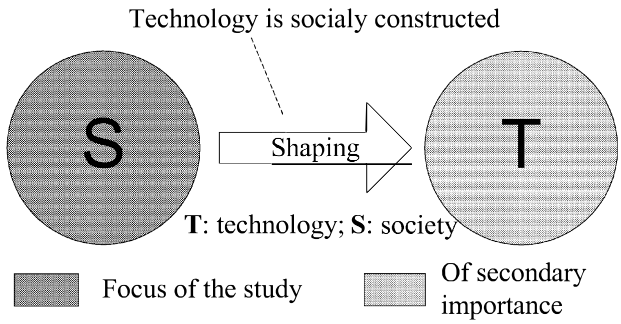

FIGURE 7 Social models

Analyzing the three models presented above, it can be said that none of them alone is sufficient for studying the development of cellular telephony (Fomin and Keil 2000), a complex networked infrastructural technology (Lyytinen and Damsgaard 1998), which has already proved to have had a prominent impact on people's lives (Harris 1999; Brown-Humes 2000, 2000, 2000). Instead, it is argued that *diverse social, political, economic, and technological forces* are operating in the process of technological development, and in the process of innovation and standardization. The task then is to identify a model capable of addressing the *interplay between technology and society*. We need a theory capable of dealing with non-rational actors, with information asymmetry, and with complex networked technologies.

Based on the literature studies and the research findings, various rationales will be acknowledged as driving technological development (Fomin and Keil 2000). Technology and society will be viewed as a *sociotechnical ensemble*, "as an intimately interconnected, heterogeneous ensemble of technical, social, political, and economic elements" (Bijker 1995, p.249), as a *seamless web* of human and non-human actors (Hughes 1986).

3.3.2 The chosen approach – sociotechnical ensembles

Bijker (1995) lists three approaches, which can be used to address sociotechnical ensembles: the systems approach, the actor-network approach, and the social construction of technology (SCOT) approach. All these three approaches seem to be relevant to our study.

The systems approach emphasizes a *macro perspective* of technological development. It uses a somewhat technological deterministic view, assuming that technologies during the course of their development acquire a *momentum* (Hughes 1993), that "seems to drive them in a specific direction within a certain autonomy" (Bijker 1995, p.250) (see figure 8). Similar ideas, with respect to networked technologies, can be found in the works of Hanseth, Monteiro, and Ciborra (Hanseth, Monteiro, and Halting 1996; Monteiro and Hanseth 1995; Ciborra and Hanseth 1998). They agree that the installed base of technology, that is, the "basement" of infrastructure can be cultivated to enable the seamless growth of that infrastructure. The notion of *economies of scales* helps to understand how complex networked technologies gain momentum through an enlarged installed base.

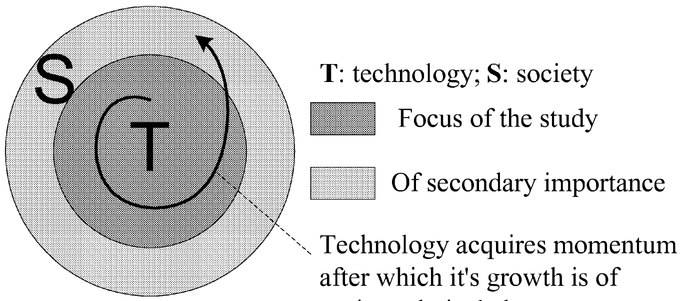

FIGURE 8 The systems approach

The SCOT approach posits that artifacts are socially constructed. It addresses the principle of symmetry by introducing the notion of *"interpretative flexibility"*, an acknowledgement that the meaning of the same artifact can be seen somewhat differently by different social groups, thus making notions of success and failure arbitrary and wholly dependent on the particular standpoint of a social group. Pinch and Bijker (1984), introduce a descriptive model where technological artifacts are first *deconstructed*, that is, different meanings attributed to the same artifact by different social groups are revealed. This is followed by a process of closure, where *social construction* has a crucial role in the stabilization of the artifact, the relevant social groups have come to the same understanding of the artifact (see figure 9).

The actor-network approach addresses the issue of the technological development process by looking at actors who possess enough power to change the direction in which the technology develops at critical points. The power of actors however, is not something inherently individual in them, but originates from the networks they may control (Callon and Latour 1981). Those actors who exert influence on a technology's trajectory are referred to as *gatekeepeers*. The ontological position given to power in the actor-network approach makes it possible to break away from a traditional *micro-macro division*. The *principle of symmetry*, as a way to address the success or failure of a particular technology, is applied by actor-network theory by analyzing the human and non-human world in the same manner, and thus "the explanation of the development of sociotechnical ensembles involves neither technical nor social reductionism" (Bijker 1995, p.251) (see figure 10). Callon's notion of *translation* (Callon 1986) is central to the actor-network approach. The notion of translation is used to describe the changes that take place in sociotechnical networks, as the negotiation process between the involved actors unfolds. A successful translation stabilizes the network of actors and creates a base and commitment to go ahead with innovation.

The idea of non-human actors is often met with resistance by those who are not acquainted with actor-network theory. Hughes (1986), gives an example of human and non-human actors by referring to Callon's case study on the French attempt to design an electric vehicle: "His actors include electrons, catalysts, accumulators, users, researchers, manufacturers, and ministerial departments defining and enforcing regulations affecting technology" (Hughes 1986, p.288).

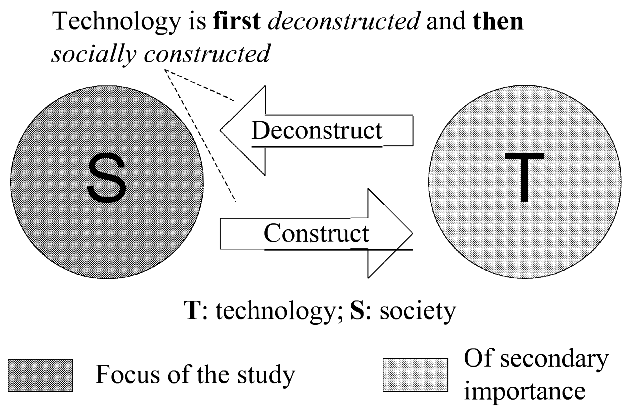

FIGURE 9 SCOT approach

Non-human actors should not be thought of in terms of cognitive abilities; rather, what is central to the role of actor is the influence it exerts on other actors, the way it mandates other actors to behave in a certain way. For instance, think of a computer table exhibited in an IKEA shop, a few years ago the designer of the table would have definitely reserved a place for the central block, but with the advent of iMac, tables now feature this design less often. Thus, the iMac becomes an actor in the development of work@home furniture design.

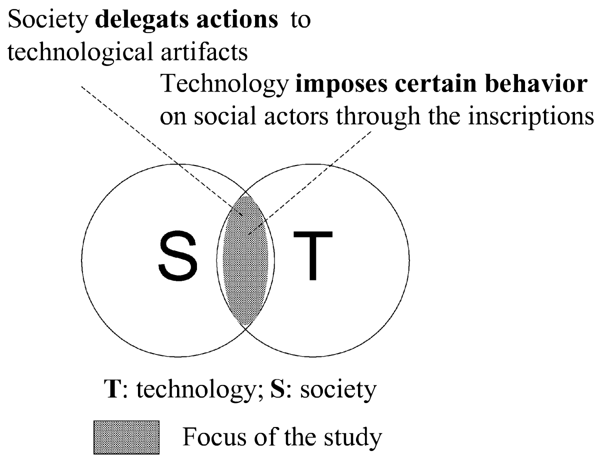

FIGURE 10 ANT approach

Another example of addressing inanimate actors (or actants) in ANT is described by the terms "delegating" and "delegates" (Latour 1999). Humans "*delegate*" actions to other (nonhuman) actants that share our human existence (Latour 1999, p.190). Our meanings and actions are translated into other kinds of expressions in such a way that an object becomes *a delegate* that can stand in for an actor and create an asymmetry between absent makers and occasional users (Latour 1999, p.189). Through delegation actants are carrying past acts of the makers into the present and permit their "many investors to disappear while also remaining present" (Latour 1999, p.189).

The notion of *inscription* helps us to understand how technology becomes an *actant***.** Quoting Hanseth and Monteiro (1997, p.186), "the designer works out a scenario of the system together with the interaction between the users and the system. This scenario is inscribed into the system. The inscription includes programs of action for the users, and it delegates roles and competences to the users as well as the components of the system." Inscriptions impose programs of action on the artifacts' users, and by so doing give a technology the active role of an actor (Hanseth and Monteiro 1997, p.186).

Thus, an actor-network is composed of a series of heterogeneous elements, both human and nonhuman, that have been linked to one another for a certain period of time. For such a network to stabilize, the interests of these actants must be aligned.

When studying the alignment of interests, technology can be seen as providing *interfaces* between different groups of users (Fomin and Lyytinen 2000). The alignment of interests is the result of a successful translation of "the images and concerns of one world into that of another" (Star 1991, p.32). It is a somewhat counter-action to what God did in the story of the Tower of Babel in the passage (Gen. 11:6): "Come, let us go down, and there confuse their language, that they may not understand one another's speech." According to Callon (1986) it is necessary to *interest* the actors if they are to speak the same language again[22]. The degree of alignment of interests (and therefore that of networks) depends on the degree of the success of the translation (Callon 1992). If the alternative translations become improbable, the chosen path becomes irreversible.

From the viewpoint of ANT, advances in a negotiation process can be achieved by simplifying *(black boxing)* the actor networks, after which their behavior becomes predictable independently of its content (Callon 1992, p.90). In ANT, black boxing is a means of coping with complexity. Any socio-technical network we can think of is complex, consider the number of actors involved in the development of the Pan-European or Global standard! How do we attribute the interests of all the actors involved, at all organizational levels? The answer is "by black boxing the actor networks". Hence, we come back to the notion of translation. It is through a successful translation that we reduce the complexity. We make actors speak one language, as if they were building the Tower of Babel: "to translate is… to establish oneself as a *spokesperson*. At the end of the process, if it is successful, only voices speaking in unison will be heard" (Callon 1986, p.223). It is through the aforementioned translation that micro actors *construct* themselves as important and become spokespersons, speaking for many. As Latour (1997) remarks, "Instead of opposing the individual level to the mass, or the agency to the structure, we simply follow how a given element becomes strategic through the number of connections it commands and how does it lose its importance when losing its connections" (Latour 1997).

As already mentioned, studies of technology based on ANT reveal the interplay between a technology and society, and the role of technological artifacts in the formation of socio-technical networks. IS and management studies have traditionally looked at this interplay over time, but merely as a top-down approach to IS/IT building and implementation. This approach was criticized by Ciborra (1998) and others. On a broader level, with reference to the philosophy of science, this problem was first raised by Husserl (1970), and then more recently by Latour (1999). The problem they raise is that reality may not be accommodated within any *a priori* reduction, but is *discovered through practice* (Latour 1999, p.15; Ciborra 1998, pp.1,16). The crucial question is to identify which method is appropriate for grasping the technical and social aspects of science (technology) simultaneously.

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22 "To interest other actors is to build devices which can be placed between them and all other entities who want to define their identities otherwise" (Callon 1986, p.208).

What kind of *practice* enables us to mobilize human and nonhuman agents in one explanatory paradigm? The author argues that actor-network theory is capable of performing this task. Through using ANT in this research, a seamless web will be created, tracing the relations and dependencies between the actors through time. The study will try to reveal the most important players and show how the "construction of facts and artifacts" (Pinch and Bijker 1987) took place during the evolution of cellular technology.

3.4 How Actor-Network theory contributes to the interpretation of the standard setting process

> To transform academic sociology into a sociology capable of following technology through its elaboration means recognizing that its proper object of study is neither society itself nor so-called social relationships but the very actor networks that simultaneously give rise to society and to technology.
>
> (Callon 1993, p.99)

How can ANT contribute to the interpretation of the standard setting process, compared to other sociological explanations? The study of standard making/ setting involves an investigation of the sociotechnical ensembles involved in the process. These are nothing but an intricately interwoven networks of technical and social elements. The complexity of such networks cannot be accounted for simply by invoking *either* social *or* economic/technical factors (Fuller 2000), without resulting in social or technical reductionism (see quotation above). A critical social study would try to separate the social from the technical, but in so doing, by viewing the interaction of technological and social actors only through the lens of social relations, social theorists would be unable to explain why "artifacts enter the stream of our relations, why we so incessantly recruit and socialize nonhumans" (Latour 1999, p.198).

In contrast, ANT focuses on practices linking humans and technologies within and through organizational boundaries (Lehoux, Sicotte, and Denis 1999, p.441) (see figure 10). This focus allows us to analyze how an innovation competes with other existing technologies and humans, thus tracing alternative development paths, and to 'follow' the links between technologies and humans through different contexts of development and use (Lehoux, Sicotte, and Denis 1999, p.441). Thus, one important advantage of ANT compared to either SCOT or more critical sociological approaches, is its linking of human and nonhuman agents (Latour 1999, p.198).

One notable advantage of actor-network theory compared to Hughes's (1983) systems approach, is that of contextual character. Studies of technology for instance, have been criticized for not addressing the contextual settings of the described events. The network approach however, eliminates this separation of context and content, for if a system has an outside, an external environment, then a network by definition does not (Callon 1993, p.100). As Hughes (1986) states, "The organizers of networks leave nothing outside" (Hughes 1986, p.290). Any actor who falls under the lens of analysis and is found to be in interaction with other actors becomes a part of the network regardless of their role or context. "Inventors, engineers, managers, and financiers who have taken a lead in creating and presiding over technological systems show a way of grasping the seamless web" (Hughes 1986, p.285).

As it is argued in this thesis, the process of standard making must be analyzed from its inception to that of market diffusion. To support this proposition, the concept of an actor-network can be successfully used, as it can explain both the first stages of the invention and the gradual institutionalization into the without distinguishing between successive phases (Callon 1993, p.100). The engineers involved in the design and development of a technological system, particularly when radical innovations are involved, must permanently combine scientific and technical analyses with sociological analyses: The proposed associations are heterogeneous from the start of the process, and ANT presents a useful tool in tracing them (Callon 1993, p.100).

3.5 Difficulties in conducting the research, and possible solutions

The reason for having so many different models for technology studies is twofold. First, different schools of thought have evolved gradually, either replacing obsolete ones or finding the possibility to co-exist with those already in existence. The other reason is that no theory alone can fully and comprehensively address the development process of a complex technology (Fomin and Keil 2000). In a similar vein therefore, the actor-network approach also presents difficulties for conducting research based on it. These must now be considered.

3.5.1 How to account for the impact of technology on society?

Winner (1993) has criticized the actor-network and SCOT perspectives for not addressing the impact of technology on society at large. Bijker (1995) partly in response to this, introduced the concept of "technological frame". A technological frame structures the interaction between the relevant social groups built around a technology. The concept "forms a hinge in the analysis of sociotechnical ensembles; it is the way in which technology influences interaction and thus shapes specific cultures" (Bijker 1995, p.252). It also explains how a technology is constructed by the relevant social groups. Nevertheless, this concept still overlooks the impact of technology on society, unless an impact-chain reaction originating from the initial social groups and spreading towards the boundaries of society is assumed, just as ripples on water spread from the place where a stone thrown into the water has penetrated its surface. As Winner (1993, p.375) comments, "They [social constructivists] also show us the fascinating dynamics of conflict, disagreement, and consensus formation that surround some choices of great importance. But as they survey the evidence, they offer no judgment on what it all means, other than to notice that some technological projects succeed and others fall, that new forms of power arise and other forms decline."

This study aims to overcome this criticism by providing a rich account of the consequences caused by the success or failure of a particular technological system. Besides revealing the reasons for success and failure, it will also be shown what consequences these have had for developments in the field of mobile communications. The roles of particular players, whether they be a country, a telecom, or a manufacturer, will be considered and an insight into the future of cellular technology offered. In so doing, the aim will also be to consider the social impact of this technology. A failure which Winner (1993) has criticized studies of technology for omitting:

> "In a peculiar way, then, this is a sociology of technology that has little concern for the ways in which technologies transform personal experience and social relations. The object of fascination is social construction of technical artifacts and processes. But why such innovations matter in the broader context is no longer of any great concern".
>
> (Winner 1993, p.369)

It is necessary therefore to clearly define who are "the relevant" impacted social groups. For example, is the everyday person on the street affected by the technology we study? The question then of "who is affected by technology and who is not" should be asked on different levels, whether it be from R&D laboratories, from regulatory bodies, from persons steering and chairing the development processes, or from the person on the street; "What is your opinion? How did this particular technology change your life?"

3.5.2 How to find out who's in and who's out?

> In order to produce accurate and useful results, the complexities of the organizational context have to be incorporated into an understanding of the phenomenon, rather than be simplified or ignored.
>
> (Orlikowski 1993, p.311) in (Kumar, Dissel, and Bielli 1998, p.201)

Hughes (1986) has criticized studies on the history of technology and science for their internalist and non-contextual nature. He argued that these histories have merely presented the invention of artifacts and the discovery of facts as a chronological narrative, in which technology has been usually defined as the technical artifacts, that is science as knowledge. This as Hughes (1986) states, left the question of the relationship between context and content untouched. "If the relationship between context and content were not specified, then the reader was left asking if context constructs content, if content shapes context, or if there is an interaction" (Hughes 1986, p.283).

The SCOT approach, as noted above argues that the interplay between society and technology can be grasped by including the relevant social groups into the analysis. Winner (1993) responded to the idea of relevant social groups however, by asking a seemingly simple question: "who are they?"

> "Who says what are relevant social groups and social interests? What about groups that have no voice but that, nevertheless, will be affected by the results of technological change? What of groups that have been suppressed or deliberately excluded? How does one account for potentially important choices that never surface as matters for debate and choice?".
>
> (Winner 1993, p.369)

It is the author's opinion that Hughes's (1986) approach can best overcome these contradictions, through using the actor-network approach in conducting a socio-historical study, as a means to resolve the issue of context vs. content and relevant vs. irrelevant.

3.5.3 How to become global while maintaining sovereignty?

This thesis is concerned with technologies, which even though they might have been developed in the lab of a single organization, cannot be utilized without the appropriate legislative actions. A unique quality of mobile technology is that it uses the radio spectrum, a scarce and strictly "regulated" resource in any country. This suggests, and paying heed to the issue of "relevant social groups", that actors representing legislative bodies need to be taken into account in the study. If regulatory legislation is influential, then the design of the device reflects the requirements anticipated. Technical artifacts reflect the background or environment, so that the "so-called social and political background are embodied in the technology" (Hughes 1986, p.290). Political questions are not only however related to legislative bodies. Referring to Kling et al. (1980) and Markus and Robey (1983), Kumar and his colleagues (1998, p.200) write, that organizations need to be considered as a forum for political activity, where actors are engaged in conflict, intrigue, and negotiation based on their private interests. Consequently, power and politics become the key concepts in which the interplay of conflicting objectives and the operation of supposedly "non-rational" choice processes determine the consequences of technology.

These inter- and intra-organizational political processes can be associated with regional players. Nowadays, technologies rarely stay within the boundaries of sovereign states. Ancarani (1995, p.654) points out an interesting implication of globalization:

> "… some new institutional factors of globalization, such as the emergence of great multinational corporations (MNCs) and other transnational actors on the world scene, have affected world politics by causing a shift in the environment of international relations… One possibility for change is that these new actors, by

> vigorously challenging the authority of the nation-states, may compel governments to adjust their policies".

We can see this situation clearly in the case of GSM, where an EU directive was issued to force EU countries to allow GSM handsets to be used freely, despite these countries' own regulations. For example, in Greece, there existed strict control over radio receivers and transmitters as a potential threat to national security, and GSM mobile phones would fall into that "forbidden" category. As a member of the EU however, Greece had to tow the line, and the use of cellular telephones became possible:

> "… in other countries, such as Greece, the possession of radios was considered a matter of state security. Therefore even if the PTT in Greece would like to adopt the NMT system and exchange the traffic with the Nordic countries, and possibly they could not have done so without having the national law changed. Because security interests dictated that transmitters were not allowed to be owned by individuals. Only receivers, and receivers for only TVs and radios. Therefore, to make it European, you needed a directive, and a directive is above the national legislation. You have to implement the national legislation so that it is in accordance with the directive".

(Fomin 2000)

Ancarani (1995, p.656) emphasizes the importance of the above issue: "growing interdependence means that increasingly a variety of issues cannot be addressed, let alone solved, on a national basis. They require a wider approach and deserve ample international agreements, effective control and management activities, and huge allocations of resources". This very well depicts the environment in which the GSM standard has been developed. International coordination was needed and crucial at some points. To an even greater extent this coordination and steering will be required in the development and implementation of the 3G cellular systems. One of the contradictions inherent in the term "globalization" is that countries are trying to preserve their national freedoms whilst at the same time benefit from international interdependence (Ancarani 1995, p.659). This contradictive endeavor is reflected into the design of the technological systems these countries cooperatively develop. A striking example is frequency allocation policy. Although a scarce resource in every country, frequency allocation is to some extent also regulated and coordinated by international bodies, for example, the WARC[23].

3.5.4 How to account for culture in the global village?

Does culture of a particular actor determine her behavior? How does the social constructivist approach deal with the issue of culture with respect to studies of technology? Winner (1993, p.371) has criticized social constructivist approaches in that "insofar as there exist deeper cultural, intellectual, or economic origins of social choices about technology or deeper issues surrounding these choices, the

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23 World Administrative Radio Conference.

social constructivists choose not to reveal them" (Winner 1993). This study aims to overcome such criticism by including within it cultural and political aspects. The author does not regard actors as having homogenous patterns of behavior, but as having a possibility to alter "standard" decisions depending on cultural, political, intellectual or other considerations, and hence having a bounded rationality (Simon 1977). The importance of culture shouldn't be underestimated. As Layne (2000) remarks, "Just as the addition of "gender" to anthropological (and other social) theorizing meant more than "add women and stir," the inclusion of a broader understanding of "culture" in STS[24] is transforming some of the fields fundamental understandings of where and how technoscience is produced" (Layne 2000, p.369). The importance of the cultural issue in technology studies has been shown by Kumar and his colleagues (1998). Results of a case study on inter-organizational information systems revealed that techno-economic and socio-political perspectives are insufficient to provide an explanation of the failure of the studied system, and that the culture of actors plays an important and crucial role (Kumar, Dissel, and Bielli 1998). As Kumar et al. (1998) state, "While economic, technical, informational and logistical elements of the bond may be self evident in industrial networks, the relevance and significance of non-economic dimensions such as social or legal dimensions are mainly culture specific" (Kumar, Dissel, and Bielli 1998, p.214).

3.5.5 How to take account of both economic and social trends?

By basing the study on a social constructivist approach, it does not mean that economic issues can be totally neglected. Although it is agreed that we may not assume that actors are *always* basing their decisions on rational (read economic) considerations (Simon 1977), as we live in a market economy world, the issue of money and profitability, for example, can not be ignored. For this purpose Layne's (2000) notion of a "technological fix" is of interest. A technological fix seeks "to use the power of technology in order to solve problems that are nontechnical in nature" (Layne 2000, p.353). From this point of view, the NMT and GSM systems can be seen as technological fixes designed in response to broader economic or political events or issues, such as The Treaty of Rome, and growing globalization. Technological systems are a part (and sometimes a very significant one) of a country's economy. This has been especially evident in the recent spectacle of frequency spectrum auctions for the 3G systems in many European countries, where more than 100m Euro were paid to the national governments budgets.

Irrespective of whether national and global technologies will be a source of income or an account of spending for a nation-state, they first have to be developed. Howells (1990) stresses, that increasing attention by policy makers has been focused on research and technology as a means to stimulate and expand national economies. "The establishment support costs of R&D

[24] STS – Science and Technology Studies.

laboratories have grown considerably in recent years as research teams demand more sophisticated equipment and facilities, whilst the sheer cost of producing a major technological breakthrough has been rising during the 1970s and 1980s. It has been the development costs that have risen fastest". (Howells 1990, p.275.)

3.5.6 Concluding remarks

How is it that from such a plethora of theories and approaches it is difficult to choose a single satisfactory one? How is it that so much criticism of existing theories has been made? Is it therefore wise to theoretically ground the research at all? Mowery and Nelson (1999) in their book on national innovation systems, state that the reasons for a lack of correspondence between industrial histories and theories are that, first, "most of these theories are applicable to a narrowly defined product line or market segment, rather then to the broad industries … In addition, the theories discussed focus on a single "life cycle" that is specific to a given product or technology" (Mowery and Nelson 1999, p.11). Following Mowery and Nelson (1999), this study will examine multiple technological generations over longer periods of historical development. In order to be able to cope with the complexity of the issue therefore, we cannot limit our scientific inquiry to a single body of theory. "Economic, or social theories alone cannot explain fully the passages of standardization processes" (Fomin and Keil 2000, p.215). The approach chosen has made it possible to employ arguments from different groups of theories. In so doing, one can analyze not only the whole standardization process of cellular telephony, from it's inception to implementation in the market, but also the development of several generations of the technology across different continents. This is in contrast to most previous research which has looked at standard creation and diffusion processes in separation, as independent knowledge creation and diffusion cycles (Farrell and Saloner 1988; Rogers 1995). Despite his criticisms, Winner (1993) clearly also sees the advantages in this use of a socio-historical approach:

> "As a way of studying the dynamics of technological change, this approach does offer some interesting advantages. It offers clear, step-by-step guidance for doing case studies of technological innovation… Another useful contribution of this approach is to reveal the spectrum of possible technological choices, alternatives, and branching points within patterns sometimes thought to be necessary. Social constructivist interpretations of technology emphasize contingency and choice rather than forces of necessity in the history of technology".
>
> (Winner 1993, p.366)

3.6 Development of cellular mobile telephony

In order to study a phenomena associated with or originating from a certain domain, we must have a concept of what that domain is. Thus if we set an objective to develop a model of standard making based on findings from processes and practices originating from the development of cellular mobile telephony, an ontology of cellular technology must be presented to the reader. In order to fulfill this task, the history and basic principles of cellular mobile telephony need to be outlined.

In the telecommunications domain new technologies are being developed at a high pace. New technologies give rise to new services. The telecommunications industry is often referred to as an "enabling industry", that is, it creates opportunities for societal development in the broader sense (Anders 1997). Cellular telephony emerged as an addition to traditional wireline telephony and inherited from it, its basic features (Manninen 1999; Toivola 1992). Originally, it was considered as a "special access" to the telephone network, but due to the rapid growth of the significance of mobility and the ever-widening range of services it provides, it has acquired the status of an independent industry, despite the fact that it still uses wireline networks as a transportation system.

The telecommunications infrastructure, and cellular telephony in particular, forms a tangible system. In The Oxford Encyclopedic English Dictionary (Oxford 1991) *infrastructure* is defined as (1) "the basic structural foundation of a society or enterprise; a substructure or foundation," and (2) "permanent installations as a basis for military etc. operations." The telecommunications infrastructure can be studied in a similar way to railroad or highway systems. Edwards (1998), describes these systems as "true systems, with one or a few basic functions, relatively stable properties, and readily identifiable boundaries" (Edwards 1998, p.13). According to Edwards (1998, p.13), "the 'system-builders', and key organizations can be located and carefully studied. Comparative international studies of the same kinds of systems in different countries shed light on the social, political, and cultural shaping of those systems" (Edwards 1998, p.13). In developing a systematic and comprehensive account of standard making, a basic understanding of the technologies standardized is needed. The tangibility of the infrastructure involved in cellular technologies gives us an advantage in pursuing this goal in this study. It will be considered how differences in the external process environment have shaped a standard's development process. The social, political, and cultural shaping of those systems will be considered.

In one of the most respected works on the development of cellular telephony published in 1988, Calhoun evaluates the problems of the technology of cellular mobile telephone systems in the light of a larger question: "how and when will the two hemispheres of communication – the wireline network… and the emerging wireless systems of the future – grow together, *interconnect*, and become… *transparent* to one another?" (Calhoun 1988, p.5). Today, in 2001, it appears that the two hemispheres are mingled to the extent that they have become *transparent* to one another and also to their subscribers. Nevertheless, they still remain distinctive infrastructures each with their own history and lineage, up to the point when they first married to give birth to what we call today a *wireless cellular telephony*. In the subsequent sections we will take a journey through time to trace the development of radio and wireline telephony in order to understand what challenges were and are associated with the development of the cellular telephony we use today.

3.6.1 Development of telephony

To explain what *cellular telephony* is, telephony itself must first be defined. To do so, it is first necessary to distinguish between a physical telephone network and a telephony service (or *teleservice*). A *telephone network* is the bearer of the service called *telephony* (see figure 11) (Anders 1997). Network operators can offer their customers telephony services and bearer services. Bearer services provide a transport system for transmuting data only, whereas teleservices are somewhat more "complete", that is, they encompass transport services, network connection functions, plus a uniform "language" for communication. The point of a teleservice is to set up a connection between two telephone subscribers, so that they can talk to each other.

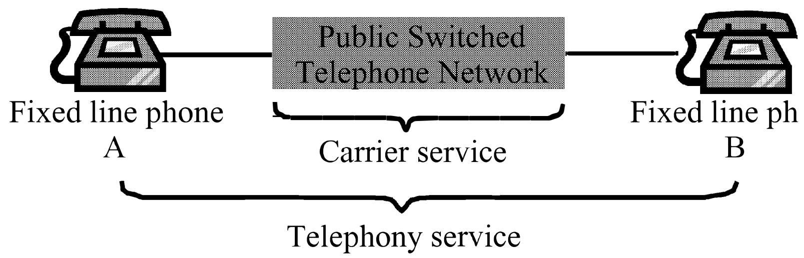


FIGURE 11 Bearer and telephony services

In 1861, a German schoolteacher named Johann Philipp Reis invented a device for transmitting the vibrations of human speech over an intermittent circuit to another location, where it was reproduced (Calhoun 1988, p.145). Reis called his device a "*telephone*". The telephone was introduced to the public in 1876 at the Centennial exposition of the United States in Philadelphia. Alexander Graham Bell showed how it was possible to transmit speech electrically over a copper wire circuit of several hundred feet in length (Calhoun 1988, p.7). In the following year a "speaking telegraph" was offered for business and residential service. Initially, deployment of Bell's invention was constrained by the need to construct and maintain a network of "transmission facilities, millions of miles of poles, wires, cables… to link each user physically with the switchboards in the nearby 'central office'" (Calhoun 1988, p.7). These "millions of poles, wires, and cables" became known as the Public Switched Telephone Network (PSTN) as in figure 11. The PSTN is often referred to as the *infrastructure* needed to provide teleservices.

In the modern phone system, an electronic switch has replaced the traditional switchboard operator. Regardless of the type of operation performed, this switch became known as a *telephone exchange*. The first telephone exchange was installed in New Haven, USA, in 1878 (Anders 1997).

With the growth of telephone networks and the advancement of technology, operator assisted manual *circuit switching* was replaced by automatic circuit switching. Already in 1889, Almon B. Strowger (Kansas City, USA) applied for a patent for an automatic telephone exchange (Anders 1997). Initially, automatic exchanges were electromechanical, later they were replaced by digital computer-controlled switches.

3.6.2 Development of radio

In parallel to the development of telephony, the development of the radio took place. During the 1890s and 1900s, the Italian inventor Guglielmo Marconi pioneered the practical application of radio waves and was the first to commercialize his invention (Lindmark 1995). He called the transmission of electro magnetic waves *Radio* (Calhoun 1988, p.8). Twenty years after the commercial introduction of radio broadcasting in the United States in 1921, more than 90% of American households had a radio set (Calhoun 1988, p.8). One of the reasons for such a rapid adoption compared to the only 15% penetration rate of the telephone after 50 years of commercial service (Calhoun 1988, p.11), was that the use of a radio did not require the building of a huge infrastructure. This advantage was early recognized, amongst others, by John J. Carty, regarded as the founder of the scientific tradition that led to the creation of Bell Laboratories. Even before he became head of engineering for AT&T, he wrote in 1891 in regard to the electromagnetic waves discovered by Hertz that: "A system of telephony without wires seems one of the interesting possibilities" (Calhoun 1988, p.9).

From the beginning of the radio era, two-way mobile radio communications (between a base station and a mobile) were utilized, for example, by the U.S. Navy. In the early days, due to technical challenges it was not possible to build transceivers mounted on land vehicles. In the 1920s however, the Detroit Police Department first experimented with a one-way land vehicle radio broadcast system (Calhoun 1988), and by the end of the same decade, a two-way vehicle-mounted mobile radio system had been developed. Motorola, a U.S. based radio company, developed its first car radio telephones in the early 1950s, in response to a request by the U.S. monopoly telephony service operator AT&T, which launched the world's first commercial mobile telephone service in St. Louis in 1946 (West 2000). This, and the other early mobile telephone systems consisted of a radio base station and vehicle terminals (Lindmark 1995). The radio base stations were connected to the fixed telephone network and used its carrier service. The analogous technology used however, was not able to provide for an efficient utilization of a scarce resource like the radio spectrum, for as the demand for mobile radio telephony grew, the utilization of the spectrum grew proportionally, which resulted in a lack of capacity of available frequencies. The critical innovation needed to solve the capacity problem was that of the *"cellular"* network.

3.6.3 Emergence of the cellular idea

The *cellular* concept was first described by D.H. Ring of AT&T in 1947, but the first fully licensed cellular telephone system in the U.S. did not become operational until 1983 (West 2000). The idea of a *cellular network* held the promise of a virtually "unlimited" system capacity (Calhoun 1988). The increase in capacity resulted from the reuse of frequencies (see figure 12).

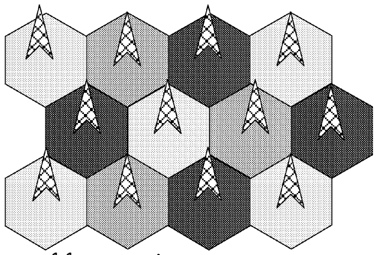


FIGURE 12 Cell pattern for reuse of frequencies

Cells are individual service areas, each of which has a group of discrete channels assigned to it from the available spectrum. Frequency reuse allows the discrete channels assigned to a specific cell (for example, cell #1) to be used again in any cell which is separated from cell #1 by sufficient distance to prevent co-channel interference (Mehrotra 1994, p.1). For example, the two cells filled in with the same color in figure 12 can reuse the same frequencies.

3.6.4 The architecture of cellular systems

The development of cellular telephony can be better grasped when an understanding of the building block upon which the technology rests is clarified. In order to emphasize the complexity of cellular systems it is necessary first to become acquainted with the architecture of cellular mobile telephony systems.

Similar to the concept of a wireline telephony service (see figure 11), a wireless teleservice must set up a connection between two telephone subscribers, so that they can talk to each other, with at least one of the two using a mobile telephone device. When calling either a wireline or wireless network, a switch makes the connection between the line of the person calling and the line of the person called. Switches thus transfer calls between different users, and both types of networks rely on them. A simplified architecture of a cellular mobile telephony system is shown in figure 13.

The major technical difference between wireline and wireless networks arises from an obvious distinction, namely the use of wires versus radio signals. The above implies that in a wireless network, instead of having a circuit connection established over a copper wire, a radio circuit must be set up between an user's mobile terminal (MT) and a base station /antennae/ (BS), which is connected to the PSTN through a switch (MTX) (see figure 13 through

16). Moreover, it is assumed that any mobile telephone system conforms to the following service objectives (Calhoun 1988, p.276):

- It utilizes full-duplex, telephone-type circuits, rather than the simplex, push-to-talk circuits commonly used in pre-cellular mobile radio systems;
- It provides the equivalent of single-party service, that is, circuits are not simultaneously shared among many users;
- It is a fully trunked, *multiple-access* system, that is, there is no preassigning of specific channels to specific users, but circuits are assigned to individual users at the time of call set-up.

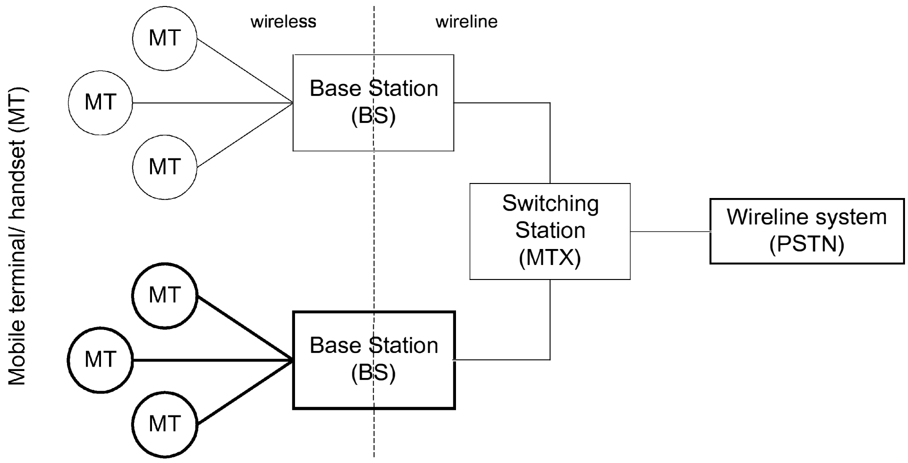


FIGURE 13 Outline of a typical mobile communication system[25]

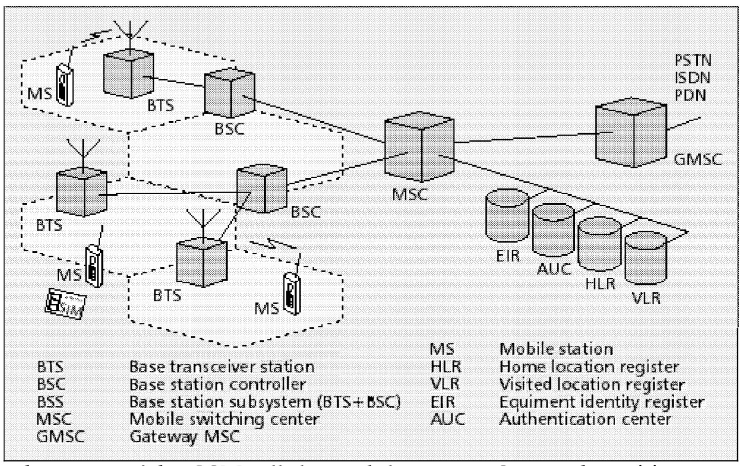
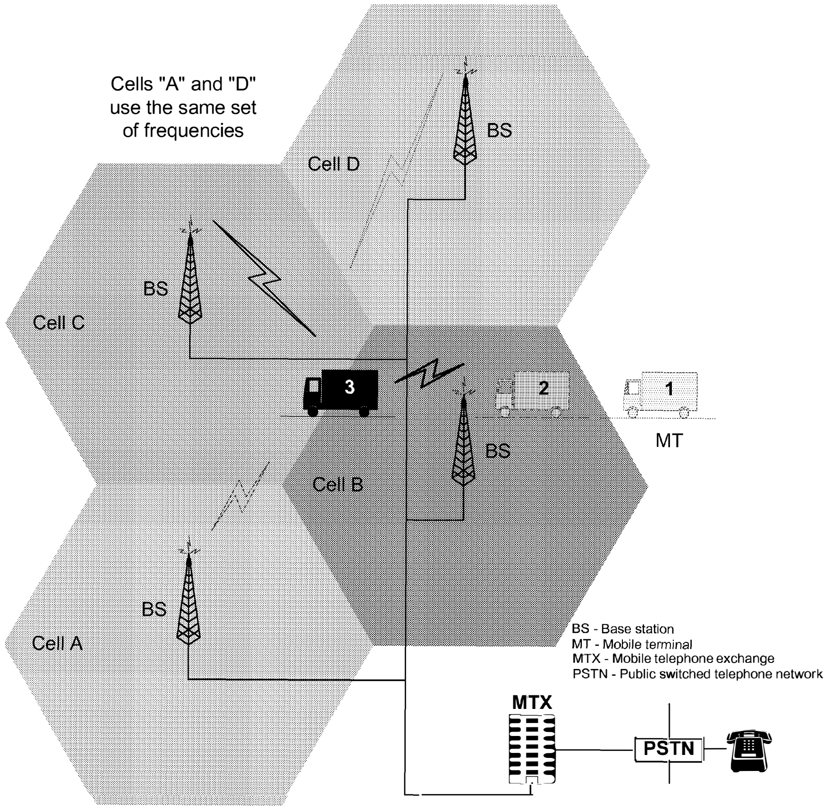
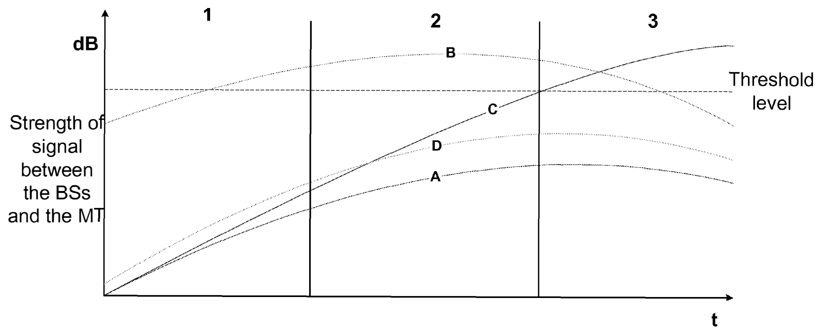


FIGURE 14 Architecture of the GSM cellular mobile system. Source: http://www.uwc.com

[25] The emphasized part of the system is depicted in figure 16.



Measuring signal strength in different cells (A,B,C,D)
for the moving truck's positions (1,2,3)



As the signal in cell "B" declines, the circuit will be handed over to cell "C", which shows the highest signal level

FIGURE 15 Handover mechanism in cellular systems

In order to function as an ordinary telephone system, the cellular solution requires two additional functions: handover and roaming (Lindmark 1995). A *Handover* mechanism ensures that the phone call is not interrupted when the mobile terminal is moving from one cell to another. The system is "handing over" the phone call from one base station to another and from one frequency to another (Lindmark 1995). *Roaming* forms a function, which allows the system automatically to set up incoming calls, regardless of the mobile's location. It implies that the system must know where the mobile is located at the moment of the call set up (Lindmark 1995). Both these functions require advanced intelligence, high speed signaling, and a high memory capacity. *Memory capacity* is needed to maintain a subscribers' location register, as the system must know at any moment where a particular mobile is located (see figure 14), and *high signaling speed* is needed for measuring *signal strength* as part of a handover operation (Lindmark 1995) (see figure 15).

The introduction of these two functions, handover and roaming, made it possible to make uninterrupted phone calls when moving from one cell to another, and the automatic set up of a phone call regardless of the mobile terminals' location.

It should be remembered that national landline telephone networks have been interconnected since the beginning of the century. As the cellular network would use the PSTN as a transport carrier (figure 11), it would therefore become possible for mobile service subscribers to use the service when abroad, as long as there was radio coverage for it. International automatic roaming therefore, would be an essential building block of the Global Information Infrastructure

3.6.5 Radio access techniques

According to the requirement of multiple-access capability, a method must be established for allocating individual circuits to individual users on demand (Calhoun 1988, p.283). There are at least three common access techniques used by cellular telephone networks for transmitting information:

- Frequency Division Multiple Access (FDMA)
- Time Division Multiple Access (TDMA)
- Code Division Multiple Access (CDMA).

Multiple access means that more than one user (multiple) can use (access) each cell[26] (See figure 16). Frequency, Time, and Code refer to the nature of the access method used and, *division*, tells us that it splits calls based on that access method. When utilizing FDMA, each user is assigned a different frequency channel (See figure 17). Thus, FDMA uses one telephone circuit per channel. The 1G analogue cellular systems utilized this technique.

TDMA is a digital technique for channel sharing, which assigns each call a certain portion of repeating *time slots* on a designated frequency, where each time slot constitutes an independent telephone circuit (see figure 18). Because the data from each user always appears in the same time slot, the receiver (MTX) can separate the signals. GSM is based on this technique.

CDMA is another digital technique that enables cell phone users to share a frequency channel. It gives a unique *code* to each call and spreads it over the available frequencies by splitting the signal into many "chips" of data (see

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26 A comprehensive explanation of techniques for non-expert use is given by Brain & Tyson (2001).

figure 19), each of which is tagged with the user's code. The receiver (MTX) also uses the same code to select the proper transmission from among the many simultaneous spread-spectrum circuits in operation (Calhoun 1988, p.288). CDMA is the basis for the IS-95 standard.

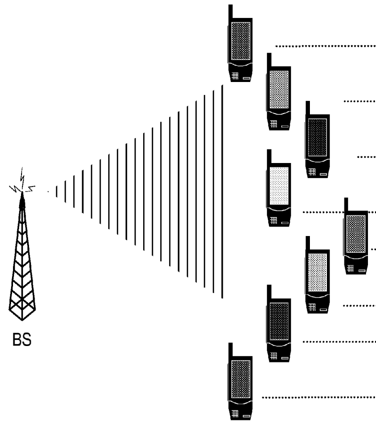

FIGURE 16 Multiple access technique

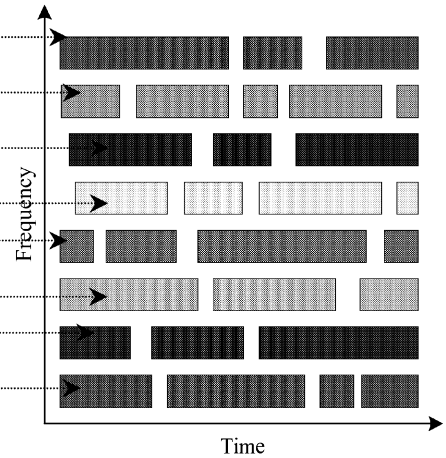

FIGURE 17 Frequency Division Multiple Access – FDMA[27]. Adopted from (Harvey 2000)

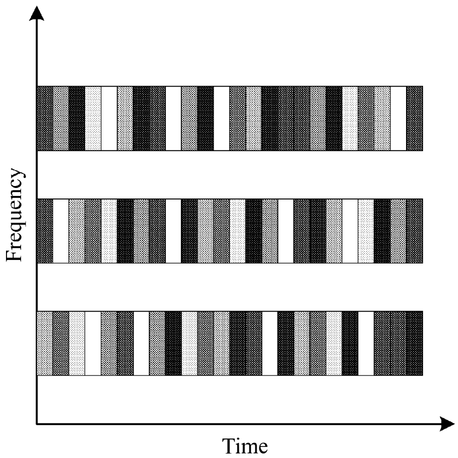

FIGURE 18 Time Division Multiple Access – TDMA. Adopted from (Harvey 2000)

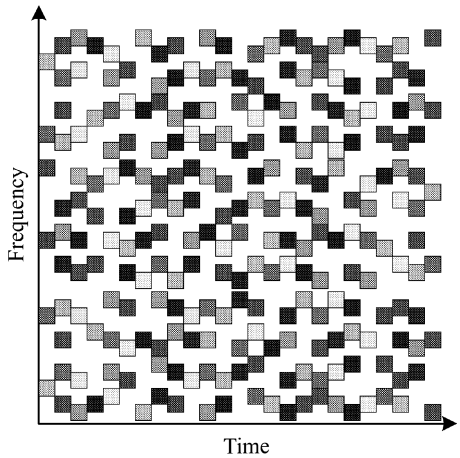

FIGURE 19 Code Division Multiple Access – CDMA. Adopted from (Harvey 2000)

A tightly synchronized format like TDMA or CDMA could significantly increase the complexity and the cost of mobile units. FDMA uses one channel

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27 Breaks in the colored bars indicate that the channels are not in constant use. It is a consequence of the nature of human conversation – one does not speak uninterruptedly. A circuit is established only when a person is speaking, thus leaving idle (or unused) fragments of the radio channel.

per circuit, and while being easy to implement, does not provide efficient use of the radio spectrum. There are also different possible modifications/ combinations of these three main techniques. For instance, the Wideband Code Division Multiple Access (W-CDMA) technique which will be used in the 3G systems is a refinement of CDMA, that spreads the chips of the wireless signal over a much wider band of frequencies.

3.6.5.1 Radio access as a critical part of standardization

The link between the BS and the individual mobile-telephone user is an essential part of the cellular system. The choice of *radio technology* will determine to a great extent the economic and performance characteristics of the cellular system (Calhoun 1988, p.297). By radio technology it is meant a combination of the radio access *(modulation)* method and *voice coding* technique. Modulation is defined as a method of imposing the information signal onto the carrier signal in order to accomplish cost effective and accurate transmission, to achieve maximum range and minimum interference. Starting from the early 1980s, when digital cellular system development projects were initiated in different countries, the question of *radio access* became crucial. Unlike FM transmission which appeared to be technologically stable and which was used in the early 1G analogous systems for voice transmission, and against which there were really no competing options in the early 1970s, digital transmission systems multiplied by the dozens (Calhoun 1988, p.432). The rate of generational technological change with respect to coding and modulation is about three to five years (Calhoun 1988, p.432). This means that in five years the performance characteristics of today's coders will have been superseded by a factor of two or more. Approximately the same time is needed to standardize voice coding. Thus, selecting a modulation technique, and hence radio access, in the course of the standardization of a cellular telephony system is a critical issue. Moreover, as there is a great diversity of digital processing schemes, each manufacturer has its own proposals for coding and the associated techniques. Having invested large amounts in R&D to develop these techniques, manufacturers will stick with them, even given their technological inferiority compared to others (Manninen and Fomin 1999; 2000). It is a question not only of losing money invested, but also of having to pay royalties on IPRs to the owner of the chosen technique (Bekkers and Liotard 1999).

Voice coding and carrier modulation (radio access technique), the two fundamental technologies in a digital mobile system, are logically interdependent processes (Calhoun 1988, p.334). Any coding algorithm may be combined with any modulation technique. Improvements in coding and improvements in modulation generally favor spectrum efficiency, the number of telephone voice circuits used per megahertz of spectrum.

Circuit spectrum efficiency is an important baseline comparison for different technological designs, as the radio spectrum is inherently limited in capacity and subject to strict governmental regulation (West and Fomin 2001).

An overview of different cellular systems and the radio access techniques used is given in table 12.

TABLE 12 Different generations of cellular systems and radio access techniques used. Source: (Funk 1998), (Funk and Methe 2001), (Calhoun 1988), (Bekkers and Smits 1998)

Generation of technology	System / Year of introduction	The standard's country of origin	Utilized radio access technique	Frequency band	Channel bandwidth,
1G – analog	AMPS (83)	US	FDMA	800	30
	MNT (81)	Scandinavia	FDMA	450	25
	TACS (84)	UK	FDMA	900	25
	CNETZ (86)	W.Germany	FDMA	450	20
	RC2000 (85)	France	FDMA	200, 420, 900	12.5
	NTT (79)	Japan	FDMA	800	25
	RTMS (85)	Italy	FDMA	450	--
2G – digital	DAMPS (92)	US	TDMA/ FDMA	800, 1900	25
	GSM (92)	Western Europe	TDMA/ FDMA	900, 1800, 1900	200
	PDC (93)	Japan	TDMA/ FDMA	800, 1500	25
	CDMAOne (95)	US and Korea	CDMA	800, 1900	1.25
3G – digital		Western Europe	W-CDMA	2000	--
		Japan	W-CDMA	2000	--
		US	Various	--	--

3.6.6 The drive for innovation

As depicted in table 12, within cellular mobile telephony we can distinguish three generations of technology[28]. First-generation systems (1G) which were analog and circuit switched. Voice links were poor, handoff unreliable, capacity low, and security non-existent. Furthermore, 1G systems originally did not have the capability of data transmission. Second-generation systems (2G) on the other hand, use digital signal/voice encoding. These protocols support voice and limited data communications, measured in kbits/s[29]. They offer auxiliary services such as data, fax, and SMS. Most 2G protocols offer different levels of encryption and security. 2.5G protocols extend 2G systems to provide additional features such as packet-switched data transmission (GPRS) and enhanced data rates (HSCSD, EDGE). Finally, third-generation protocols (3G) support much higher data rates, measured in Mbits/s, intended for applications

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28 Indeed, the development work of forth generation (4G) technology has already began, but it will take at least a decade before any plans for implementation are made.

29 See also table 13.

other than voice. 3G networks are expected to start in Japan in October 2001 and in Europe in 2002 or 2003. 3G will support such applications as full-motion video, video conferencing, and full Internet access.

Despite the aforementioned differences, the fundamental principles of a cellular network remain the same regardless of the generation of technology used. What however changes, is the radio access technology used (See table 12) and the scope of services (see table 13) the end-user has access to, through the service. These two variables, efficiency and service, can to a large extent explain the drive behind the development of different generations of cellular systems, from 1G in the 1970s to 3G at the turn of the millennium.

The evolution of cellular telephony to a large extent has been driven by increasing demand for both service volume (number of users) and scope (number of different services besides voice). Each generation of cellular telephony has had its own limitations, the overcoming of which required the development of new technological innovations.

3.6.6.1 Spectrum efficiency

The most critical limitation of cellular mobile telephony in the light of ever growing demand is the limited frequency spectrum available for service provision. Having said that each new generation of cellular telephony has had a more efficient spectrum utilization than its predecessors, advanced digital signal processing, compression, coding, network-control techniques, have all been used to conserve radio bandwidth.

Shortly after the introduction of the NMT-450 system in the Nordic countries at the beginning of 1980s, teleoperators faced rapidly growing demand for the service. Congestion of radio channels in large cities became commonplace (Lyytinen, Manninen, and Fomin 1998). Allocating additional spectrum bonds for the services would only solve the problem temporarily, and even this was not possible due to the strict regulations imposed in many countries. Thus, developing more efficient modulation and voice/data coding techniques was often the only solution to the spectrum shortage problem[30].

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30 One of the biggest determinants of a cellular system's capacity is the frequency re-use factor. The capacity of a cellular system will almost triple when the frequency factor is reduced from 7 to 3 (see figure 12). The problem in assessing different cellular systems, however, is that the re-use distance for a given standard is difficult to establish. Although some articles may mention re-use distances (or re-use factors) as if they were inherent to a standard, in fact they are not. They depend on (from correspondence with Rudi Bekkers):

- the required signal-to-interference ratio of the radio interface;
- the frequency band of the system in question;
- the experience of the cell planners;
- the exact locations of cells (an antenna below a rooftop, for instance, generates less interference for other cells, and lowers the allowed re-use factor);
- the radiation patterns of the antennas used;
- the use of addition features such as frequency hopping, discontinuous transmission (DTX), and so on.

3.6.6.2 Security

The FDMA of first generation systems supported clear communications, but the transmissions were easy to intercept on a standard radio receiver. An even bigger problem was the unauthorized use of the system, or fraud, when an unknown person could forge a caller's identity and thus "hang" call charges on the subscriber. The large number of fraud calls in the NMT system caused teleoperators to establish special interception groups in order to trace such misuses (Lyytinen, Manninen, and Fomin 1998).

The introduction of digital second generation systems solved most of the problems associated with the service security of the 1G systems. Personal Subscriber Identification Modules (SIM) are used, for example, in GSM handsets, which can be activated only by entering a four-digit Personal Identification Number (PIN) code. The voice transmission is also encoded which prevents eavesdropping.

The current trends in Internet security have imposed new requirements on cellular mobile systems. With the advent of WAP and i-Mode technologies which enable Internet access from a mobile terminal, security techniques commensurable with those of the Internet must also be implemented in handsets. In the search for a "killer application" for the 3G system, Japanese developers anticipate that cellular telephone devices could be used as an electronic wallet (Stevenson 2001). If this were to become reality, stricter security measures than those offered by SIM/PIN combination must be implemented in the 3G systems.

3.6.6.3 Uses of data

The first generation of cellular systems could not provide data transmission use due to the inefficiency of the handover mechanism. There was an interruption of the signal when the MTX switched the phone call from one base station to another. This interruption was unnoticeable in voice communication, but any data message which was transmitted through the cellular channel at the moment of handover was lost (Calhoun 1988, p.111).

The development and introduction of digital systems eliminated that problem. Through the use of digital coding and modulation, data transmission became much more efficient than voice transmission. According to Calhoun (1988, p.113), in the time it would take to read this sentence aloud, it is possible to transmit several pages of text at 9.6 kbits/s, the data rate of GSM.

The introduction of data transmission into cellular telephony enabled the use of fax, short messaging (SMS), Internet access, and other specialized services. However, the data transmission rates of the 2G system compared to those of wireline modems were very low, compare the 9.6 kbits/s offered by GSM to the 56 kbits/s of today's wireline modem. Therefore, as many cellular service providers regarded data communications as a potentially large market, efforts were taken to develop new techniques for more efficient data transmission. As a result, 2.5G systems were introduced on the GSM network (see table 13).

The growth of the Internet and the possibility of using mobile communications as a means of exchanging large amounts of data suggests that there may be a large potential need for a third generation system (Funk 1998, p.438). The 2.5G will be a good test-bed for evaluating the market potential of wireless data communication.

TABLE 13 Uses of data in 2G and 2.5G mobile networks[31]

Type of data	Size, kB	Transfer time on the 2G network (GSM, speed 9,6 kbits/s)	Transfer time ont 2.5G network (GSM+GPRS, speed 30 to 384 kbits/s)	Transfer time in 3G network (speed 114 kbits/s to 2 Mbtis/s)
10-15 lines of email text	1	1 sec[32]	< 1 sec	< 1 sec
6 pages of Word document	70	1 min	2 .. 20 sec	0.3 .. 5 sec
Picture in GIF format	100	1.5 min	2 .. 30 sec	0.4 .. 7 sec
10 pages of Power Point presentation	1000[33]	15 min	20 sec .. 5 min	4 sec .. 1.1 min

3.6.7 Institutional influence

Institutional actions can either stimulate or retard IT development and/or diffusion. Supply-push and demand-pull market forces are linked to the influence and regulatory authorities of institutions (King et al. 1994). The development of wireless communications (radio) depends on a scarce resource, the radio spectrum, which requires government policy to allocate these resources to service providers. Governments' historic role in the development of telephony has been that of regulating the monopoly or oligopoly of service providers, which has had indirect effects upon the innovations of the manufacturers (West and Fomin 2001). The convergence in the early 1980s of the mobile radio and telephone sectors, with distinct industry structures and technological competencies, accelerated the role of institutional intervention on the diffusion of the resulting product, cellular mobile telephony. King et al. (1994, p.143) write that innovation immerges from a complex interplay of precursing economic and institutional conditions, "the perceptions and

31 In this table the transfer time is calculated for pure data. In reality, data must be encoded for transmission, resulting in increased volume and longer transfer time. 9.6 kbit/s is 1.2 kB/s (1 Byte = 8 bit).

32 In the 2G GSM system one must always add 20 to 30 seconds for establishing the network connection. In the 2.5G and 3G systems the mobile terminal is "always connected" to the network, which means that no additional time for establishing the connection is needed.

33 1000 KB is 1 MB (one megabyte). 1 megabyte (MB) corresponds to about 800 normal WAP pages, 900 e-mails (25 kilobytes each) or a 90-page Word document.

decisions of entrepreneurs, and the ongoing refinement and improvement of the innovations as expertise is gained in their production and application" King et al. (King et al. 1994, p.143). Thus, besides the technological aspects affecting the rise of cellular mobile technology, institutional factors had a significant role. In particular, it can be argued that such seemingly mundane but yet inseparable aspects of wireless telephony such as numbering and billing, gave the Nordic NMT system much broader acceptance and success in local markets compared to its North American "technological twin" AMPS in the early 1980s.

The developers of NMT and later the GSM made an additional effort to develop an ingenious numbering plan for these systems (Lyytinen, Manninen, and Fomin 1998; 2000). This decision was prompted by the way the developers of the system conceptualized it. They regarded cellular mobile telephony as an extension of the existing wireline telephony service (Manninen 1999; Toivola 1992), and thus the new system had to inherit all the institutional principles of it's predecessor. One of these "rules" was that the calling party would bear the call charges. Thus, when placing a phone call from a wireline (fixed) network to a subscriber of a cellular network, the caller needed to know from the number called that the cost of the call would be different and usually higher from that of a call to another subscriber on the fixed network.

In the North American AMPS system designers envisioned a different scheme, whereby both calling and receiving parties would share the cost. The caller would not be able to tell from the number whether the recipient was subscribed to a fixed or mobile network. In this way, by not following the charging principles of the fixed network, the North American cellular systems changed subscribers' attitudes towards the telephone service, and they became reluctant to answer calls, knowing that they would bear a charge. Moreover, the charging policies reduced the incentive for users to distribute their phone numbers or keep them switched on (Funk 1998, p.434). As a result, the diffusion of cellular services in the US witnessed a slower momentum compared to that of Europe and other countries which adopted the European systems operational principles.

King et al. (1994, p.14) point out the importance of institutional factors in the kind of situation as described above:

> "What explains those instances in which all the apparent obstacles to diffusion are overcome and yet an innovation still does not diffuse in a manner predicted by a rational economic action among disaggregated actors? ...It explains why economic historians have begun to describe institutions as a source of powerful interventions that encourage or discourage potential innovators by altering the incentives to innovate".

Similarly, institutional influence on the diffusion of cellular technology is apparent from the introduction of the world's first commercial cellular system in Japan in 1979. Japan's MPT originally started it's monopoly teleoperator's Nippon Telephone Telegraph (NTT) cellular mobile communications service in order to create an *amukudari* post for an MPT official[34]. Neither MPT nor NTT believed there was a large market for mobile communication services in Japan and thus they agreed to set user fees at high levels (Funk 1998, p.434). MPT wanted to set fees high in order *to prevent* people who could not afford the service from subscribing and thus minimize complaints. MPT was apparently influenced by the Ministry of Transportation whose offices were adjacent to those of MPT at that time (Funk 1998, p.434). As a consequence, the NTT system after more than a decade since it's introduction had a very low number of subscribers and penetration rates compared to it's Scandinavian and North American "counterparts" (see table 14).

TABLE 14 Selected information for selected mobile communication systems. Source: (Funk 1998)

System	Introduction date	Country of origin	Subscriber data for selected years (end of)	
			No of subscribers (1000)	Penetration rate (%)
NTT	1979	Japan	75 (1986)	0.06 (1986)
NMT	1981	Scandinavia	310 (1986)	1.4 (1986)
AMPS	1983	US	681 (1986)	0.27 (1986)

3.6.8 Technological regimes

As described above, cellular communications has historically observed the convergence of two previously unrelated technologies (radio and telephony) into one, to the extent that it has appeared to the end-user as a transparent mobile telephony service (see figure 20).

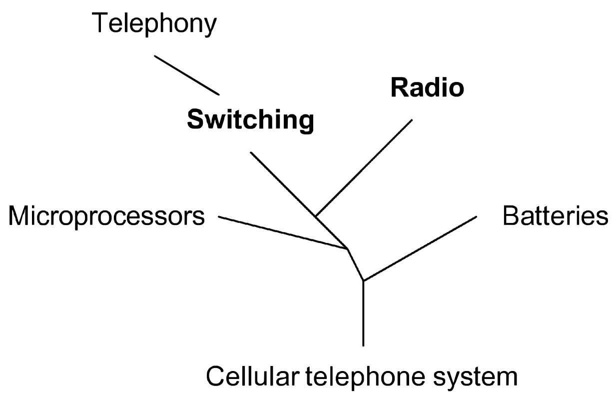

FIGURE 20 Convergence of technologies in development of NMT. Adopted from (Fomin and Lyytinen 2000)

At the time when the development of cellular technologies took place, wireline telephony had already in place an advanced and sophisticated switching

[34] *Amukudari* literally means descent from heaven. It is used when high ranking government officials take a corporate position (Funk 1998, p.434).

technology (exchanges). Nevertheless, a different approach to switching design was needed to enable the access of a mobile device to the PSTN. This marked the first occasion when engineers from both wireline and wireless technologies met to discuss what in future was to become a *mobile telephone exchange* (MTX) (Lyytinen, Manninen, and Fomin 1998). The merging of switching and radio, made handover and roaming possible. However, as the latter two required high computational capacities, microprocessor technology was needed. This was provided by improvements in batteries and microchip technologies, which allowed the replacement of vehicle-mounted cellular phones by portable ones, then later by handheld, and finally pocket sized ones.

The role of joining two previously unrelated technologies, that of *radio* and *switching* has been often emphasized as one of the key success factors in the development of NMT (Manninen et al. 2000; Lyytinen, Manninen, and Fomin 2000, 1998). This however, would not have become possible without utilizing computers.

It is interesting to look at the pattern of technological convergence in the process of the development of Nordic Mobile Telephone (NMT) from the point of view of what Hughes (1993) called *reverse salients*, or "*stubborn socio-technical problems that hinder the realization of overarching system*" (Edwards 1998, p.11). Edwards sees reverse salients as "*key events in the history of large systems*". From the viewpoint of the contemporary understanding of mobile telephony, the convergence of radio and switching technologies was achieved through the resolution of a *reverse salient*, the *sociotechnical* problem of how to enable such key features as automatic roaming and handover. The problem was *technical*, because this was a technological innovation. At the same time it was a *social* problem, two distinct engineering cultures had to come together to design an artifact (Lyytinen, Manninen, and Fomin 1998).

At the present time, computerized telephone switching systems control the vast majority of telephone connections worldwide, but in the late 1970s, when the NMT group started developing the system, digital switching had not yet been introduced in Europe (Manninen 1999), and the idea of a microprocessor-based-software-controlled-radio-signaling-enabled circuit switch was not yet in the minds of engineers. Indeed, for this to happen the whole meaning of a circuit would need to be changed, as what was known previously as radio modulation would become a radio air circuit. Therefore, through the successful convergence of previously unrelated technologies, the engineers laid the foundation for a fundamental shift in technology, that is they established a new *technological regime*.

This thesis is based on a longitudinal case study. The time spans of each of the technologies were not less than 10 years, the time it takes for a fundamentally new technology to be realized (Lyytinen, Manninen, and Fomin 1998). We shall refer to the time span between two consecutive fundamental shifts in technology as "*technological regime*". Nelson (1994, p.50), terms a technological regime as a cognitive cumulative improvement "proceeding along particular lines of advance that reflect both what *technologists understand* they can likely achieve, and what *entrepreneurs believe* customers will buy" (Nelson 1994, p.50, emphasis added). In other words, during the cumulative advances of technology within the frame of a single technological regime, there are *visions* and *beliefs* of what it is possible to achieve and/or sell. In the domain of telephony, whether it be wireline or wireless telephony for instance, two basic functions are *communication* and *control*[35]. In a historiographical retrospective of the development of information and communication technologies (ICT) and infrastructures, significant shifts can be observed in forms of both communication/media and control (see table 15).

It is the notion of technological regime which points to the importance of *timing* and *vision* in standard making. The case of the development of the NMT and GSM telephone standards' are rich with examples of how the designers of these complex socio-technical systems were able to estimate the *timing* of the development process, that is the time needed for a new technology to be developed. We also find it important that the *visions* of both *technologists* and *entrepreneurs* played a substantial role in shaping the cellular telephony technology (Fomin and Lyytinen 2000).

TABLE 15 Technological Regimes in ICT Infrastructure

Years	Regime	Control	Media/Communication	Examples of technology
Before 1970	Analogous	Analogous: Circuit switching[36]	Analogous: Amplitude modulation	PSTN
1970-1980	Analogous+Digital	Digital: Microprocessor-based	Analogous+Digital	NMT, AMPS
1980-1990	Digital distributed	Digital	Digital	GSM, CDMA
After 1990	Digital integrated: Intermodal[37] Infrastructures	Digital	Digital: Convergence of different ICT domains	WAP, Bluetooth, etc.

Each new technological regime has a higher degree of convergence of different technologies. The convergence of technologies requires the development of *"gateways"*, standards enabling the interlinking of different technologies and/or infrastructures (for instance, there must be a gateway standard to connect the radio air interface with the wireline network in mobile telephone technology). Also new technologies give rise to new standards. With changing technological

35 Communication is the transmuting of data (voice can be seen as one of the instances of data) between two remote terminals. Control in telephony is usually referred to as switching, i.e. establishing and controlling (time, quality) the connection between the two terminals.

36 In later tech-regimes, mechanical circuit switching was gradually replaced by program-controlled digital switching. Though the idea of connecting two remote terminals still remains.

37 (Edwards 1998) uses the word "intermodal" when referring to inter-linked infrastructures, for instance, that of telephone, Internet, and the power grid.

regimes, standards become more complex. The complexity and the number of required standards is dictated by the number of converging technologies. If before the 1970s, the standards utilized in the domain of telephony were merely related to, and limited by that domain, then nowadays such standards as WAP[38] and Bluetooth, bridge several "traditional" technological domains such as the computer, Internet, radio, and telephony.

3.6.9 Merging technologies and infrastructures

In order to foresee the future one must be acquainted with the past. We see definite similarities between the development of the Internet's global network and the evolution of the cellular global infrastructure. Cellular telephony systems emerged as local networks in different countries already by the early 1960s, almost at the same time as ARPANET[39], and cellular networks grew from city-wide to country-wide. International roaming, introduced first through the NMT-450 made a seamless region-wide network possible. The Pan-European GSM system for example, has witnessed a truly global success. Despite the successful globalization of certain cellular technologies however (Funk 1998; Funk and Methe 2001), similar to that of personal computers and computer networks, non-compatible systems and networks were, and still are commonplace. According to Edwards (1998), "from its earliest beginning in the ARPANET of the late 1960s, the most fundamental principle of Internet design has been to assume heterogeneity in the networks being linked together" (Edwards 1998, p.15). What we see today in the domain of the development of global cellular telephony is that 3G cellular systems are being built upon existing cellular infrastructures, assuming their heterogeneity (West and Fomin 2001).

Advances in microchip technology make it possible to manufacture handsets capable of working in many of the existing cellular networks, regardless of the substantial differences in utilized technologies. If in the Internet "protocols operate around and on the top of existing (computer) networks, requiring from them very little, if any, internal change" (Edwards 1998, p.15), then in the 3G cellular networks, the role of the protocols will be played by intelligent microchips and the pocket-sized handsets' software (see figure 21). NTT DoCoMo i-Mode handsets already today feature Java interpreters (Stevenson 2001), and WAP handsets are also about to take this step.

Another interesting similarity to computer development, is that technical capabilities were not the only force driving the global linkage of computing and communications. Socioeconomic factors were also of considerable importance. With respect to the NMT standard, these factors can be identified in the

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38 Wireless Application Protocol.

39 ARPANET stands for Advanced Research Projects Agency (ARPA) Network. It was developed by the ARPA in 1969 and was funded by the Department of the Defense of the United States. ARPANET was established to help its users to share information and resources.

building of the Pan-Nordic welfare system; for the GSM, in the building of a Pan-European cellular infrastructure; and for the 3G global cellular service, in the enlarging of existing markets for handset manufacturers, and allowing the operators to offer subscribers a true global service and enjoy economies of scale.

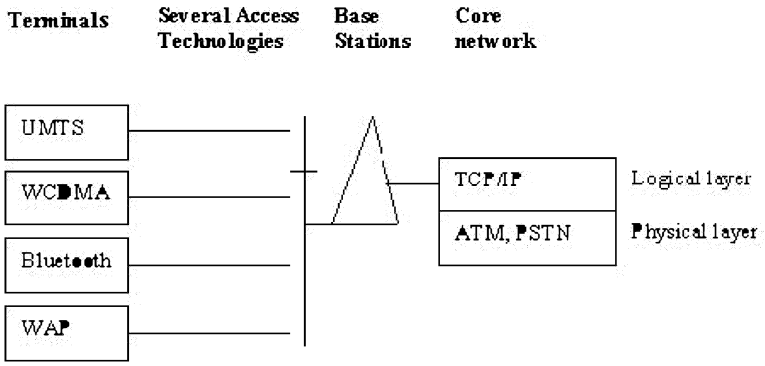

FIGURE 21 Conceptual Scheme of 3G Cellular Mobile Technology

Today, telephone systems, both fixed and cellular, the Internet, electric power grids and other large systems are linked to form an *"intermodal infrastructure"* (Edwards 1998, p.21). The emergence of intermodal infrastructures provides another incentive to study the constituting infrastructures as building blocks of the future GII.

Nevertheless, the convergence of standards, technologies, and whole infrastructures does not answer the question of whether tomorrow's cellular technology will merge into one global standard or not. In 1988, during the era of 1G cellular systems, when the GSM was still under development, Calhoun (1988) posed a question: "Can the industry agree on a standard? Could the FCC, or anyone else, enforce it? The question is not *should they?*, but, given the political system under which we operate and the tremendous diversity of digital technology, *will they?* ...It is thus likely that the cellular industry will have to cope with a standardless world, whether it wants it or not!" (Calhoun 1988, p.432). How does Calhoun's question relate to the convergence of infrastructure we observe today? Is it what Hiroshi Kojima, the director of the Telecommunications Systems Division for the Japanese MPT called "destandardized standards", that is, standardization based on user needs and shifted from single standards to sophisticated standards (Calhoun 1988, p.428)? Whatever the cellular market of tomorrow will be, either a single truly global standard or a variety of "destandardized standards", it does not reduce the importance of knowledge of the standard making process.

In this thesis we take a fascinating journey into the realm of cellular mobile telephony's standardization practices in order to learn *how* the standardization process evolved, and *what* are its most important characteristics. Knowledge of the process it is believed will ease the endeavor of practitioners on their way to creating the socio-technical cellular world of tomorrow. As Markus and Robey (1988) state, “Prediction of patterned regularities over time is one of the goals of process theory research... Findings can be generalized to other settings, and predictions can be tested in later research”. (Markus and Robey 1988, pp. 592-593.)

4 RESEARCH METHODOLOGY

> The ultimate goal of sociohistorical technology studies is to understand the interplay between technology and society.
>
> (Bijker 1995, p.238)

The previous chapters have looked at different ways to approach sociotechnical ensembles and the important issues and factors to be aware of when conducting the research have been identified.

In this chapter, the selection of research method and its utilization within this research project is discussed. First, based on the aims of the research project, a choice of methodology is justified. Then, methodological implications specific for our cases are presented, and finally, data collection and analysis techniques are described.

4.1 Identification of the research approach

Two approaches to conduct research work are distinguished: qualitative and quantitative. Qualitative research aims at a holistic analysis of the phenomena under investigation. This approach typically deploys unstructured interviewing, participant observation, and archival data retrieval techniques, as well as non-statistical data analysis (i.e. non-quantitative). The phenomenon under investigation is analyzed as a whole and in natural settings (Adams and Schvaneveldt 1991; Stake 1994). On the other hand, in quantitative research, data gathered in surveys are analyzed using statistical methods.

The aim of this research work is to provide an in-depth description and analysis of processes that evolved over decades. To fulfill this goal, neither surveys nor participant observation are likely to be of any help.

Surveys are helpful in providing insights into immediate problems: "what is the situation now". The sample size in a survey must be large, which in our case would have meant that responses from a large number of people involved in the standardization process(es) would have had to be obtained. Given the research limitations imposed by funding, geography, and time, surveys wouldn't have contributed much to fulfilling the research goals.

Since we are studying multiple processes and their dynamics, participant observation might have been a good candidate as a data collection technique, but due to the longevity of the processes under investigation, this technique if not rejected completely, had to be sidelined for the purposes of gathering data on the contemporary (impact) aspects of process dynamics.

The complexity of the phenomena studied, the descriptive character of the research goals, the holistic approach chosen, as well as the broad formulation of research questions, all necessitated us to exclude quantitative methods (Adams and Schvaneveldt 1991; Stake 1994). Based on theory selection and case specifics, a longitudinal case study methodology and qualitative data analysis were deemed most appropriate (Adams and Schvaneveldt 1991; Altheide and Jonson 1994; Stake 1994; Tuchman 1994). In the following sections the choice of research methods will be justified and the conduct of the study will be described.

4.2 Selection of case study method

The importance of practice in scientific discourse has been already emphasized. Here we must also emphasize the importance of practice in conducting studies of technology. First, a study itself is a practice, and this is why the methodology of this practice must be outlined, to show that it has been undertaken in a correct way. Second, the development of technology is a practice too. If we want to analyze phenomena represented by a practice, which inevitably takes place over time, then we must collect evidence from different periods of time and space and recollect it on the "laboratory table" (Latour 1999, p.38), so as to make the facts and artifacts commensurable and juxtapositionable. Edwards (in press) uses the term *mutual orientation* to describe the problem: "…if to be modern is to live within multiple, linked infrastructures, then it is also to inhabit and traverse multiple scales of force, time, and social organization" (Edwards in press). A way to "traverse multiple scales of time" is by conducting a socio-historical study.

A longitudinal case study approach allows us to describe or assess the dynamics of a process over a long time span. For example, the two main cases of our study, the NMT and GSM standardization processes, evolved over a time period from 1970 to 1981 and 1980 to 1991 respectively. Thus, in this research work we have to determine and describe what occurred in the case processes over this time. In the following section we present the methodological guidelines and important points specific to our cases. In so doing, it is intended to show that the selected methods are appropriate, and therefore that the internal validity of the study is high.

4.2.1 Conducting an analytical historical study

According to Kranakis (1988), the assessment of technology has three practical functions: forecasting, monitoring, and control. As we have no intention to control in any way the development of cellular mobile communications, we shall focus on the remaining two functions, those of *forecasting* and *monitoring*. Technological forecasting is used to predict the short- and long-term consequences of technological change. Monitoring refers to the carrying out of either ex post or ad hoc impact studies in order to determine the validity of predictions (Kranakis 1988, p.291). The latter two functions of historical research are at the same time the practical objectives for conducting technology assessment studies. Besides knowing the objectives of the investigative work, one must also have "a certain foundation of theoretical and empirical knowledge" (Kranakis 1988, p.291). In the study, theoretical approaches of how to study the technology have been presented. Our choice of a multidisciplinary approach (Fomin and Keil 2000) is confirmed by Kranakis (1988): "Given the wide range of concerns that technology assessment potentially embraces (technical, economic, social, political, cultural, and so on), a multidisciplinary approach is clearly essential" (Kranakis 1988, p.292).

Historical works may be divided into two categories: descriptive and analytical. Since the aim of this study is to give a detailed account of technological development, and also to show the mutual *impact* and *interplay* between technology and society, an *analytical* historical approach seems to be more appealing. An analytical historical study aims at explaining the nature of historical processes and the forces that produce change. In the case of a descriptive history, events and situations are not described in their entirety, but only from a *specific perspective*.

The task of providing a comprehensive study is very ambitious. In order to be able to make forecasts, certain patterns need to be revealed in past processes. The patterns to look for can include those of research traditions, of economies of scale, and of political leadership (Mowery and Nelson 1999; West and Fomin 2001). According to Kranakis (1988), there are at least three ways in which this can be done: a) by analyzing a particular historical event within some broader context; b) by isolating a particular variable and tracing how it is either influencing or influenced by other historical developments; c) by means of a comparative analysis (also by examining how technologies are shaped by different environments). This study will use a combination of approaches a) and c).

Historical research has several important functions (Kranakis 1988). One is that it provides new empirical data and information, which constitutes a necessary foundation for theoretical analysis. As has already been emphasized, there is no one existing theory capable of addressing the complexity of the technological innovation process. The role of socio-historical research in the *development of theories of innovation* needs then to be considered:

> "…Historical studies have provided much of the knowledge necessary to develop

more accurate concepts and models of the innovation process: … knowledge about the patterns and regularities that characterize it, knowledge about the underlying complexities that need to be taken into account, and so on".

(Kranakis 1988, p.296)

Another reason why historical research is an indispensable guide in formulating and testing theories about economic and social processes is because dynamic, evolutionary processes must be viewed over time in order to be clearly analyzed and understood. A view over time is particularly necessary when it is a question of attempting to understand how technological change is linked to social change (and vice versa).

4.2.2 Actor-network approach as a methodological tool

The actor-network approach was used as a framework to conduct the research work and to reveal the patterns of behavior in the course of a systems' development. Based on these patterns forecasting can be made. However, another body of theory is needed for conducting the research work itself, the *know how* of the historical study. The research work implies, according to Latour (1997, p.3),

> "a deeply different social theory: it has no a priory order relation; it is not tied to axiological myth of a top and of a bottom of society; it makes absolutely no assumption whether a specific locus is macro- or micro- and does not modify the tools to study element 'a' or the element 'b'; thus, it has no difficulty in following the transformation of a poorly connected element into a highly connected one and back".

The validity of the findings can be questioned by asking whether they are a rich historical description of the processes that took place. Are we able to satisfactorily describe "how" and "why" developments in the standard making process took place through the archival work undertaken and the interviewing of key personnel which was carried out? One of the possible aims of the research work can be to provide different views of the development of the standardization processes and to find out *how* this changes the understanding of what happened and *what* are the lessons learned. Yet the actor-network approach goes a step further. It offers a methodological frame to register the description of actor-networks, which by "connecting with one another provide an *explanation* of themselves, the only one there is for ANT" (Latour 1997, p.7, emphasis added). Latour (1997, p.7) defines this explanation as the attachment of a set of practices that control or interfere on another,

> "The very divide between description and explanation, hows and whys, blind empiricism and high theorizing is meaningless for ANT as the difference between gravitation and space in relativity theory. Each network by growing 'binds' so to speak the explanatory resources around it and there is no way they can be detached from its growth".

In other words, there is no difference between "how" and "why". It is by precise and rich description that we are able to obtain valid explanations. The rich description of the actor-networks is achieved through the activity of *network tracing*: "a network is not a thing but the recorded movement of a thing" (Latour 1997, p.9).

Yet in our research we would like to go beyond the level of mere descriptions and explanations. By describing the past, we would like to offer the reader insights into future standardization processes and practices, that is, the aim is to fulfill the two functions of historical research, that of monitoring and forecasting.

> "It is thus necessary, after having traced the actor-networks, to specify the types of trajectories that are obtained through highly different mediations. This is a different task and the one that will make ANT scholars busy for a number of years to come".
>
> (Latour 1997, p.10)

4.2.3 Methodological implications for studying infrastructural technologies

As has already been emphasized, mobile telephony technology is not of a single product type, but is a complex networked, and *infrastructural* technology. Star (1999) points to the necessity to pay special attention to the methodology of studying *infrastructure* as a whole, as opposed to just that of a homogenous technology as is often implied. Cellular mobile telephony is an infrastructural technology, it is indeed an *infrastructure* in its own right. Star (1999) points out that infrastructure is a "fundamentally relational concept, becoming real infrastructure in relation to organized practices" (Star 1999, p.3). Therefore, what can be studied is the relationship of a certain actor to a given technology, within the meaning of a given technology for a given actor within a given context. In order to succeed in this uneasy task, we have to perform, according to Star, an *infrastructural inversion*: "foregrounding the truly backstage elements of work practice" (Star 1999, p.4). The methodological implications of studying complex networked and infrastructural technologies (Lyytinen and Damsgaard 1998) encompasses "decisions about encoding and standardizing, tinkering and tailoring activities…, and the observation and *deconstruction* of decisions carried into infrastructural forms" (Star 1999, p.5). Comprehensive understanding of the processes underlying the technological development process is needed due to the path-dependant property of a technology. Different forms of practice, culture and norms are inscribed "at the deepest levels of design. Some are malleable, changeable, and programmable… Others… present barriers to users that may only be changed by a full-scale social movement" (Star 1999, p.10).

It is interesting to note, that despite (or because of) the ever growing popularity of Science and Technology Studies (STS) and ANT in particular, its practitioners have not developed a uniform methodological and axiological orientation (Fuller 2000, p.27). Case studies based on ANT are typically evaluated merely in terms of their descriptive adequacy ("Does it tell a good story?") (Fuller 2000, p.8). For this reason, the findings can be of potential use to a wider range of users, including those who do not share the views of ANT or a social constructivist approach to technology studies.

4.3 Problems and advantages associated with data collection

A problem that arises in conducting longitudinal case studies is how to collect sufficient evidence to answer the research questions. Many events that took place in the past may be forgotten or remembered wrongly by the participants involved in the processes. Thus, using interviewing alone as a source of data is likely to give unsatisfactory results. In this case counterevidence must be obtained. The process of establishing counterevidence is known as triangulation and refers to verification (Adams and Schvaneveldt 1991; Stake 1994; Yin 1994).

Counterevidence to support research findings can be obtained from historical records. Documents, such as minutes of the meetings, correspondence between the participants, and memos, are referred to as primary sources and help researchers to avoid errors in interpretations and fill in the gaps in the story. Secondary sources, such as the recollections of those who did not participate in the processes under investigation, and commercial historical publications, can also be useful as additional sources of verification.

When studying contemporary phenomena, political or social conditions may not permit investigators to obtain complete information. This problem is less likely when conducting a historical case study. The use of documents in a socio-historical study gives therefore an advantage *vis-à-vis* the accessibility of data. On the other hand, documents based research has limitations with respect to understanding events of the past or the assessment of specific social problems (Adams and Schvaneveldt 1991). In this case, uses of secondary (commercial and scholarly publications of analytical and descriptive historical records) and primary (interviews with participants) sources becomes of crucial importance.

To summarize the aforesaid, in conducting our research work evidence from different sources had to be collected to assure that an in-depth and comprehensive *description of the past events* and *relationships between them* was obtained. At this point a bigger problem arises: given the broad scope of the research and the time span of the processes under investigation, what amount of evidence may be considered sufficient? While the time perspective is critical for understanding and assessing linkages between events (Adams and Schvaneveldt 1991), is it possible to account for all the events that took place in the past, and if not, what kind of events must we look for?

Thus, we face the issue of the validity and reliability of the research findings, which will be discussed in the following section.

4.4 Data collection, analysis, and validity of the findings

Two measures to assess the validity of research findings are distinguished: internal and external ones (Adams and Schvaneveldt 1991). Internal validity pertains to the effect of specific methods on the reported results. In other words, the assessment of internal validity is needed to answer the question "can the methods utilized to conduct the research assure the trustworthiness of the findings?" External validity pertains to the generalizability (or representativeness) of the research findings (Adams and Schvaneveldt 1991, p.89). In other words, by assessing external validity we may determine to what extent similar research findings would be obtained if the same methods were used in different settings, or studying different phenomena. External validity is a matter of sampling (Adams and Schvaneveldt 1991, p.89; Stake 1994, p.243).

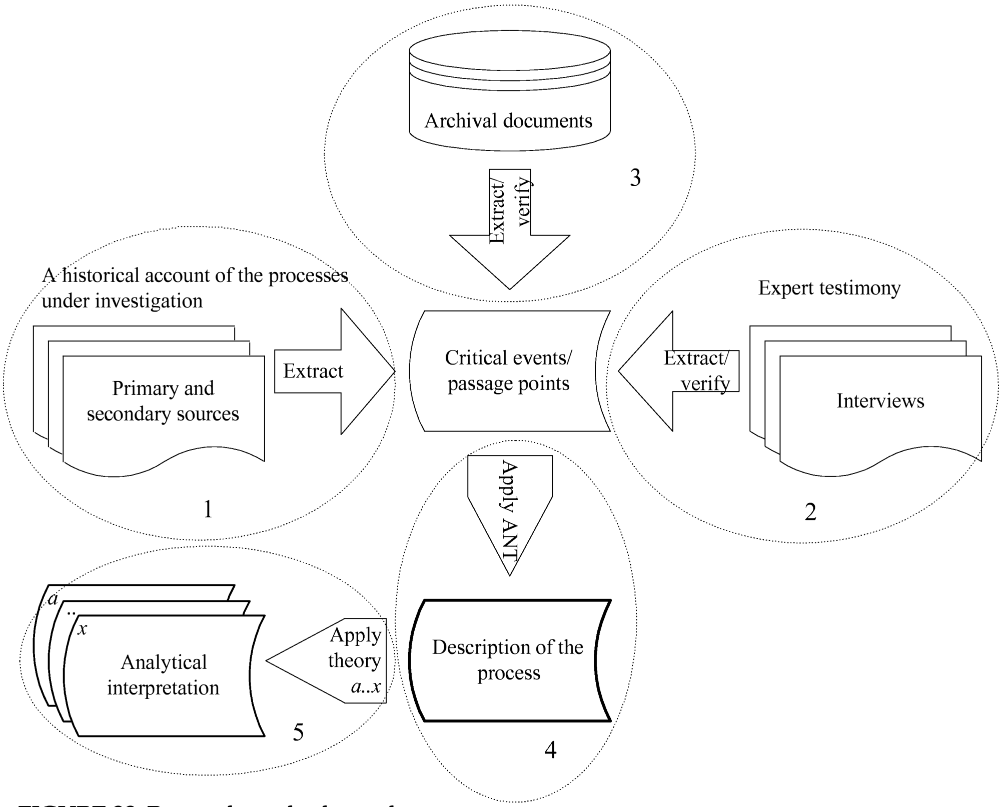

FIGURE 22 Research methods used

In the previous section we pointed at the need to use different sources of data in the research process. This method, known as *triangulation* (Denzin and Lincoln 1994, p.2.), pertains to the validity of the findings. What we want to discuss in more detail in this section is what methodological guidelines we had to follow to assure a high internal validity of the findings.

As already mentioned, collecting evidence from different sources alone as a method, can not assure high validity, for the simple reason that the processes under investigation are very broad and complex. Due to the complexity of phenomena, the issue of what is *relevant* evidence arises. What evidence must we look for in order to obtain an in-depth, comprehensive description of the case processes and to avoid the "relevance trap" quoted from Winner (1993) above?

The scholars of ANT have so far not agreed on any unified methodological tools (Fuller 2000, p.27). Neither have the authors of actor-network theory proposed such. For these reasons, in our endeavor to study the development of complex socio-technical networks, we decided to primarily focus on those points in time, where socio-technological development could have taken a different path. This decision was mandated by the logic of the actor-network approach: "ANT traces the interactions between human and non-human actors and seeks to identify points in time, where technology could be designed in more than one way, and to explain the dominance of one choice over another" (this volume, p.34).

Thus, in our case studies we look at the critical points, the relevant network configurations and the actors involved. We aimed to identify decisions which either enabled or did not enable the alignment of actor-networks at these critical points (see figure 22).

To summarize the theoretical considerations above, with respect to our study and the validity of the findings, it must be described what techniques were employed to obtain the rich description of the cases.

4.4.1 Internal validity of the study

First, in what Stake (1994) calls a collective case study – a collection of instrumental studies aimed at providing an insight into an issue or refinement of theory, where the cases play a supportive role – we employed triangulation (Stake 1994, p.241; Yin 1994) in order to reduce the likelihood of misinterpretation (see figure 22, delineated areas 1, 2, and 3). This method of assuring validity is of particular help, since by acknowledging that no observations or interpretations made in the course of the study are perfectly repeatable, triangulation serves to clarify meaning by identifying different ways in which a phenomenon can be seen (Stake 1994, p.241), be it a historical description, or a conceptual framework based on empirical data. The data collection processes and the interpretation of the findings depicted in figure 22 will be described in more detail in the following paragraphs.

The case study began with an overview of historical accounts (both primary and secondary) of the NMT and GSM standardization processes (figure 22, area 1). Both purely theoretic and case-analysis literature streams were considered. Thus, the initial list of critical events in the standardization processes was created. As an example of historical accounts, the works of Meurling and Jeans (1994) and Toivola (1992) can be referred to.

During the case studies a large number of interviews were conducted and archival materials collected (appendix 1; figure 22, area 2). As presented above, an extensive literature review helped to identify the directions of the theoretical propositions. Interviews with key personnel in the standardization process allowed us to get first hand insight into the rationale and sequence of events. In particular, interviews were a very helpful tool for *corroborating* findings of the literature review. All the interviews were transcribed immediately after the interviewing. The transcripts were then sent to the interviewees for cross-checking. In so doing, high internal validity of the interview data was maintained.

Furthermore, written documents, memos and public announcements were used to corroborate the findings from the interviews and literature review wherever possible (figure 22, area 3). Documents were content analyzed and the results of the analysis were used to corroborate findings from the interviews. Archival documents were selected in the following order of preference:

- minutes of the meetings;
- committee's reports;
- technical documentation, and;
- correspondence and other documents pertaining to certain specific issues in the standardization process.

Those documents whose meaning was ambiguous were sent to the chairmen of the NMT and GSM standardization committees whenever possible in order to obtain expert testimony (Adams and Schvaneveldt 1991) and eliminate the ambiguity.

The NMT and GSM projects' documentation was acquired from public archives in Uppsala, Sweden. Collected documents included minutes, letters, and project correspondence. In total, over 7900 pages of documentation were scanned and processed using optical character recognition (OCR), making a content analysis possible. Paradoxically, the increase in primary data only proved to generate more questions on the specifics of the standardization processes under study. In the search for answers more interviews (Lyytinen, Manninen, and Fomin 2000; Manninen and Fomin 1999) were conducted and archival data acquisitions from Sonera (Finland) and Telenor (Norway) took place.

Triangulating data from different sources (figure 22, areas 1, 2, and 3) allowed us to establish high validity for our choice of critical events[40]. The critical events, and the relationships between them, were identified using actor-network theory (figure 22, area 4). The outcome of the "network tracing" resulted in the developing of a rich description of the case processes. These descriptions in concise form were used in the Original Articles as the description of the cases. Following the tradition of ANT, these descriptions were not biased to any *a priori* theoretical postulates, but were used as an input

40 An example of obligatory passage points in the development of cellular mobile telephony is given in the Original Article 1.

for analytical interpretations (figure 22, area 5) as different theories were deployed to analyze the processes of standard making. For example, in the Original Article II, National Innovations Systems (NIS) theory (Mowery and Nelson 1999; Mowery 1996; Nelson 1993) was used, and in the Original Article IV, various theories were used for the analysis.

4.4.2 External validity of the findings

It was emphasized, that the problem in studying technology is that one's grasp of the research object may be superficial, "failing to do justice to the phenomena one wants to explain and interpret" (Winner 1993, p.362). Achieving consistency of results when using the same method in different settings is the essense of external validity (or reliability, as it is often referred to) (Adams and Schvaneveldt 1991, p.95). The problem faced when developing a conceptual model of the standard making process is that one generalizes from a limited range of vaguely understood examples of technical applications and attempts to identify universal implications "from a sample that is perhaps too small to carry the weight placed upon it" (Winner 1993, p.362). To cope with this problem, a proper selection of cases must be made (Stake 1994, p.243).

In conducting instrumental case studies, nothing is reported to be more important than making a proper selection of cases (Stake 1994, p.243). Our cases in this sense can be seen as well representative of the various standardization processes. The cases of the NMT and GSM standard making processes for example, differ significantly in the complexity of the technology involved, the number of industries, individuals and firms enrolled, and in the time length (see table 16[41]). For these reasons, we believe our findings are analytically generalizable.

TABLE 16 Cases' description

Case	Type of standard/ fora	Size of fora[42], persons	Cultural settings	Time frame, years
1. NMT	Committee, de-facto	10-30	Nordic, homogeneous	10+
2. GSM	Committee, de-jure	30-100	European, heterogeneous	10+

The generalizability of the research findings (i.e. higher reliability) derives from the different settings in which the case processes evolved, and from the different characteristics of the case processes themselves. In the Original Article V, data from yet another case were used to develop the model of the standard making process. The addition of the third case increased the reliability of the findings.

41 See more detailed description of the cases in the Original Articles.
42 Number of people on the technical committee responsible for specifications' development.

5 ORGANIZATION OF THE THESIS

In this chapter we will summarize the main parts of the study. We will also briefly characterize the purpose of the research for each of the Original Articles included in the thesis. The main part of the work is reported in the included Articles.

In the Article I socio-technical networks are analyzed by looking at the process of standard making. As a framework for analysis, actor-network theory is chosen. In this Article the authors suggest that ANT is an appropriate tool for studying standards as socio-technical phenomena and addressing technology as an intangible artifact. Additionally, the notions of layer and a multi-layered structure to the analysis of socio-technical processes are introduced.

In the Article II the authors study the cellular telephony industry as a national innovation system (NIS) and the findings are compared to those of other NIS studies. The authors show that while in many cases mobile telecommunications industries can be viewed as compatible to such systems, several differences suggest the need for theoretical extension.

In the Article III the author attempts to develop a theoretical model of the standard making process. The works contribution to theory is by proposing a model of equilibrium and transformation in the standard making process. This is seen as a novel approach to the socio-technical perspective of the standardization process.

In the Article IV the authors engage in an analysis of the economic and social theories applicable to the studies of standards and standardization processes. By integrating different streams of literature, the authors show how the processes of strategizing, sense making, and negotiation jointly explain the emergence and success of technical standards.

In the Article V the authors integrate the findings of two previous publications to further develop a model of the standardization process. It is shown that the standard making process consists of the recursive and mutually embedded processes of sensemaking, negotiation, and choice. The findings suggest that more complex innovation and standardization process models are needed, drawing on multiple bodies of literature rather than the simplistic waterfall models that have been employed to date.

Owing to the fact that the dissertation includes published articles, the treatment of some issues is repeated in them.

5.1 How to Distribute a Cake Before Cutting it into Pieces: Alice in Wonderland or Radio Engineers' Gang in the Nordic Countries?

Fomin, V. V., & Lyytinen, K. (2000). How to distribute a cake before cutting it into pieces: Alice in Wonderland or Radio Engineers' Gang in the Nordic Countries? In K. Jakobs (Ed.), *Information Technology Standards and Standardization: A Global Perspective*. Hershey: Idea Group Publishing. pp.222-239.

This article analyses social networks by looking at the processes of standard making. As a framework for analysis, actor-network theory is chosen. Standards are of particular interest for actor-network theory for they provide mechanisms to align interests of multiple social groups organized in networks that have a joint incentive in working with the standards and/or associated technologies. These social groups include scientific communities, government institutions, and social movements (industrial groups, companies, and consumers) that are interested in regulating and innovating new technologies. Standards provide the mechanisms with which subsequent behaviors that are expected to become persistent over time can be inscribed.

In the IT domain most standards are intangible, such as protocols, data formats, and signaling levels. There have only been a few attempts to apply actor-network theory to the analysis of abstract, intangible standards. One of these rare examples is the work of Hanseth and Monteiro (1997) on electronic data interchange (EDI) standardization. Using actor-network theory as an approach when dealing with abstract technological knowledge, and when addressing standards as social processes, new notions should be introduced to the theory. The authors introduce the notions of layer and a multi-layered structure in order to enable a better understanding of the socio-technical processes, which take place in the highly complex, networked, and infrastructural domain of IT. Using the notions of layer and multi-layered structure one can better understand how the diverse interests of actors are negotiated and aligned, how actors from one organizational and/or hierarchical level are enrolled into processes on other levels.

This article is co-authored with Kalle Lyytinen. Lyytinen's contribution to the article was in providing advice and guidance in the construction of a logical and relevant account of the development of the NMT system.

5.1.1 Changes and amendments since the publication

Since the publication of this article the research has progressed. The authors found that when referring to technology as a black box further explanation was required. The notion of technology as a *black box* in the context of this article should therefore be understood as technology that has predetermined and predictable impacts on the adopting agent and /or society. When stating in the article that "the story of the success of the NMT, indeed, proves ones again that technology is not a black box due to the fact that…" the intention is to say that it had different cycles of development and different degrees of success in different countries.

5.2 When Government Inherently Matters: National Innovation Systems in the Mobile Telephone Industry, 1946-2000

West, J. & Fomin, V. V. (2001, August 5-7). When Government Inherently Matters: National Innovation Systems in the Mobile Telephone Industry, 1946-2000. Presented at *The 2001 Academy of Management Meeting*, Washington DC.

Mowery & Nelson (1999) outline how "industrial leadership" reflects the comparative advantage held by a firm, a national industry, or some combination in between. They show how user demand, government policy, and industry structure help determine which firms and industries will be successful in technologically-driven industries.

The global cellular telephone industry shares many common characteristics with the three electronics-related industries in the Mowery & Nelson (Mowery and Nelson 1999) study, and many of these earlier observations would also apply. However, the industry demonstrates several key differences that suggest the need for extensions to prior theories of national innovation systems for telecommunication industries.

In particular, the telecommunications infrastructure depends on scarce resources that require government policy to allocate those resources to specific service providers. The limited number of providers means that these buyers play a far greater role in technology development than in industries where buyer concentration is not an issue. Thus, a focus strictly on equipment producer (rather than buyer) success may reflect an obsolete conceptualization of economic welfare in the New Economy.

This article is co-authored with Joel West. The work on the article evolved over more than a year, and contributions of both co-authors are commensurable. Nevertheless, Joel West took a lead in finalizing the work and preparing it for publication.

5.3 Equilibrium and transformation in the standard making process

Fomin, V. V. (2000, June 2-3). Equilibrium and Transformation in the Standard Making Process. In proceedings of *The Fourth Pacific Asia Conference on Information Systems (PACIS 2000)*, Hong Kong. pp.600-614.

This article provides further analysis of the standardization process. It analyses the dynamics of the standard making process by explaining these dynamics in terms of equilibrium, and through the transformation of power, interests and knowledge of those involved. Two questions are considered: *1) how do transformations take place,* and *2) what are the conditions for achieving equilibrium*. The analysis is based on arguments from economic and social theory. By *equilibrium* it is meant a *specific configuration* of interests, relations, environment settings, which are the result of a successful negotiation process. By *transformation* it is meant the *transformation of interests and relations* between those involved and possible changes in the process environment. The transformation reflects the changes caused by the advance of the standardization process. The article's contribution to theory is by proposing a novel approach to the socio-technical perspective of the standardization process. The work's contribution to practice is to provide a fresh view of technological development cycles for managers involved in standardization initiatives.

In the empirical part of this paper the standard making processes are examined, which spanned for several decades from the 1960s. The different forces shaping the decision making process, the enrolment of actors, the sense making process, and, finally, how the interests of different parties are aligned during the negotiation process either around a boundary object, a standard, or not are looked at. The approach presented encompasses arguments from economic and social theory. This approach allows for the analysis of the whole standardization process from the inception of an idea to the implementation of the standard by the market, whereas most of the previous research has only looked at these processes in separation (Farrell and Saloner 1988; Rogers 1995).

Similar to models of catastrophe theory which examine incremental and radical changes in firm behavior and account for the *interactions between short-run equilibria and long-run dynamic processes*, the author proposes an iterative model of *equilibrium and transformation* in the standard making process.

The analysis of the three cases reveals several interesting aspects about how standards are made. A continuous negotiation process was emphasized, and showed how communication channels between the actors in the core network and beyond its boundary need to be established in order to provide an efficient standardization process. In contrast to many existing models, which take either a macro- or micro- perspective on organizational processes, the proposed model can be used for both *macro- and micro-* analysis. By recognizing both levels of organizational analysis it allows for the contingency in the path of technological development to be accounted for.

5.3.1 Changes and amendments since the publication

Since the original publication, criticism received helped the author to re-evaluate the model presented in the paper. The first important change is that concerning the inappropriate use of the term "shared meaning" (Boland 1996). Instead, the term "common understanding" must be used to describe the stage in the standardization process, when different parties, based on the outcome of a sensemaking process, must come to a common understanding (not necessarily a shared one).

Other critique received was that of the nature of the process itself. The graphical representation of the model in the paper creates an illusion of linearity and unidirectionality of the process of standard making, having four finite stages and terminating when the fourth stage is reached. A professional participant of a 3G standardization committee suggested that "chaotic' is a more appropriate word [for the description of the development process] than 'predictable' or 'planned'". Thus, the dependence relationships between the stages of the model had to be rethought.

The critique received, and the gathered additional empirical data allowed us to re-work the standard making process' model and re-introduce a new model in the article, which is presented in Chapter VI in this thesis.

5.4 Standardization: Bridging the gap between social and economic theory

Fomin, V. V., & Keil, T. (2000). Standardization: Bridging the Gap Between Economic and Social Theory. In the proceedings of *The Twenty First International Conference on Information Systems ICIS 2000*, December 10-13, Brisbane, Australia. pp.206-217.

Technological standards play an important role in many high technology industries. Standardization is a major challenge in the system development/implementation process. It is also emerging as a key challenge and enabler of B2B electronic commerce. In industries such as computer technology, telecommunications, and consumer electronics, the setting of or at least the influencing of technical standards has become one of the core strategic challenges. In these industries, competition often takes a "winner takes all" form, in which the firm that successfully establishes a technical standard receives large returns, whereas its competitors may be effectively locked out of the market (Schilling 1998).

In this article *standardization* as a process of standard making is examined, whereby "a *'standard'* is to be understood, for the present purposes, as a set of technical specifications adhered to by a producer, either tacitly or as a result of a formal agreement" (David and Shane 1990, p.4). Despite its importance, our understanding of the process of setting standards and establishing a standard's dominance in the marketplace is still relatively limited and fragmented.

This paper contributes to filling this gap in the literature. It integrates the literature about the creation and diffusion of technical standards from industrial organization economics, strategic management and innovation economics with recent literature concerning the social construction of technology in order to analyze the process of standard setting. In particular, the authors analyze how the processes of strategizing, sense making, and negotiation jointly explain the emergence and success of technical standards.

This article is co-authored with Thomas Keil. The work on the article evolved over more than two years, and contributions of both co-authors are commensurable. Nevertheless, the author of this thesis took a lead in finalizing the work and preparing it for publication.

5.5 Standardization: towards integrating fragmented theory

Fomin, V. V., Keil, T., & Lyytinen, K. J. (2001). Standardization: towards integrating fragmented theory. Manuscript. Jyväskylä: University of Jyväskylä.

In this article it is aimed to propose a process model of the standard making process. *Standardization* is examined as a process of creating a technical standard and diffusing it into the market place. The paper is based on grounded theory methods, empirically deriving a model from three cases of standardization in the telecommunications domain. In particular, with the help of case studies, it will be shown that standardization proceeds through processes of sensemaking, negotiation, and choice. Rather than following a linear sequence of activities as proposed in the development of innovation models of the systems approach, these process modes cut across different activities. Furthermore, it will be shown that the process modes are mutually embedded and often recursive. The results suggest that more complex process models are needed drawing on multiple bodies of literature rather than on the simplistic singular models that have been employed to date.

It is argued that the three processes identified are recursive, concurrent, and chaotic, in other words, *non-linear*. For this purpose, it is demonstrated graphically how the processes that took place at each of the stages in the presented examples are interlinked.

It is argued that the pattern of the engagement is not only non-linear, but is not subject to any system. Thus, we prove empirically, the correctness of the proposition: "standardization [process] is not a linear, straightforward, or cumulative process… 'Chaotic' is a more appropriate word [for the description of the development process] than 'predictable' or 'planned'".

This article is co-authored with Thomas Keil and Kalle Lyytinen. Lyytinen's contribution to the article was to provide advice and guidance in the construction of a logical and relevant theoretical argument. Lyytinen also took the lead in finalizing the work and preparing it for publication. Fomin was responsible for the visualizations presented in the article. The contributions to content of Keil and Fomin can be regarded as equal.

6 LIMITATIONS AND FUTURE RESEARCH

In this thesis the process of standard making in the domain of cellular mobile telephony was studied. Several relevant issues were covered:

- The origins of cellular technology.
- The design and development of the first commercially successful cellular standard – NMT.
- The divergent paths of world cellular standards.
- Theories appropriate for studying the process of standard making.
- A model of the process of standard making.

In the introduction to the thesis the importance of cellular mobile telephony and its role in bringing a radical change to the traditional telecommunications industry, which has not seen major restructuring since it's emergence at the end of the 19th century was described. The role of cellular mobile telephony in everyday life was also discussed.

This thesis touches upon three distinct research domains:

- The development of cellular mobile technology.
- The standardization process.
- Uses of actor-network theory in studies of IT.

While the focus of the thesis is on the intersection of these three, each of the research areas is covered to a limited extent. The development of cellular mobile telephony is presented to the extent that it provides a) an overview of the technology and its complexity, and b) the role of standards in the development of the cellular industry.

The standardization process in the thesis is analyzed using different theoretical frameworks, albeit placing special emphasis on actor-network theory. Theoretical elaborations on the process of standard making are of special importance, as no integrated model exists which could adequately and comprehensively account for the complexity of the process. Thus, an attempt to develop such a model is regarded as an important contribution to the field. On the other hand, no models exist which could reflect the complexity of reality, and so the model put forward is of use only as a methodological tool for scholars and practitioners of standardization practices.

The applicability of actor-network theory in studying complex infrastructural technologies has not been widely studied. The findings of the literature review suggest that while providing a promising methodology to grasp the complexity of phenomenon which is studied over a long time span, ANT still has its own limitations.

The main contribution of the thesis is a model of the standard making process. Future research must reveal the applicability of the model to standardization processes other than examined in the study, including those of different industries. While we believe in the robustness of the model due to it's sound theoretical and empirical grounding, further studies are needed to test the model and to assess it's usefulness in studies of the standardization practices of different industries.

APPENDIX 1

CONDUCTED INTERVIEWS[43]

Name	Position	Company	Country
Pekka Vennamo	Director General	Finnish PT	Finland
Olavi Koistinen	Director	Telecom Finland Oy	Finland
Matti Makkonen	VP[44]	Telecom Finland Oy	Finland
Lauri Melamies	Sr.VP, mobile switching, cellular systems	Nokia Telecommunications	Finland
Lauri Kivinen	VP, communications	Nokia Mobile Phones	Finland
Tapani Pökkä	Business Development Director	Telecom Finland Oy	Finland
Keijo Toivola	Manager, radio department (retired)	Finnish PT	Finland
Thomas Haug	Ex-chairman GSM	Telia	Sweden
Eric Berthels	VP, marketing & sales	Ericsson Radio Systems AB	Sweden
Per Björndahl	Manager, systems management GSM/DCS/PCS, Telecom Standardization and Regulation	Ericsson Radio Systems AB	Sweden
Osten Mäkitalo		Telia AB	Sweden
Hans Myhre	Ex-chairman NMT	Telenor	Norway
Per Velde	Manager, product development	Telenor	Norway
Ole Lauridsen	Corporate director, R&D	TeleDanmark	Denmark
Ole Poulsen	Operations Support Manager	TeleDanmark	Denmark
Henrik Olsen	Engineer, radio department	TeleDanmark	Denmark

43 Interviews with persons whose names are given in italics were transcribed by the author.
44 VP – Vice President.

APPENDIX 2

LIST OF ACRONYMS

Acronym	Description	Page#
1G	First Generation (cellular mobile)	57
2G	Second Generation (cellular mobile)	61
3G	Third Generation (cellular mobile)	16
AMPS	Advanced Mobile Phone System	64
CDMA	Code Division Multiple Access	57
FCC	Frequency Control Commision	70
FDMA	Frequency Division Multiple Access	57
FM	Frequency Modulation	58
FPLMTS	Future Public Land Mobile Telephone System	16
GII	Global Information Infrastructure	11
GSM	Global System for Mobile communications	12
ICT	Information and Communication Technologies	11
IPR	Intellectual Property Rights	32
IRC	Internet Relay Chat	15
ISDN	Integrated Service Digital Network	17
IT	Information Technology	12
MTX	Mobile Telephone Exchange	56
NMT	Nordic Mobile Telephone	12
OCR	Optical Character Recognition	79
OECD	Organisation for Economic Co-operation and Development	18
PC	Personal Computer	15
PSTN	Public Switched Telephone Network	29
R&D	Research and Development	12
TDMA	Time Division Multiple Access	57
UMTS	Universal Mobile Telephone System	16
WAP	Wireless Application Protocol	15
WARC	World Administrative Radio Conference	49
WWW	World Wide Web	15

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1G	First Generation (cellular mobile)	57
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AMPS	Advanced Mobile Phone System	64
CDMA	Code Division Multiple Access	57
FCC	Frequency Control Commision	69
FDMA	Frequency Division Multiple Access	57
FM	Frequency Modulation	59
FPLMTS	Future Public Land Mobile Telephone System	16
GII	Global Information Infrastructure	11
GSM	Global System for Mobile communications	12
ICT	Information and Communication Technologies	11
IPR	Intellectual Property Rights	32
IRC	Internet Relay Chat	15
ISDN	Integrated Service Digital Network	17
IT	Information Technology	12
MTX	Mobile Telephone Exchange	54
NMT	Nordic Mobile Telephone	12
OCR	Optical Character Recognition	79
OECD	Organisation for Economic Co-operation and Development	18
PC	Personal Computer	15
PSTN	Public Switched Telephone Network	29
R&D	Research and Development	12
TDMA	Time Division Multiple Access	57
UMTS	Universal Mobile Telephone System	16
WAP	Wireless Application Protocol	15
WARC	World Administrative Radio Conference	48
WWW	World Wide Web	15

APPENDIX 3

GLOSSARY. Source: http://www.symbian.com/technology/glossary.html

Term	Definition
1G	In mobile telephony, first-generation systems were analog, circuit-switched. Voice links were poor, handoff unreliable, capacity low, and security non-existent. 1G systems are not now under active development indeed, in some areas the 1G spectrum is being auctioned for 2G and 3G use.
2G	In mobile telephony, second-generation protocols use digital encoding and include GSM, D-AMPS (TDMA) and CDMA. 2G networks are in current use around the world. These protocols support high bit rate voice and limited data communications. They offer auxiliary services such as data, fax, and SMS. Most 2G protocols offer different levels of encryption.
2.5G	In mobile telephony, 2.5G protocols extend 2G systems to provide additional features such as packet-switched connection (GPRS) and enhanced data rates (HSCSD, EDGE).
3G	In mobile telephony, third-generation protocols support much higher data rates, measured in Mbits/second, intended for applications other than voice. 3G networks are expected to be, starting in Japan in October 2001, in Europe and part of Asia/Pacific by 2002, and later in the US. 3G will support bandwidth-hungry applications such as full-motion video, video-conferencing, and full Internet access.
AMPS	Advanced Mobile Phone System: a 1G standard which operates in the 800-900MHz-frequency band. It is still widely used in the United States.
Analog	The simple way to transmit speech, which is translated into electronic signals of different frequency and/or amplitude. The first networks for mobile phones, as well as broadcast transmissions, were analog. Due to being longer established in some countries, analog networks may offer better coverage than digital networks, however analog phones are less secure and suffer more from interference where the signal is weak. Analog systems include AMPS, NMT and ETACS.
API	Historically, "application programming interface". Practically, an API is any interface which enables one program to use facilities provided by another, whether by calling that program, or by being called by it. At a higher level still, an API is the set of functionality delivered by a programming system, and as such the mix of APIs in a particular system tells you what that system can do.

Bluetooth	An open specification for seamless wireless short-range communications of data and voice between both mobile and stationary devices. For instance, it specifies how mobile phones, WIDs, computers, and PDAs interconnect with each other, with computers, and with office or home phones. The first generation of Bluetooth permits the exchange of data up to a rate of 1 Mbps per second, even in areas with much electromagnetic disturbance. It transmits and receives via a short-range radio link using a globally available frequency band (2.4 GHz ISM band).
Bps	Bits per second: a way of quantifying data transmission throughput. It is the number of pieces of information (bits) transmitted or received per second.
CDMA	Code Division Multiple Access: a digital wireless telephony transmission technique. 1. CDMA allows multiple frequencies to be used simultaneously (Spread Spectrum). The CDMA idea was originally developed for military use over 30 years ago. 2. The CDMA standards used for second-generation mobile telephony are the IS-95 standards championed by QUALCOMM.
Cellular radio	The technology that has made large scale mobile telephony possible. Current cellular networks reuse the same radio frequencies by assigning them to cells far enough apart to reduce interference. A cell is the geographical area covered by one radio base station transmitting/receiving from the centre of the area. The size of each cell is determined by the terrain, transmission power, and forecasted number of users. Service coverage of a given area is based on an interlocking network of cells, called a cell system.
Circuit-switching	Means of creating a connection by setting up a dedicated end-to-end circuit which remains open for the duration of the communication.
Communicator	An information centric device with voice capability. Mobile by nature, Communicators include richer functionality than a Smartphone: the ability to link seamlessly with a PC, with printers, with the Internet, to send and receive files, to synchronise seamlessly and practical to carry around. In effect a fully featured palmtop and digital phone in one unit. Symbian licenses EPOC for Communicators.
Content Provider	A company that provides services to mobile phone users or network operators. These services could be shopping, web surfing, chatrooms, playing games, and accessing data such as

	music and books through a server.
D-AMPS	Digital AMPS (Digital-Advanced Mobile Phone Service) is the digital wireless standard widely used throughout the Americas, Asia Pacific, and other areas. D-AMPS uses digital TDMA on the one hand, and is required to be compatible with installed AMPS base station networks on the other. D-AMPS operates on the 800 and 1900 MHz bands.
DCS 1800	Digital Communications System: another name for GSM working on a radio frequency of 1800 MHz. Also known as GSM1800 or PCN, this digital network operates in Europe and the Asia Pacific region.
Digital	A way of encoding information. On digital networks, data doesn't need to go though the extra step of being converted to analog signals, voice is sampled and coded in a way similar to how it is recorded on a CD. Digital networks are fast replacing analog ones as they offer improved sound quality, secure transmission, and can handle data directly as well as voice. Digital networks include mobile systems GSM, D-AMPS, CDMA and TDMA.
Dual band	Dual band mobile phones can work on networks that operate on different frequency bands. This is useful if you move between areas covered by different networks. Some networks operate on two bands, for instance GSM-1800 in town centres and GSM-900 in the rest of the country.
Dual mode	Dual mode mobile phones have more than one air interface and hence can work on more than one network. One example is phones that operate on both digital and analog networks. They are quite useful if you want the advantages of a digital phone, but regularly visit areas where analog is the only service available.
EDGE	Enhanced Data Rates for GSM Evolution. An enhanced modulation technique designed to increase network capacity and data rates in GSM networks. EDGE should provide data rates up to 384 Kbps. EDGE will let operators without a 3G licence to compete with 3G networks offering similar data services. EDGE is not expected before 2001 at the earliest.
E-TACS	Extended Total Access Communications System: a 1G mobile phone network developed in the UK and available in Europe and Asia.
GPRS	General Packet Radio Service: a radio technology for GSM networks that adds packet-switching protocols, shorter set-up time for ISP connections, and offers the possibility to charge by the amount of data sent rather than connect time. GPRS promises to support flexible data transmission rates typically up to 20 or 30 Kbps (with a theoretical maximum of 171.2 Kbps), as

well as continuous connection to the network. A 2.5G enhancement to GSM, GPRS is the most significant step towards 3G, needing similar business model, service and network architectures. GPRS started to be introduced in some networks during the year 2000.

GSM — Global System for Mobile communications, the most widely used digital mobile phone system and the de facto wireless telephone standard in Europe. Originally defined as a pan-European open standard for a digital cellular telephone network to support voice, data, text messaging, and cross-border roaming. GSM is now one of the world's main 2G digital wireless standards, present in more than 140 countries. GSM is a time division multiplex (TDM) system. Implemented on 900, 1800 and 1900 MHz frequency bands.

HSCSD — High Speed Circuit Switched Data: dedicated circuit-switched data communications technology for GSM which boosts data throughput up to 14.4 Kbps in a single channel, and by aggregating channels, up to 57.6 Kbps. An asymmetrical service can be offered where, for instance, one channel is allocated for the uplink and several are aggregated for the downlink. HSCSD can provide a fixed bit rate (transparent mode) or a variable one (non-transparent mode). In most cases HSCSD is available to network operators as a pure software upgrade. HSCSD started to appear in some networks in 1999.

IMT-2000 — International Mobile Telecommunications-2000: term used by the International Telecommunications Union (ITU) for the specification for projected third-generation wireless services. Formerly referred to as FPLMTS, Future Public Land-Mobile Telephone Systems.

i-Mode — Proprietary packet-based information service for mobile phones. i-Mode delivers information (such as mobile banking, train timetables, etc.) to mobile phones and enables the exchange of email from handsets on the PDC-P network. Launched in 1999 by NTT DoCoMo, i-Mode is very popular in Japan (especially for email and transfer of icons), but is not currently being used elsewhere.

IrDA — 1. A suite of protocols for the infrared (IR) exchange of data between two devices, up to 1 or 2 metres apart (20 to 30 cm for low-power devices). IrDA devices typically can have throughput of up to either 115.2 Kbps or 4 Mbps. IrDA protocols are implemented by Symbian devices, in addition to Palm, Nokia communicators, printers from Hewlett-Packard and others.

2. The Infrared Data Association, the industry body that

	specifies IrDA protocols, originally founded by Hewlett-Packard and others.
Java	Industry standard object-oriented language and virtual machine, invented by Sun Microsystems and formally released in 1996. Java is an ideal language for network applications and applets. Sun's Java specifications include many Java APIs and platforms, including the JavaPhone API and PersonalJava platform, which Symbian is including in its own technology platform.
JavaPhone	A Java API specification controlling contacts, power management, call control, and phonebook management, intended specifically for the programmability requirements of Smartphones and Communicators.
MExE	Mobile Station Application Execution Environment (GSM 02.57): a framework to ensure a predictable environment for third-party applications in GSM or UMTS handsets (i.e. the Mobile Station). MExE does this by defining different technology requirements called "classmarks". MExE classmark 1 is based on WAP, and classmark 2 on PersonalJava and JavaPhone. Other classmarks may be defined in the future. MExE specifies additional requirements for all classmarks, for instance a security environment, capability and content negotiation, a user profile, user interface personalization, management of services, and virtual home environment. A handset can support any number of classmarks.
Network operator	Company with a licence to provide wireline and/or wireless telephony services.
NMT	Nordic Mobile Telephone. One of the earliest 1G cellular network developed jointly by Sweden, Norway, Finland, and Denmark. Originally operated on the 450 MHz band. And also later on the 900 MHz band.
Packet-switching	Technique whereby the information (voice or data) to be sent is broken up into packets, of at most a few Kbytes each, which are then routed by the network between different destinations based on addressing data within each packet. Use of network resources is optimised as the resources are needed only during the handling of each packet. This is an ideal model for ad hoc data communication, and works well also for voice, video, and other streamed data. Devices with packet-switched communication appear to be "always connected" to the data network, whereas in the case of circuit-switched connections, setup time takes around 30 seconds to connect from a wireless information device through a GSM phone to an ISP (and it is harder to use). Use of a packet-switched network can be charged according to the volume of data transferred and not to any

	notion of time spent online.
PCN	Personal Communications Network: another name for GSM 1800 (it is also known as DCS 1800). It is used in Europe and the Asia Pacific region.
PCS	Personal Communications Service: an American generic term for a mass-market mobile phone service, emphasising personal communication, independent of the technology used to provide it. PCS includes such digital cellular technologies as GSM 1900, CDMA and TDMA IS-136.
PDC	Personal Digital Cellular: the 2G TDMA-based protocols used in Japan, owned by NTT DoCoMo. PDC services operate on the 800 and 1500 MHz bands.
Service provider	A company that provides to phone users and mobile phone networks, services and subscriptions.
SIM	Subscriber Identity Module. The SIM card is the smart card inserted inside all GSM phones. It identifies the user account to the network, handles authentication and provides data storage for basic user data and network information. It may also contain some applications that run on a compatible phone (SIM Application Toolkit).
SMS	Short Message Service: available on digital GSM networks allowing text messages of up to 160 characters to be sent and received via the network operator's message centre to your mobile phone, or from the Internet, using a so-called "SMS gateway" website. If the phone is powered off or out of range, messages are stored in the network and are delivered at the next opportunity.
TACS	Total Access Communication System: a British 1G analog mobile telephone standard based on the US AMPS system. It was later adopted in other countries including Hong-Kong and Japan.
TDMA	1. Time Division Multiple Access: a digital wireless telephony transmission technique. TDMA allocates each user a different time slot on a given frequency. GSM, D-AMPS, PDC, and DECT use TDMA in one form or another. 2. A name generally used for D-AMPS. TDMA networks are operated in the US, Latin America, New Zealand, parts of Russia, and the Asia Pacific region.
UMTS	Universal Mobile Telecommunications Service, part of the IMT-2000 initiative, is a 3G standard supporting a theoretical data throughput of up to 2 MBps. It will be available commercially initially in Japan in 2001, and should be rolled out in most of the world by 2005.
W-CDMA	Wide-band CDMA: a CDMA protocol originated by NTT

DoCoMo and now adopted for third-generation use by ETSI in Europe. W-CDMA supports very high-speed multimedia services such as full-motion video, Internet access, and video conferencing.

WAP — 1. Wireless Application Protocol: a set of communication protocol standards to make accessing online services from a mobile device simple. WAP can be used for accessing internet type services on mobile phones.

2. WAP was conceived by four companies: Ericsson, Motorola, Nokia, and Unwired Planet (today called Phone.com). The WAP Forum is an industry association with over 200 members.

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YHTEENVETO (FINNISH SUMMARY)

Fomin, Vladislav Vladimir Francis

Standardin kehittämisen prosessi. Tapaustutkimus solukkoverkkoon perustuvasta matkapuhelintekniikasta.

Tämä väitöskirja tutkii matkapuhelintekniikan standardin kehittämisen prosesseja vuodesta 1946 tähän päivään saakka. Väitöskirjatutkimuksessa pyritään ymmärtämään miten nämä prosessit ovat tapahtuneet solukkoverkkoon perustuvan matkapuhelinteollisuuden sisällä, sekä tarjoamaan yleisemminkin näkökulmia standardin kehittämisen prosesseihin kompleksien infrastrukturaalisten informaatioteknologioiden sisällä.

Tutkimus tarkastelee solukkoverkkoteknologian historiaa ja kehitystä sekä tämän teknologian standardin kehittämisen prosesseissa ja käytännöissä tapahtuneita muutoksia. Tarkastelussa tukeudutaan tapaustutkimuksiin, kirjallisuuskatsaukseen sekä arkistojen tutkimiseen. Standardin kehittämisen prosesseja ja teknologian kehittymistä on analysoitu actor-network teorian näkökulmasta.

Tutkimuksella on neljä erityistä tavoitetta. Ensiksi se pyrkii NMT- ja GSM-standardien historian ja kehityksen monipuoliseen ja systemaattiseen tutkimiseen. Toiseksi tutkimus hahmottelee telekommunikaatioteollisuuden kehittymistä ja muuttumista, ja näiden muutosten sosiaalisia vaikutuksia. Kolmanneksi se pyrkii osoittamaan eri solukkoverkkoteknologioiden (standardien) menestymiseen tai epäonnistumiseen johtaneita tekijöitä. Neljänneksi tutkimuksessa kehitellään standardin kehittämisen prosessin malli.

Tämä väitöskirjatutkimus koostuu kahdesta pitkittäistapaustutkimuksesta, joissa tarkastellaan standardin kehittämisen prosessien käynnistymistä ja kulkua solukkoverkkoon perustuvan matkapuhelintekniikan yhteydessä. Tutkimuksen metodologia sisältää sekä prosessien kuvausta että teorianmuodostusta. Tutkimuksen pääpaino on useiden vuosien aikana kehittyneiden monitahoisten prosessien tarkastelussa.

Tutkimuksen tulokset tarjoavat näkökulmia solukkoverkkoteknologioiden, ja erityisesti niiden standardin kehittämisen strategioiden ja käytäntöjen kehittymiseen. Tutkimuksen tärkein anti on sen ehdottama malli standardin kehittämisen prosessille, joka on yleistettävissä ja siten myös sovellettavissa muiden kompleksien infrastrukturaalisten teknologioiden analysointiin.

Avainsanat: standardin kehittäminen, solukkoverkkoon perustuva matkapuhelintekniikka, prosessi, standardi, actor-network teoria

I

HOW TO DISTRIBUTE A CAKE BEFORE CUTTING IT INTO PIECES: ALICE IN WONDERLAND OR RADIO ENGINEERS' GANG IN THE NORDIC COUNTRIES?

DOI: 10.4018/978-1-878289-70-4.ch014

II

WHEN GOVERNMENT INHERENTLY MATTERS: NATIONAL INNOVATION SYSTEMS IN THE MOBILE TELEPHONE INDUSTRY, 1946-2000

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WHEN GOVERNMENT INHERENTLY MATTERS: NATIONAL INNOVATION SYSTEMS IN THE MOBILE TELEPHONE INDUSTRY, 1946-2000[1]

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Abstract

Mowery & Nelson (1999) outline how "industrial leadership" reflects comparative advantage held by a firm, a national industry, or some combination in between. They show how user demand, government policy and industry structure help determine which firms and industries will be successful in technologically-driven industries.

The global cellular telephone industry shares many common characteristics with the three electronics-related industries among the Mowery & Nelson study, and many of these earlier observations would also apply. However, the industry demonstrates several key differences that suggest extensions to prior theories of national innovation systems for telecommunication industries.

In particular, telecommunications infrastructure depends on scarce resources that require a government policy about allocating those resources to specific service providers. The limited number of providers means that these buyers play a far greater role in technology development than in industries where buyer concentration is not an issue. Thus, a focus strictly on equipment producer (rather than buyer) success may reflect an obsolete conceptualization of economic welfare in the New Economy.

We begin by considering the technological and industry antecedents to the first-generation cellular systems in Europe, the U.S. and Japan. We then review the three generations of cellular standards from 1980-2000, considering both the process of technological innovation and the concurrent national policies governing such innovations. Finally, we contrast the patterns of industrial leadership in the cellular industries with the industries in the earlier study to develop additional observations about the role of national innovation systems in high-tech industry development.

1 We are grateful for feedback from Henry Chesborough, Jason Dedrick and Kalle Lyytinen on earlier versions, but the remaining errors are entirely our own.

1 Introduction

Since the 1970s, the success of high-technology industries has been seen as essential for the economic growth of developed nations. Researchers have naturally gravitated to study the national differences in systems for technological innovation.

Among theory-developing empirical research, early studies (Porter 1990; Nelson 1993; OECD 1999) consider the differences at the macroeconomic level between countries, while Mowery and his colleagues (1996; Mowery and Nelson 1999) have examined the national innovation systems in specific industrial sectors. The studies have identified potential antecedents to innovation success, such as the role of suppliers, customers and government policy. But the results have varied dramatically between countries and sectors, raising concerns about generalizability given the small number of sectors studied.

Here we examine the cellular telephone industry, a sector with a markedly different industry structure than those previously studied. The industry has two other unusual characteristics, reflecting a convergence in the early 1980s of mobile radio and telephone sectors — with distinct industry structures and technological competencies. At the same time, like other telecommunications industries, the production of goods is inextricably linked to the consumption of services, with a complex three-way relationship between manufacturer, service provider and end-user.

We use a similar methodology to Mowery & Nelson (1999) — supplemented by participant interviews — and contrast our results to their earlier I.T. national innovation studies. While many results are consistent with the earlier studies, we show that when the buyers are limited to small numbers by government policy, that both those policies and the "small numbers" feedback of those buyers have a major impact on producer success.

2 Prior Research

2.1 Research on National Innovation Systems

Economists since Schumpeter have examined the role of technological innovation as an engine for economic growth, both through the production of high-tech goods and also the productivity growth enabled by their use. While scientific R&D is essential for a successful technological innovation, success also requires other skills such as engineering, production and market analysis (OECD 1999).

Research on "national systems of innovation" has sought to identify the systemic factors that explain differences between nations in innovation commercialization. Implicitly or explicitly, the models assume an evolutionary view of economics based on variation and market selection — different firms try different technological approaches, and the best approaches survive through their products and firms. While this research has identified the central role of learning and institutions in successful innovation, the result has been a conceptual framework for analysis rather than formal theory (Edquist 1997).

This research has examined differences in innovation systems at the national level, characteristics of specific industrial sectors, or the interaction of the two levels. Most studies assume that the locus of technological advantage is external to the firm — Mowery and Nelson (1999) offer the concept of "industrial leadership" to encompass advantage that stems from either a firm's internal factors or its external environment (e.g., from an industry cluster or national institutions). They are also among the first to assume that industrial leadership is cyclical rather than inherently permanent.

Early studies attempted to isolate specific "national" patterns of innovation common across all high-tech industries in a given country. So the studies edited by Nelson (1993) show that industries with high up-front R&D costs tend to be found in large, affluent countries — except for those smaller countries (e.g., Sweden, Israel, Korea) with disproportionately large defense industries. The more successful firms have been exposed to stronger competition, typically but not always in their home market. The results on upstream and downstream linkages are more equivocal, with some industries in which upstream (to domestic suppliers) or downstream (to demanding home-market clusters) linkages improve the odds of success, but others where these factors appear to be unimportant (Porter 1990; Nelson 1993).

The sheer heterogeneity of firms and industries — even within a common national institutional system — has prompted subsequent research into national differences within a specific industrial sector. Thus, the study of Mowery (1996) and colleagues into software development suggested a significant (but declining) importance of local ties to upstream suppliers, i.e. hardware vendors. However, differences in home market demand had encouraged specialization of the respective domestic software industries in the U.S., Japan and Western Europe, a specialization likely to be maintained by those demand factors.

2.2 Explaining the Mobile Telephone Industry

With the exponential price/performance growth of digital electronics since the invention of the microprocessor, the computer and communications industries have converged to reflect a common set of "information technology" industry characteristics. However, the telecommunications market continues to differ in crucial ways from that for computers:

- the user benefit is primarily from a service — not the product — so the manufacturer's innovation is only indirectly related to user adoption;

- scarce resources and economies of scale tend to limit the service to a small number of providers;
- concentrated buyers have traditional supplier relationships, typically concentrating each nation's telecom industries into (at most) a handful of manufacturers;
- governments matter, because of their historic role regulating monopoly or oligopoly service providers, and the indirect effect of those government policies upon the innovations of the manufacturers.

Together the central role of services and the concentration of service providers mean that those providers span both the "producer" and "user" roles of Mowery & Nelson (1999). And the prevalence of "national champion" producers linked to monopoly operators are inconsistent with an evolutionary economics approach, in that domestic markets lack the diversity and selection processes characteristic of, say, the software and computer industries.

Among services provided by traditional telecommunications carriers, the highest growth has been in cellular telephone service, which in the U.S. alone has grown from non-existent to more than $50 billion annually in less than 20 years (CTIA 2000). Despite the rapid growth of both producers and providers during the subsequent two decades, market entry has been constrained by government allocation of scarce radio spectrum resources to a small number of providers.

The pattern of technological and industry development is also dramatically different from the semiconductor, computer and software industries analyzed in Mowery & Nelson (1999). While the scientific invention of cellular radio was American, unlike in the computer industry essential technological and management innovation occurred outside the U.S., providing a contrast of three distinct national innovation systems vying for industrial leadership in this industry. And while the failure of mobile telephone national champions matched those in the computer industry, the path to success was far different from that enjoyed by an IBM, Microsoft or Intel. Finally, despite a common explicit "European" innovation policy for the industry, heterogeneity in market size and industry structure has led to major intra-European differences in national systems for innovation.

3 Context of Cellular Deployment

3.1 Industry Structure

The mobile telephone industry is based on three main types of commercial transactions:

1. an equipment manufacturer sells to the provider of cellular telephone service (operator) certain stationary *cellular infrastructure* equipment, consisting of multiple radio base stations and one or more telephone switching systems;
2. the equipment manufacturer sells a *mobile telephone* to the service provider (or other agent), who in turn sells or leases that handset to the ultimate end-user;
3. the service provider (or agent) provides *mobile telephone service* to the end-user, typically charging some combination of monthly and per-minute access fee.

Thus, the demand for the cellular technology is based on the individual customer's use of the service, with the equipment characteristics being only one of the factors considered in a user's service adoption decision. Thus, an examination of the industry leadership requires a consideration of both the equipment manufacturer and the service provider.

While the technological development of mobile telephony owes as much (if not more) to mobile radio, the institutional frameworks for the service and its regulations are far more consistently aligned with wire-based telephone service. Incumbent "wireline" telephone carriers were granted a mobile telephone license in all the leading countries — usually the first license and in some cases, the only license for many years. And, as will be seen later, most of the early research into mobile telephone service was done by the incumbent telephone carrier.

In most of the G-7 and other developed countries, that service was provided by a post, telephone & telegraph (PTT), either as a government department or as a quasi-private state-owned corporation; the notable exceptions were in North America, where AT&T and its former Canadian subsidiary provided regulated monopoly service throughout most (though not all) of the continent. The PTT's were served by long-term suppliers, usually local firms protected by government purchasing policies. Again, the U.S. and Canada were the exception, where vertically integrated service providers largely relied on their subsidiaries for equipment.

Finally, no matter which company provided mobile telephone service, nearly all mobile telephone calls depended on the wireline public switched telephone network (PSTN) for origination, termination, or inter-office transmission; the mobile networks served as an extension of the PSTN rather than an independent parallel network as with, say, the Internet. Because of this interdependence and interconnection, cellular service was usually regulated by the same government ministry or agency that regulated wireline and earlier non-cellular mobile telephones. In some cases, the policies for allocating revenue between the PSTN and mobile network for mobile calls determined the success or failure of mobile operators.

This institutional continuity assured that the existing wireline telecommunications carriers played a major role in the provision of cellular telephone service. In some cases, the carriers maintained existing supplier relationships, although the new technology provided opportunities for new entrants as well. These past patterns provided wireline suppliers little advantage in mobile handsets, which were sold to consumers rather than PTT customers.

3.2 Early Mobile Telephones

AT&T launched the world's first commercial mobile telephone service in St. Louis in 1946. A similar technology was used by the national telephone companies in other major cities of the developed world. These initial car-mounted telephone systems used one set of frequencies for an entire metropolitan region (thus limiting capacity) and also required manual operator connections (increasing the cost per call). This limited capacity and high cost meant that pre-cellular mobile telephone service was used by very few people and thus played a minor role on the finances of telephone companies and the policy deliberations of government regulators.

AT&T operated systems in most large U.S. cities throughout the 1960s and 1970s, and developed a series of enhancements to improve the capacity, call quality and convenience of the system. In 1964 it introduced the Improved Mobile Telephone System (IMTS), which remained in service more than 20 years, far longer than anticipated due to delays in deploying cellular technology (Young 1979; Calhoun 1988).

In Europe, the first system came in Sweden in 1956, when the PTT offered a car-based telephone service for public use in Stockholm and Göteborg; a second system was deployed in the three largest cities beginning in 1965, while a nationwide system, MTD, was deployed beginning in 1971 (Gerdes 1991). West Germany deployed a series of systems from 1959 through 1981, limited to no more than 15,000 customers nationwide (Spindler 1986). In Finland, the state PTT began in 1969 to deploy a highway-based radiotelephone network called ARP based on a similar system already operational in Denmark (Toivola 1992). Comparable systems were also deployed in the U.K. and other industrialized countries. In Japan, a government research lab developed a pre-cellular mobile telephone system in 1967, but because it could not accommodate the likely demand for such service among commercial customers, it was reserved for government use only (Ito and Matzuzaka 1978).

The one major advance in some countries was the addition of automatic dialing, which allowed customers to dial outgoing connections to the public switched telephone network without use of an operator. This was gradually phased into updated mobile telephone systems, beginning in 1956 in Sweden and 1964 for the U.S. But all systems had such limited capacity as to be nearly useless, with, for example, AT&T's New York system serving 543 customers in 1976 with a waiting list of nearly seven times as many potential subscribers, and a market penetration of less than 0.01% (Calhoun 1988).

3.3 Cellular Technologies

The solution to mobile telephone capacity had been discovered in 1947, when D.H. Ring of AT&T Bell Labs determined that a region could be subdivided into a series of smaller areas called "cells." As long as adjacent cells did not use the same frequencies (which would cause interference at the boundaries), it would be possible to cover a large metropolitan area through a series of cells and eventually re-use the same frequencies many times.

Despite early recognition of the key concepts necessary for cellular telephony, the technology necessary to implement commercial cellular telephone systems did not become available until the 1970's. Three technological developments were necessary:

- Frequency synthesizers. Early mobile telephones used oscillator crystals that limited them to about 30 radio channels. For added capacity, efficient use of that capacity and to avoid interference in adjacent cells, hundreds of channels were needed for cellular systems. Low-cost frequency synthesizers allowed telephones to support a large number of frequencies beginning in the early 1970's (Young 1979; Calhoun 1988).
- Digital Switching. Computerized telephone exchange switches were introduced for "wireline" service in the mid-1970's. They solved the crucial problems of mobile telephone service, including billing, finding the mobile terminal, continuing calls as the mobile moved between radio cells ("handoff"), and allowing customers to use their phone ("roam") outside their home service territory (Meurling and Jeans 1994).
- Microprocessors. Nearly the same level of computing power was required in the mobile telephone handset as in the land-based switch. The solution was the same as in the personal computer: the microprocessor, which was first introduced in 1971. The car-mounted telephone used in AT&T's 1978 Chicago field trials used an Intel 8080 microprocessor — the same as in the Altair 8800, an early PC (West 2000).

When compared to the pre-cellular systems deployed in the 1960s and 1970s, these breakthroughs dramatically increased the capacity of metropolitan mobile telephone systems, as well as reducing the per-subscriber cost of building and operating such systems.

4 Systems of Innovation for First Generation Cellular Technology

The first-generation analog cellular systems were developed on three continents during the 1970s and early 1980s. Although mutually incompatible, they shared a set of common technological characteristics (Stocker 1984; Lee 1998, p.100-101):

- Using the same FM two-way radio transmissions employed in military/police mobile radios, existing car telephones, and two-way private mobile radio
- Using UHF frequencies in the 450-950 MHz range, with 25-30 kHz channel size
- Each call uses a control channel and separate transmit/receive voice channels
- Cell radius of 5-20 km with automatic handoff between cells
- Variable-power mobile transmitters with a maximum power of 10 watts

In this, the NTT, NMT and AMPS/TACS systems show all the common characteristics of a dominant design.

Despite similar institutional constraints, the system and manufacturer success did not depend on some generic "American" or "European" pattern. Instead, the results depended on whether the cellular innovation policy was controlled by well-protected wireline incumbents, competition-focused policymakers, or export-oriented manufacturers.

Nelson (1993, Ch. 16) notes that technologically successful firms typically have either strong domestic customers or an immediate export focus that puts them in touch with foreign customers. Among first-generation analog systems, there were national champion producers with assured domestic customers who were not particularly demanding. Meanwhile, producers with a small (or not very assured domestic) customer base more quickly became export focused and competitive on a global market.

4.1 Domestic-Focused National Champions

The institutional patterns of wireline telecommunications infrastructure were repeated in the initial cellular systems developed in the three largest industrial economies: U.S., Japan, and West Germany. In each case, the national telecommunications carrier worked with existing suppliers to design a system to meet domestic requirements.

4.1.1 United States

The American Telegraph and Telephone Company was a vertically integrated provider of telecommunications services and equipment. It had long enjoyed a monopoly on long distance service and provided local service as the monopoly carrier in most of the U.S., using equipment designed by Bell Labs and manufactured by Western Electric. While it was a for-profit (rather than government-owned) corporation, it was guided by a public service ethos that in many ways paralleled a government PTT (Temin 1987).

With limits to its IMTS capacity, AT&T began in the late 1960s to request additional frequency spectrum for cellular service, which was initially awarded by the U.S. Federal Communications Commission in 1970. But both AT&T and the FCC had trouble adjusting to the increasing liberalization of U.S. telecommunications services: regulatory conflicts involving the two sides — and also other potential rivals for products and services — dragged out the approval process by more than a decade. While AT&T was granted permission to build a Chicago development system in 1977, it was not licensed by the FCC for commercial use until October 1983 (Calhoun 1988; West 2000).

Similarly, the AT&T Bell Laboratories design of its AMPS cellular system was predicated on quick approval of an AT&T monopoly on cellular service using an AT&T design. AT&T filed its first system design with the FCC in December 1971 and began AMPS functional testing in November 1976. The AMPS radio interface specification was frozen by the FCC in April 1981, although commercial deployment was more than two years away. By that time, AT&T had agreed under government pressure to spin off its local operations into seven "Baby Bells," which were born in January 1984. In 1996, AT&T initiated a second divestiture, spinning off its telecommunications (including cellular) equipment design and manufacturing into a new company, Lucent Technologies (Young 1979; West 2000).

The FCC awarded two AMPS licenses in each of 306 urban or suburban markets, with one license reserved for the local wireline telephone carrier — usually but not always a "Baby Bell" company. Five years after the first system began service, an area corresponding to 75% of the population had service available from at least one cellular carrier available (Paetsch 1993).

By the end of 1995, when digital systems began to be deployed nationwide, AMPS coverage was ubiquitous. At around 13%, the penetration rate lagged behind Northern Europe (around 20%) but remained well ahead of Japan, the U.K. and the rest of Europe.

4.1.2 Japan

The Nippon Telegraph and Telephone was established as a government corporation in 1952 with a monopoly on nearly all telecommunications services. The company had its own research laboratories, which were among the country's major centers for basic and applied research. However, its equipment was manufactured by its "den-den" family of suppliers: Hitachi, NEC, Fujitsu and Oki Electric (Vogel 1996; West, Dedrick, and Kraemer 1997).

NTT developed its own analog cellular design in the 1970s, which was manufactured by NEC, Oki and other Japanese firms. In December 1979, NTT deployed the world's first cellular system, but adoption was slow due to limited expectations. As one former executive explained:

> "NTT's marketing team thought they [would serve] executives, or lawyers, doctors — only for business use. The price of the cellular phone doesn't matter for them — so a very expensive price was set on the cellular phone system". (Ozawa 1997.)

In 1985, telecommunications liberalization ended NTT's service monopolies and spun off NTT as a publicly traded company, although still majority-owned by the government. At the same time, a competing cellular carrier was licensed in each of nine national markets, of which two used the NTT standard. In response to U.S. trade pressure, seven markets used the TACS standard based on the U.S. AMPS standard. However, prices remained high and penetration rates lower than the U.S. (Funk 1996; West 2000).

4.1.3 Germany

By virtue of its domestic market, the Deutsche Bundespost was Europe's largest PTT. As with NTT, the DBP helped design its systems but relied on four domestic suppliers to produce the equipment; the two largest being Siemens and SEL, ITT's German subsidiary; the two together made 70% of the central telephone switches. This closed system resulted in high prices for DBP and German consumers, and was also the subject of trade friction with the U.S. A 1989 liberalization spun off the telecommunications services into a new company, DBP Telekom and removed its monopoly on some services, including mobile telephony (Noam 1992).

Beginning in 1985, DBP introduced its third, or "C" network, the first to incorporate cellular technology and automatic handoff. The system, developed internally by Siemens, reflected an advanced design, which when coupled with DBP's marketing goals, made it extremely expensive and thus attracted a limited number of subscribers (Spindler 1986).

4.1.4 Ad hoc Export Policies.

The leading manufacturers adopted the technology of their domestic systems for export to other countries, although this was not a primary goal of the PTT customers (table 1). Many carriers also exported their capital and expertise in operating cellular systems to less developed markets lacking domestic suppliers, usually specifying the same technology that they operated in their home country. Nordic carriers helped establish NMT systems in Eastern Europe and the Middle East. U.S. "Baby Bell" carriers such as Bell South and Pacific Bell (later AirTouch) partnered with foreign operators to launch AMPS networks, mainly in Latin America.

TABLE 1 Deployment of early first-generation cellular systems. Source: Adapted from (Commission 1997), (Spindler 1986), (Paetsch 1993), Mobile Communications International

Date	Country	City	Operator	Primary Equipment Maker
1979-Dec	Japan	Tokyo	NTT	NEC
1981-Aug	Mexico	Mexico City	Telefonos de Mexico	NEC
1981-Sep	Australia	Melbourne	Australian Telecommunications Commission	NEC
1981-Sep	Saudi Arabia	Riyadh	Kingdom of Saudi Arabia PTT	Ericsson
1981-Oct	Sweden	Stockholm	Televerket	Ericsson
1982-Nov	Spain	Madrid	Telefonica	Ericsson
1983-Mar	Finland	Helsinki	Tele	Nokia
1983-Oct	U.S.	Chicago	AT&T	AT&T
1985-Sep	Germany	*nationwide*	Deutsche Bundespost	Siemens
1985-Jan	U.K.	London	Cellnet Vodafone	Motorola Ericsson

4.2 National Consumer-Focused Strategies

In two cases, the policies for analog cellular systems were designed to maximize buyer adoption and utility. Not surprisingly, these two systems enjoyed the highest adoption rates in Europe and among the highest rates in the world.

4.2.1 Nordic Countries

The deployment of first-generation cellular systems in Northern Europe was guided both by direct government policies (with the decision to build a pan-Nordic system) and also the indirect role of the governments through their respective PTTs.

In 1971, the four Nordic PTTs established a formal committee to look at regional collaboration on radio issues; the committee was primarily led by Sweden and Norway, with lesser roles for Denmark and Finland. The committee was assigned to develop plans for a pan-Nordic car telephone system to replace each country's existing car telephone system(s), a system later named Nordic Mobile Telephone. The NMT group — numbering from 10-25 during the next decade — was a small, cohesive team using a shared language and institutional outlook to achieve specific pragmatic goals, with the top priorities being a common technical design and radio frequencies. In 1975, the group finalized system requirements, and in 1977 solicited manufacturer proposals to build cellular networks (Manninen 2001; Meurling and Jeans 1994).

As government-owned carriers, the PTTs were not then in direct competition with each other, and so pooled their knowledge towards a common design. However, there was a very conscious and carefully designed effort to pool the knowledge of various European, Japanese and American manufacturers. On the one hand, the questions and suggestions of the manufacturers were incorporated into the design without revealing which firm had provided them, or other proprietary producer data. On the other hand, no manufacturer was allowed to control the process — if one manufacturer said a task was impossible, that was cross-checked against the capabilities of other producers (Fomin and Lyytinen 2000).

Despite the presence of domestic manufacturers, the PTTs' supply contracts were put out to competitive bid in which existing supply relationships reportedly were but one factor in the evaluation. Eventually they narrowed their choices to four finalists — Ericsson of Sweden, Telefenno of Finland, Motorola of the U.S. and NEC of Japan — with the initial infrastructure contract awarded to Ericsson in 1978 (Manninen 2001; Lyytinen, Manninen, and Fomin 1998, 2000).

The design goals in Northern Europe were quite different from those in Germany:

> "I think Bundepost also thought that this is just a small niche market for the kind of high executives. And I think Finnish and Swedish PTT's, they had already in their minds some kind of … Nordic democratic way of thinking: it's not only for the high executives, it's maybe also for the at least *[laughs]* smaller executives, and maybe even to the man on the street". (West 1996.)

The initial 450 MHz band systems were launched in the four countries beginning in 1981, and were immediately successful, attracting new subscribers at twice the projected rate; by 1987 all four systems had reached maximum capacity. Thus, in 1983 planning began for building an updated NMT system in the 900 MHz range, which began service in 1986 (Paetsch 1993).

4.2.2 United Kingdom

While the Nordic governments had sought to maximize competition between producers (while essentially perpetuating the monopoly of the respective PTT operators), the U.K. sought to maximize competition between operators to reduce service prices.

Lagging the research efforts in the U.S., Japan and the Nordic countries, and lacking a domestic industry skilled in mobile telephony, British regulators chose to be technical followers by adopting a modified version of the American AMPS system. However, the U.K. led Europe and most of the world in competitive innovations with its aggressive liberalization and regulation of the previously monopoly British Telecom. From the beginning, it licensed two competing systems, Cellnet and Vodafone which both began service in January 1985; it also limited BT to a 50% share of the former network. In the early 1990s, Britain was Europe's most competitive cellular market with seven licensed carriers (Taylor 1985; Paetsch 1993; Vogel 1996).

4.3 Firm-Level Export Strategies

Among cellular equipment manufacturers, the national champions of the largest countries remained focused on their domestic markets. But four firms that lacked such guaranteed markets were more aggressive in adapting their products and technologies to meet unserved export markets. One, Motorola, competed directly with the largest telecommunications operator and manufacturer in its home market (ATT). The other three — Ericsson, Northern Telecom and Nokia — were dominant in their home markets, but those markets were small in scale.

Motorola's eventual role in the cellular industry could be directly traced to U.S. competition policies. As part of a 1956 anti-trust settlement, AT&T was excluded from operating or manufacturing two-way mobile radio systems, and Motorola quickly became the key supplier to a myriad of independent operators. Similarly, when the FCC allowed radio common carriers to operate IMTS pre-cellular systems, Motorola was the leading supplier. Finally, the arguments of Motorola and others convinced the FCC to reject AT&T's original proposal for a single (wireline) cellular operator in each market, instead requiring the AMPS design to support two competing operators. Many of these "non-wireline" operators were successors to the radio carriers that had been and remained loyal Motorola customers (Calhoun 1988; West 2000).

This institutional background meant that Motorola had a dramatically different customer orientation than its major domestic rival, AT&T (later Lucent). The latter had historically sold only to internal customers, and even after the 1984 breakup, retained strong ties to the Baby Bell operating companies. Meanwhile, Motorola had sold to a highly fragmented group of small operators, successfully competing with E.F. Johnson and other radio system manufacturers.

Motorola leveraged its radio and market expertise to export AMPS systems outside the U.S. One of its first major markets was the U.K., where it supplied the initial system for Cellnet. The other operator, Vodafone, used equipment supplied by Ericsson. Ericsson was Sweden's largest producer of telecommunications equipment; largely locked out of the domestic market by the PTT's subsidiary, 80% of Ericsson's 1980s revenues came from exports (Noam 1992).

In 1919, Ericsson had also co-founded Svenska Radio Aktiebolaget (SRA). The firm became Sweden's leading radio manufacturer, a national champion that made radio receivers, radio and TV transmission equipment, and military radios. SRA eventually divested its consumer business to focus on military radios and civilian mobile radio systems. While Ericsson bought out its remaining partner and converted SRA into a wholly-owned subsidiary in January 1983, the division was considered a backwater in the telecommunications-dominated firm. But within 10 years, the successful exports of mobile telephone equipment to the U.K., U.S. and elsewhere made the former SRA Ericsson's largest division (Meurling and Jeans 1994).

Another export-focused small telecommunications firm was Northern Telecom, Canada's leading telecommunications maker, majority-owned by its largest customer, Bell Canada. The Canadian Bell group was the country's largest source of patents, accounting for nearly 20% of industrial R&D in 1988 (Nelson 1993, p.307).

Northern Telecom's major export market in the 1970s was independent U.S. telecom operators, but with the 1984 breakup of AT&T, NT expanded its market to include most of the U.S. Baby Bells (Newman 1995). Unlike Ericsson, NT lacked radio expertise and had teamed with GE in the initial AT&T AMPS trials. In 1992 Northern Telecom announced a marketing joint venture with Motorola — which historically was weak in switching equipment — but the venture lasted barely 18 months before dissolving due to conflicting technology strategies.

The most unusual example an export strategy came from Finland, where a forest products company named Nokia diversified into telecommunications and later divested all other holdings.

Finland had developed a domestic military radio industry during World War II and used radio exports to pay postwar reparations to Russia. Three firms eventually made ARP car telephones: Salora, Televa and Nokia. In 1975, Salora was so successful that it began exporting ARP telephones to the other Nordic countries, and also entered into a marketing agreement with Nokia where both firms would market Salora phones and Nokia radio base stations; in 1979 the companies assigned both product lines to a new manufacturing joint venture, Mobira. Similarly, in 1977 Nokia pooled resources with the third mobile radio company, Televa, to form a telephone switching manufacturing joint venture named Telefenno. Nokia eventually bought and consolidated Mobira and Telefenno as subsidiaries (Manninen 2001).

Like Motorola, Mobira realized early success both domestically and in exports by quickly making the shift from car-mounted to hand-portable telephones. The two companies supplied portable telephones for the systems built by their respective rivals (AT&T and Ericsson), which lacked portable products. After supplying phones for all four NMT operators, Mobira's big breakthrough came in 1984 when it provided private label AMPS handsets for sale by Radio Shack, a major U.S. retailer. Nokia also made private label handsets for Ericsson and Northern Telecom until 1991, when it switched to its own brand (McCoy 1984; Moore 1987; Fox 2000).

5 Export Considerations in Second Generation Technologies

The 2nd generation cellular systems employed digital technologies to provide higher capacity, more features and potentially better service quality. While industrial leadership in digital technologies was related to that in analog ones (tables 2,3), an explicit export-oriented 2nd generation policy aided European producers in competition with U.S. and Japanese rivals.

5.1 Export-focused Industrial Policy

The first digital cellular system deployed was GSM, a pan-European digital standard, developed with explicit policy support from the European Commission.

The standardization effort began in the early 1980s, when several Northern and Western European PTTs approached the Conference of Postal and Telecommunications Administrations (CEPT), a PTT technical cooperation group that included both EC and non-EC European members. In 1982, the CEPT set up a study group, later known as Groupe Spéciale Mobile. GSM's initial goal was to define a common cellular standard across Western and Northern Europe, with the use of digital radio transmissions not formally adopted until 1987.

The GSM project built directly on Europe's only multi-country cellular project, NMT. The NMT operators had the most experience in both collaborative development and operating cellular systems. The first chairman of the GSM group, Thomas Haug, was an employee of the Swedish PTT who had held the #2 position in the NMT group. The four Nordic countries played a major role in the GSM development, although all but Denmark were outside the EC. The GSM project also used NMT-style knowledge-transfer mechanisms with prospective manufacturers, who included both European and a few non-European firms.

TABLE 2 Leading producers of cellular handset equipment, 1998[2]. Total sales: 163 million units (1998). Source: (Dataquest 1999; 2000)

Brand	Country	1998 Global Share†	Mergers and acquisitions	Origins
Nokia	Finland	22.5%	Mobira joint venture with Salora (1979) Bought Salora (1984)	Paper and natural resources
Motorola	U.S.	19.5		Leading U.S. maker of portable radio equipment
Ericsson	Sweden	15.1	SRA spun-in 1983	Export-oriented telecom supplier
Panasonic (Matsushita)	Japan	8.4		Leading prewar provider of radios
Alcatel	France	4.3	Created by merger of Compagnie Generale d'Electricité with ITT's telecom business (1986) Merged cell phone unit with Thomson (1999)	CGE: supplier to France Telecom ITT: leading exporter of telecom equipment Thomson: electronics for French market

TABLE 3 Leading producers of cellular infrastructure equipment, 1998

Company	Country	Mergers and acquisitions	Origins
Ericsson	Sweden	Bought Qualcomm CDMA infrastructure division (1999)	Independent telecom supplier to Europe and North America
Lucent	U.S.	Spun-off from AT&T (1996)	Western Electric and Bell Labs divisions of AT&T
NEC	Japan		Leading NTT supplier of telecom equipment
Nortel	Canada	Spun-off from Bell Canada's holding company (2000)	Co-founded by Bell Canada, Western Electric

2 Includes proportionate customers from minority investments in foreign subsidiaries

Despite this Nordic leadership, and the quasi-governmental role of the CEPT members, the success of GSM depended on the EC's policy support through three crucial decisions:

- In November 1984 the European Council of Ministers issued a single-market policy framework to "stop the fragmentation of the European market, to help users to have cheap prices, and to help the European industry to have a wide market."
- In June 1987, the council required its member states to reserve a common 900 MHz frequency band for use by a pan-European cellular network.
- Also in June 1987, the EC published its "Green Paper" on telecommunications, which advocated liberalization of telecommunications equipment and services, so that European customers could enjoy more economic service, and so that European producers could become more technologically innovative (Bernard 1989).

GSM was not Europe's only cooperative R&D project of the 1980s. The EC sponsored two projects, ESPRIT (computers) and RACE (telecommunications), while EUREKA was a French technology initiative that included non-EC members; together, their budgets totaled 10 billion ECUs. All were motivated by European fears of local manufacturers falling behind the U.S. and Japan firms in high-tech industries (Sandholtz 1992).

And while the CEPT-sponsored GSM group included operators and not manufacturers, many of the deliberations were driven by the industrial policies of the respective member states. In particular, in 1987 the group reached impasse between a Franco-German radio encoding method and a more flexible Nordic design. While French and German PTT representatives privately favored the Nordic plan, their governments opposed it due to the R&D investment by French and German manufacturers in their specific technology — a technology abandoned several months later when Germany endorsed the Nordic plan (Lyytinen, Manninen, and Fomin 2000).

In September 1987, the GSM standard was approved by representatives of 13 European countries. Two years later, control of the technology was transferred from CEPT to the European Telecommunications Standards Institute, an EC research lab. GSM service began in 1991.

5.2 Telecom Liberalization Ideology

The deployment of digital service in the U.S. and Japan was more associated with liberalization and new entrants than with a conscious effort to aid manufacturer exports.

5.2.1 United States

Digital service was delayed "in part because there is no immediate need for what has been touted as its primary advantage—the ability to deliver increased capacity" (Mason 1993, p.7). In a few markets (such as Las Vegas) where subscriber density overwhelmed system capacity, a narrowband version of AMPS was deployed to provide a threefold improvement. Another factor was the desire of operators to recoup existing 1st generation infrastructure investments, which through the end of 1994 totaled $18.9 billion, vs. $51.1 billion in total revenues to that point (CTIA 2000).

Another factor was U.S. telecommunications policy. The U.S. had aggressively pursued an ideology of liberalization and competition, which culminated in the Telecommunications Reform Act of 1996 that reversed some AT&T breakup policies and carried others to their logical end.

Unlike in Europe or 1st generation U.S. standards, the U.S. government did not mandate a specific 2nd generation standard. The original D-AMPS (aka "TDMA") standard was approved by a U.S. manufacturer's trade association in 1990, but the delay in digital system deployment enabled the entry of a competing digital standard — Qualcomm's CDMA — which was approved in 1993. The competing standards further raised confusion and delayed investment.

What finally motivated existing carriers to deploy their long-planned digital systems was the appearance of newly-licensed operators in a "PCS" band. The FCC used a $17 billion auction to license three major operators for each of 51 markets, and the systems began to be deployed in late 1995. In another departure from 1st generation policies, industry groups were allowed to determine the technologies used for PCS systems, and eventually selected seven. Three of these were widely deployed — 1.9 GHz version of the D-AMPS and CDMA (later cdmaOne) standards, plus a U.S adaptation of the European GSM standard.

These policies were later claimed to harm both U.S. interests, because of the fragmentation of the subscriber base between competing technologies hindered both producer manufacturing efficiencies and customer convenience. At the same time, without such competition, it is unlikely that Qualcomm's CDMA technology would have been commercialized (Jenkins 1999).

Both the D-AMPS and CDMA technologies were exported as digital upgrades to Latin American AMPS networks. CDMA was also adopted in a few Asian markets — Hong Kong, Korea and later Japan, due to its capacity advantages and the relentless lobbying by Qualcomm, which was motivated by the prospects of patent royalties on all CDMA equipment (Poe 2000).

5.2.2 Japan

As in the U.S., Japan faced the policy question of encouraging competition to its dominant carrier at the same time that digital cellular systems were being deployed. Japan initially approved a single 2nd generation standard, NTT's

PDC; licenses were granted to four competing nationwide networks, with two of the systems sharing infrastructure in the rural parts of the country (MPT 1996). NTT was the first to deploy digital networks in 1993, a year ahead of its competitors.

The Japanese telecommunications ministry developed a second domestic digital standard, PHS, based around a low power, lightweight and low-cost handheld telephone. The entry of the three nationwide PHS systems brought price competition for the existing cellular networks, shifting Japan from being a laggard to one of the leaders in mobile telephone adoption. But to give PDC carriers a chance to get established, PHS deployment was delayed more than 5 years, until 1995. By then, the relative size advantages of PHS were less dramatic and its service reliability problems were more objectionable. The technology developed a reputation as a low-quality cellular service, enduring chronic losses (Funk 1996; Ozawa 1997; Landers 2000).

Despite the large number of competitors, as in Europe the incumbent PTT retained many advantages and the dominant market share: as of mid-2000, NTT DoCoMo's PDC service held 52% of all mobile subscribers, vs. 22% for its next closest competitor. Meanwhile, PDC and PHS were exported to Asia but lagged GSM and even CDMA in their adoption levels (Yoshino and Sugiyama 2000; Funk 1998).

6 Future: Global Competition of Firms and Technologies

6.1 Export Focus and Trade Friction

Most first- and second-generation cellular standards were set at the national level. For cost reasons, follower countries inevitably adopted a derivative of one of the existing standards, and chose radio frequencies that were similar to some existing market. But most of the decisions were made without international roaming in mind.

The success of GSM in promoting roaming within Europe and key export markets, as well as the frustrations seen by a few elite travelers roaming between continents, prompted members of the Geneva-based International Telecommunication Union to begin efforts towards a common third-generation global standard. The first step came in 1992, when frequencies for such "3G" systems were set aside by delegates to the World Administrative Radio Congress.

If the second-generation systems were driven by the benefits of digital service (particularly increased capacity), the 3G design effort was prompted by a desire for high-speed "multimedia" applications. In 1998, a European-led consortium proposed a W-CDMA ("Wideband CDMA") standard backed by Ericsson and Nokia that would maximize the reuse of GSM infrastructure technologies for both manufacturers and operators of 3G systems. The plan was based on radio transmission technologies developed by NTT and thus backed by Japanese representatives.

Meanwhile, U.S. manufacturers and operators sought a 3G technology that would be compatible with cdmaOne systems and, as much as possible, the infrastructure design of the AMPS network — which was incorporated in both D-AMPS and cdmaOne digital systems. They developed a competing standard called cdma2000, incompatible with W-CDMA.

Beginning in April 1998, a patent dispute between cdmaOne and the W-CDMA backers delayed the entire 3G process. Qualcomm and other U.S. firms lobbied Congress and trade officials to fight the W-CDMA plan as a *de facto* trade barrier; the dispute ended with Ericsson's March 1999 purchase of Qualcomm's infrastructure division. In November 1999, the International Telecommunications Union adopted a policy that each individual service provider could select its preferred radio interface, without mandating a single global standard.

A third competing standard, TD-SCDMA was developed by Chinese researchers in collaboration with the German manufacturer Siemens. While only China planned to adopt it as its primary 3G standard, the potential demand in one of the world's largest cellular markets prompted interest in the technology from other manufacturers, particularly those from Korea.

6.2 Global Consolidation of Service Providers

As with 1st and 2nd generation systems, 3rd generation cellular licenses were awarded by national governments for operations within that nation's territory. However, the licensees were increasingly multinational companies rather than merely sheltered domestic-only PTTs.

While most countries had nationwide cellular operators, the "wireline" half of the U.S. AMPS licenses were split among seven "Baby Bell" companies, GTE and dozens of smaller local telephone companies; non-wireline licenses were even more fragmented. Throughout the 1980s and 1990s, these licenses were graduated consolidated through mergers and acquisitions. Similarly, the fragmentation of Japanese carriers was reduced through mergers in the late 1990s.

Such mergers also occurred across national boundaries. One crucial motivation was cost reduction; operators in the most competitive markets — notably the U.S. and U.K. — gained a competitive advantage in cost management (Turk and Montes 1995). In 1999, the most efficient carrier from each country combined with the $60 billion purchase of AirTouch by Vodafone.

Meanwhile, former PTTs and other large carriers sought to expand outside their home markets through acquisitions and minority equity stakes (table 4). Among the reasons cited were attracting global corporate customers and international business travelers, as well as concerns about efficient scale. In advance of 3G license contests that began in 2000, firms also sought to establish equity ties to purchase and deploy 3G licenses. A few firms sought to promote specific technologies, as with Japanese and German investments in the U.S.

7 Analysis

7.1 Support for Earlier Findings

Many of our results are consistent with the findings of Mowery & Nelson (1999) and earlier studies of national innovation systems. Among these confirmatory findings:

- *Success of focused firms.* The manufacturers that had the greatest proportion of their revenues in cellular equipment — Ericsson, Motorola and Nokia — were the ones that were most successful in that segment. Large diversified companies such as AT&T (Lucent), Siemens and NEC were far less successful, despite their huge advantages in resources.
- *Failure of national champions.* As with the European computer industry, national champions in telecommunications were left behind by more competition-oriented firms: Siemens and Alcatel in mobile phones were not much more successful than Siemens and Bull in computers. This is consistent with Henderson's (1999) finding that computer companies were imprinted by the conditions at the time of their finding and unlikely to subsequently adapt.
- *Military as lead user.* Mobile radio (but not telephony) was seeded by military-sponsored R&D and procurement. Motorola and Nokia's predecessors had their origins in WW II radio production, while military procurement in 1960s & 1970s were crucial to Ericsson's SRA. Meanwhile, the CDMA digital cellular standard developed by Qualcomm from 1985-1995 was explicitly based on U.S. military secure communications technologies.
- *Importance of formal knowledge transfer structures.* NMT was exemplary in knowledge transfer unlike other first generation standards where knowledge resided almost entirely in one firm. The NMT structure was deliberately designed to pool knowledge among operators, between operators and manufacturers, and also to draw upon university knowledge. The NMT group also transferred their process knowledge — for technical collaboration and consensus building — directly to the GSM group, which was an important factor in its success.

TABLE 4 Largest cellular operators, Dec. 2000. † Includes proportionate customers from minority investments in foreign subsidiaries. All numbers in millions

Company	HQ; other countries	Subscribers	Mergers and acquisitions	Origins
Vodafone	U.K.; U.S., Germany	59†	Bought AirTouch, 1999 Bought Mannesman, 2000 US jt. venture with Verizon, 2000	One of 2 original U.K. cellular licensees
China Mobile	China	47	Spun-off from China Telecom, 2000	Former subsidiary of Chinese PTT
Deutsche Telekom	Germany; U.K., U.S.	35†	Purchase of One2One, 2000 Purchase of VoiceStream Wireless pending	Former German PTT
DoCoMo	Japan; H.K., Neth., U.S.	32	Merged with NTT Personal, 2000 Bought 19% Hutchison Telecom, 1999 Bought 20% KPN Mobile, 2000 Bought 16% of ATT Wireless, 2000	67% subsidiary of NTT, Japan's PTT
Verizon	U.S.	26	Bell Atlantic bought Nynex, 1997 Merger of GTE and Bell Atlantic, 1998	Two of original "Baby Bell" companies
France Telecom	France; Italy, Germany, U.K.	25†	Establishes Wind J.V., 1997 Bought 29% of Mobilcom, 2000 Bought Orange, 2000	Former French PTT
Cingular	U.S.	19	Merger of Bell South and SBC wireless licenses, 2000	Four of original seven "Baby Bell" companies
BT	U.K.	18†	15% of Japan Telecom, 1999	Former British PTT
China Unicom	China	16	Start-up, 1994	Sponsored by electronics and railway ministries
AT&T Wireless	U.S.	13	Bought by AT&T, 1994 15% of Japan Telecom, 1999 Scheduled spin-off, 2001	Former McCaw Cellular, leading non-wireline cellular company

- *Limited role of local upstream linkages.* The origin of components used in cellular equipment did not appear to play a role in the successful production of complete systems. The most successful analog standard, NMT, incorporated Japanese analog circuitry and an American microprocessor. In subsequent 20 years, goods have become even more globally sourced.

7.2 New Contributions

We believe there are three findings that extend the prior industrial leadership work:

- *Sometimes, Governments Inherently Matter.* While the trends of the past 40 years have largely been towards liberalization and deregulation, this does not mean that all decisions affecting industrial leadership will be made by the market. In particular, scarce resources held in public trust — such as radio spectrum or public right of way — ensures an ongoing government role in resolving competing claims for such resources. In such cases, there will be inevitable variations in national or subnational policies that affect the comparative advantage of their respective companies.

For mobile telephone service, governments allocated licenses, thus determining who, when and how many the operators are. They also mandated (or not) a common technology for all operators and performance standards for the systems. Together, differences of government policies clearly lead to differences in competition, pricing, domestic manufacturer proficiency and adoption rates of consumer services.

- *Industrial Leadership in Services.* In the evolution towards a "post-industrial" or "information" society, services will play an increasingly important economic role. This is particularly true for information technology industries, where computing today is used more for communicating than processing information.

Where the end user value is determined by services, the equipment cost must of necessity be less than the value of the service provided by that equipment, or there would be no reason to buy the equipment. As an example, the investment by e-commerce firms in servers and networking equipment has been driven by a desire to profit from Internet-based services such as online shopping and music downloading. The Internet will also provide a mechanism for the global export of information goods and services, thus allowing the same form of cross-border market competition that makes relevant a study of industrial leadership in tangible goods.

- *Collaborative Leadership by Producers and Buyers.* As Mowery & Nelson and others have noted, intelligent and capable buyers are often crucial in the design and development of advanced technology products. For example, Lynn, Morone and Paulson (1996) document how Motorola and other technology companies use an iterative relationship with buyers to refine their designs of radical innovations.

But what if the product is but a fraction of the user value provided from a bundle of goods and services? Or what if regulation or other barriers to entry lead to monopsony or other extreme buyer concentration. The experience of the cellular industry suggests that such buyer concentration magnifies the effect of buyer feedback, for better or for worse.

If so, then this buyer concentration may explain why U.S. manufacturers did not enjoy the same industrial leadership as did the U.S. computer and software industries. In the face of high technological uncertainty, European manufacturers were able to work with a smaller number of operators using a common technology to refine that technology. Meanwhile, the U.S. cellular policy of the 1980s and 1990s — which encouraged fragmentation of cellular service providers and rival standards to increase competition — also fragmented the knowledge-creating feedback mechanisms for U.S. cellular manufacturers such as Motorola and Lucent. Under this model, the recent combination of both U.S. and other cellular operators into global powerhouses should provide increasing opportunities for manufacturers to discern clear guidance from their buyers.

Finally, we leave one question unanswered. While it is hard to generalize based on a small number of firms, the results do not seem to support the observation of Porter (1990) that strong home market competition makes for stronger producers. In particular, Japanese producers faced a fiercely competitive market in handsets and, through seven separate operators, a fragmented market for infrastructure as well. And yet companies like NEC played a comparatively small role in the global cellular industry, particularly when compared to firms like Nortel, Ericsson and Nokia which faced much lower home market competition.

Our instinct is that the home market competitiveness is dwarfed by the decision — whether intentional or serendipitous — of the technology in which to invest. So while Europe's home market competition was weaker than that of the U.S. and certainly Japan, its technology and diffusion strategies were superior, thus enabling its most competitive manufacturers to become world-proficient.

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III

EQUILIBRIUM AND TRANSFORMATION IN THE STANDARD MAKING PROCESS

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IV

STANDARDIZATION: BRIDGING THE GAP BETWEEN SOCIAL AND ECONOMIC THEORY

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V

STANDARDIZATION: TOWARDS INTEGRATING FRAGMENTED THEORY

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