Fredrik Gessler

The development of the DECT standard

An example of technical standardisation in wireless communications

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A dissertation submitted to the Royal Institute of Technology, KTH, in partial fulfilment of the degree of Licentiate of Technology

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Abstract

This thesis treats the development of the Digital Enhanced Cordless Telecommunications, DECT, standard for cordless telephony. It explores the relationship between the development of the DECT standard, and the general research and development efforts in wireless communications. The role of the DECT standard as a link between technological development in wireless communications, and the market diffusion of products adhering to the standard, is also considered.

The empirical basis for the thesis is a case study of how the DECT standard was developed. DECT is an open, de jure standard that was designed in co-operation between a number of telecommunications manufacturers. The standard was formally approved by the European Telecommunications Standards Institute, ETSI, in 1992. The case study has been complemented with extensive literature studies into the areas of technical development, and standardisation.

The main result of the thesis is a conceptual framework for how a technical standard such as DECT is developed. The framework demonstrates that the development of the DECT standard was influenced by the pre-history of the standard in terms of existing cordless telephony systems, and research and development that had been pursued in related fields. It furthermore shows that preconceptions of market needs, and user behaviour, were key elements in designing the standard. Competition and regulation also affected the design of the DECT standard, but in a more contextual fashion.

The pre-history of the DECT standard, as well as the market preconceptions, originate in the semi-independent processes of technological development, and market diffusion, respectively. When the time frame of the conceptual framework is expanded, generations of standards following upon each other can be identified. Each new generation incorporates new developments, and improved functionality and performance, but it also builds on existing solutions. The technical standards, e.g. DECT, act as wasp-like waists between the technological development and the market diffusion processes.

Apart from the conceptual framework, the thesis shows that the standardisation of DECT to a great extent was a technical development effort. The process also consisted of political, competitive, and regulatory deliberations, but the technical content was often the form even for such discussions. This points to the importance of viewing standardisation as a development activity. A consequence of this is that companies wanting to influence a particular standard-setting activity must

be in the forefront of research and development related to that standardisation effort. This is the key to leading the development of new technical standards.

Contents

Preface

Writing a thesis is not something one can do alone. The help and support of people in one's surroundings are essential. I would here like to thank those who in different ways have contributed to my work.

The nature of my thesis is such that it touches two different disciplines at KTH: Industrial Economics and Management, and Radio Systems Technology. As a result, and due to various practical reasons, I have had no less than five different advisors for my research. The first of them is Albert Danielsson, who invited me to become a PhD student at the Department of Industrial Economics and Management, and who was my first main advisor. I am very grateful for all the opportunities he has created for me. Claes Gustafsson took over as main advisor after Albert's retirement, and this thesis has improved thanks to his comments. In my co-operation with the Radio Systems Laboratory at KTH, Jens Zander has acted as my co-advisor. I am very grateful for the interest he has taken in my work, and the way in which he has welcomed me into the Radio group. At Industrial Economics and Management, Jacob Gramenius has been my co-advisor for the last two years. Without his patient advice, in which he has helped me channel my own thoughts and ideas, this thesis would still be unwritten. Jacob took over as co-advisor from Mats Engwall, who helped me the first few years of my study. I wish I had been more attentive to Mats comments, it probably would have saved me some time.

At the Department of Industrial Economics and Management, a number of people have taken of their time to comment my work, and support me when times have felt hard. A special thanks to: Magnus Aniander, Henrik Blomgren, Bo Karlson, Fredrik Lagergren, Mats Lindberg, Thomas Sandberg, Anna Sjögren-Källqvist, Per Storm, Pernilla Ulfvengren, Paul Westin, and Sten Wikander. To all those that I haven't mentioned, know that you also have been important in creating an environment that I find exciting and stimulating.

I also want to thank the members of the Radio Systems Laboratory at KTH for accepting me as part of the group, and taking an interest in my work. I have shared many interesting discussions with the group, especially with Olav Queseth, Matthias Unbehaun, and the other participants of the 4GW project.

As part of my studies, I spent the academic year of 1998-99 at Stanford University. I am very grateful to Prof. Donald C. Cox for accepting me as a visiting researcher with the Personal Wireless Communications group. It was an opportunity for me to experience a new country, an excellent university, and a different academic environment. I learned a lot from the experience, and am grateful for the openness that the Wireless group showed me.

While at Stanford, I also, informally, had the chance of participating in the Scandinavian Consortium for Organisational Research, SCANCOR, community. This gave me an entirely new set of views on my research, and I thank Prof. James G. March for inviting me, and the people visiting SCANCOR for contributing their comments and ideas to my material.

Finally, I must thank the people that have been most important to me during my studies: my family and friends. My parents were extremely encouraging when I several years ago told them that I was considering to study for a PhD. They, as well as my sister, have continued to be very supportive throughout my studies, even though I suspect that the academic world sometimes seems a bit strange to them. Almost equal in their support, have been my friends. I can't mention all of you, but know that without the encouragement you have given me, I would never have had enough endurance to do this. Now, all that remains is to keep working, and aim for the next step. Please bear with me.

Stockholm, May 2000.

Fredrik Gessler

1. Introduction

In this introductory chapter, the study underlying this licentiate thesis is outlined. The objectives of the study are presented. Some basic characteristics of standards and standardisation, as well as fundamental terminology are discussed. The background of the thesis is related, and, the methodology with which the study has been pursued is treated.

1.1 The study and its objectives

This is a study of how a technical standard for radio communication was developed. Standardisation is an activity that has become increasingly important for the information and communications technology industry. Standards are perceived to be a key element of competition between companies in high technology settings (Shapiro & Varian 1999), and a deeper understanding of the processes through which standards are developed is thus warranted.

The purpose of my thesis is to explore how radio communications standards are developed, and, in a broader sense, the relationship between standardisation and the technical[1] development of wireless communications. It is the development process itself, as well as the outcome of the development in terms of the design of the standard that is of interest here. Whether the standard comes to succeed or fail in the marketplace, a common focus for studies of standards (Arthur 1994; David 1985), is not discussed.

As noted, in the present thesis, I view standardisation efforts as development activities that to a large extent are technical in nature, albeit set in a social context. The empirical basis for the thesis is a case study of the development of the Digital Enhanced Cordless Telecommunications, DECT, standard. It is on the basis of this case study that I have framed my research questions, and from it that I draw my findings.

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[1] Please note that I use the terms “technical” and “technological” synonymously throughout the thesis. The reason is not to ignore the difference in meaning between these terms. However, this difference is not of importance for the present work. By interchanging between the terms, I hope to achieve a more varied use of the English language.

The first research question of the thesis is:

- What is the relationship between the development of the DECT standard, and the general research and development efforts in wireless communications?

The development of a standard is one of the steps that is taken when the results of research and development is transferred from the laboratory, or computer simulation, to products in the marketplace. Because of its importance in the process of generating successful product solutions, effective standardisation is a key objective in the development of wireless communications technology. While thus being a result of R&D, it also drives the development process. It is both a result, and an objective, all in one. What is the nature of this tension between a broad research and development process, and a specific standardisation effort?

In order to answer the above question, it was necessary for me to create a model that described the development of the DECT standard. The second research question is therefore:

- How can the development of the DECT standard be described in order to illustrate its role as a link between technical development in wireless communications, and the market diffusion of products adhering to the standard?

What would characterise a model of standard-setting that has this as a starting point? What are the key concepts of such a model? It is reasonable to ponder whether the formal standardisation processes of standards organisations really encompass this role in its entirety. What more factors in than is found if the formal procedures are studied? Do historical considerations play a part? How do technical deliberations affect the process? What about market drivers for the development?

These are all examples of issues that are part of the larger research question formulated above. The creation of a model, in which the factors affecting the development of a technical standard are captured, has been a major part of the undertaking to write this thesis. The resulting conceptual framework is presented in a separate chapter.

A case study

The development of standards in wireless communications is a time-consuming and costly endeavour that requires technical expertise in highly complex systems. It always involves assessments of non-technical parameters such as production costs, market potentials, and user behaviour. Frequently, the standardisation process is part of a larger political or competitive framework in which companies, authorities and nations are active participants. In consequence, one relevant way of studying the development of standards in this area is through in-depth case studies of particular standardisation efforts. This is the approach that I have used in my research.

As previously mentioned, the empirical basis for the thesis is a case study of the development of the Digital Enhanced Cordless Telecommunications, DECT, standard. DECT is a standard for cordless telephony, i.e. a system in which one or more handheld wireless telephones (or other terminals) communicate over a radio interface with one or more base stations that in turn are connected to the fixed telephone network (or some other type of network). The DECT standard provides for scalable systems. Systems adhering to the standard can operate as the simple cordless telephone that can be found in many homes today, or as a sophisticated network of multiple base stations, inter-connected by a private branch exchange (PABX or PBX), between which a call can be handed over as the user moves about, i.e. similar to a mobile telephony system. The DECT standard documents have been established by the European Telecommunications Standards Institute, ETSI.

The objectives of the case study were:

- To describe how the DECT standard was developed.
- To identify the key contextual factors for this development, i.e. what influenced the standard-setting process?
- To determine the key technical developments of the standardisation effort.

The case study of the DECT development makes up the bulk of this thesis[2]. As the study has progressed, I have complemented the empirical data with literature studies, and broader discussions regarding standards and standardisation. In this sense, the case study has been the means of accomplishing further ends.

As the case study, and especially the analysis of the case, was carried out, it became increasingly apparent that standardisation efforts were not as well defined entities as I had originally expected. First of all, I soon realised that in the case of DECT, a lot of system design work was done within what was considered to be a standard setting task. In addition, many important considerations related to the emerging standard appeared to be heavily influenced by technological developments that often preceded the standardisation process by many years.

On the other hand, it seemed that the engineering design efforts were coloured by the fact that they implicitly, or explicitly, were aimed at producing a standard. An

[2] See chapters 4 to 8, and appendix 2.

official standard was the outcome that engineers and others more or less took for granted. The tension between development and standards-setting became apparent.

1.2 Standards and standardisation in wireless communications technology

Hardly a day goes by without articles in major newspapers, business magazines, etc, that discuss the relative merits of two or more information technology standards, or the strategies of this or that company in relation to the development of new standards in some area. Obviously, standards and standardisation efforts have become key factors in information technology, and in wireless communications perhaps more so than elsewhere.

The impact of standards

For a long time, standards-setting in information technology had a poor reputation. It was considered a tedious and bureaucratic affair, conducted in formal committees consisting of industry and government representatives, that only occasionally led to useful results. Within many companies it was thought of as a boring activity that some corporate staff department of marginal importance was involved in. Standards took years to be accepted, and the even if the resulting documents were good they ran the risk of being outdated before they could be adopted.

Naturally, few people outside the engineering community had any interest in the standards-setting process. This is argued by Paul David, who writes:

> "Once upon a time, in a simpler world, the business of setting technical standards was not an item on the agenda of economists and political scientists. It was held to be one of those arcane and tedious matters best relegated to the attention of engineers. During the past decade, however, standards and standards-setting have emerged as subjects of strategic economic importance demanding the attention of corporate executives and research managers, especially those whose firms are in the business of supplying equipment, operating networks and providing enhanced network services in the computer and telecommunication industries."
>
> (David 1995:15)

Today, as David notes, the standards-setting process is known both to have more far-reaching consequences than were considered before, and to be a more comprehensive process, in which aspects ranging from technical development to market diffusion are relevant. Companies actively use standards-setting as a form of competition. By supporting technologies favourable for the own company in the standardisation of a system, they can gain royalty revenues, have a shorter time to market than the competitors, and perhaps even achieve a limited monopoly.

In a recent article, the economists Carl Shapiro and Hal Varian go as far as to dub the process of establishing standards a "standards war". They note that:

> "Standards wars – battles for market dominance between incompatible technologies – are a fixture of the information age. ...
>
> There is no doubt about the significance of standards battles in today's economy. Public attention is currently focused on the Browser War between Microsoft and Netscape (oops, America On-Line). ... The 56k Modem war of 1997 pitted 3Com against Rockwell and Lucent. ... Most everyone remembers the Video-Cassette Recorder Duel of the 1980s, in which Matsushita's VHS format triumphed over Sony's Betamax format. ... This year, it's DVD versus Divx in the battle to replace both VCRs and CDs.
>
> Virtually every high-tech company has some role to play in these battles, perhaps as a primary combatant, more likely as a member of a coalition or alliance supporting one side, and certainly as a customer seeking to pick a winner when adopting new technology. The outcome of a standards war can determine the very survival of the companies involved."
>
> (Shapiro & Varian, 1999:8p)

The authors focus on cases where competing standards fight it out in the market place, or to be precise, where *products adhering to different standards* compete in the marketplace. Nonetheless their argument is probably equally valid for cases where companies jointly develop *one* standard and the standards-setting process itself is the "battle ground".

Standards in a wireless environment

The role of standards in a competitive sense is generic to at least all information technologies[3]. In wireless communications, in addition, there are technical and scientific reasons for why standards are important. Key among these is the fact that all radio communication is conducted in a shared frequency spectrum. In principle therefore, all transmitters will affect each other. The influence that different transmitters have on each other has to be regulated, and regulation is often inti-

[3] Shapiro and Varian go as far as to state that standards wars have been waged in many different industries over a long period of time. They cite historical examples such as railroad gauges, electric power and colour television. (Shapiro & Varian 1999:9pp)

mately related to standardisation. By influencing the design of a standard, regulatory goals can be accomplished.

Another, fairly self-evident characteristic of any communications system, whether wireless or not, is that it consists of at least one transmitter and one receiver. In order for the receiver to be able to interpret the signals from the transmitter, it has to know something about the nature of these signals, i.e. they have to adhere to some sort of standard[4]. Although the shared knowledge of the nature of the signal does not have to have been decided upon by a formal standards body, we can still think of it as a standard.

Definitions of standards

The empirical data that this thesis rests upon comes from one specific case of standardisation: the development of an open, co-operative, formally adopted, technical standard for a wireless communications system. When the term *standard* is used in the thesis, a technical standard is therefore implied unless otherwise stated.

There are several ways of defining what a standard is. According to the Merriam-Webster dictionary (1986), the word standard originated from the Old French word *estandard*, a rallying point. Among the various meanings the word has today, the following two are most relevant for the present study[5]:

> "... something that is established by authority, custom, or general consent as a model or example to be followed …"
>
> "... something that is set up and established by authority as a rule for the measure of quantity, weight, extent, value, or quality …"
>
> (Merriam-Webster 1986:2223)

As far as technical standards are concerned, the International Organization for Standardization, ISO, posts the following one on their homepage:

> "Standards are documented agreements containing technical specifications or other precise criteria to be used consistently as rules, guidelines, or definitions of characteristics, to ensure that materials, products, processes and services are fit for their purpose."
>
> (ISO WWW 2000)

[4] Obviously, this knowledge in itself is not enough to build a good receiver. Among other things, it is also necessary to know something about how the signals are distorted or interfered by the channel over which they are transmitted.

[5] Other definitions relate to other types of meaning of the word such as banner, flag, or tree of a certain shape.

As with any all-encompassing definition, this tells us little of what the actual content of a technical standard is, or the form in which it is represented. Neither does it give us any guidance as to how standards are established, and what the consequences are of the different situations in which standards emerge.

Standards for communication systems focus on the interfaces between components in the system, as well as between the system and its environment (including other systems[6]). The interfaces are generally defined in terms of two categories:

1. Functional characteristics, e.g. protocol definitions for everything from the physical layer to the application layer, physical layer definitions such as signal modulation.

2. Performance characteristics, e.g. signal strength, noise figure, out of band emissions.

Apart from determining the types of content that a technical standard of this kind includes, it is also relevant to consider different conditions under which a standard can emerge, which relates to the process of setting standards. Here several typologies can be used. The most well established one is probably the dichotomy between *de facto standards*, and *de jure standards*. De facto standards emerge because a certain product dominates a market, e.g. Microsoft Word. De jure standards, on the other hand, "... are officially planned, developed and approved in recognized committees according to formal procedures" (Naemura 1995:94).

In a guidebook for making good standards, the European Telecommunications Standards Institute, ETSI, makes a related classification. They discuss the differences between standardising *emerging technologies*, and a posteriori setting standards to *harmonise existing technologies*. Their argument is that in the first case, the urgency of determining solutions is high, as is the level of freedom. In the second case, the focus is on creating error free standards, and decisions are often made through formalised consensus. (ETSI 1996a:16)

A third important distinction is that of *open* versus *closed* standards. An open standard is one were any company, for a fee, can partake of the standards documents. A closed standard is instead based on proprietary solutions that are generally not made available to other firms.

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[6] What is of special interest is the interference generated by the system. Two systems adhering to the same standard, and thus operating in the same frequency band, will obviously interfere each other. This is of course accentuated if the systems are not coordinated, which is often the case in private (business or residential) applications. Furthermore, all radio systems will in principle interfere with each other, or at least run the risk of doing so, since they share an unshielded communication medium.

In terms of the above typologies, DECT was obviously developed as an open, de jure standard. However, the presentation of the case will also show that systems developed prior to DECT, and that in several ways provided a basis for the DECT development, more properly can be described as closed, de facto standards. Products were developed first, and the systems were sometimes later adopted as (interim) standards by ETSI.

In the late 1980s, when DECT was being considered by ETSI, digital wireless communications was very much an emerging technology. For a variety of reasons, the sense of urgency in developing a standard was high. This fits nicely with the categories defined above. At the same time, however, the DECT standard was established in an environment built on formalised consensus, which is at odds with how emerging technologies are normally standardised according to the categorisation.

1.3 Background to the thesis

The research underlying this thesis has been conducted at the Royal Institute of Technology, in Stockholm, Sweden. It is the result of a co-operative research project between the Industrial Economics and Management department and the Radio Communications Systems laboratory. This means that the study has been supervised from both departments, thus allowing the research to incorporate both technical and social aspects on the topic of standardisation.

Issues regarding standardisation are considered worthwhile problems to study from the point of view of both disciplines. From the technical perspective, standards and standardisation have a great impact on how technology develops in a certain field. From the social science perspective, standards are interesting in their effect on markets and competition, and the process of standardisation is relevant in terms of being e.g. an organisational issue, or an example of how technology is socially constructed. Engineers who develop standards work in a world where both perspectives are relevant.

Even though there is a common interest in the phenomena of standards and standardisation, traditions, problems, methods and models obviously differ substantially between a social science department and a technical department, even if they exist side by side at the same university. In consequence, the types of research issues also differ between the disciplines[7].

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[7] A typical thesis in radio communications develops a new strategy, or algorithm, for efficient sharing of a limited frequency resource. A typical thesis in industrial economics and management, on the other hand, studies a development process, an organisational form, an

This thesis draws on knowledge and experience from both technology and the social sciences. As a student and a researcher, I have received schooling from both fields. However, the contribution of the thesis is within the social sciences, while at the same time providing interesting reading to engineers involved in standards related efforts.

Perspectives on standardisation

A thorough literature review will be presented in chapter 2, but in the interest of aiding the reader, it is relevant to give an overview of the different perspectives from which standards and standards-setting have been studied. It is thus possible to position the present study in relation to prior research in the field.

First of all, it should be noted that this thesis rests on the assumption that standards-setting is a development activity. This means that setting a standard involves a development effort that I to a great extent view as technical in nature, but that I set in a social context. The case of DECT, presented further on, will confirm this assumption. As a consequence, two different areas of literature have been important to take into account: studies of standards and standards-setting, and studies of technical, or technological, development activities.

Secondly, it is important to consider the fact that different researchers have conducted studies at various levels of aggregation within both these areas. The same is true of models and theories that have been formulated. Studies can be found that treat everything from the intentions of the individual engineer, to policy aspects of standardisation as a general phenomenon.

Here, standards-setting is viewed as a technical development activity. There are at least four sets of literature that treat different aspects of technical development:

1. Studies of innovation and entrepreneurship (e.g. Eliasson 1995; Kline & Rosenberg 1986; Mölleryd 1999; Utterback 1994; Vedin 1992). These studies have typically been carried out at a high level of aggregation, and tend to focus the economic and societal benefits of innovative activities. Whether standardisation is an innovative activity or not is of course open to debate, but in cases when standards document new systems and the standards-setting activity is part of the development of these systems, it could be argued that it is.

2. Studies in the history of technology (e.g. Flichy 1995; Friedlander 1995; Helgesson 1999; Hughes 1987; 1998; Kaijser 1995) and economic his-

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investment situation, etc, where social, financial, organisational, economic, technical, etc, issues are interwoven.

tory (e.g. Rosenberg 1982; 1994). Here the development of a technology and its related industries are presented as a history from which we can learn how such developments take place, and what factors affect their outcome.

3. Studies of the social shaping of technology (e.g. Bijker 1995; Bijker & Pinch 1987; Callon 1987; Latour 1996). In these studies, the non-technical influences on the development of technology are highlighted, an aspect that is of obvious relevance in the setting of standards.

4. Studies of the product design process (e.g. Clark & Fujimoto 1991; Karlson 1994; Trygg 1991). Although these studies focus the development of products, as opposed to standards, the development processes are similar in many respects. Both processes consist of engineering activities that create the specification of a new object.

The fact that standards-setting of the type studied here takes place in a formal process, supported by a standards organisation, must not be disregarded. Therefore prior research on the formal standardisation process has also been studied. Two main branches of this literature have been identified:

1. Institutional aspects of standardisation (e.g. Besen 1995; Helgesson, Hultén & Puffert 1995; Skea 1995). Here the processes employed to set standards are focused. An important question is how different processes affect whether a standard is chosen or not, and how long it will take to establish it.

2. Organisational studies of formal standardisation processes and standards organisations (e.g. Brunsson 1998a; 1998b; Tamm Hallström 1998a). How standards-setting activities are organised is treated, and the relative merits of different organisational forms for the effective development of standards are discussed. Also, standards are considered in terms of being a form of organisation, comparable to that of the market, or the hierarchy.

Finally, the wealthiest area of literature related to standards is that which focuses market aspects of standardisation. This research has mainly been conducted by economists and economic historians. As Nathan Rosenberg notes in his exploration of the black box of technology: ”... the diffusion process is one of the most intensively explored subjects in economic history” (Rosenberg 1982:19).

In relation to market aspects of standards, two areas of literature are apparent:

1. Market diffusion studies (e.g. Arthur 1994; David 1985; Liebowitz & Margolis 1990). Here the competition between two or more standards

(or more precisely, products) is discussed in terms of path dependence and network externalities.

2. Policy studies (e.g. David 1995; David & Shurmer 1996; David & Steinmueller 1996; Davies 1994; Farrell 1995; Smoot 1995). In these studies, desired market effects are considered in relation to how standards-setting activities should be organised and regulated to achieve them.

This brief overview, which will be elaborated later, clearly illustrates that many studies of standardisation take as a starting point the market effects of standards. This is especially true of studies at a higher level of aggregation. Studies of technical development efforts, on the other hand, are generally not focused on the development of standards, but rather on the development and design of products[8]. Finally, studies that focus on the formal standardisation process often restrict themselves to doing just that, without involving either market or development aspects. The present study focuses the relationship between technological development and standardisation, and thus is broader in scope than most of the research related above.

Limitations

Although all the perspectives mentioned above have been useful, especially in terms of giving my research a context, the present study differs from them in various ways. This study has an engineering perspective on standards-setting. With that I mean that standardisation is viewed as an engineering activity that takes into account both technical and social aspects. This does not mean that the individual engineers have been focused. Rather, their deliberations relating to technological and social problems in setting a technical standard have been of interest.

In contrast to many studies of standards, the present one does not focus the market diffusion of the established standard. Neither does it take into account products designed based on the standard. Instead, the *development* of a technical standard is explored. This includes the formal standardisation process, but is more than so. Above all, there is a strong coupling to the general technological development in the field to which the standard belongs.

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[8] I realise that I use this concept vaguely, thus allowing it to encompass everything from services to complex systems. The important point to be made here is of course that a product has different characterstics than a standard, e.g. that a product is more than a specification and that it is intended to be sold on a market.

The empirical studies are limited to one case, the development of the DECT standard. This means that predecessors to the DECT standard, and contemporary developments have not been studied in their own right. They enter into the research only in terms of their relationship to the development of the DECT standard.

The single case study approach also makes generalisations from the present material difficult. This is enhanced by the fact that there are many types of standards and standardisation processes, even if we only consider technical standards. If a different type of standardisation process had been studied, e.g. the setting of a de facto standard, or the development of a closed standard, other findings might have resulted.

There are of course also benefits of using a case study approach. It has allowed me to penetrate the development of the DECT standard more deeply, and gain a fuller understanding than other methods would have provided. This is discussed more thoroughly later.

The formal process as a starting point

When I began this study, my initial idea of a standardisation effort was the formal decision making process that took place in non-profit organisations such as Conférence Européenne des Postes et Télécommunications, CEPT, or the European Telecommunications Standards Institute, ETSI. After long deliberations and negotiations, the members of the forum would decide on a technically sound standard that defined relevant interfaces and performance parameters.

Although this description is rather naive, it is not very far from the descriptions that standardisation bodies give of themselves. The following statement can be found on the ETSI homepage:

> "ETSI (the European Telecommunications Standards Institute) is a non-profit making organization whose mission is to produce the telecommunications standards that will be used for decades to come throughout Europe and beyond. Based in Sophia Antipolis (France), ETSI unites 773 members from 52 countries inside and outside Europe, and represents administrations, network operators, manufacturers, service providers, research bodies and users.
>
> Any European organization proving an interest in promoting European telecommunications standards has the right to represent that interest in ETSI and thus to directly influence the standards making process.
>
> ETSI's approach to standards making is innovative and dynamic. It is ETSI members that fix the standards work programme in function of market needs. Accordingly, ETSI produces voluntary standards - some of these may go on to be adopted by the EC as the technical base for

> Directives or Regulations - but the fact that the voluntary standards are requested by those who subsequently implement them, means that the standards remain practical rather than abstract."
>
> (ETSI WWW 2000)

In their statement, ETSI highlights that it is an open forum, with many different participants, and that ETSI produces voluntary standards of a practical nature. However, the statement also gives the impression that the standards are actually created within ETSI. Initially, this was also my perception of standardisation work: that it was carried out within standards bodies, albeit in which the participants to a great extent came from manufacturers, operators, regulators, etc.

As a consequence, in the beginning, my studies focused the standards bodies involved in the development of the DECT standard, and the decisions that were made within these bodies relating to DECT and similar systems. The questions that I sought answers to were related to how the DECT standardisation activity within ETSI was organised, which alternatives the participants chose between, which firms teamed up to support the different proposals, etc.

During the course of my studies, I started to notice that reasons for why a certain systems design was adopted for DECT, why certain participating companies teamed up, why certain decisions where made at certain times, etc, were often to be found outside the formal standard-setting process. Notably, the technological development that in part had preceded the standardisation effort seemed to be important. Moreover, when I started interviewing people from the companies that had participated, and were participating, in the DECT standardisation, it became apparent that their work with DECT was part of a larger development activity. DECT was one of the outcomes of the research and development conducted e.g. within Ericsson, but several other outcomes were generated around the same time. They ranged from incremental improvements of existing systems, to studies of fundamental issues in radio communications, and even the development of other standards, such as GSM[9].

Similarly, many explanations of design characteristics, etc, were related to competing systems (or standards), or user needs and wants. The market for products adhering to the future standard thus was a relevant factor as well.

Development - a part of standardisation

Depending on the technical system that is standardised, and the setting in which the standardisation activity takes place, there are several ways in which a standard

[9] The Global System for Mobile communications.

can develop. The differences between de facto and de jure standardisation, as well as standardisation of emerging technologies as opposed to harmonisation of existing technologies, have been discussed briefly above. Both these categorisations point to a strong interrelationship between standardisation and technical development. This motivates a deeper study of this coupling.

As an engineer, and considering the fact that my research has been performed as a co-operative project between Industrial Economics and Management, and Radio Communications Systems, both at KTH, it was very natural that my interests turned to development issues as my comprehension of standard-setting processes grew. This feeling was accentuated further when I spent one year with the Wireless Personal Communications group at Stanford University. It is in the development of new wireless technology that standardisation becomes a phenomenon of interest for engineering researchers.

When I thus began studying standardisation in relation to technical development efforts, the support that I could get from the Radio Communications Systems group became important. Documents, articles and books that treat the development of cordless standards, systems, and products, are to a large extent written by engineers with a substantial technical know-how and experience. Similarly, the people that I could interview were often engineers that had been involved themselves in the development work. To be able to interpret the development process, understand what was difficult, what problems had arisen, etc, it was very beneficial to both have a technical expertise myself, and receive tutoring and input from researchers in the field.

As my focus shifted, the tension between standardisation and technical development became apparent. On the one hand, technical development preceding a standardisation effort seemed to determine many aspects of the design of the standard. On the other hand, the technical development was conducted very much with standardisation in mind.

The formal standards setting process existed as a wasp-like waist between technical development efforts related to the system being standardised, and a market diffusion of products adhering to the standard.

1.4 Case study methodology

As I have already noted, this thesis is based on a *case study*. In this section, I will present how this methodology was used, and discuss why this particular method was relevant. I will also relate the different steps of the study, and present the sources upon which my findings are based.

Choosing a case study methodology

The research methodology that has been chosen for this study is that of the *case study*. The choice of methodology was primarily a consequence of the type of study that I wanted to make, as well as the study object that I was interested in. However, it is only fair to note that the choice of study object and focus for the study was made within the tradition established at the Industrial Economics and Management department, where case studies have been the favoured way of approaching the posed research questions (see e.g. Blomgren 1997; Engwall 1995; Gramenius 1997; Karlson 1994).

In his comprehensive book on case study research, Robert Yin (1994) defines five different research strategies in the social sciences: experiments, surveys, archival analyses, histories and case studies. Regarding the choice between different strategies, he argues:

> "Each strategy has peculiar advantages and disadvantages, depending upon three conditions: (a) the type of research question, (b) the control an investigator has over actual behavioral events, and (c) the focus on contemporary as opposed to historical phenomena."
>
> (Yin 1994:1)

Yin goes on to discuss the choice of research strategy thoroughly. In relation to case studies, his conclusions are that they are suitable for studying what he refers to as *how* and *why* questions, i.e. questions that have an explanatory nature. Moreover, these questions should be asked over a set of events over which the researcher has little or no control, and the events should be contemporary. In the continued discussion, Yin relaxes these requirements somewhat. For example, he notes that exploratory and descriptive case studies are also possible, and that the line between a case study and a history is sometimes fluid. (Yin 1994:5pp)

The nature of the study presented in this thesis is such that a case study strategy was the most suitable approach. First of all, the types of questions posed in relation to the DECT development are clearly of the "how" and "why" categories that Yin defines. His two other criteria are also met in that I as a researcher had no control over the events that I was studying, and that the phenomenon that I have studied, the development of standards in wireless communications, in every respect is a contemporary issue. The particular standardisation effort that I have considered, DECT, began more than ten years ago, but the phenomenon itself is not of historical nature. Also, Yin does point out the fluid line between histories and case studies.

A second important argument for the choice of a case study methodology is the complexity of the system under study. Wireless communications systems, in technical terms, are highly complex entities. Standardisation efforts relating to such systems are even more so. There are a number of different actors involved. They have different goals due to their technical expertise, market position, legal rights, etc. It is difficult to understand what aspects influence choices and decisions. Is a design choice a consequence of technical feasibility, of perceived market needs, of regulatory control, of competitive forces?

In cases where the objective of a study is to understand a certain phenomenon and describe, or model, it, the case study is a viable method. This is noted by Ulf Lundahl and Per-Hugo Skärvad, who state:

> "... case studies can also be used both to *develop theories and test theories*, especially in studies of complex problems."[10]
>
> (Lundahl & Skärvad 1982:135)

Other authors, especially practitioners of case study methodology, have a similar point of view of how complex processes should be studied. One example can be found in a study of decision processes in projects conducted by Kerstin Sahlin-Andersson (1986). In the study she motivates the choice of a case study methodology in the following way:

> "A comprehensive picture that captures the complexity of the processes should therefore be composed from different sources. The theory-developing aim requires a thorough study of the courses of events that the approach to the problem treats. The empirical study has therefore been organised in the form of case studies, where different forms of data production (interviews and studies of documents) have been combined ..."[11]
>
> (Sahlin-Andersson 1986:17)

In conclusion, the case study methodology is highly suitable for studies of the kind presented here. This is both due to the research questions that I have posed, and to the complexity of the process that I have studied.

The nature of my study

To some extent, the nature of the study underlying this thesis has already been treated. Nevertheless, there are three aspects of the study that are worth commenting.

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[10] My translation, emphasis according to original.

[11] My translation.

First of all, this is quite obviously a qualitative study. As the choice of research methodology indicates, a single case study is the empirical basis for the thesis. Within this case study, no quantitative analyses have been made. The broad sense in which empirical data has been a basis for the thesis is a trait common to qualitative analyses.

> "Consideration of and focus on open empirical data with various meanings is a central criterion, even if many qualitative methods stress the importance of categorisation."[12]
>
> (Alvesson & Sköldberg 1994:10)

Secondly, it is important to note that the research process in this study has gone through several different stages. Initially, the study was rather exploratory, and the aim, and the study object were only loosely defined. As the work progressed, however, the precision has increased. The resulting thesis therefore has a more explanatory character.

Thirdly, the interest for technological aspects of standardisation that is shown in this thesis should be commented. It is fair to say that the setting in which this study has been conducted was extremely supportive in this respect. I believe the type of co-operation between engineering and social science researchers that is manifested in this thesis is fairly uncommon. It has meant that I have had the opportunity to study aspects of standardisation that have an intimate relation to the technology being standardised.

Practicalities of the study

The case study presented in this thesis was carried out over a period of approximately three years. Other duties, such as coursework and teaching assignments, were performed in parallel.

The research can be divided into four parts:

1. General studies of telecommunications and standardisation.
2. Studies of wireless communications systems.
3. DECT specific studies.
4. International outlook.

The study was conducted using conventional methods of interviews and literature studies. Apart from these traditional tools, an important aspect of the study has

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[12] My translation.

been my participation in the wireless research community. For example, I have taken courses together with Ph.D. students and industry researchers, written joint (technical) papers (Queseth, Gessler & Frodigh 1999), participated in seminars and conferences, and simply spent time discussing technical and engineering issues in wireless communications at the Radio Systems Laboratory at KTH, and the Personal Wireless Communications group at Stanford University. This has provided invaluable insight into both wireless technology, and the wireless communications industry. The seminars at the Industrial Economics and Management department have been of equal importance to my research by providing me with comments and criticism from researchers with great experience of studies of this type.

1. General studies of telecommunications and standardisation

This part of the research consisted of both interviews and literature studies. The interviews were carried out during the fall of 1996, and covered representatives from the Swedish regulatory authority (Post- och Telestyrelsen, PTS), the Swedish telecommunications standards body (Informationstekniska Standardiseringen, ITS), the former Swedish PTT (Telia), the national Swedish broadcasting company[13] (Teracom), and the major Swedish telecommunications equipment manufacturer (Ericsson). In all cases, the interviewees were selected because of their involvement in technical standardisation efforts and strategic technological development issues.

The interviews were conducted in a semi-structured manner (similar procedures have been used for interviews in the other parts of the study). A questionnaire[14] was generally distributed before the interview, in order to allow the interviewee to prepare for the meeting. During the interview, the questionnaire was used to insure that no pre-planned areas were missed, but the interviews did not slavishly follow it. Rather, the expertise and experience of the interviewee were allowed to direct the interview. By beginning each interview with a brief presentation of my research findings, and the issues under study, the interviews could nonetheless stay fairly focused.

2. Studies of wireless communications systems

As has been noted, one important part of my research has been to study wireless communications technology. This has been done in a fairly conventional manner,

[13] Teracom handles all distribution and broadcasting for the national Swedish radio and television, and also leases e.g. microwave links to telecommunications operators and other corporations.

[14] See appendix 1 for a typical questionnaire.

involving courses and literature studies. The courses have been PhD level courses in wireless communications systems at the Royal Institute of Technology and at Stanford University. They have covered topics such as propagation models, performance criteria for communications systems, modulation techniques, broadcast systems, radio links and multi-user systems, i.e. the standard topics of radio communications systems.

The aim of these general studies of wireless communications systems was to learn enough within the discipline to be able to discuss technical issues with the interviewees of the case study, and to understand e.g. standards documents and technical studies of DECT.

3. DECT specific studies

The DECT specific studies commenced in the fall of 1996 through interviews with Ericsson and Telia representatives who had participated in various stages of the development of the DECT standard. The interviews were conducted according to the same procedure as discussed above. The most important interviewee was without doubt Dag Åkerberg from Ericsson, who is generally considered to be the "father of DECT". The early work with the DECT standard was carried out by a relatively small group of people of which only a few can be found in Sweden. Therefore, interviews have not been the greatest source of information for the DECT specific studies. Instead secondary sources have been used to a great extent.

The documents that complemented the interviews were:

- minutes of standardisation meetings from the Conférence Européenne des Postes et des Télécommunications, CEPT, the European Selective Paging Association, ESPA, and the European Telecommunications Standards Institute, ETSI,
- reports from feasibility studies conducted by CEPT, ESPA, Ericsson, and ETSI,
- drafts of standards documents,
- standards documents and technical reports from standards organisations.

These documents have been valuable in indicating what design concepts were considered at different periods in time, as well as for understanding both how different choices were motivated, and how technical possibilities and limitations were perceived.

4. International outlook

One of the initial shortcomings of this study was that a great deal of the material upon which it was based originated from Swedish firms, especially Ericsson. Therefore, an effort was made, primarily during the fall of 1998, to alleviate this and introduce more "international" perspectives in the study. This effort coincided with a one year stay at Stanford University, which offered an excellent opportunity to receive new influences. Interviews were conducted with researchers from American universities and companies working with cordless telephony related issues. The value of an American perspective is especially great in light of the fact that no country has a higher percentage of telecommunications subscribers with cordless access[15] to the fixed network than the United States.

During this phase of the research, a greater emphasis was put on the comparison of DECT with other cordless systems. This entailed a more detailed study of a contemporary cordless development, CT2, which in turn explained some aspects of why the DECT development took the direction it did.

1.5 Structure of the thesis

In this introductory chapter the research questions, fundamental standards terminology, the background to the thesis, and the methodology with which the studies have been performed, have been presented.

The second chapter outlines the theoretical framework of the thesis. A broad treatment is made of relevant literature since there are many different ways in which standardisation has been studied. From the broad survey, a set of research endeavours is identified, and serves as the theoretical context for the present study.

In the third chapter, a conceptual model of the development of the DECT standard is presented. This is one of the most important outcomes of the study. The conceptual framework is my own analytical tool. I have developed it in order to describe and understand the standardisation of DECT. It has primarily grown from my empirical studies, and has thus evolved in parallel with the case study.

In chapters four to eight, the empirical work on which the thesis is based, is reported. This is the bulk of the thesis, and gives one important example, the development of the DECT standard, from which concepts and conclusions have been drawn. The structure of the presentation basically follows the structure of the conceptual framework presented in chapter three.

[15] Please note that a distinction is made between cordless and mobile (or cellular) telephony.

Chapter four gives an overview of what a cordless telephony system adhering to the DECT standard would look like. The purpose is to demonstrate for the reader what a cordless telephony system can be, how it operates, and what type of functionality and performance it can offer.

In chapter five, the formal standardisation process for DECT is presented. A chronology of the activities of various organisations involved is related, and the participants are introduced.

The sixth chapter deals with the pre-history of the DECT standard. Earlier cordless systems, as well as contemporary wireless system developments, are discussed. Research and development efforts preceding the DECT development are also treated.

In the seventh chapter, market aspects of the DECT standard are discussed. The perceived market needs at the time of the development of the standard are presented, as well as their translation into development objectives for the standardisation effort. The impact of competition and regulation is also considered.

In chapter eight the key technical problems in the development of the DECT standard are identified. The formulation of these problems is a result of the merger between available technical knowledge, and the perceived market demands for the standard.

In the final chapter, conclusions based on the case study are drawn, and future research is discussed.

2. Theoretical framework

In the preceding chapter, a brief outline was given of literature related to this study. I will now make a more thorough treatment of this literature. As was noted earlier, studies of standards and standards-setting generally do not have the same starting point as this study. One consequence of this is that the literature of relevance for the study is broad in scope. Many different theories touch upon standards or standards-setting as important phenomena, even though they are not the prime issues that a particular school deals with.

In order to be consistent, I have chosen to structure the literature survey in the same manner as the overview from the preceding chapter. The literature survey is thus organised into the following subchapters:

1. The development phase
2. The formal standardisation process
3. The diffusion phase

This structure does not take into account the fact that different studies of standardisation activities have been performed at different levels. The dominant area of literature on standardisation, are books and articles authored by economists. They generally take an interest in competition between firms, standards, technologies, etc, i.e. at a level “above” the individual firm. Studies of standardisation at lower levels are not as numerous.

In the final subchapter, I summarise the literature that I have found especially useful for my own research. From the broad survey presented here, I there identify my own theoretical framework. This is also the literature that I use throughout the rest of the thesis. Due to the fact that there are so many different theoretical bases from which standardisation has been studied, I have found it necessary to make a broad literature survey in order to position the present study although I do not use all the literature treated in this chapter in my continued discourse.

This thesis describes the development of technical standards as an engineering process. As has been recognised earlier, the relationship between technical development and standards-setting is of special interest. The discussion in this chapter will serve to show that this way of studying standardisation is fairly uncommon, although many studies and theories either support it, or provide contextual descriptions that are useful.

2.1 The development phase

Research and development activities related to standardisation efforts can, and have been, studied at various levels. At an aggregated level, we might discuss the development of standards as an example of innovation, thus allowing us to draw on studies of innovation and entrepreneurship, or as a historical case, allowing impressions from the history of technology. At a less aggregated level, the development leading up to a standard could be considered in terms of being a case of social shaping of technology, or the early stages of a product design process. These four sets of literature have been explored in relation to the development phase.

Innovation and entrepreneurship

How technologies and industries develop is often studied in terms of innovations and entrepreneurship. A recent example is a thesis by Bengt Mölleryd (1999), where he poses the question: ”How did entrepreneurship over time contribute to the development of the Swedish mobile telephone system?” (ibid p. 19). The development of mobile telephony is obviously closely related to the DECT development studied here. Mölleryd describes the mobile telephony development as a three-staged entrepreneurial spiral where “... standardising processes, technical development and market feedback increasingly become concurrent and interrelated processes” (ibid p. 179).

Mölleryd views technical developments as one of several aspects that drive the development of an industry. From his point of view, the market impact of the mobile telephone systems that he has studied is the key determinant of how successful this industry is. He does not, however, focus the particular technical characteristics of different mobile telephony systems, and thus does not take a specific interest in how the cellular standards that he covers have been developed.

A second study, also focused on innovation in the telecommunications area is Bengt-Arne Vedin’s (1992) book on the development of the AXE exchange. Vedin’s study is more similar to the present one in that it treats a development effort, albeit a proprietary product development project rather than the co-operative development of an open standard. Vedin’s book is written for a broader audience than the academic one, and is thus popular in style. Nevertheless, it is worthy of attention even in a research endeavour. What is of special interest here is the way that Vedin’s study treats a development process, and the rich description he gives of this process. He incorporates the people involved in various aspects and stages of the development, and he discusses the environment in which the development takes place in terms of organisational factors, as well as market and industry development. Last but not least, he deals with the technical aspects of the development, both the particular technical issues in AXE, and the broader technological development of which AXE was a part.

The two studies outlined above serve to illustrate the various different levels at which innovation can be studied. The same is obviously true of the theoretical foundations upon which these empirical cases rest. At an aggregated level, the prerequisites for successful innovation is discussed in terms of what factors need to co-exist in order to create a beneficial setting for technical and economical development. Erik Dahmén uses the term "development blocks" (Dahmén 1989) to capture this, a concept which Gunnar Eliasson has adapted to "competence blocks", which more strongly focus the infrastructural factors needed to generate innovation (Eliasson 1995; Eliasson & Eliasson 1996).

Microeconomic analyses of technological innovation can also be found. Like the development block theory, they are also intended to answer questions at an aggregated level. This is amply illustrated by Edwin Mansfield, who in an article from 1986:

> "... describes briefly some of the principal work that has been done to help answer the following questions: (1) What has been the effect of research and development (R&D) on the rate o productivity growth? (2) What has been the rate of return from investments in industrial innovation? (3) What have been the size, determinants, and effects of imitation costs? (4) How much effect have patents had on imitation costs and the rate of innovation? (5) How great has been the rate of inflation in R&D? (6) What factors determine the rate of diffusion of an innovation? (7) To what extent has the rate of international technology transfer increased?"
>
> (Mansfield 1986:307)

The aggregated studies of innovation processes are not primarily of interest for the present study. Rather, models that treat the development of individual innovations are more relevant. An excellent example of such a model is the "chain-linked model" formulated by Stephen Kline and Nathan Rosenberg (1986). Their description of the process of innovation is in many ways a critique of the linear model that until then had been the dominant view. In the linear model, the different stages of the process, from research to production, are sequential. The outputs of one stage are the inputs of the next (ibid p. 286). What Kline and Rosenberg instead suggest is that several paths of activities influence each other and generate mutual feedbacks. They summarise the interdependency of the stages of the process by stating:

> "A perceived market need will be filled only if the technical problems can be solved, and a perceived performance gain will be put into use only if there is a realizable market use. Arguments about the importance of 'market pull' versus 'technology push' are in this sense artificial, since

> each market need entering the innovation cycle leads in time to a new design, and every successful new design, in time, leads to new market conditions."
>
> (Kline & Rosenberg 1986:289p)

An additional insight that the chain-linked model very elegantly expresses is that the individual innovation process is coupled to scientific knowledge and research of a more general character. Kline and Rosenberg further point out that this linkage does not only come into play at the beginning of the innovation process, but rather is found throughout all its stages.

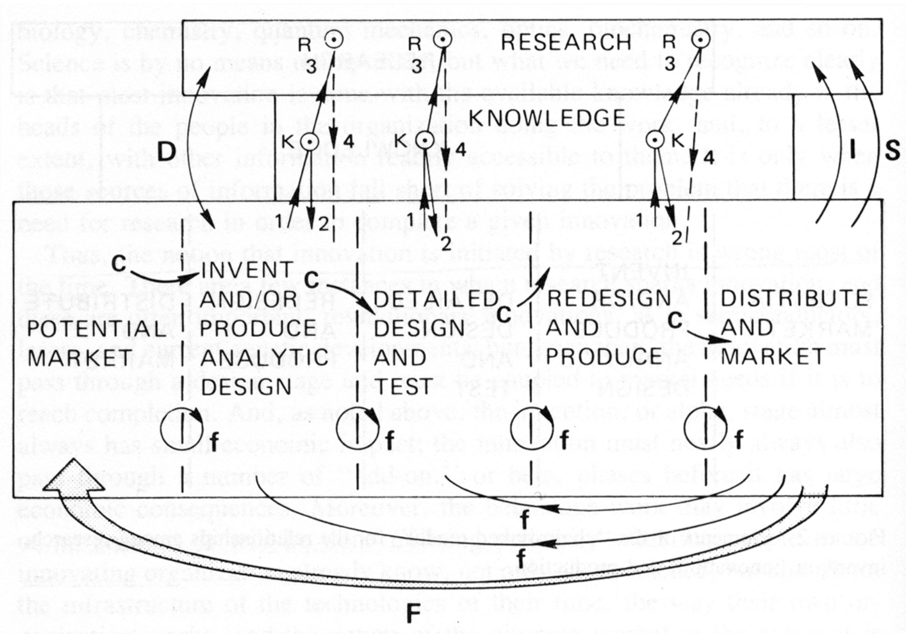

Figure 1: The chain-linked model of the process of innovation (Kline & Rosenberg 1986:290).

A second approach to modelling the individual innovation process can be found in James Utterback's concept of "dominant design", and the related cycles of product and process innovations (Utterback 1994). Utterback defines his concept in the following way:

> "A dominant design in a product class is, by definition, the one that wins the allegiance of the marketplace, the one that competitors and innovators must adhere to if they hope to command significant market following. The dominant design usually takes the form of a new product (or set of features) synthesized from individual technological innovations introduced independently in prior product variants."
>
> (Utterback 1994:24)

Although Utterback's idea of a dominant design was not intended to describe an official standards-setting process, it captures the aim of such an effort remarkably well. In a way, one could say that the standardisers strive to make the standard a dominant design, which suppliers and others jointly accept before products are developed and brought to market. In other words, to a certain degree, a successful standard documents the requirements of the dominant design.

The concept of a dominant design is relevant in that it gives us an indication of how the outcome of a technical development is determined. Utterback also discusses how the industry in which a dominant design emerges is affected by it. He notes that once the dominant design has emerged, the number of competing firms often drops sharply. He attributes this to a change in competitive forces. No longer is just product performance a competitive factor, but costs and scale as well. (Utterback 1986:31, 87)

In a further development of Utterback's concepts, Andrew Davies (1997) discusses the product life cycle for "complex product systems". He determines that for such a system, there are three types of product innovations: architectural innovation, component innovation, and systemic innovation. While architectural innovations exhibit the traits of Utterback's product innovation phase, i.e. they take long time, re-shape the industry, and lead to the emergence of a dominant design, the other innovation types do not have the same characteristics[16]. Component innovation, for example, can be made independently of other parts of the system. Successive generations of component innovations can thus take place within the same architecture. The same is true for systemic innovation, although the nature of such innovations is that they require changes in (several) other parts of the system. Davies thus establishes that even if architectural change has not taken place, several generations of component and systemic innovations can arise within the same product system.

Obviously, standards-setting is similar to innovation processes, or is perhaps partly an innovative endeavour. Models describing the process of innovation are therefore useful in understanding the development of technical standards as well.

History of technology and economic history

One very natural starting point for any treatment of the history of technology is the research conducted by Thomas Hughes (1987; 1994; 1997; 1998). In his studies of

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[16] One example of architectural innovation used by Davies is the cellular concept in mobile telephony. It was invented in the late 1940's, and since the implementation of the first commercial cellular systems in the early 1980s, has become the dominant way of designing radio communications systems. (Davies 1997:239pp)

large scale technological systems he has developed a number of highly useful concepts that are relevant for any student of the development of technology. To begin with, he defines the concept of a ”technological system” in the following way:

> “Technological systems contain messy, complex, problem-solving components. They are both socially constructed and society shaping. Among the components in technological systems are physical artifacts, such as the turbogenerators, transformers, and transmission lines in electric light and power systems. Technological systems also include organizations, such as manufacturing firms, utility companies, and investment banks, and they incorporate components usually labeled scientific, such as books, articles, and university teaching and research programs. Legislative artifacts, such as regulatory laws, can also be part of technological systems. Because they are socially constructed and adapted in order to function in systems, natural resources, such as coal mines, also qualify as system artifacts.”
>
> (Hughes 1987:51)

He goes on to refine his definition by expressing a number of characteristics of technological systems:

> “Because they are invented and developed by system builders and their associates, the components of technological systems are socially constructed artifacts.”
>
> “Because components of a technological system interact, their characteristics derive from the system.”
>
> “... in a technological system, the convention of designating social factors as the environment, or context, of a technological system should be avoided.”
>
> “Two kinds of environment relate to open technological systems: ones on which they are dependent and ones dependent on them. In neither case is there interaction between the system and the environment; there is simply a one-way influence.”
>
> (Hughes 1987:52p)

In these technological systems, that obviously incorporate many non-technical, social factors, there is still a technical core (Hughes 1994:105). The systems are generally large scale, at least in the examples used by Hughes, and thus develop over a long period of time. In relation to the development of the systems, Hughes defines two useful concepts: “reverse salients” (Hughes 1987) and “technological momentum” (Hughes 1987; 1994). A reverse salient is a system component that lags behind in the development, thus slowing the evolution of the entire system.

Technological momentum, on the other hand is a way of describing the inertia that a technological system, or part of it, gains as it develops. Hughes uses this concept in contrast to alternative interpretations such as technological determinism (i.e. society is shaped by technology) or social construction (i.e. social factors shape technology). He argues that:

> ”A more complex concept than determinism and social construction, technological momentum infers that social development shapes and is shaped by technology. Momentum is also time dependent.”
>
> (Hughes 1994:102)

The structured way of describing a technological development that is offered by the technological system concept is very useful. In understanding the impediments, as well as the inertia of the development, reverse salients and technological momentum serve as powerful analytical tools. An author who uses Hughes' framework is Andrew Davies (1996), who has studied the development of the telecommunications network. He takes an interest in how innovation affects the rate and direction of system growth. Davies explains Hughes' concept of “momentum” by the economies of scale, scope, and system[17] that lie behind it. He thus complements Hughes' analysis with an economic analysis of technical change.

Several economic historians also study technological developments. One well-known author is Nathan Rosenberg (1982; 1994), who reacts against the “black-boxing” of technology that is common among economists. In his book from 1982, where he tries to peer into the ”black box of technology”, the preface begins with the following statement:

> “The central purpose of this book may be simply stated. Economists have long treated technological phenomena as events transpiring inside a black box. They have of course recognized that these events have significant economic consequences, and they have in fact devoted considerable effort and ingenuity to tracing, and even measuring, some of these consequences. Nevertheless, the economics profession has adhered rather strictly to a self-imposed ordinance not to inquire too seriously into what transpires inside that box.”
>
> (Rosenberg 1982:vii)

[17] Economies of system refer to reductions in cost due to improvements in control components of a system. In telecommunications, this has to do for example with how the traffic load is managed. (Davies 1996:1163pp)

Rosenberg emphasises the value of actively taking an interest in history, when studying technological progress and development (Rosenberg 1982:4pp). In the first of his two “black box” enquiries, he elaborates on a number of characteristics of technologies. The following three have been most useful for me because they illustrate aspects of the development process that I have studied:

1. Technological interdependence

2. Technological expectations

3. Learning by using

In his discussion of “technological interdependence” Rosenberg focuses the systemic character of technologies. In a manner not unlike Thomas Hughes’, treated above, he argues that technological developments (he uses the term “specific innovations”) are embedded into a network of technological relationships, and that technologies often interact with each other. The complementarities between different technologies are what give them their systemic nature. (ibid pp. 56)

According to Rosenberg, a key determinant of the adoption of an innovation is the “technological expectations” that relevant actors have, i.e. the adoption is determined by expectations on future technological developments (ibid pp. 105). What is especially interesting in relation to the present study is that he notes:

> “Not only the diffusion of technologies but also the effort devoted to the development of new technologies may be decisively shaped by expectations as to future improvements and the continued superiority of existing technologies.”
>
> (Rosenberg 1982:115)

Rosenberg contends that individual technological developments must be understood in relation to the larger system of technologies of which they are a part, and that developments are shaped in part at least by expectations on future developments within this system. In order to discuss the actual research and development process, Rosenberg views it as a learning process (ibid pp. 121). He argues that an important type of learning is ”learning by using”, i.e. a learning that can take place only after new products are used. This can lead to feedback in the design process:

> “... the early experience with a new technology leads to better understanding of the relationship between specific design characteristics and performance that permit subsequent improvements in design. In this case, the result is an appropriate design modification. What we are describing here is a feedback loop in the development stage. Optimal design often involves many iterations.”
>
> (Rosenberg 1982:123)

As is obvious from the above presentation, Rosenberg's arguments and theoretical concepts are quite similar to those of Thomas Hughes. They have provided useful tools for this study. Apart from developing these theoretical concepts, Rosenberg has also analysed several industries undergoing technical change. One such "sectoral" study of technological change has been carried out for the telecommunications industry (Rosenberg 1994). In this study, Rosenberg uses some of the concepts he has developed. He shows the inherent systemic character of telecommunications, and also discusses how technological expectations have evolved in relation to research and development work, and how difficult it is to foresee the consequences of technological change. Rosenberg also discusses the "path dependent" character of technical development in telecommunications, a concept that I will return to further on.

Not only Rosenberg has studied the telecommunications industry from a historical perspective. In a series of studies of the history of specific infrastructures, Amy Friedlander (1995) has considered the development of the telegraphy and telephony infrastructures in the United States from 1837 to 1940. She discusses the diffusion of telephony in terms of how it offered a universal service, and became a natural monopoly. A similar approach is taken by Claes-Fredrik Helgesson (1999), who in his thesis discusses the Swedish telecommunications monopoly. The development of the Swedish telecommunications infrastructure has been studied from a technological system perspective by Arne Kaijser (1995). A fourth example of historical studies of telecommunications can be found in Patrice Flichy's (1995) account of the development of communications from the time of the optical telegraph to today.

What differs the mentioned historical studies of telecommunications from the present one is above all their scope. The authors focus on the development of an entire industry over rather long time frames. The present study instead focuses a particular development, of the technical standard DECT.

There are of course yet other types of historical studies relating to telecommunications. One category is the company history, which has provided me with interesting reading about some of the companies involved in the development of the DECT standard. In the case of Ericsson, John Meurling and Richard Jeans (1994; 1995; 1997) have written three books intended for a popular audience about important developments for the company. The history of the Swedish PTT Telia (formerly Televerket) has also been treated in a series of book with a more academic style. The most recent one was written by Heimbürger and Tahvanainen (1989) and treats the period from 1946 to 1965.

Social shaping of technology

While economists often take an interest in the economic and social effects of technological development, some sociologists in essence try to do the opposite. They study how social factors shape technology, e.g. how the development or adoption of a new technology is socially determined.

One of the most influential researchers on the social shaping of technology is Wiebe Bijker, who refers to his own research as "sociohistorical technology studies" (Bijker 1995a). In the article with the same name, Bijker discusses three classes of models for how technological artefacts are developed:

> "The first class focuses on the *technology itself* as its explanatory basis, thus stressing the relative autonomy of technological development; the second class consists of evolutionary and rationalistic models, taking technological *knowledge* as the key characteristic for modelling technology; and the third class finds its starting point in the *social practices* related to technology and focuses on the social shaping of technology. The three classes of models are to some extent complementary – they stress different but important aspects of the development of technology. In other respects, however, they are contradictory, and I will argue that the models presented below give successively more adequate descriptions of the development of artifacts. They do so because they provide successively better instruments to analyze the development of technology *in its relations to society*."[18]
>
> (Bijker 1995a:237p)

What I find especially valuable in Bijker's work (and in the work of e.g. Wiebe Bijker and Trevor Pinch, 1987, Michael Callon, 1987, and Bruno Latour, 1996) is that it introduces the concept of social factors shaping a technological development process. This is very relevant, whether you take as a starting point the social practices related to technology (as Bijker emphasises above), or the technological development itself, which is natural for myself as an engineer to do.

In his studies, Bijker analyses technological development as a social process. In this endeavour, he uses a few interesting concepts. First of all, he determines that there are a number of "relevant social groups" that shape the development of the particular technology under study. Different social groups have different interests in the technology, they require different things from it, and they perceive it in different ways. As a technology develops, there is initially a large "interpretative flexibility" as to how it should be perceived. As the process continues, however,

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[18] Emphasis according to original.

"closure" reduces the interpretative flexibility, a stabilisation takes place, and "exemplary artifacts" embody the relevant social groups conception of the technology. The artefacts, together with the knowledge, goals and values of the relevant social groups make up the "technological frame" in which the development takes place. (Bijker 1995b)[19]

Bruno Latour (1996) has given us a rather unusual presentation of a technological development in his story of Aramis, the French rapid transport system. In a prosaic style, he relates how the Aramis system developed, which in his tale is very much a case of social shaping of technology. An interesting aspect of Latour's book is that he allows the technology itself, the "unborn" Aramis system, be one of the actors in the play. He thus recognises that, although socially shaped, technology still has some form of existence of its own.

Especially Bijker's structured presentation of different concepts relating to how social factors shape technology have been useful for my understanding of the development of the DECT standard, which in every respect is both a technical and a social process.

The product design process

Related to models of the process of innovation are descriptions of the design process. The product design process in a sense is a sub-process within the broader context of innovation. In the case of communications standards, especially when co-operative official standards are considered, the design process is logically preceded by standards-setting. The design of products is based on a standard, which the products must fulfil. Obviously the sequentiality is idealised. In practice product design and standards-setting are highly parallel activities.

While studies of innovation ranged from the macro level (geographical region or industry) to the level of the individual innovation, product design studies range from the individual design project or the individual firm, to the individual designer, and his or her knowledge or expertise.

In a thesis from my own department, Bo Karlson (1994) gives a thorough presentation of different types of product design studies. In his discussion, he illustrates the different levels at which product design has been studied by both covering studies of the skills of the individual designer, and studies of the design process. It is the design process that is of primary interest for the present study.

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[19] It is difficult to ignore the similarities between the social shaping of a technology, where closure reduces interpretative flexibility thus generating an exemplary artefact, and the emergence of Utterback's (1994) "dominant design".

Karlson contrasts sequential and simultaneous models of the design process with each other. Like Kline and Rosenberg (1986) did for innovation, Karlson shows that descriptions of product design have moved from viewing activities as taking place in sequence, to describing them as parallel events with strong feedback qualities. This is supported by e.g. Lars Trygg (1991), who in his thesis makes the same point in an analysis of the literature on the organisation of product development.

In a typical textbook in engineering design, Gerhard Pahl and Wolfgang Beitz (1988) take a systematic approach to product design. From their point of view this entails making design work "more logical, more sequential, more transparent, and more open to correction" (ibid p. 5). The sequential character of the design process permeates their descriptions of it. A design effort starts with a well-defined task, goes through a number of sequential activities, and ends with a solution. Between the activities of the design sequence, feedbacks and reiterations are possible, but aside from the task definition, essentially no external influence exists.

A somewhat different approach is taken by Kim Clark and Takahiro Fujimoto (1991), who in their study of product development in the automotive industry focus on information flows in the design process. By doing so they highlight the feedbacks within the design process, and demonstrate that feedback also comes from outside the task-to-solution process depicted by Pahl and Beitz. They discuss "product development as a simulation of consumer experience" (ibid p. 22), and show that anticipated as well as actual consumer satisfaction, and the behaviour of the consumption process, generate information vital to the design process. In their own words:

> "The development of a new product involves creating a new design concept and building and testing prototypes. One way of interpreting what engineers do during this process is to think about how they decide whether a design is attractive. Though they follow a variety of technical specifications and established test standards, if we cut through all the formal detail, at the core of the evaluation, engineers are simulating what future customers will experience."
>
> (Clark & Fujimoto 1991:22p)

By describing product design in this way, Clark and Fujimoto show the impact of market and customers on the design process, which is apparent even before the product being designed has actually reached the market place.

Returning to Bo Karlson's thesis, he goes on to develop an yet more aggregated description of the design process, where he takes the "product family" (Karlson 1994:44) as the unit of analysis. In his "wave metaphor" (ibid pp. 44), he characterises the development of products as a series of waves, where each wave represents a major or minor adaptation of the products within a family. New products are thus often developed based on existing ones, or based on concepts familiar to the product family they belong to. In this way Karlson manages to expand the time frame within which a design effort can be considered[20].

With respect to the work at hand, Clark and Fujimoto's focus on information flows in the design process is very useful. They present a way of understanding how users, customers, and the market place, can influence a design effort even before the object of the effort has been realised. In relation to this, Karlson's wave metaphor is also important, since it illustrates the other end of the spectrum, i.e. how existing products, solutions, and concepts set the stage for current design efforts. Both these aspects are relevant for the development of technical standards.

2.2 The formal process

The formal standardisation process has been studied in different ways. I will focus on two sets of approaches that in some ways are related. The first approach focuses the institutional setting of a standardisation effort, and standards-setting as an institution. The second approach focuses the organisation of formal standards-setting procedures, and discusses standardisation as a way of organising.

Institutional theory might well be used to analyse e.g. the development phase, just as it is used for the formal standardisation process. However, as will be shown below, authors using this approach in relation to standards-setting tend to focus on the formal process. The same comment is in fact valid for research dealing with how standards-setting is organised.

The institutional setting of standardisation and standards as institutions

The environment of the individual organisation is the focus of institutional analysis. This *institutional* environment can be characterised as rules and requirements that the organisation must adhere to, and it influences the way in which the world is perceived by individuals inside the organisation. (Scott 1987:126, 129p, 154p)

Standards-setting bodies, such as ETSI[21], ITU[22] or ISO[23], can be considered to be institutions, and standards themselves can also be analysed as institutions. A dis-

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[20] Andrew Davies (1997) elaboration of Utterback's dominant design concept, which was treated above, is similar to Karlson's discussion of succesive generations of products in a product family.

[21] The European Telecommunications Standards Institute.

[22] The International Telecommunications Union.

cussion of the latter can be found in an article by Claes-Fredrik Helgesson, Staffan Hultén, and Douglas Puffert (1995). They argue that the institutional setting of the standard has been overlooked in studies of standardisation, whether they have been made from an economic or a technological perspective. The institutional starting point is motivated in the following way:

> "An established standard can ... be seen as an institution. It is a widely accepted code facilitating coordination that is embodied in a regulatory regime. Vested interests and the momentum of the installed base enforce its further acceptance and conservation. This means that any given standard cannot be understood apart from the regulatory regime establishing and maintaining it."
>
> (Helgesson, Hultén & Puffert 1995:171p)

They go on to note that:

> "A change of standard is no less than an institutional change, demanding not only the standard itself to be changed, but also demanding other components connected to it to change."
>
> (Helgesson, Hultén & Puffert 1995:172)

There are obviously both benefits and drawbacks from standardisation. Viewing standards as institutions demonstrates this duality in the following manner:

> "From an institutional point of view, standards are vehicles for facilitating coordination of economic activities. Instead of repeated coordination between actors, a standard solves a number of dilemmas for actors within the industrial system. A standard therefore diminishes the need for short-run coordination. On the other hand, there is an increased need for concerted action when standards are created or changed."
>
> (Helgesson, Hultén & Puffert 1995:167p)

In the article, the authors use the institutional perspective on standards to analyse European standards for telecommunications terminal equipment. Their point is that changes in the framework in which standards come about by definition are slow, and, specifically, that establishing common terminal standards is difficult, will be costly, and will require serious effort.

In an analysis of standards-making institutions, Richard Hawkins (1995) explores one of the key attributes of the negotiation of voluntary standards, the ”consensus ideal”. He establishes that the efficiency of the standards-setting process often conflicts with this ideal and discusses various ways of combining consensus and

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[23] The International Organisation for Standardisation.

efficiency. He concludes by noting that the growing number of requirements in standardisation efforts may necessitate more than one institutional structure.

Stanley Besen (1995) views technical standards-setting processes from a similar perspective. He argues forcefully for the importance of understanding the actors in the standardisation process in order to be able to judge its efficiency:

> "... one cannot analyse the performance of the standards process without understanding what the participants in the process expect to gain from it. If participants prefer no industry standard, or will settle only for their own, agreements on a standard are unlikely and changes in the process to make agreements easier to achieve will be difficult to bring about. In short, improvements in the process will occur only if participants believe they are better off with those improvements."
>
> (Besen 1995:145)

Besen identifies four basic situations that reflect different types of objectives among participants in a standardisation effort (ibid pp. 138):

1. All participants have a common interest in the standard, and quickly and efficiently want to determine a good standard. Since interests are similar, everybody is welcome to join the process, and decisions are reached by consensus.

2. The participants have directly opposed interests and want their own solution to be adopted as standard. This often leads to "standards wars" and the emergence of de facto standards through market mechanisms.

3. The participants prefer their own solution, but are even more interested in actually establishing a common standard. The process allows some competition, but ultimately leads to agreements (compromise), often through some form of voting procedure.

4. At least one participant wants to slow down the process of establishing compatible products through open standards, thereby e.g. fortifying a strong market position.

This typology is useful in determining the institutional setting of a particular standardisation activity, and Besen uses it in trying to understand how standards-setting in telecommunications and information technologies has changed, and how the processes might be improved. Similar types of analyses can be found for other areas, e.g. procedures for setting environmental standards, which are explored by Jim Skea (1995) and Francois Leveque (1995).

The institutional perspective the analysis of standards-setting processes is valuable in that it focuses the participants in the process, and their interests. This is of course a way of capturing the systemic nature of technical standards, and the way in which standards-setting is perceived is not unlike what was found in the historical approaches, or the social shaping of technology approach.

Organising standards-setting, and standards-setting as a form of organisation

The organisation of standardisation processes is obviously closely related to the institutional perspective treated above. One might say that organisational studies are a subset of institutional studies. Nevertheless, there are certain nuances, for example in the level at which standardisation is studied, that warrant a separate treatment.

A great deal of current Swedish research treating the borderland between organisational studies and studies of standardisation has been elegantly summarised in an anthology edited by Nils Brunsson and Bengt Jacobsson (1998). The nature of the book is such that it has a fairly broad scope. A number of examples of standardisation are included, but they all treat administrative standards (e.g. ISO 9000) rather than technical standards.

Standards are described as a particular type of rule, and the authors distinguish it from two other categories of rules: instructions and norms[24]. Instructions are generally explicit, often even written down, and it is mandatory to follow them. Norms on the other hand, are internalised rules that we often follow unconsciously, and that become apparent only when they are broken. Standards fall in between these two categories. They are explicit rules, but voluntary, and there are no repercussions associated with breaking them. (ibid pp. 13)

In the final chapter of the anthology, Brunsson (1998a) explores standardisation as a social form. Instead of taking an interest in how standardisation processes are organised, he turns the tables and claims that standardising is a way of co-ordinating and controlling. The same discussion can be found in one of his contemporary research papers:

> "Standardization is a fundamental form of co-ordination, control, and choice in society. In this paper I shall compare standardization with other basic forms: namely, markets, hierarchies, and normative communities. I shall show that the different forms sometimes occur together, but that they may also represent alternatives. The absence of one form creates a need and opens the way for another; the extent and range of standardization thus depends on the prevalence and strength of the other forms. Finally, I

[24] In Swedish: "direktiv" and "normer".

> shall argue that standardization is favoured by two major contemporary trends, individualization and globalization."
>
> (Brunsson 1998b:1)

One of the examples in Brunsson & Jacobsson's anthology is Kristina Tamm Hallström's (1998a) study of one of ISO's technical committees, TC 176, that develops the ISO 9000 quality management standards[25]. Her chapter discusses the character of the committee in terms of how it is organised, how the work processes it contains are organised, and how the participants in the committee can be characterised. In her analysis, she relates the description of TC 176 to four principles of organisation:

1. Expertise. Neutral, independent experts should participate in the standardisation activities.

2. User orientation. Users should participate in, or otherwise influence, the standardisation process.

3. Representation. Different nations and geographical regions should be represented in the standardisation committee.

4. Efficiency. The standardisation work should be conducted in an efficient way.

Tamm Hallström goes on to show that these four principles often conflict with each other, which in turn leads to tension in the standards-setting process.

The study by Tamm Hallström is very illustrative of the approach taken in organisational studies of standardisation. She makes a thorough presentation of the organisation, procedures, and participants, but neither the content of the standardisation effort (*what* people actually do, as opposed to *how* they do it), nor the object of the effort, the actual standard, are discussed. For me, it therefore becomes difficult to understand the standardisation process.

What I strive to do in this thesis is to understand the content of the standards-setting activities related to the technical standard DECT. By doing this I believe other aspects of standardisation can be shown than is possible if only the organisation of the process is studied. Perhaps this is especially relevant for technical standards, where issues such as what is technically possible, feasible, and reasonable, are an integral part of standards-setting. For administrative standards it might well be that such issues are less important.

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[25] The study has been the basis for a number of papers that discuss essentially the same problem (see Tamm Hallström 1998b; 1997).

2.3 The diffusion phase

As I have noted earlier, the most comprehensive area of literature with regard to standardisation is that which treats their market diffusion. Here, economists describe markets and their development in terms of increasing returns, path dependencies, and network externalities. Although these studies in general have a different aim than my own, they are worth discussing.

Related to the competitive aspects of standardisation are policy aspects. Here a different perspective is taken in the analysis of the market effects of standardisation. Often regulatory solutions are focused. For the present study, such research has primarily contextual value.

Standards and competition

There are two classic cases of technological lock-in, or path dependency that are quoted in almost all articles and books on the subject. The first one is the QWERTY keyboard layout, made famous by Paul David (1985). The second one is the VHS versus Betamax controversy, where perhaps the most well-known "story-teller" is Brian Arthur (1994). Path dependencies, as well as network externalities (or network effects), are often the starting point for economic analyses related to technical standards.

In his article on the QWERTY keyboard, Paul David provides us with a definition of what path dependence is:

> "A *path-dependent* sequence of economic changes is one of which important influences upon the eventual outcome can be exerted by temporally remote events, including happenings dominated by chance elements rather than systematic forces. Stochastic processes like that do not converge automatically to a fixed-point distribution of outcomes, and are called *non-ergodic*. In such circumstances 'historical accidents' can neither be ignored, or neatly quarantined for the purpose of economic analysis; the dynamic process itself takes on an *essentially historical* character."[26]
>
> (David 1985:332)

David develops three concepts that he uses to explain why the development of type-writer (and later computer terminal) keyboards "locked-in" on the QWERTY design instead of allowing keyboard designs to develop towards allegedly better

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[26] Emphasis according to original.

solutions such as the "Dvorak Simplified Keyboard", thus giving the development the qualities of path dependence.

The first concept is the "technical interrelatedness" of the physical keyboard and the typing knowledge of the operator. If an employer purchased a QWERTY keyboard, the operators trained in using this configuration would be available as workforce.[27]

The second concept is the "scale economy" that emerged as the QWERTY configuration gained in acceptance, thus generating a larger amount of trained operators, which in turn decreased the costs of using the configuration. This is a self-reinforcing mechanism that, according to stochastic theory, in time will result in only one configuration remaining. However, it is impossible to beforehand tell which solution will emerge as the winner. This will be determined by "historical accidents".

The third concept is the "quasi-irreversibility of investments" that is apparent for the typing knowledge of the operators in the keyboard case. Because it was easier to adapt machines than peoples habits, that is what was done.

The moral of David's story is that an economic analysis has to take into account the historical development of the industry or market under study.

Brian Arthur (1994) takes a slightly different approach than Paul David, although they are interested in the same phenomena. In an anthology were his most important papers are collected, he focuses mainly on how increasing returns due to market adoption, and the path dependent processes that are a consequence of this, can be modelled mathematically. In his mathematical models, he shows that the outcome of the market adoption of a product, for which returns increase due to the degree of market adoption, will lead to the dominance of one supplier (ibid pp. 21). He also shows that which supplier will emerge as the dominant one is impossible to know beforehand. Small events are amplified due to the properties of the stochastic processes in the model, which leads Arthur to argue for historical studies in economics (ibid pp. 28, p. 46).

Of special interest for the present study is Arthur's discussion of competing standards[28]:

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[27] This is similar to the discussions of the systemic nature of technology that can be found in Rosenberg's (1982) and Hughes' (1987) work.

[28] Nathan Rosenberg (1994:225) makes a similar argument for how the choice of a standard leads to technological lock-ins. In an analysis of the telecommunications industry, he notes that an actor, by choosing to adopt a certain standard, also chooses a certain systemic development path. This is mainly due to that future investments must be compatible with the chosen standard.

> "In the case of *competing standards*, early adopters are affected by the choices of *later* adopters, who may or may not fall in with one's choice and follow suit. Now agents will choose partly on the basis of their expectations. ... if a technology gets ahead by chance, expectations that it will eventually lock in narrow the absorption barriers – the fundamental market instability is exacerbated."[29]
>
> (Arthur 1994:26)

The essence of Arthur's discourse is that he analyses how markets behave when some of the conventional assumptions of the micro-economic model, e.g. decreasing returns, are not fulfilled. The major impact this has for my study is two-fold. Firstly, Arthur pinpoints the market impact of expectations of adoption, which is not unlike Rosenberg's (1982) discussion of technological expectations. Secondly, the way Arthur models market behaviour has had an impact on how development engineers expect markets to actually behave. The VHS versus Betamax example pops up in almost any discussion relating to competing technologies, or competing standards.

What both Paul David (1985), in the case of the QWERTY keyboard, and Brian Arthur (1994), in the case of VHS and Betamax, do in the presentations of their cases, is that they represent the losing technology as the superior one. The market thus "fails" to choose the "right" solution. This point of view has been criticised by other economists who have studied the same cases. One example of such criticism is found in an article by Stan Liebowitz and Stephen Margolis (1990), where they dispute David's argument that e.g. the Dvorak keyboard layout was technically superior to QWERTY. They substantiate their claim by analysing a number of studies of keyboard layouts, ranging from "typing competitions" to ergonomic analyses.

While criticising the starting point chosen by David, Liebowitz and Margolis nevertheless agree with his conclusion that economic theory would benefit from studying historical events. However, they mean that David is too marked by the economic models that he uses. The consequence is that he allows "historical accidents" to be the explanatory variable, and does not really ask how the winning solution (or standard) achieved its position. It's just something that happens.

For the present study, that to some degree explains the way in which a technical standard comes about, Liebowitz and Margolis critique of the QWERTY story is

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Rosenberg's arguments do not take the market place as a starting point, but rather an actor's investment decision. It is thus valid not only for standards competing on a market.

[29] Emphasis according to original.

encouraging. I would argue that this study contributes to the type of understanding they argue is lacking in David's work.

Policy aspects of standardisation

Like he has been for discussions regarding competition and standardisation, Paul David is also an influential researcher when standardisation policy is considered. In an article together with Geoffrey Rothwell (David & Rothwell 1997), he analyses the problem of determining how much uniformity is best to maintain during the development of new technology. The analysis is made from the point-of-view of a central agent[30], e.g. a public authority. In the article, the classical policy issue is defined as follows:

> "The kernel of the problem posed for private and public decision-making with regard to the setting of technology standards can be construed to be nothing more, and nothing less than the fundamental issue with which all social organizations are confronted: where to position themselves on the terrain between the poles of 'order' and 'freedom'"
>
> (David & Rothwell 1997:185)

In order to avoid a too simplistic view of standardisation, where standards are viewed as inhibitors of innovation, David and Rothwell argue for an examination of the ways in which standardisation and innovation are related. They note that standardisation in some forms may be beneficial, for example through learning-by-doing and learning-by-using effects. There might thus exist "optimal standardisation paths" where the tension between freedom and order is balanced. (Ibid pp. 187)

An organisation that takes an active interest in the public policy issues related to industrial development is the Organisation for Economic Co-operation and Development, OECD. In a report treating the economic aspects of information technology standards (OECD 1991), the role of public policy is described in the following way:

> "Public policy may be increasingly called for to focus on standards-setting mechanisms and organisations, to promote co-operation between all interested parties and ensure the transparency of the processes. Policy-makers will thus have a broad responsibility to ensure that the institutional environment is conducive to the evolution of standards – and in particular fosters the discussion of all relevant aspects by all relevant interests. Prescribing directions for developing technological trajectories, when

[30] This is the predominant perspective taken in policy related studies.

> necessary, should be designed (for example through functional standards) so as to avoid giving an edge to standards which may turn out to be inferior to other alternatives."
>
> (OECD 1991:8)

The report continues by focusing in particular on the setting of information technology standards. It is noted that policy at some level is always concerned with efficiency, an almost implicit assumption in the David and Rothwell article discussed above. The OECD report distinguishes between static and dynamic efficiency, and presents the policy issues as:

> "In standards setting, concern with static efficiency often raises issues of standardization: 'How much standardization should there be? On which standard should we standardize?' Dynamic efficiency, on the other hand, tends to involve problems of technological lock-in or technological dead ends: 'How can we prevent our technological system from proceeding down a bad path? How can we facilitate the shift from a bad to a good technology?' To overstate the case somewhat, the concern here is largely to prevent standardization."
>
> (OECD 1991:33)

The OECD report determines that standardisation processes are inherently uncertain since the relative merits of competing standards are almost impossible to establish. This is of course a serious problem for the policy-maker. Nevertheless, the report argues that government plays, and should play, an important role in standardisation efforts[31]. With respect to this, four different roles for government are defined:

1. Government as a user of information technology products and services.
2. Government as a producer of public goods.
3. Government as a regulator of competition.
4. Government as a safe-guard for consumers.

Especially the last of these four roles is focused in several policy related studies, where it is noted that user participation in standardisation processes is unusual.

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[31] An interesting analysis of government policy with regard to the development of mobile telephony standards, can be found in an article by Andrew Davies and Tim Brady (1998). They illustrate how the United States, Japan, and the EU countries have acted in different ways for different generations of cellular standards, which in turn resulted in different preconditions for the adoption of the standards that have been developed.

This is due to the high cost and limited benefits for the user that participates in the process, and to the difficulty for users to have informed opinions about systems that have not yet reached the market. (Jakobs, Procter & Williams 1998; 1997; 1996)

Apart from discussions of user participation in the standardisation process, three major issues are treated in standardisation policy literature: pricing competition, intellectual property rights (IPR), and the role of formal standards development organisations (SDOs) versus informal consortia.

Paul David and Edward Steinmueller (1996:823pp) discuss the ways in which companies use pricing strategies in relation to standards. A typical such strategy is to price products below cost in order to damage rivals' ability to compete, while regaining profit on complementary products or services. The authors note that such anti-competitive pricing (below costs) is very difficult to identify, since the borderline between such intents, and a simple, aggressive thrust to gain market share is unclear. A second, questionable strategy is super-setting, i.e. adding a feature to a product that is not supported by the standard it adheres to. By doing this, the company hopes to attract loyal users, but one consequence is that the standards-setting process is disrupted.

Intellectual property rights and standards are intimately related. However, there is a potential conflict between the standards process and the intellectual property system. The protection of intellectual property reflects the trade-off between encouragement of innovation by profiting the innovator, and widespread diffusion of the innovation. Standardisation instead orients towards the good of the consumer by increasing competition through a common product platform. (Shurmer & Lea 1995)

A question that arises from the potential conflict between IPR and standards is whether the protection of intellectual property is too strong. Here views differ. Some researchers are of the opinion that in industries where standards and network externalities are important, e.g. telecommunications, it would be beneficial to relax the protection (Farrell 1995). Others argue that the balance of current patent and copyright laws is reasonable, and that a relaxation of intellectual property protection would only result in reduced invention and innovation (Smoot 1995).

The third and final policy issue to be discussed here is how formal standards developing organisations (SDOs), are being outmanoeuvred by informal consortia. Paul David and Mark Shurmer (1996) coin this effect an "institutional failure", a paraphrasing of the "market failure" discussion that was touched upon earlier. The main reason that is voiced for this institutional failure is the inefficiency of the SDOs in developing timely standards. This is primarily a result of slowness at the political level. The technical work is often completed relatively quickly, but then delayed by the political processes of the SDOs.

David and Shurmer pinpoint a number of risks with the increasing number of informal, private consortia that are developing standards. One important issue is that while SDOs generally strive to create standards that are in the interest of the public, this is not guaranteed with an informal consortium. Another issue is whether private consortia will continue to support standards they develop, thus showing a long-term commitment.

In the above discussion I have tried to illustrate some of the policy related research on standardisation that is being conducted. The issues that are treated often differ substantially from the present study, but there is a contextual value in policy research that makes it hard to ignore. Policy aspects influence even the individual standard-setting activity.

2.4 Concluding remarks

In the literature that has been discussed above, there are a set of theories and models that I perceive to be most relevant for the present study. I would like to focus on them as I conclude this chapter.

The chosen approach

The approach chosen in the present study is one where the actions in the standardisation process are of primary interest. At the level at which the study has been performed, these actions are primarily engineering related. As with any engineering activity, standardisation encompasses both technical and social issues. In a sense, this thesis tries to focus the content of the standards-setting process rather than its form. It will thus offer a perspective complementary to that found in organisational studies of standardisation (e.g. Tamm Hallström 1997; 1998a; 1998b).

When placing an engineering activity in a social context, the work of Wiebe Bijker (1995a; 1995b), and others involved in the discussion of how technology is socially shaped, is useful. Although Bijker's work is more oriented towards understanding the actors than is the present study, his concept of "technological frame" offers a system for incorporating social aspects in the study of technology.

Similarly, Hughes' (1987) concept of "technological systems", and Rosenberg's (1982) discussion of the systemic nature of technology and the "technological interdependencies" that arise from this, offer a structured way of analysing the development of technology in a social setting.

In the analysis of my case, I have this type of approach. I view the development of the DECT standard as part of a larger technological system, and as part of a larger social setting.

Models of development processes

One of the aims of the present study has been to give a reasonable account of the standards-setting process for technical standards. The result is found in the form of a conceptual framework that is discussed in the next chapter. In creating my own framework, other models of innovation processes and product design processes have been an important source of inspiration. A number of such descriptions have been treated above. Let me summarise them.

Kline and Rosenberg (1986) present a critique of the linear model of the innovation process. Instead they propose the "chain-linked model", where the different phases of the innovation process take place in parallel, with feedback loops between them. They also emphasise that there is feedback between the particular innovation process and research and scientific knowledge in related fields.

A critique of the linear process can also be found in Utterback's (1994) research. He takes an interest in how "dominant designs" emerge. Although, in Utterback's examples, the market place generally decides what design shall become dominant, the analogy to standardisation is apparent. The development of a technical standard is a way of defining a dominant design outside the market.

A model of product design that has qualities similar to Kline and Rosenberg's can be found in Clark and Fujimoto's (1991) study of the auto industry. They describe the design process in terms of information flows, thus capturing the feedbacks of the process. They show that engineers need feedback from the market place even before the products being designed have reached it.

The market expectations that Clark and Fujimoto express are not unlike the "technological expectations" described by Nathan Rosenberg (1982). He contends that both the market diffusion, and the effort put into the development of a particular technology, is influenced by people's expectations of future technological developments. This is similar to Thomas Hughes' (1987; 1994) concepts of "reverse salients" and "technological momentum" that inhibit and amplify, respectively, a certain development.

Bo Karlson (1994), in his "wave metaphor", offers us a way of describing how a technological development builds on earlier ones. This might be one example of how "technological momentum" shows itself. Andrew Davies (1997) discussion of different types of innovation in complex product systems, demonstrates similar aspects. He shows that within a product system, successive generations of component and systemic innovations follow each other, while the architectural innovations have a longer life cycle.

In summary, the literature study has shown that a linear model of how standards develop is insufficient. There are feedbacks between different phases, and knowledge of the market-to-be, as well as the technology-to-come, is important for how the development effort is shaped. The development effort will be influenced by prior technical solutions, and certain solutions will gain momentum, while certain problems will inhibit the development.

In my own conceptual model of the development of technical standards, which is presented in the next chapter, I take these findings into account.

Contextual aspects

While different models of innovation and design processes have been useful in a very direct way, other parts of the reviewed literature has had a more contextual value.

Theories that take the market place as a starting point are not useful when the objective is to understand how a development activity of the kind studied here takes place. The questions asked are simply different. However, research conducted by e.g. Paul David (1985) and Brian Arthur (1994) is relevant in that it feeds back into the engineering process by changing engineers expectations of the result of their efforts. “Path dependence” and “increasing returns” are concepts that have impacted our understanding of how markets work.

Policy studies (e.g. David & Rothwell 1997; David & Shurmer 1996), on the other hand, have a more direct contextual value. They help us understand the driving forces of different actors in the process, especially regulatory authorities or government. This is part of the context in which a standard-setting activity takes place.

The same can be said regarding institutional analyses of standardisation (e.g. Besen 1995; Helgesson, Hultén & Puffert 1995). In Besen’s (1995) typology of the objectives of actors in the standards-setting process, we can easily identify the situation for DECT. Like in many similar standardisation efforts, the participants in the DECT standardisation preferred their own solutions, but perceived the value of a common standard to be greater yet. This is one example of how such studies have helped me understand the context in which the DECT standard was developed.

3. Conceptual framework

During the course of my studies it has become necessary for me to create a conceptual framework through which I can understand the complicated world of communications systems standardisation. This framework is an important result of the study. It has grown from the empirical studies that I have performed, and has been complemented by impressions from literature that I have studied. The order in which the chapters appear in this thesis is therefore not chronological, but rather a way of using the theoretical framework to strengthen my own, conceptual framework, and then using both frameworks when relating the case study.

The framework as it is presented here has played two important roles in my work. First of all, as indicated, it has helped me structure my thoughts and identify important relationships in the standardisation act. Secondly, it has helped me relate my work to other studies of standards and standardisation processes. I have discussed relevant literature above, and will return to it in my continued discourse.

Descriptions of standard-setting processes can obviously be made from several different starting points. The one that I present here is focused on the actions that precede, are part of, and follow a formal standardisation effort. The actions themselves, their mutual relationships, and external factors that influence them are included in the description. The organisational relationships between people and companies involved in the process have not been considered in this description. This is not to say that they are unimportant, but since the aim of this study is to investigate the relationship between standardisation, and research and development in the development of a technical standard, it was more relevant to focus the *actions* that were part of this activity, rather than the *actors* participating in it.

3.1 The formal standardisation process

As I have previously noted, the starting point for my studies was the formal standard-setting process, such as it is conducted when official, de jure standards are created. In Europe, telecommunications standards of this type are often developed by the European Telecommunications Standards Institute, ETSI. One example is the DECT standard that provides the case for this thesis.

There are numerous standards organisations around the world with missions similar to that of ETSI. They all have in common that standard-setting activities follow a set of procedures that determine such things as:

- how suggestions can be made,
- how drafts should submitted,
- how remarks and comments can be made,
- how revisions should be performed,
- how voting should be conducted,
- how the standard should be adopted, and
- how the final document should be formatted and made available.

The procedural aspects thus often determine the time it takes for a standards-setting organisation to produce a new standard, and the result is a process that in theory can take perhaps half a year to a year, but in practice often takes longer. In general, the telecommunications standards organisations are slower than e.g. Internet or computer related organisations.

In either case, the standard-to-be must be taken through the formal process in order to be accepted as an official standard. As a result, if all goes well, the final standard should be robust and relatively error-free, and should answer its purpose well. On the other hand, if the process moves along less smoothly, the resulting standard may become too much of a compromise between opposing wills, and the standardisation process itself might become drawn out due to conflicting aims among the participants.

The final outcome of the formal standardisation process is an approved standard, i.e. the document that defines the system, interface or component that has been standardised.

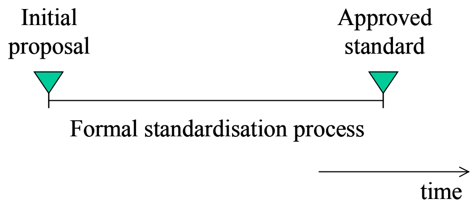

Figure 2: The formal standardisation process.

In the literature review, I demonstrated that the formal standardisation process has been studied in terms of how it is organised (Tamm Hallström 1998a; 1998b; 1997), and in terms of how the institutional setting of the process affects its efficiency (Besen 1995; Hawkins 1995). However, this literature has limited value here since it does not focus the object of the standard-setting activity, i.e. the standard. The present study, as noted, discusses how a technical standard is developed, and what factors determine the design of the standard.

3.2 Diffusion of standards

Different sectors tend toward different styles of market diffusion of emerging standards. In the Information and Communication Technology (ICT) industry, the telecommunication, computer and Internet sectors all behave in different ways in terms of when standardisation, commercialisation and diffusion take place in relation to each other. While standardisation comes early in the telecommunication sector, it generally follows commercialisation and diffusion in the computer sector. (Choh 1999:172p)

In the case of open, de jure standards, such as DECT, the adoption of an official standard means that suppliers can start offering products and services that adhere to the standard. These products, as well as products adhering to other standards, can then compete in the market place, thus allowing the standard to diffuse. Although we to be precise should note that products, not standards, are the entities with which different suppliers compete, we can nevertheless consider this a form of competition between standards.

Since most of the important actors within an industry generally participate in the formal standards-setting procedures, the competition between standards is rarely fierce when de jure standards are considered. When closed standards, i.e. proprietary solutions, are considered, the opposite is true. Here different solutions compete for dominance, and the winner can emerge as a de facto standard. This was illustrated by the examples quoted from Shapiro and Varian (1999) earlier. Theoretical treatments of how standards compete have been performed by for example Brian Arthur (1994:26) who contends that markets have a tendency to lock in on one particular standard, thus making it the winner.

While it is obvious that the market diffusion of standards is an important subject, we must also realise that standards do not move straight from adoption to diffusion. At least not in the case of a telecommunications system. The standard in itself only sets the requirements that products adhering to the standard must fulfil. It is a form of detailed specification of the intended system. The products must of course be designed, manufactured and brought to market before any traditional market competition can take place. As a consequence, many different product solutions can spring from one standard. The products have certain common characteristics, but apart from that can be designed in many different ways. Just look at cellular phones. Two phones can look differently (e.g. design, colour, weight), have rather different performance (e.g. battery life), and slightly different functionality (e.g. menu options, built in games), and still follow the same standard.

Since this thesis focuses the standardisation activity in relation to research and development, issues such as product design, manufacturing, marketing, etc have not been examined in detail. In the conceptual model, they are therefore bunched together in a phase called market diffusion.

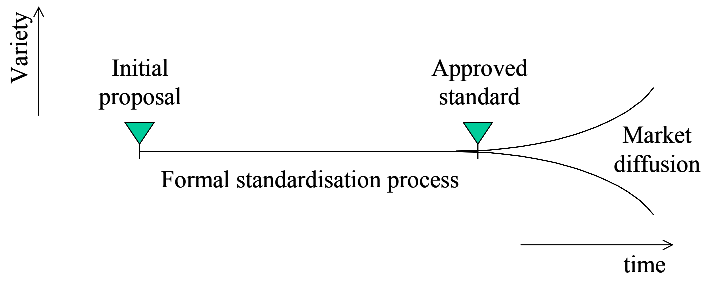

Figure 3: Market diffusion of approved standards.

The models of market diffusion that were discussed in the theoretical framework all define the market as the setting for technical development (see e.g. Arthur 1994; David 1985; Shapiro & Varian 1999), whether it be in terms of technical standards, or otherwise. Questions relating to the engineering effort required to design e.g. a standard are not important in these models. The same is in part true for Utterback's (1994) dominant design concept, where the market is the determinant of what solution becomes dominant.

The present study does not deal with how a technical standard is adopted by a market. Rather, the market diffusion becomes relevant only in how it affects the development of the standard. This will be explored more thoroughly later.

3.3 Development work leading up to technical standards

As has just been described, an adopted standard often leads to a variety of different products, supplied from at least several different companies. Similarly, there is a broad input to the formal standardisation process from many different actors. One might say that they pursue research and development that in time leads to a standard-setting effort.

It is difficult to precisely define what research and development results determine the possible directions a particular standardisation effort can take, i.e. the design of the standard. There are at least three reasons for this:

1. Different actors conduct parallel research efforts.

2. Research and development work is done with many different time frames in mind.

3. A standard specifies a system that incorporates knowledge from a variety of disciplines. Research, and to some extent development work, on the other hand, is disciplinary, and thus generic to many standards.

Nevertheless, it seems fairly obvious that research and development efforts set the stage for a standards-setting activity. The knowledge created during this type of work is essential in determining what system designs are feasible from a range of viewpoints. In other words, technical research and development work that precedes the standardisation effort will determine the outcome of that effort. In some cases, as the DECT study will show, development activities are very much part of the standard-setting activity. The development activities do not end with the initiation of the formal standardisation process.

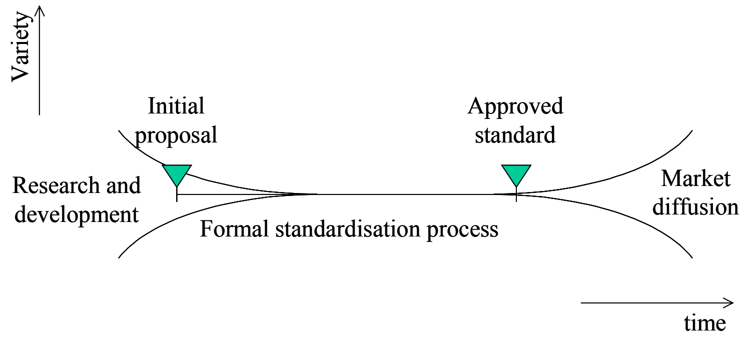

Figure 4: Research and development preceding standardisation efforts.

The distinction made in the model between technical research and development, and standardisation activities, as well as the interaction between these two phases, is similar to the approach of Stephen Kline and Nathan Rosenberg (1986). In their chain-linked model, they illustrate how research and scientific knowledge feed into the individual innovation process. In the present framework for the development of the DECT standard, the result of research and development is an input to the standard-setting process.

3.4 Sequential or parallel phases?

The conceptual model such as it has been presented so far indicates three separate phases: development, standardisation and market diffusion. The temporal relationship between these three phases is of course relevant to consider.

In the creation of an official standard, such as DECT, the three phases illustrated above follow a logical sequence. In order to standardise a particular system, the underlying technical development must be completed, at least to great extent.

Similarly, final product design efforts, as well as manufacturing activities, cannot take place until the standard has been officially adopted. A market diffusion of the standard (or rather: products adhering to it) thus has to follow the standardisation phase. In this respect the present framework is not unlike other sequential models of development processes, e.g. the traditional model of the product design process presented by Pahl and Beitz (1988).

While the logical sequence of events related to standardisation of this kind is thus clear, the start and end points of the different phases are generally not well defined. As has already been noted, a certain amount of technical development might well remain, even though the formal standardisation phase has been initiated. In the standardisation of DECT, development work of this kind was actually considered to be part of the standards-setting activity.

The same observations can be made concerning when standardisation ends and market diffusion begins. Companies naturally begin their product design efforts before the final standard has been approved, and in some cases market related activities can even take place before a standard exists. To some degree, the three phases of the model simply overlap.

Yet another circumstance that complicates things is the fact that several standardisation efforts take place simultaneously. This can be especially relevant if they have similar technical qualities or are performed by the same actors. In such cases, the possibility of distinguishing between the three phases decreases. Research and development might provide input to several standardisation processes that take place over time, and it becomes difficult to identify what research and development results were important for a particular standard.

Standards are often updated over a long period of time, thus creating several generations of a particular standard, just as there can be several generations of products within the same family (Karlson 1994), or innovations within the same product system (Davies 1997). For different generations of the same standard, the three phases outlined above will take place somewhat in parallel. For example, research and development that provides the basis for the second generation of a standard probably takes place at the same time as the first generation is being formally standardised, or products adhering to the first generation are being designed and brought to market.

When temporal relationships between the phases of my conceptual model are considered, issues of the kind discussed here become apparent and relevant. Nevertheless, the three distinct phases that have been identified do follow a logical sequence to some extent, and they are the key phases of a standardisation activity.

3.5 The nature of relationships between the three phases

This study focuses the role that technological development plays in the standardisation of wireless communications systems. As we have already noted, there is a logical sequence in which the research and development phase precedes the standardisation phase, while in practice the two phases sometimes overlap, or take place in parallel. The same was of course true of the third phase as well.

However, even if we disregard the tendency of the phases taking place simultaneously there is a relationship between the research and development phase and the phases that logically follow it. It takes the form of preconceptions.

Research and development efforts often strive towards some sort of goal. When wireless communications systems are considered, this goal is often formulated in terms of the other phases in the standards-setting process. For example, it is often taken for granted that the outcome of research and development work within a company should be useful as a basis for standardisation, as well as a basis for future product design. Similarly, what is perceived to be a problem warranting further development effort is often something related to performance and functionality of the final system or product, i.e. aspects that will make a difference when it comes to market demand, and user behaviour.

One thing that is common to all these aspects, that are important inputs for research and development tasks, is that they temporally lie in the future. Nevertheless, the engineers involved in the development activities have to formulate some kind of *preconceptions* of e.g. user needs and behaviour, implementation practices and market competition. This has been noted by Clark and Fujimoto (1991) in their studies of design practices in the automobile industry. They show that engineers need input from the market before products can be designed, and that they get this information by "simulating" the experiences of future customers. In his discussion of "technological expectations", Rosenberg (1982) has shown us that there also exist preconceptions of e.g. future manufacturing practices, and future design possibilities.

While preconceptions, by their nature, are forward-looking, it should be noted that a standardisation effort also has a *pre-history*. For example, earlier generations of standards may exist. If this is the case, there are probably systems and products available on a market, as well as users of these systems. In a sense, the preconceptions are a translation of the pre-history through the lens of the current standards-setting endeavour.

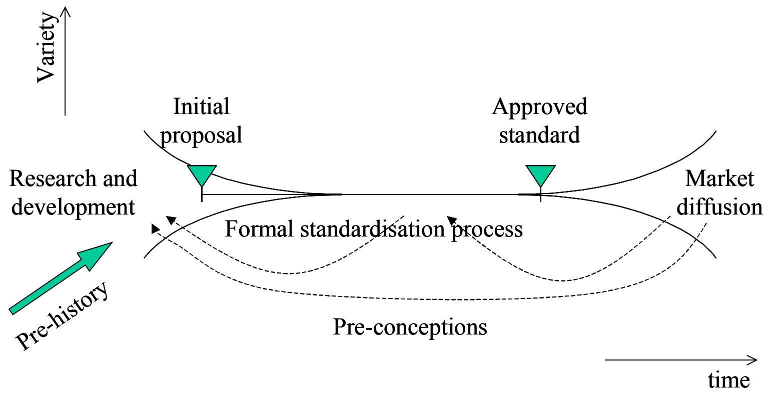

Figure 5: Relationships between the phases.

In the words of Thomas Hughes (1987), one might say that existing technical solutions, manifested as products and systems in operation, have a certain ”momentum” that will influence the development of e.g. new standards. James Utterback’s (1994) dominant designs exhibit the same attributes, which is amply demonstrated especially in Andrew Davies (1997) elaboration of Utterback’s concept. Davies shows us that while certain types of innovations (component and systemic) will arise in generation after generation, they must always adhere to an existing architecture, which in turn has appeared as an effect of a more fundamental type of innovation. This architecture is an example of the pre-history of a standardisation effort.

3.6 The impact of regulation and competition

While the model thus far has focused heavily on the engineering efforts leading up to the creation of a standard, and the market diffusion of the standard, it is obvious that there are also regulatory interests that influence how this process comes about. The same is true of competitive relationships between the actors in the standard-setting process.

I have chosen to focus my conceptual model on the act of standardisation, and the activities (primarily engineering related) that make up that act. Needless to say, standardisation does not take place in a vacuum. The two most important contextual aspects are those of regulation and competition.

Regulation is the classic fellow of standardisation. In Europe, during the days when the national monopolies, PTTs, were the dominant telecommunications operators, no distinction was made between the regulator and the operator. They were essentially one and the same (Davies 1994). In those days most standards-setting activities were driven by PTTs. This left little room for the suppliers to influence the process.

In most countries, separate government authorities today handle regulation. As far as wireless communication is concerned, their most important function is the allocation of frequency spectrum. In some cases such frequency allocations specify the use of a certain standard as a requirement on the operator. There is therefore a strong interdependency between standardisation and regulation.

Issues related to competition were of limited consequence when telecommunication standards were developed by national PTTs. The reason of course being that PTTs didn't compete with each other. Once suppliers became the prime movers in standardisation efforts, the story changed. The standardisation arena now became part of the greater competitive scene. Through their actions in standards-setting processes, they can e.g. block competitors that have a head start in some area or promote solutions that are favourable in light of their own competencies or existing products.

Due to their importance in relation to standardisation efforts, regulation and competition are treated as key contextual parameters in my conceptual framework.

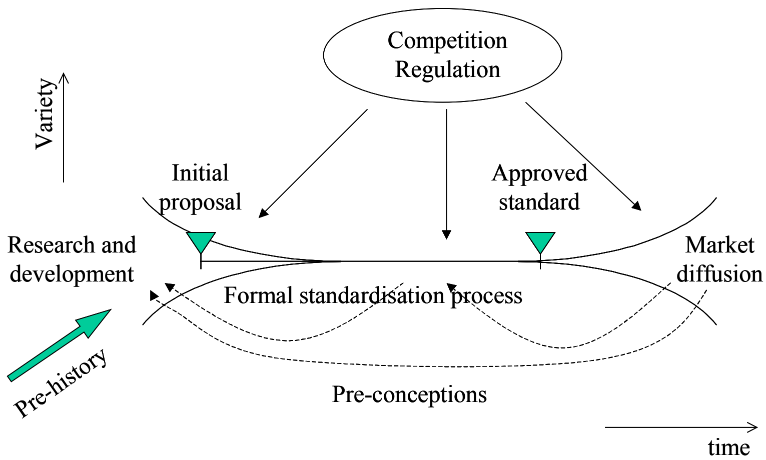

Figure 6: The impact of regulation and competition.

It would of course be entirely possible to view standardisation as a process in which firms compete with each other by advocating their own preferred solutions as standards (Davies 1996:1167p). The reason why competition here is treated as a contextual variable is twofold. Firstly, this thesis treats the design deliberations of the standard-setting process, i.e. how the design of a technical standard comes about. Secondly, the case from which the conceptual framework has grown was such that competitive issues seem to have played a largely contextual role for the development of the DECT standard. Had the study covered a different development effort, aspects of competition might have been more significant.

Similar arguments can be made for the regulatory influences on the design process. In the studied case, they had fairly specific impacts in terms of e.g. frequency allocation. However, regulatory demands were something that had to be fulfilled, rather than something that was intimately part of the actual development process. Again, a different case might have attributed greater importance to regulation.

3.7 Multiple generations of standards

The model presented thus far, has focused the individual standard-setting process. However, it is fairly obvious that different standardisation efforts are related. Either in terms of belonging to similar technologies, or in that a new standard follows one or more generations of existing standards, systems, products, and services.

It is thus relevant to expand the conceptual framework to embrace several standardisation activities, each of which has the characteristics identified for the individual activity. It will thereby be possible to understand how preconceptions are shaped in the individual standard-setting endeavour, and where the pre-history of a particular standardisation effort is formed.

In the figure below, the technological development in wireless communications is described as a semi-independent process. Through standards, and ultimately the systems and products they lead to, there are links to the second semi-independent process, that of market diffusion.

The treatment of technical development as a semi-independent process that interacts with the individual standard-setting effort is supported by Kline and Rosenberg's (1986) chain-linked model. In their model, they depict two independent variables of research and scientific knowledge that interact with the innovation process.

The arrows leading in to the second generation standard serve to illustrate how the technical pre-history of the standard, as well as preconceptions of market needs, based on the market for existing systems, affect the development of the standard. The preconceptions of user behaviour and market needs are translated into expectations of what the market situation will be like when products based on the standard have been brought to market. The same is true regarding product design and manufacturing, where a certain degree of "forward-looking" is also necessary.

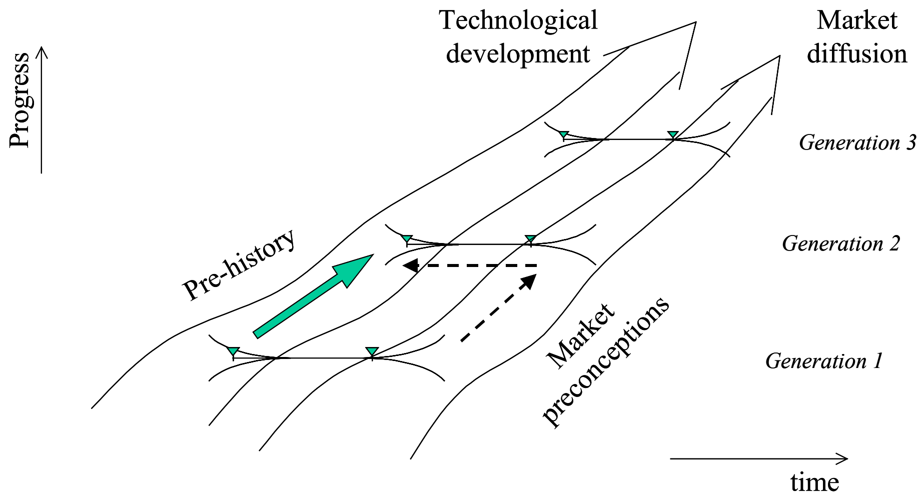

Figure 7: Generations of related standardisation efforts.

In each generation of a family of technical standards, a new system design is determined. Although the type of standardisation process under study here is not a market-based de facto standards-setting, the design that emerges has several of the traits of Utterback's (1994) dominant design. However, while the systems undergo major changes from one generation to the next, we still consider them to be standards within the same product system. Although first and second generation cordless telephony standards differ substantially, we still perceive them to be standards for cordless telephony. In this generation-by-generation development, Andrew Davies (1997) has shown us that certain, architectural aspects of the system remain unchanged for the entire life of the system, while systemic and component innovations can change parts of the system from one generation to the next.[32]

The pre-history component of the present model thus depicts both that which remains unchanged, which the new standard must accept as predetermined, and that which has been or is being researched for the next standard generation. It thus illustrates the impact of a chosen development path (Rosenberg 1994) on the design of particular standard. Quite obviously, later generations of standards are not independent of earlier generations.

3.8 Standardisation and related processes

The conceptual framework that has been presented thus far in this chapter is focused on the development of an individual technical standard, and on the development of several generations of standards. It has been noted repeatedly, that the

[32] Bo Karlson's (1994) wave metaphor for different generations of products within the a product family contains the same idea.

process of setting standards has relationships with other processes that are part of creating systems and products. Examples of such processes are: research and development, product design, manufacturing, and market diffusion. The standardisation process generates outputs to these processes, and receives inputs from them.

One way of illustrating the interchange between the processes can be found in the figure below. The unbroken lines in the figure represent the logical sequence of deliverables in the development and diffusion of a wireless system. Research and development produces the knowledge necessary to standardise a system. Once the standard has been defined, products can be developed that follow the standard. These products can then be manufactured, and sold on the market.

The dashed lines serve to illustrate that information exchange between processes does not only take place when the outcome of a particular process is complete, but in stages. For example, the input provided by standardisation work to the product design process does not come in one single packet, i.e. the adopted standard, once the standardisation is done. Product design efforts start before the standard is decided, and receives running input from the standardisation process.

The dotted lines, finally, show the feedback that runs in the opposite direction of the logical sequence. This can take several forms. For example, the coupling between the market diffusion process and the manufacturing process is fairly tight since production volumes depend on the market impact of the system. In the case of the standardisation process, as well as the research and development process, the feedback from product design, manufacturing, and the market, takes on a slightly different character. Here, it is necessary for engineers, and others, involved in standards-setting and research activities to have a qualified understanding of what the market demands, and how users will behave (compare Clark & Fujimoto 1991). This knowledge, previously referred to as preconceptions, will be based on historic and current information on what is possible to design, what is difficult to manufacture, what the market needs, etc (compare Rosenberg 1982). This information, furthermore, has to be translated to the future point in time when a new system will be realised.

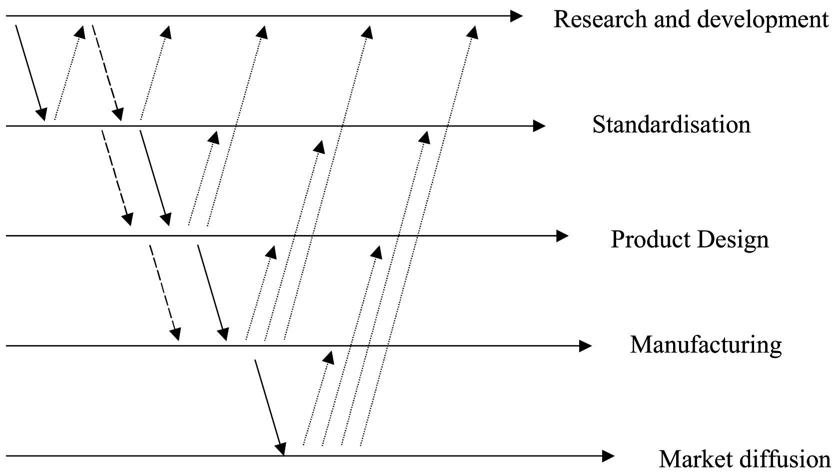

Figure 8: The interchange between standardisation and other processes.

Within each process, new developments have a pre-history. A new standard for cordless telephony, for example, builds on standards that have preceded it. Their functionality and performance set the stage for what should be achieved in the next standardisation effort.

3.9 Summarising the conceptual framework

In this chapter, a conceptual framework for the development of technical standards in wireless communications has been presented. The model that this framework results in describes the individual standardisation process as having three phases:

1. A development phase
2. A formal standardisation phase
3. A market diffusion phase

The market diffusion phase is considered to incorporate those efforts required to actually bring products, adhering to the standard, to market. Such efforts include product design, manufacturing, marketing, etc.

Apart from the logical sequence of development-standardisation-diffusion, the model contains three important relationships that influence the outcome of a standardisation effort.

First of all, a new standard-setting endeavour always has a pre-history in the form of existing standards, existing products, and existing markets.

Secondly, the development of a standard requires knowledge of the market, what can be manufactured, what can be designed, etc. This takes the form of preconceptions. In addition, a powerful preconception of research and development work is that it should generate standards.

Thirdly, the individual standardisation effort is influenced by regulatory decisions, e.g. the allocation of frequency resources, and the competitive setting in which the standard is developed, i.e. the competitive strategies of the participating companies.

Expanding the framework

The model of the individual standardisation effort has also been expanded to include several generations of standards. Here, the two processes of technological development, and market diffusion are treated as semi-independent. The couplings between them are the standards-setting endeavours that are the process by which technical knowledge is transformed into specifications for the creation of products.

Finally, the relationships between the different processes that constitute the development of wireless systems have been illustrated. The processes are:

- Research and development
- Standardisation
- Product design
- Manufacturing
- Market diffusion

The framework shows that there are several sets of information exchange between these processes, and that feedbacks in the logical sequence of events exist. These feedbacks are also translated to future contexts, the setting in which the standard being developed will be used.

Digital Enhanced Cordless Telecommunications DECT

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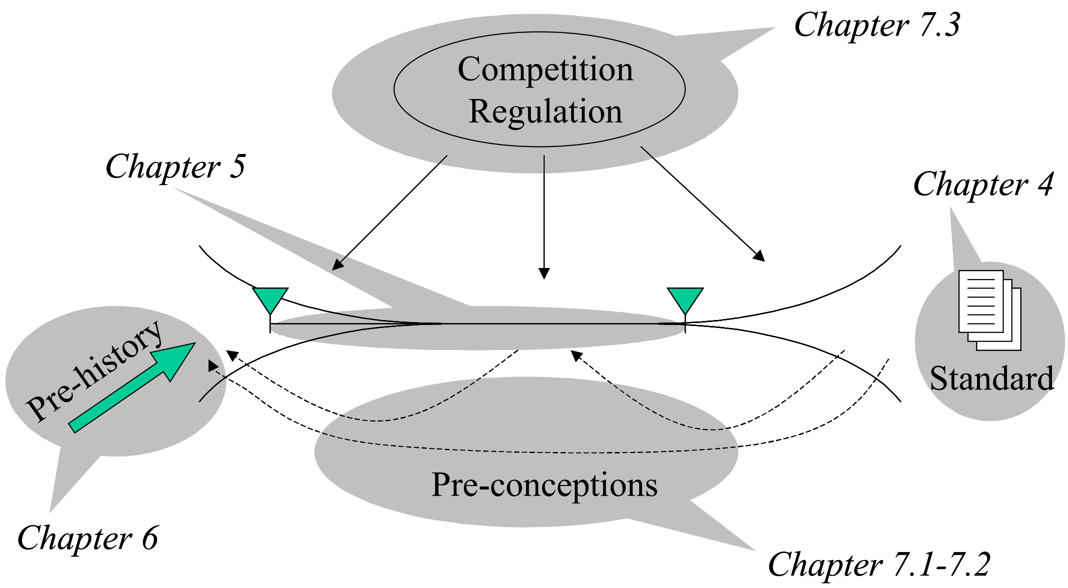
A case study of the development and standardisation of a system for wireless communications.



Chapter 4 gives an overview of cordless telephony systems in general, and the DECT standard in particular. The functionality and performance of a system adhering to the standard is discussed.

Chapter 5 relates the formal standardisation process of the DECT development. A chronology of important events, and the participants are presented.

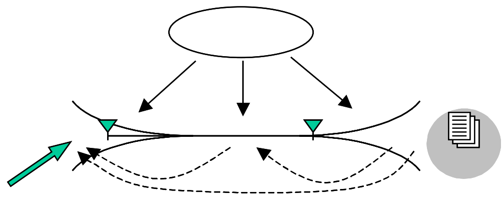
Chapter 6 examines the pre-history of the development of the DECT standard in terms of existing systems, and research and development efforts that preceded the standardisation.

Chapter 7.1-7.2 discuss the pre-conceptions of market needs that were apparent in the development of the DECT standard, and the design objectives that they led to.

Chapter 7.3 examines the impact that competition and regulation had on the standard-setting process.

Chapter 8 focuses the key technical problems that had to be solved in the development of the DECT standard.

4. What is DECT?



This case study tells the story of how the DECT standard was developed. While the standard is a sort of system specification for DECT, product design work, manufacturing, and installation remained after the standard was approved, before functioning systems could be realised. Although the present study does not take into account the products and their development, but stops when the standard had been set, a presentation of DECT as a system will be beneficial for the readers of this thesis by giving them a picture of what the system is, and what it can do. Some basic concepts of cordless telephony in general, and DECT in particular, will therefore be presented here. In several cases cordless telephony will be compared to mobile telephony since I assume that most readers are more familiar with such devices.

4.1 A cordless telephone

Two basic aspects of cordless telephony, that will serve to give the reader an idea of what cordless telephony is, are how users are expected to behave with their cordless telephones, and how a system in practice can be implemented.

User behaviour

Most people by now are familiar with mobile, or cellular telephones, and probably have at least some idea of how such systems work. In a *mobile telephony* system, the idea is that the users should be able to use a phone while moving around, often at fairly high speeds (i.e. while driving a car, typically at 50 km/h or higher). The system should allow uninterrupted conversation, whether the user is stationary, or moving around.

A *cordless telephony* system is based on slightly different assumptions. Here the phone is seen more as an extension of a fixed, wired telephone. The user is thus not expected to move around to the same extent as with a mobile phone, and if he or she does move, it is at low speeds (i.e. walking, typically at 5 km/h or lower). As a consequence, usage takes place in a geographically limited area, for example an indoor office environment. This type of definition of how cordless telephones are used can be found in both ETSI documents and technical overviews (see e.g. ETSI 1995b:14p; Cox, Arnold & Porter 1987:765).

These simple outlines of the assumptions of how mobile and cordless phones are used, are very important for the design of these two types of systems. The reason is that the radio environment will differ substantially between the two cases. The first difference is the size of the area that the system should cover. The second issue is the nature of that area. Indoor and outdoor environments differ in terms of e.g. topology, which means that shadowing and signal fading have different traits. The third question is the speed at which users move, and thus the speed with which the radio environment changes. (Cox, Arnold & Porter 1987:765)

Practical implementations

In their physical design, cordless telephones are not unlike mobile phones. For example, most DECT phones that are on the market are of only slightly greater size than modern mobiles, have approximately the same weight, etc.

In its most simple applications, a cordless phone comes as a terminal, i.e. the telephone, and a base station. The base station is the unit that is connected to a power outlet, and to the telephone outlet, thus making it both a battery charger for the terminal, and the connection to the fixed telephone network.

In more advanced applications, it is possible to have many portable handsets connected to several base stations, which they then share. The base stations are in turn connected to some sort of private automatic branch exchange, PABX, of the type found in most companies, that routes calls and keeps track of users. In this type of configuration, many users can be connected to the same network, and each user can move through the entire coverage area and still use his or her terminal. (Bud 1990:96pp)

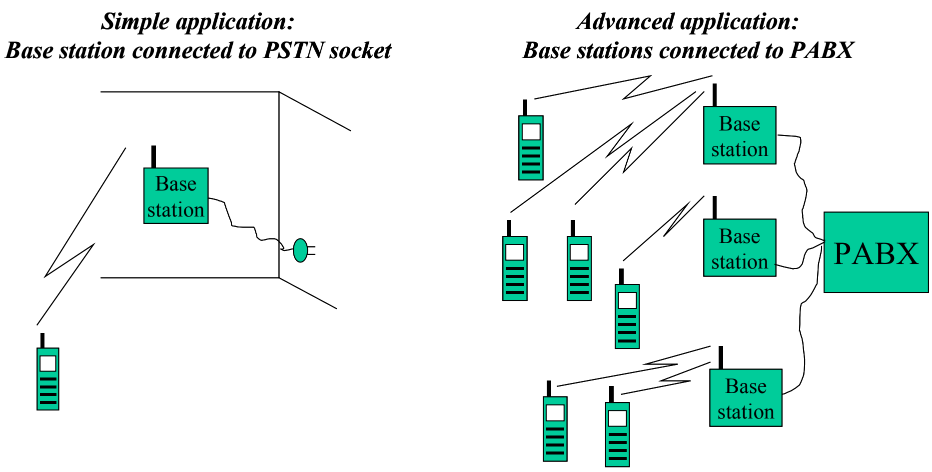


Figure 9: The two typical telephony configurations for DECT.

It is also entirely conceivable to have other types of terminals than telephone devices. DECT, for example, can be used as a wireless data network, allowing communication between e.g. a computer and a local area network, LAN (Owen & Bud 1997:268). The DECT standard was designed to have a "base standard", the Common Interface Standard ETS 300 175 (ETSI 1992b-i), from which Profile standards for specific applications could be developed. A Profile Standard uses the common air interface, and provides interoperability for a certain application, e.g. speech, data, or local loop. The first DECT products in fact used proprietary profiles, but since then a number of Profile Standards have been accepted by ETSI. This case study, however, primarily takes into account the development of the initial DECT standard, supporting telephony applications.

4.2 An access system for several infrastructures

One thing that distinguishes DECT from mobile telephony systems, such as the Global System for Mobile communications, GSM, is that a mobile telephony system is a complete public network with specific services, while DECT is a generic *radio access system* that interworks with local and/or public networks, providing wireless access to these networks. Examples of the types of networks that the DECT Profile Standards support access to are: POTS[33], ISDN[34], GSM, or local area networks (LANs).

In the standard, the interface between the DECT base station and the fixed network is defined in terms of an interworking unit, IWU (ETSI 1993a:117). The IWU interface translates signals between the systems, thus allowing the DECT terminal to work in the same way as e.g. a GSM phone if the base station is linked to a GSM network. If the base station instead is connected to an ordinary fixed telephone system (POTS), the terminal will act as a conventional, wired phone.

The fact that DECT is purely an access system is important when understanding its design and functionality. Since the network between base stations is not part of the actual standard, DECT in this sense has a narrower scope than a mobile telephony standard. At the same time, however, the standard offers wireless access to many different types of backbone networks, i.e. many different types of appli-

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[33] POTS, Plain Old Telephone System, is an often used acronym for the conventional fixed telephone system.

[34] ISDN, Integrated Services Digital Network, is a telephony based network offering digital data services at higher speeds than is possible with a conventional modem over a fixed telephone line.

cations, thus making it more versatile than a mobile telephony standard. The DECT standard defines the functionality and performance of (ETSI 1993a):

1. A portable part, i.e. terminal of some sort.
2. A fixed part, i.e. base station.
3. A common (radio) interface between terminal and base station.
4. The functionality of a number of interworking units (IWU), mentioned above, that allows DECT base stations to be connected to several different network infrastructures.

The main issues in the DECT design are thus related to the radio interface between the terminal and the base station. The classic issues of wireless technology, i.e. radio channel coding, speech coding, error correction, signal processing, etc, are therefore key.

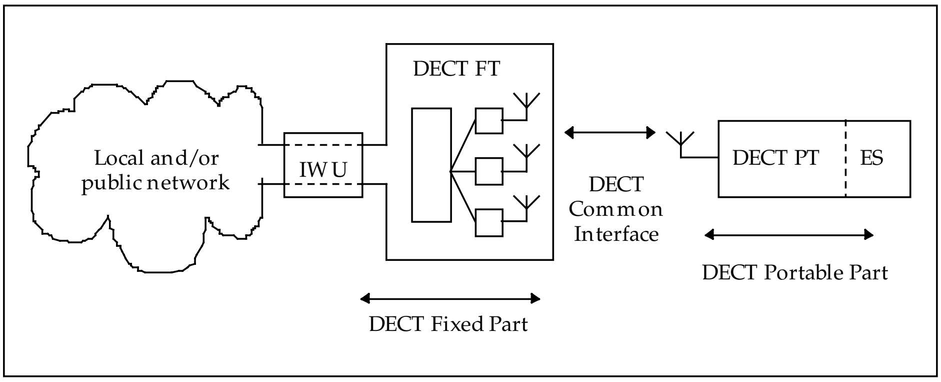

Figure 10: A schematic of the DECT system (Åkerberg 1996:3).

The schematic in the figure above shows the components and interfaces of the DECT system, named according to the conventions of the DECT standard. Examples of current DECT products are found in the picture below.

Ericsson BS330

Siemens Gigaset 3010 Classic

Ericsson HT50

Figure 11: Typical DECT products (courtesy of Siemens and Ericsson).

The Siemens Gigaset 3010 Classic and the Ericsson HT50 are handsets with simple base stations, intended for residential applications. The Ericsson BS330 is a base station for wireless PABX applications. It is contained in a box, approximately the size of a laptop computer, and is generally wall mounted. The terminals are similar (or identical) to the ones used in residential applications.

4.3 Functionality and performance of DECT

Some basic characteristics of digital radio systems are discussed below, and the specific characteristics of the DECT radio interface are outlined.

Benefits of a digital system

By definition, radio waves are analogue. However, it is possible to generate analogue radio waves from digital signals. DECT, as the acronym indicates, is a digital system. This means that signals within the components of the system are processed as binary data. (Ahlin & Zander 1997:13pp)

There are two important benefits of the digital design. Firstly, it is possible to share the frequency spectrum available to the system in more ways. In an analogue system, each user must basically have one frequency over which the signal is transmitted continuously. Furthermore, separate channels are needed for uplink, terminal to base station, and downlink, base station to terminal, communication. In digital systems, several users can share the same frequency, for example by buffering the data bits to be transmitted and allowing each user to transmit bursts of bits in short, sequential time-slots. Similarly, both up- and downlink transmissions can be fitted into the same frequency.

The second key benefit of digital radio is that it allows digital signal processing. This dramatically increases the possibility of correctly interpreting received signals. For example, various coding techniques add extra data bits to the information bits being transmitted. The added bits allow more precise interpretations of the received data, thus trading redundancy for reduced error probability. Also, the waveform that is selected for transmissions can be matched to the characteristics of the channel over which the transmission takes place. (Ahlin & Zander 1997:13)

Specifics of the DECT standard[35]

The DECT system has 120 unique speech channels. This means that 120 simultaneous users can be close enough to interfere each other's transmissions, yet still be allocated individual channels[36]. The channels are organised into 10 frequencies and 12 time-slots. Each frequency/time-slot combination is a unique channel, for a certain user. This means that DECT has a combination of Time Division Multiple Access, TDMA, and Frequency Division Multiple Access, FDMA, two methods of dividing the frequency spectrum between multiple users in a wireless system.

To separate uplink and downlink communication, i.e. terminal-to-base and base-to-terminal, a Time Division Duplex (TDD) scheme is used. This means that in one of the 10 available frequency bands, 12 uplink slots are followed by 12 downlink slots, etc.

Since DECT uses a TDMA scheme to provide multiple channels, each portable station can listen to other channels when it is not transmitting or receiving. Each terminal thus has good information on the radio environment in which it is operating. In DECT this is used to dynamically assign and update the channels for different users. If a terminal experiences degrading quality, for example due to fading

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[35] The DECT specific information provided in this, and following sections is based on the DECT standards documents (ETSI 1992b-j), ETSI Technical Reports (ETSI 1991a; 1992a; 1993a; 1995b), and technical overviews (DECT Forum 1997; Ochsner 1997b; Olanders 1995; 1997; Åkerberg 1996). An overview of the DECT standard is given in appendix 2.

[36] This is not entirely true. Due to adjacent channel interference those users that are located on adjacent frequencies probably interfere with each other to a certain extent since their signals "spill over" into the adjacent frequency. In principle, however, 120 unique channels exist.

or interference, it can relocate to a different channel. This is often referred to as Dynamic Channel Assignment or Dynamic Channel Allocation, DCA. Thanks to the use of TDD, the listening capabilities are not compromised by the need for receiving a transmission. The TDMA solution also allows a single base station to transmit to and receive from several users at once, using the same radio. With an FDMA scheme separate transceivers would have been necessary for each user.

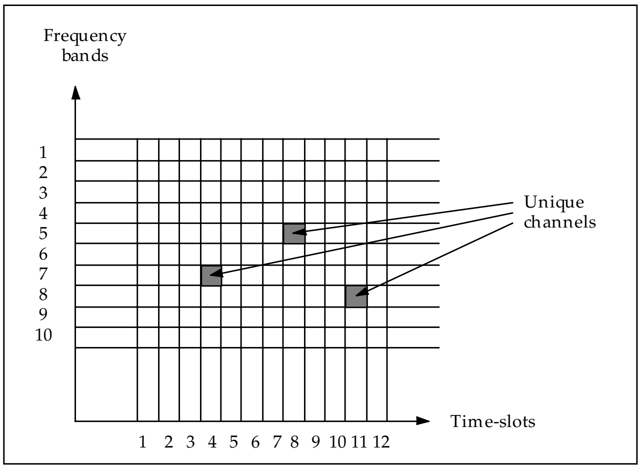

Figure 12: Unique channels in DECT.

To illustrate the capacity of DECT we can make some simple statistical calculations. Let us assume that approximately one tenth of the available channels can be used in a certain location where there are several users. The rest we assume are being used by users in other locations, but close enough to interfere with "our" group. Using queuing theory, conventional telecommunications assumptions[37], and accepting a blocking probability of 1% (i.e. 1 attempt out of 100 will receive a "busy signal"), we will receive a capacity of approximately 6 Erlang. This means that 180 calls per hour, with an average length of 2 minutes, for each base station (note that each base station is assumed to be able to accommodate a maximum of 12 simultaneous calls). As long as each base station covers a sufficiently low amount of users, i.e. small area, this means that DECT is a fairly high capacity system.[38]

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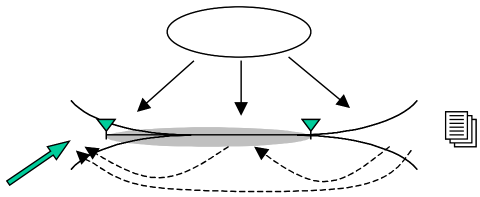
[37] We assume that the arrival of new calls in the system is Poisson distributed and that the duration of the calls is exponentially distributed, with a mean duration of 2 minutes. This is the classic Erlang blocking system.

[38] In an ETSI Technical Report (1995b:9), the capacity of DECT is stated as 10 000 Erlang per sq. km per floor. The number of actual calls that this is equivalent to depends on what assumptions we make regarding their duration and arrival intensity, i.e. what stochastic processes these parameters follow, as well as what blocking probability we can accept.

Obviously, one important issue is what kind of area coverage a DECT base station actually has. This is determined mainly by three parameters: the radio frequency, the transmitter power and the receiver sensitivity. The received signal increases with increased transmitter power, and decreases with increasing frequencies (due to the properties of radio wave propagation). The receiver sensitivity is relevant since it determines what signal to interference ratio is needed to interpret the desired signal from surrounding interference.

DECT operates between the frequencies of 1880 and 1900 MHz, and has a low output power, in the order of tens of milliwatts. This can be compared with GSM, which uses the 900 MHz frequency band, and has an output power in the order of watts. This means that DECT systems have cells (i.e. the area covered by one base station) with a radius in the order of tens or hundreds of meters, while GSM has cells with radii in the order of a hundred meters to tens of kilometres. This is reasonable since cordless systems normally are not intended for wide area coverage, but rather service indoor areas with a high concentration of users.

5. The formal standardisation process



Determining the starting point of a standardisation effort is not entirely easy. More well-defined, however are the start and end points of the formal standardisation process, running from the initial proposal to the final approval of a standard. In this section, a chronology of the DECT standardisation is presented, and the participating companies are introduced.

The presentation below, as well as many of the following discussions, is full of acronyms used within the wireless industry. In many cases, I have found it more practical to use the acronym than the full name of an organisation, etc. However, I have tried to spell out the full name the first time an acronym is used, and there is also a list of acronyms in appendix 3.

5.1 Chronology

Apart from company specific research and development that preceded it, the formal DECT development can be said to have started in 1985 when the Conférence Européenne des Administrations des Postes et des Télécommunications, CEPT, initiated a study into the second generation of cordless telephony. In fact, a similar study had also been started by the European Selective Paging Association, ESPA, and two years prior to this. The work within ESPA was later continued by the European Conference of Telecommunications and Professional Electronic Industries, ECTEL, and the work within CEPT was in time transferred to the European Telecommunications Standards Institute, ETSI.

ESPA and ECTEL are both organisations for manufacturers of telecommunications systems and equipment. CEPT, on the other hand, is an organisation in which only the national PTTs, i.e. operators, were members at the time of the DECT development. In those days, CEPT was the organisation that produced European telecommunications standards. In 1988, this role was taken over by ETSI, a privately operated forum (i.e. not government led) open both to operators and manufacturers, where non-European companies are welcome as well.

The ESPA and ECTEL studies

ESPA, as noted above, was an association for manufacturers of paging equipment that was also active in standards related activities. In the mid 1980s, paging was typically a business application, with corporations using either wide area or on-site paging systems to make their employees "accessible" when out of the office.

The ESPA study was initiated in 1985 with the intent to find business applications for cordless telephony. This was mainly perceived to involve wireless PABX solutions, where the companies' internal telephone networks would be extended to give cordless capability within an office complex or factory. One of the leading participants in the ESPA discussions was the Ericsson paging division. (Dag Åkerberg, interview 961218)

Although Ericsson was an important participant in the ESPA study, the organisation to begin with would not support any single development effort. Instead, several different alternatives were studied and evaluated. Among the systems that were considered, the CT2 alternative, proposed by a number of UK firms, and the CT3 system, developed by Ericsson, were the most prominent ones. The merits of a contemporary development, taking place at Bellcore, in the United States, were also considered. (ESPA 1985b)

Concurrently with the ESPA initiative, CEPT also began studying possible second generation cordless systems. As part of this effort, the Swedish PTT, Televerket, proposed the CT3 system developed by Ericsson as a candidate.

In 1986 a report detailing the ESPA study was published. In it, a rudimentary system design was outlined. To large extent, it was similar to the CT3 proposal submitted to CEPT. In effect it meant that for business applications, which were the focus of ESPA, the association supported the TDMA/TDD solution proposed by Televerket and developed by Ericsson. (Dag Åkerberg, interview 961218)

As mentioned, the work done by ESPA was continued by ECTEL. ECTEL created three work-groups that studied different aspects of the future cordless standard. These groups would later become part of the CEPT effort regarding the DECT standardisation.

The work within CEPT and ETSI

CEPT's interest in second generation cordless systems was triggered by the proposal put forward by UK interests (fronted by the UK PTT, British Telecom) to adopt the CT2 system being developed in the United Kingdom as a European standard. The Swedish counterproposal that followed showed that an evaluation of what type of system should be standardised was necessary. (Tuttlebee 1990:29)

Initially, the CEPT discussions were heavily influenced by the work done on CT2. This is obvious from early definitions of service requirements posed on the system being developed. Both residential and public services are defined, whereas business services (such as wireless PABXs) are mentioned only briefly and then only with restrictions regarding system capacity. (CEPT 1985)

Although British interests forcefully advocated the CT2 solution, no majority was reached in CEPT. In 1987 the European Commission installed a Standstill Directive to slow down the CT2 development, and allow the different options for a second generation standard to be evaluated. (Tuttlebee 1990:29)

In January of 1988, CEPT decided that the next generation cordless telephony system, named DECT, was to be based on the Multicarrier TDMA/TDD solution of CT3. Several of the system characteristics were changed however. The frequency was altered from the 900 MHz range to slightly below 2 GHz, and the number of time-slots per carrier, as well as the number of carriers, was also changed. Once CEPT had decided what route to take, the Standstill Directive was lifted. As a compromise, it was decided that interim national standards would be allowed while DECT was being developed, thus paving the way for limited adoption of both CT2 and CT3. (Tuttlebee 1990:31)

The work within CEPT resulted in a Reference Document that was presented in 1989. In it, the main system requirements for DECT were identified, as well as several preferred technical solutions for the system (CEPT 1989). At the same time, the work was transferred to the newly started European Telecommunications Standards Institute, ETSI. The new organisation was a private enterprise with members from both the operator and manufacturer communities, as well as the national regulatory authorities. ETSI was chartered to administrate all European standardisation activities relating to telecommunications. (Ochsner 1997:110p)

The PT10 project team

The DECT Reference Document was formalised into a memorandum of understanding (MoU) that was signed by the members of CEPT in 1989. It outlined the fundamental delimitations for the standard under development. With this as a guideline, CEPT/ETSI appointed a special project team, PT10, to formulate the details of the system. The team consisted of representatives from a number of telecommunications equipment manufacturers. Originally, six firms participated: Ascom (Switzerland), Ericsson (Sweden), Olivetti (Italy), Philips (the Netherlands), Siemens (Germany) and TRT (France). They were later joined by a representative from Motorola (United States). (Dag Åkerberg, interview 961126)

The PT10 project team conducted its work over a period of two years, from 1989 to 1991. The participating engineers were all dedicated full time to the standardisation effort, and the group was located in Nice, France. The work was supervised by ETSI, which meant that frequent meetings were held where the results of the team were presented and debated. In 1991 a comprehensive design of the standard had been reached and was submitted to ETSI for formal acceptance.

According to interviews with one of the participants of PT10, Dag Åkerberg from Ericsson (interview 961218), the work carried out by the project team was quite unusual since seven different companies dedicated one representative each for a period of two years. Since most of the important manufacturers were a part of the development, the work was very free from conflicts. Everybody was set on producing a good standard that fulfilled the requirements of the MoU, and any decisions regarding the standard were taken by the different ETSI groups that supervised the work. A key notion was to create a flexible standard in terms of use and in terms of proprietary extensions. Therefore several escape routes (allowing proprietary solutions in various areas) and reserves (allowing future standardisation of new applications and services) were incorporated in the DECT standard.

Formal procedures

The ETSI approval procedure was initiated by a public enquiry from September to December of 1991. The voting procedures were carried out from February to May the following year, and the DECT Common Interface standard ETS 300 175 was published in October of 1992 (ETSI 1992b-j). The standard was complemented by an interim standard (ETSI 1992k) that defines basic test specifications for the fixed and portable parts, i.e. to verify that products actually comply with the standard. The basic test specifications became a full standard in late 1993. Since then, many new editions, amendments and complementing profile standards within the DECT system have been developed and adopted by ETSI (an overview can be found in ETSI 1995c).

At the same time as DECT was passing through the formal procedures of ETSI, the regulatory authorities in Europe were discussing the allocation of frequency spectrum for the system. Through a European Community, EC, directive in late 1991, the necessary frequency spectrum (1880-1900 MHz) was made available in all EC and EFTA countries (ETSI 1995c:11). The first DECT products, from Siemens and Olivetti respectively, gained type approval the following year (Trivett 1997:158).

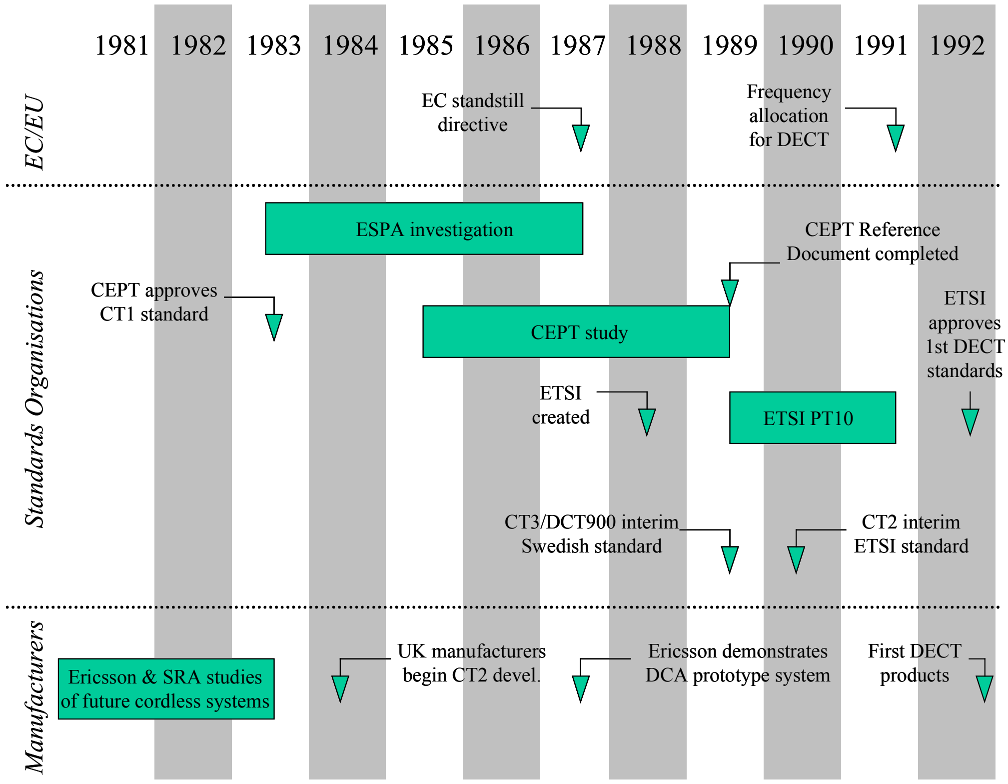


Figure 13: The main events of the DECT standardisation.

5.2 Participants

The actors that have participated in the development of DECT can be described on several different levels. At the lowest level, there was of course a set of individuals who performed various development tasks, participated in standardisation meetings, etc. This discussion, however, focuses the firms and authorities that these individuals belonged to. In some cases, individual firms or authorities are used as examples, but in general they are grouped in to different categories.

Spectrum authorities and operators

Telecommunications is a resource that most countries have traditionally considered to be of such importance that it should be managed by government agencies, or state-owned firms, with a monopoly. Often referred to as PTTs, these agencies provided postal-, telegraphy- and telephony services. In Sweden the postal services were handled by Postverket, while telegraphy and later telephony was provided by a separate agency, Telegrafverket (in time known as Televerket, and today Telia AB).

Practically from the birth of telephony as we know it today (i.e. transmission of sound by electricity), at the end of the nineteenth century (Flichy 1995:82), and for more than a hundred years the national PTTs enjoyed more or less untroubled monopoly positions on their respective markets (Karlsson 1995). In many ways was this positive, because the PTTs from different countries could co-operate in development efforts without fearing to share vital technology. The national operators therefore became the dominant force in the industry, dictating the terms under which supplier firms developed new systems and technologies. The operators themselves were in general technologically competent buyers of telecommunications systems.[39]

At the same time as the benefits of monopoly were apparent in the form of a co-operative spirit between national operators, there were also drawbacks. The development efforts, often in the form of establishing joint standards in international standards organisations, became tedious and bureaucratic. Since none of the involved parties had any serious competitors, there was no great need for haste, and important discussions could go on for years to ascertain every participant's acceptance of the final solution. (Karlsson 1995)

In the 1970s and 1980s, a wave of deregulation swept through the telecommunications industry. We are still in the midst of this liberalisation, and cannot yet see the full scope of it. What caused this deregulation is not of interest here. Probably it was a combination of technical and economic factors[40]. The interesting thing for the present study is the way in which deregulation has changed the setting in which wireless communications standards are developed. (Davies 1994)

In 1987 the Commission of the European Community presented guidelines for the development of the telecommunications industry in its "Green paper". Although Sweden at the time was not a member of the European Community (EC), the guidelines had a great impact, and the Swedish parliament followed them closely when they in June of 1988 decided upon a deregulation of the Swedish telecommunications market. Their decision made Sweden one of the least regulated countries in the world when it came to telecommunications. (Andersson, Ewald & Holmgren 1993:576)

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[39] Describing the national PTTs as monopolies is not entirely correct. Firstly, many PTTs initially had competition in local operators. In Stockholm for example there were two independent operators active until 1918, when the government decided to buy the private one (Helgesson 1999:229pp). Secondly, not all countries have had a national PTT.

[40] One important feature of the regulated telecommunications markets was that they allowed operators to subsidise local and regional calls by charging a premium price for e.g. international calls. The pricing structure did not follow production costs, and as technological developments made it possible to exploit pricing discrepancies, the situation became intolerable. This has led to massive changes in tariff structures. (Davies 1996:1155)

In Sweden, one important consequence of deregulation was the creation of a new regulatory authority for telecommunications, Post- och Telestyrelsen (PTS), in 1992 (Andersson, Ewald & Holmgren 1993:576). Until then the regulatory tasks had been carried out by Televerket, but in light of potential conflicts of interest it was deemed necessary to separate the operator from the regulator. To further accentuate the spirit of competition that was developing, Televerket in 1993 was transformed from a governmental agency to a state-owned corporation, Telia AB (Telia 1995). Similar developments took place throughout Europe (Davies 1994).

Deregulation allowed new operators to establish themselves to a much larger degree than had been possible before. The new operators obviously were smaller than the former PTTs, and often lacked in the technological competence of the national operators. As a consequence, their over-head costs were low, which in combination with aggressive pricing, created substantial competition for the PTTs. In Sweden, for example, one effect of this is that Telia has been forced rationalise its operations, thus to some extent weakening their technical expertise.

Similar developments are apparent throughout the world, which has led to a shift of power in the development of technical standards. No longer do operators take a naturally dominant role in the standards-setting arena. Rather, manufacturers play an increasingly important part.

Today, technological development in telecommunications is dictated mainly by the large systems suppliers. This is reflected in how technical standards-setting activities are organised. A decade ago, telecommunications standards for the European market were developed by CEPT[41], an organisation in which only the national PTTs were allowed membership, not private industry in any shape or form. Today the standardisation responsibility of CEPT has been taken over by ETSI[42], an organisation in which all players in the telecommunications industry are welcome to participate in, and influence standardisation efforts. (ETSI 1995a)

Standardisation bodies: ESPA, CEPT and ETSI

There are a number of standardisation bodies in Europe. Their names have varied over the years, as well as their relative importance in different endeavours. Telecommunications standards have traditionally been developed at various levels: national, regional, and global. The global standards-setting is conducted within the International Telecommunications Union, ITU. The ITU was originally a forum for the national PTTs of member countries. With deregulation, many countries are

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[41] Conférence Européenne des Administrations des Postes et des Télécommunications.

[42] European Telecommunications Standards Institute.

now represented by their regulatory bodies. It is within the ITU that e.g. global radio frequency allocations are coordinated. In practice, however, most decisions are made at the regional, or national level.

In Europe, there are a several standards organisations that are related to the telecommunications sector. Regulation of telecommunications is ultimately a question for the European Union, EU, and consequently, its member states. Today, pan-European regulations do come into effect. They are often based on standardisation work carried out within the European Telecommunications Standards Institute, ETSI, which today is the dominant standards organisation for telecommunications related technologies in Europe. ETSI consists of more than 700 member organisations that finance the organisation through membership fees. There are five categories of members: administrations, network operators, manufacturers, user groups, and research bodies. (Ochsner 1997a)

Although ETSI is the organisation that formally adopted the first version of the DECT standard in 1992, the work did not begin there. One simple reason for this is that ETSI was not created until 1988. In the case of DECT there are two additional standards organisations that have played important roles in the development.

The first one is the European Selective Paging Association, ESPA, where a large investigation into the future business applications of cordless systems was initiated in 1983 (Trivett 1997:157pp). The reason for such a study to be introduced within ESPA, who were dedicated to paging, was that the business side of cordless telephony as of yet was unexploited. Paging products in those days were mainly oriented towards business users, especially when it came to on-site paging. It was therefore natural to view cordless telephony in businesses as a complementary product, allowing somebody to either reply quickly to paging messages or receive a telephone call instead. Since cordless telephony systems often are highly local and are owned and operated by the firm using the system, thus not requiring a public operator, there was less interest among operators than among manufacturers to discuss these types of systems. ESPA was therefore a natural place for manufacturers to meet (Dag Åkerberg, interview 961218).

At the time it was actually slightly odd that this type of development was initiated in ESPA, and not in the major standardisation body for telecommunications in Europe at the time, the Conférence Européenne des Administrations des Postes et des Télécommunications, CEPT. One reason for this was doubtlessly that the effort in many respects was manufacturer driven.

In time, however, CEPT began to play an increasingly important role in the DECT development CEPT had been the organisation within which the CT1 standard had been developed, and in that respect was a natural standards organisation to formally adopt a cordless standard, even though manufacturers had sought other meeting grounds for discussions regarding cordless telephony. Nevertheless, early research focusing on the development of a pan-European standard for cordless telephones was initiated within CEPT as early as 1985 (see above).

In 1988, ETSI was formed, and took over the standardisation efforts of several other organisations, among them CEPT. The reason for creating ETSI was that the European Community wanted a more efficient standards organisation for telecommunications. CEPT still remains as an independent organisation and plays an important role in advisory capacities, and in making European regulations from ETSI standards. (Ochsner 1997a)

Manufacturers

When the development of the DECT standard is considered, the most important manufacturer is doubtlessly Ericsson. They played a dominant role in the standard-setting process, even if the work was conducted in co-operation with a number of other firms. Of relevance for the development, apart from the companies participating in the development work, are also the companies involved in the development of the competing CT2 standard.

Ericsson

Within Ericsson, the idea of designing a cordless telephone system actually originated from a number customers, i.e. PTTs, in the late 1970s. Ericsson received several queries regarding the possibility of developing a simple cordless telephone for residential use. All queries were rejected, but all the same they led to the initiation of a number of investigations into the feasibility of cordless telephony systems. The feasibility studies were naturally located to the paging division of Ericsson since cordless telephony was regarded as a low-cost, consumer-oriented endeavour, attributes typical for paging products. It should also be noted that the paging business at the time was generating good stable revenue to the firm, thus allowing it the freedom of doing studies on cordless, and other systems. (Dag Åkerberg, interviews 961126; 961218)

The very first discussions within Ericsson regarding a cordless telephony system focused on a simple cordless extension of fixed telephones (Ericsson 1981; SRA 1981). Two areas of use could be identified: residential and small office. All functional and technical issues remained unsolved, but there were some basic ideas on how to proceed. The cordless system should function in a way similar to wired phones, it should have a range of up to 100 meters, some form of automatic channel selection should be used, and the cost of a phone should be no higher than USD 200 (which would mean a fairly simple design by current standards). All in all, the discussions pointed to a simple, consumer-oriented device that would mainly be used in homes and small offices. In other words, not by Ericsson's traditional customers. With this in mind, it is not hard to understand why Ericsson showed little interest in developing such a system.

Nevertheless, Ericsson in 1982 initiated a study of what a concept for future office solutions for cordless telephony could look like (SRA 1982a). The study was performed by the research and development department of SRA (later to become Ericsson Radio Systems). The mission was to make a feasibility study of a digital radio system for cordless telephony. The system was to be based on Time Division Multiple Access (TDMA) and Time Division Duplex (TDD), and was to use some form of adaptive channel selection (SRA 1982b). In other words, several of the underlying technical ideas in what would later become part of the DECT standard were specified as early as 1982.

In 1982/83, SRA bought a Dutch paging manufacturer called NIRA, and consequently moved the paging division to the Netherlands. The main reason for the move was that the engineering resources in Stockholm were needed for other purposes. Ericsson was making a major effort to become one of the dominant suppliers of cellular systems in the United States (Meurling & Jeans 1994:63pp) and the former paging designers now became mobile telephony designers. The development of a digital cordless telephony system was in effect discontinued.

In 1984, discussions started in ESPA regarding a new cordless telephony standard for Europe. The issue was triggered by UK manufacturers, who perceived a need for more advanced cordless telephones. One reason for this was that the UK never had embraced the CT1 standard that was launched in 1983. The cordless alternatives available were therefore restricted to older systems, with lower capacity. The new solution was launched as a second generation cordless telephone, CT2. From Ericsson there was a swift reply in which they presented a competing solution. The British CT2 proposal was based on FDMA, essentially similar to the existing CT1 standard.

The counterproposal made by Ericsson was a TDMA based system, with many of the basic characteristics of the future DECT system. Both the UK and the Ericsson solutions were presented at an ESPA meeting in August of 1985 (ESPA 1985a). The competition between the two standards was eventually to end in a form of compromise. ETSI in time accepted both CT2 and the Ericsson system DCT900, informally known as CT3, as interim standards (Ochsner 1997a). The DECT development was to grow from the Ericsson solution, with a number of alterations in order not to give Ericsson too much of a head start in the product development following the standardisation work (Dag Åkerberg, interview 961218).

The bulk of the DECT standardisation work was carried out in the ETSI project PT10. The Ericsson representative to PT10 was Dag Åkerberg, who had participated in the studies of future cordless telephony systems from the start. He was head of the development department within the paging division. When the paging operations moved to the Netherlands, Åkerberg remained in Sweden in a central development function. Within Ericsson, Åkerberg is generally regarded as the "father of DECT". (Meurling & Jeans 1999:141pp)

From an Ericsson perspective, the DECT system is a further development of the CT3 system. All the fundamentals of DECT can be found in CT3. It is a TDMA/TDD system that uses dynamic channel assignment, although the number of time-slots is different. It has a similar network "concept" where the cordless system is a radio interface that can be connected to for example a PABX (an office telephone exchange). The speech coding is also in principle the same (Åkerberg 1990:253). In short, the DECT development had a flying start thanks to the work done within Ericsson. (Dag Åkerberg, interview 961218)

The other PT10 participants

As has been noted earlier, the development of the DECT standard had its origins within Ericsson, specifically the development department of the paging division. During the early years of the standardisation work, several more firms joined the effort in the ETSI PT10 project. Seven individuals from seven different firms were basically allowed to conduct a joint development and standardisation work outside their respective firms.

What is especially interesting is that companies with rather varying focuses participated in the development. Ericsson, as has been noted, primarily focused public operators and business users. They were, and still are, a very strong systems supplier. Philips, on the other hand, has a much stronger tradition of producing, and selling consumer products. Olivetti, in turn, is a computer manufacturer, rather than a telecommunications manufacturer. Siemens is perhaps a combination of all three, having both a strong systems supplying tradition, and a strong consumer product focus, as well as being a computer manufacturer.

The CT2 proponents

In the early 1980s, CEPT developed its first cordless telephony standard, CT1[43]. The standard was adopted in many European countries, but not everywhere. In the United Kingdom and France, for example, the CT1 standard was considered to be too complex, resulting in expensive equipment. As a consequence, simpler, national standards where introduced instead. The national standards had lower capacity than the CEPT CT1 standard, and when public applications for cordless systems began to be studied, capacity was deemed to be too poor. This triggered the UK development of the CT2 system. (Ochsner 1997a:116pp)

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[43] CT1 is presented briefly in the next chapter.

In 1984, a group of British manufacturers started developing a CT2 specification. Among the participating companies where: British Telecom, Ferranti (Libera), GPT, Orbitel, Shaye, and STC[44]. Their work was supported by the UK Department of Trade and Industry (DTI). (Trivett 1997:152)

To a large extent, the development was driven by the perceived demand for public cordless telephony applications. The foremost such application is “telepoint”, where a cordless telephone can be used in the same way as a pay phone when the user is within the range of a public base station[45]. The benefit of cordless telephony, compared to mobile telephony, in providing public services is that products are substantially cheaper (Candy et al 1997).

The early CT2 specifications, resulting in a national standard for the United Kingdom, allowed several proprietary configurations. These were later, during the late 1980s, developed to become the Common Air Interface (CAI) standard. This standard was in time adopted by ETSI as an interim standard (ETSI 1992l). Four separate telepoint service offerings were released in the UK, three in 1989 and one in 1991. Several other European countries also had public cordless services, for example France, Belgium, and the Netherlands. (Candy et al 1997)

Operators versus manufacturers

As we study the participants in the DECT standardisation, and also the CT2 development, a certain tension between operators and manufacturers becomes apparent. The tension has to do with two questions. First of all, who should initiate and drive the development of telecommunications standards? Secondly, what types of applications should telecommunications standards support?

Traditionally, operators have been the prime supporters of standardisation efforts in telecommunications. The reason for this is simply that they have had most to gain from it. By deploying standardised systems they are able to mix equipment from different suppliers, thus giving them leverage in purchasing actions. Equipment suppliers, on the other hand, do not have an entirely positive attitude to stan-

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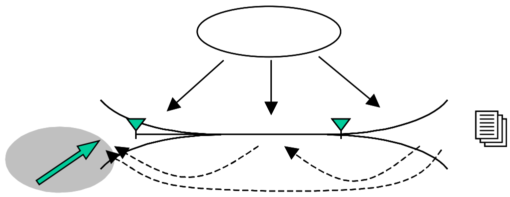
[44] Several of the participants have since then been bought by other telecommunications manufacturers. Kenwood bought the Libera patent portfolio in 1993. GPT is a joint venture between GEC and Siemens. Orbitel was aquired by Ericsson in 1996. Shaye was aquired by AT&T (later Lucent Technologies) in 1993. STC was aquired by Nortel in 1991. (Trivett 1997:153)

[45] The service, in other words, is like a mobile phone from which it is only possible to place calls, not receive them, and only within limited coverage areas. The one-way nature of the CT2 systems stemmed from the original UK licences, not from the system design. Two-way calling was possible in later deployments e.g. in France. (Candy et al 1997:39)

dardisation. On the one hand, it gives them the opportunity to reach a larger market. On the other hand, they lose the potential temporary monopoly that proprietary solutions might offer.

A broad division of applications for telecommunications systems, based on different customer segments, is: residential, business, and public. Operator firms, obviously, are interested in public applications (services), while an equipment manufacturer might well want to service all three segments. Again, we see a difference of interest.

6. The pre-history of DECT



If we consider the entire range of cordless telephony products that have been, and are, available throughout the world, it becomes apparent that there are a number of predecessors to the DECT standard. There were also related developments that took place at approximately the same time as the development of the DECT standard, but either in other regions, or of other types of systems. Both earlier and contemporary systems are presented here. Apart from the system and product solutions that preceded DECT, there was also a great amount of technical know-how and expertise that went into the development of the standard. This research and development work is also related.

6.1 Aspects of pre-history

Although there have been substantial developments of cordless telephony systems from one generation to the next, there are also certain characteristics that remain unchanged. It is thus possible for us to actually identify a certain standard as a cordless system, as opposed to e.g. a mobile telephony system. In James Utterback's terminology, we could talk of a dominant design that in part has remained through several decades of refinement.

In Andrew Davies (1997) definition of three types of innovation (architectural, systemic, and component), we find a tool to understand what things have changed or remained. For example, the architectural aspects of a cordless system that relate to how it is used, i.e. users move only locally and at low speeds, remain unchanged. Systemic innovations, on the other hand, change aspects of the system such as capacity and functionality from one generation of standards to the next. Component innovations, finally, might take place within the same generation of standards, allowing e.g. greater battery capacity, more sensitive receivers.[46]

[46] Please note the similarities between the picture given here and Bo Karlson's (1994) wave metaphor. Although his work treats the product design process, the idea of one generation of development following upon earlier generations is the same.

In some cases, innovations of an architectural type might also take place between different generations of standards. One example is that later generations of cordless standards have allowed a whole new range of applications such as the wireless PABX and telepoint. This is a substantial evolution from the cordless extension of the wired phone.

The momentum of a design

As we will see presently, for all contemporary cellular and cordless developments, a digital communications system was the preferred solution at the time of the DECT standardisation. In the words of Thomas Hughes (1987), one might say that this category of designs had gained a technological momentum. One reason for this was of course the added features that the digital design entailed, e.g. new signal processing possibilities. These new possibilities had only been explored slightly when the development of the DECT standard took place. However, the technological expectations (Rosenberg 1982) that they brought with them permeated the entire development effort (and all contemporary developments).

Research and the specific innovation process

In this chapter, wireless related developments taking place in the research and development departments of the wireless industry, as well as in academia, will be presented. As Stephen Kline and Nathan Rosenberg (1986) note in their chain-linked model, there is a constant interaction between research and scientific knowledge on the one hand, and the individual innovation process on the other. Research and scientific knowledge are the basis on which the innovation takes place, but they are generally not sufficient in themselves. The innovation process also generates new knowledge and research. In the words of Kline and Rosenberg: "… the demands of innovation often force the creation of science" (ibid p. 287).

From Kline and Rosenberg's work, we can ascertain that the study of an act of innovation requires an understanding of related technological and scientific developments. Furthermore, they treat the process of technological development (here used as a collective term research, knowledge, etc.) as semi-independent of market developments, etc. It meets the requirements of development, production, and marketing, through the specific innovation process.

6.2 Predecessors to DECT

In the 1970s the "pool-side phone" was a concept that was becoming increasingly popular in the United States. The products in question were fairly simple analogue cordless telephones intended for use at home, and perceived to be slightly more luxurious versions of ordinary telephones. The phones used a fixed pair of radio frequencies for communication between handset and base station, i.e. one frequency was used for transmission from handset to base (uplink) and one frequency was used for transmission from base to handset (downlink).

The earliest cordless systems are often referred to as CT0, i.e. Cordless Telephone 0, and operate in frequency bands below 49 MHz (Mori & Magaña 1996:314p). The functionality of the phones is fairly similar to that of an ordinary telephone, and from a wireless communications perspective they can be regarded as simple two-way radios, not unlike the traditional CB-radio used by truck drivers in the United States. Calls have an acceptable quality within short distances from the base station. Unfortunately, they can easily be overheard by anyone with a somewhat enhanced radio receiver.

Early cordless phones were not standardised to a great extent. What was specified was simply what frequency domains they should work in, and what type of power levels they should operate at (Paetsch 1993:201p). Other aspects of their functionality and performance were left to the manufacturers. The products that were developed typically had very simple radio parts, thus allowing cheap products with high reliability. This also meant, however, that functionality was very basic. For example a typical phone offered a handful of different channels, between which the user could switch manually. Therefore no more than a couple of interfering users could have telephones operating in the same frequency range as one's own. If another user happened to choose the same channel as oneself, they could overhear the conversation. Nevertheless, simple cordless phones became very popular in the United States, perhaps due to the fact that they allowed the user to move around the house while talking over the phone.

The first multichannel system: CT1

As the use of cordless phones increased, the lack of frequency spectrum was perceived to be a problem. The co-operative body for European telephone administrations, CEPT[47], therefore decided to develop a new generation of cordless telephones, CT1. The standard was launched in 1983 and offered a significant capacity increase, but at the cost of a more complex and expensive design.

CT1 operates in the 900 MHz frequency band, and uses 40 channel pairs for transmission between handsets and base stations (Ochsner 1996:117). The higher frequencies compared to earlier systems meant a more efficient reuse of the available channels. Since the signal from a transmitter does not propagate as far (at a given power level), the interference caused by each transmitter in the system

[47] Conférence Européenne des Administrations des Postes et des Télécommunications.

decreases. In combination with an increased amount of available channels, this resulted in a system with superior efficiency in terms of the potential number of users per area unit. The positive effect of more channels is accentuated by the so called "trunking gain". Twice as many channels in a system doubles the theoretical throughput of the system at a given moment. At a given blocking probability, however, the system can accommodate more than twice the amount of users. This is due to the fact that the system seldom is fully loaded. Only at brief moments are all channels in use at the same time.

A standard for the UK: CT2

The CT1 standard had limitations, for example not allowing roaming or handover. Furthermore, the capacity of the system was too low, even though the number of channels had more than doubled compared to earlier systems. In 1985 CEPT therefore initiated a research effort to develop a new standard. In accordance with its time, it was to be digital (Paetsch 1993:68p).

Outside CEPT, however, other work had already begun. One of these efforts was a system called CT2. It had its origin in the UK, where work had started in 1984. The main objective of this development was to create a cordless system that supported roaming and handover. This means that the handset must communicate with several base stations, and that the system allows the user to move from the area covered by one base station to the area covered by the next, without the call being interrupted. (CEPT 1985)

The capacity of CT2 was essentially the same as that of CT1. The system also uses the 900 MHz band, and has 40 channel pairs for communication between base and terminal. One difference from CT1, however, is that the channels are paired on the same frequency, using separate time-slots. In CT1 the uplink[48] and downlink[49] channels are on different frequencies. The new technique used in CT2 is called Time Division Duplex (TDD). CT2 was fully developed in 1989. In 1990 (Steedman 1996:353), it became adopted by the European Telecommunications Standards Institute, ETSI, as an interim standard. (Trivett 1996:152)

The Ericsson standard: CT3

When UK manufacturers in the mid 1980s proposed CT2 as a new pan-European standard for cordless telephony, there was a reaction from the Swedish PTT, Televerket. They felt that the CT2 system provided too little improvement of the

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[48] From terminal to base.

[49] From base to terminal.

existing CT1 system. As a counterproposal (Trivett 1997:158), they put forward an improved version of an Ericsson system that became known as CT3 (the original Ericsson acronym was DCT900). CT3 is a TDMA/TDD system, which originates from Ericsson studies of low-cost office communications systems carried out in the early 1980s (SRA 1982a; 1982b). In CT3, there are 16 time-slots on each frequency, thus allowing 8 uplink, and 8 downlink channels for each frequency (Åkerberg 1989).

A test system was designed by Ericsson in 1987 in order to show sceptics that a TDMA solution with Dynamic Channel Assignment was feasible, and could in fact demonstrate such benefits as seamless handover[50]. Following a CEPT decision to allow interim solutions while DECT was being developed, the Ericsson system was accepted as an interim national standard in Sweden in 1989. It has since then been adopted by many other countries worldwide. Ericsson released its first commercial products, conforming to the CT3 interim standard, in 1991. (Candy et al 1996:46; Trivett 1996:158)

The CT3 system would turn out to be the basis for the new DECT standard that from 1985 was being discussed in CEPT. Especially relevant was the demonstration of the Ericsson prototype system in 1987, and the endorsement given by the European Selective Paging Association, ESPA, to the development of a TDMA based system. ESPA, a manufacturers organisation, supported the Swedish PTT, Televerket, in their proposal of CT3 as the next generation cordless telephony standard in Europe. (Dag Åkerberg, interview 961218)

A European solution: DECT

DECT is the latest European development in cordless telephony. It is the successor of the CT2 and CT3 developments. The base standard, ETS 300 175 (ETSI 1992b-j), is the outcome of the CEPT and ETSI standardisation carried out from 1985 to 1992. Since then several Profile Standards have been added, and the DECT standard has continued to evolve within ETSI. So far, 21 technical reports describing different applications, and about 100 standards documents, have been published. Frequency spectrum has been allocated in more than 110 countries, and more than 45 million terminals are in use throughout the world. (Dag Åkerberg, interview 000512)

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[50] I.e. handover handled in such a way that it is not noticeable for the user.

6.3 Contemporary developments

Outside Europe, several cordless developments took place around the same time as the development of the DECT standard. Work was being done both in North America and Asia. Although there was a strong sense of regional separation at the time, there was nevertheless a certain awareness of what was happening in other parts of the world. This is demonstrated by the studies that were conducted by ESPA and CEPT representatives of contemporary developments (see e.g. CEPT 1985; ESPA 1985b).

Apart from cordless systems, another contemporary development was that of digital cellular systems. This development was conducted mainly in Europe and North America (the Japanese Personal Digital Cellular, PDC, was developed a few years into the 1990s). In Europe, the development of the Global System for Mobile communications, GSM, was probably the largest standards-setting effort at the time.

Non-European cordless systems

There are two important developments in cordless telephony that happened outside Europe at roughly the same time as DECT was being developed. The first of these was the Personal Access Communications System, PACS, that was developed in the United States. It was intended for the unlicensed Personal Communications Systems frequencies around 2 GHz, that the Federal Communications Commission, FCC, formally allocated in 1993 (Donald Cox, interview 980925). The second is the Personal Handyphone System, PHS, developed in Japan between 1990 and 1995.

The PACS system comes in two versions. One of them, PACS-UA, is based on PHS and the other, PACS-UB, is based on a Bellcore research project called WACS. Like DECT, PACS-UB it is a TDMA/TDD system, but with a number of differences in the design of the air interface. It uses a different modulation technique for the carrier frequency and also has different slot length, signalling characteristics and bit-rates over the radio channel. In terms of system capacity, however, the systems are comparable. The important difference is that the design of PACS has been heavily influenced by the need to conform to FCC rules for unlicensed personal communications systems. (Donald Cox, interview 980925; Noerpel 1997)

PHS also uses a TDMA/TDD scheme for the air interface. Again, many of the specifics of the modulation, etc, differ from DECT. The capacity of the radio interface is still within the same range, nonetheless. The major difference between DECT and PHS is that PHS has both a common air interface and a networking part. It is thus not a pure access system like DECT, but rather more similar to cellular standards such as GSM. This is accentuated by the coverage area supported by PHS being larger than DECT's. (Takagawa 1997)

Both the PACS and the PHS systems were developed slightly later than DECT. They were still in serious development stages when the first DECT products were released. Lately, however, especially PHS has become a serious contender to DECT in several parts of the world. The relative merits of the systems are discussed forcefully, and supporters on both sides can "show" that their system is superior, depending on which system parameters they choose to measure, and under what conditions.

Cellular systems

During the 1980s, the first digital cellular systems were developed. In Europe, the most well-known system is obviously GSM. Some of the basic differences between cordless and mobile telephony systems have been touched upon earlier. As noted, the largest difference between DECT and GSM, from a systems architecture point of view, lies in the fact that the DECT standard does not define a specific backbone network with related services, but is rather a generic wireless access system for several types of backbone infrastructures.

There are also similarities between DECT and GSM. For example, the radio interfaces in both standards use a combined Frequency and Time Division Multiple Access to share the frequency resources. While DECT uses Time Division Duplex to allow up- and downlink communication over the same frequency, GSM instead has a Frequency Division Duplex, with up- and downlink channels on separate frequency bands.

Apart from such functional differences between the actual standards, there are also a number of differences in how the standardisation work was carried out for the two standards. In the case of GSM, the standardisation process was very much controlled by the large national operators, the PTTs. The work was started and to a great extent carried out in their standards association, CEPT. The development of the DECT standard, on the other hand, began as a supplier driven standardisation effort. It was initiated by a number of telecommunications equipment manufacturers, and the operators joined first at a later stage. The resources put into the GSM standardisation were also substantially greater, and the resulting standard is much broader in scope, and more complex than DECT.

In the United States and Japan, digital cellular standards were also developed at approximately the same time. In the US, the first digital system was called Digital Advanced Mobile Phone System, D-AMPS. It is a TDMA system that operates in the 800 MHz range, and was designed to allow a practical way of migrating from analogue systems to digital without having to replace too much infra-structure. (Paetsch 1993:174)

The Japanese system is called Personal Digital Communications, PDC, and is also a TDMA based system but in the 1,5 GHz range. It was developed a couple of years after GSM and D-AMPS.

6.4 Research trends

It is obviously difficult to portray trends in the development of wireless related technologies at the time of the development of the DECT standard. Nevertheless, I will try to offer some categories and examples in this section. The reason being of course that this both constitutes a pre-history[51] to the development, and defines the technological expectations (Rosenberg 1982) present at the time.

Development with indirect implications for the design of the standard

As has been discussed in the previous literature review, technology has an inherently systemic nature (Hughes 1987; Rosenberg 1982). As a consequence, several related developments must be considered if one wants to understand the technological setting in which the development of the DECT standard took place. However, certain developments are strongly related to the design of the standard itself, whereas others are related to complementary technologies that e.g. determine what products can be designed, and the relative performance of different product realisations. In the present discussion, I have tried to focus the former areas.

In order to single out such technological developments that are related to the setting of the DECT standard, let us begin by discussing what is included in a wireless communications standard. Heinz Ochsner, a long time participant in the ETSI standardisation of DECT, gives us the following definition:

> ”Standards generally define interfaces between modules of a system, e.g. the radio interface specification between the cordless handset and its associated base station. Standards must, however, avoid describing (or even implying) possible technical realisations of modules. A standard usually will also contain rules on how to verify the compliance of a particular product to a mandatory standard (type approval).”
>
> (Ochsner 1997:112)

[51] Compare with the conceptual framework presented earlier.

What this indicates is that radio interface, and radio system related research is intimately related to the design of the DECT standard, whereas research related to the technical realisation of the standard has had a more indirect influence.

It is probably impossible to give a complete list of all technological developments that indirectly have influenced the development of the DECT standard, but we can nonetheless find some important examples, where expectations of future solutions have been relevant for the design of the standard.

Receiver and transmitter architectures

The design of radio transceivers is dependent on what the radio interface that they serve looks like. The frequency separation of different channels, the multiple access scheme used, the duration of time-slots (if a TDD and/or TDMA system is used), etc, all affect the requirements put on the design of the transceivers.

For example, channel separation, i.e. the frequency width of the channel, impacts what radio frequency filter designs are necessary. The same type of filters can not be used for a narrowband channel (tens of kHz spacing), as for a wider band channel (more than one MHz spacing). The filter design, in turn, will affect the cost of the transceivers. (Mori & Magaña 1997:304pp)

Circuit design

The radio frequency circuits, as well as the baseband circuits, are more or less individual designs for each system standard. For digital radio systems, integrated circuits are an absolute necessity in providing the needed signal processing. The development of such circuitry is obviously decisive for the type of implementations that are possible, and how costly they are. The use of digital signal processing means that simpler radio frequency designs are possible. (Mori & Magaña 1997:307)

Battery technology

While many aspects of the design of a handset are truly up to the product designer, e.g. colour, physical design, the standby and talk times that are possible are very much a combination of existing battery technology, and the design of the radio transmitter. The radio transmitter and the audio output are the greatest sources of power consumption in a portable phone (Cox 1978:36). As a consequence, the design of the radio interface will affect the power requirements for the handset, and ultimately determine battery requirements.

Digital radio systems

Let us now leave the technical realisations of a wireless standard, noting that expectations, or preconceptions, of what solutions are feasible in these areas will have an impact on the design of the radio interface. Instead, we now turn to the radio interface, and radio system aspects.

Two independent pre-studies of cordless telephony systems (Cox 1978; SRA 1982b) show that a digital radio system was more or less implied before the ESPA and CEPT studies were even initiated. Also, if we look at contemporary wireless developments, we can easily see that they were digital, e.g. GSM, D-AMPS. That the DECT standard was to be developed as a digital radio system was therefore more or less self-evident, as far as I can judge. As noted previously, this design choice had simply gained such momentum (Hughes 1987) that it was not questioned.

Multiple access techniques

What created much greater controversy, however, was the choice of multiple access schemes. The choice of multiple access method consists of two parts, first of all the sharing of frequency resources between multiple users, and secondly, the sharing of frequency resources between up- and downlinks for the same user.

Duplex

The latter of the above issues was not as debated as the former. The two main choices are Frequency Division Duplex, FDD, and Time Division Duplex, TDD. In FDD, the uplink and downlink channels are on separate frequencies, in general belonging to separate frequency bands. In TDD, they are instead located in the same frequency, but in different time-slots. Several benefits of using TDD in a cordless application were demonstrated. For example:

- The transceiver does not require a so called duplex filter that separates up- and downlink transmissions (SRA 1982b:2). This is one of the most expensive parts of a radio transceiver.

- The uplink and downlink transmission paths will be more or less identical (if the user environment does not change very rapidly) since they are on the same frequency. It is thus possible to use antenna base station diversity[52] at the base station to improve transmission in both directions. (Hulbert & Swain 1997:235)

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[52] Diversity means that several independent transmission paths are interpreted in the receiver, thus allowing better reception of the radio signal. The signal fades differently on independent paths. Paths can be independent if they are separated in space, i.e. two antennas at suitable distance from each other (determined by the transmission frequency), in time, i.e. different time-slots far enough apart, or in polarisation, i.e. the vertical or horisontal resolution of the radio wave.

- The radio frequency circuits for the base station and the terminal can be identical. (Hulbert & Swain 1997:235)

Both the CT2, and DECT developments from the outset chose TDD configurations. The reason for this was that it simplified the design of handsets, and that it fit very nicely with system considerations such as diversity and channel allocation. There thus seemed to be a common understanding when the development of the DECT standard began, that TDD was the suitable duplex solution for cordless systems.

Multiple access

The two major contenders in multiple access techniques during the 1980s were Frequency Division Multiple Access, FDMA, and Time Division Multiple Access, TDMA. Since then, Code Division Multiple Access, CDMA, has also become a commonly used technique.

FDMA essentially means that the frequency resources allocated to a system are divided into a number of separate frequencies that constitute the channels of the system. Each channel can then in principle be used without interference from the other channels, thus making the number of frequencies the key determinant of system capacity.

In a TDMA system, in its purest form, a single frequency is used for all transmissions. Individual channels are provided by dividing the transmission into a number of sequential time-slots, during which different users may transmit or receive a signal. In practice, TDMA is often combined with FDMA, thus giving a matrix of frequencies and time-slots (this has been illustrated earlier in the case description).

When the second generation of cordless systems was being considered, combined FDMA and TDMA solutions were being implemented in concurrent mobile telephony developments such as GSM. FDMA solutions, on the other hand, were used in existing cordless systems, CT0 and CT1, as well as in existing, analogue mobile telephony systems, such as NMT.

There are various technical differences between FDMA and TDMA, and they both have their relative strengths and weaknesses. For example (Hulbert & Swain 1990:170pp; 1997:235pp):

- The channel separation, i.e. the width of the carrier, is higher in a TDMA system that has the same number of channels as an FDMA system.

- TDMA requires a transmission overhead in the form of guard time, carrier recovery bits, and synchronisation bits, since each time-slot belongs to a separate transmitter-receiver set. The actual transmission thus has to have a higher bit rate than the traffic it is transmitting.

- In a TDMA system, there is an inherent transmission delay due to the fact that e.g. a telephone call is buffered for the duration of all time-slots in the system, and then transmitted during one time-slot. If the total frame of time-slots is e.g. 10 ms long, there is therefore always a minimum delay of 10 ms.

- TDMA offers more flexible frequency sharing than FDMA, especially in combination with dynamic channel allocation strategies, since the transceivers can listen to other transmissions while not transmitting. It is thus possible to generate information on the radio environment of other channels.

It should be noted that while combined TDMA/FDMA systems were being developed when the development of the DECT standard started, FDMA was the proven alternative. It was employed in existing systems, and was better known than TDMA.

Channel assignment strategies

In a radio environment where several users are in close enough proximity to interfere each other's transmissions, the strategies with which independent channels are assigned becomes an issue. The question of channel assignment is further accentuated if it is assumed that neighbouring cells should be coordinated. This is the case if for example roaming or handover capabilities are envisioned.

In existing cordless systems, in the early 1980s, fairly simple channel assignment strategies were employed. In the very early CT0 solutions, manual choice of one of a handful channels was the technique. In later systems, channel selection was handled automatically by the handset or base station, which scanned the available channels and chose a non-interfered one.

In existing mobile telephony systems, as well as in contemporary developments, a fixed channel assignment scheme is used. Here, the allocation of channels to different base stations is planned in advance in order to optimise coverage and capacity with a limited frequency resource. Changes in the mobile network based on fluctuations in demand, etc, is not possible in the extreme short term, but entirely possible within a number of days, weeks, or months, depending on the measure that is taken.

Fixed channel assignment schemes are generally suitable for the mobile telephony environment. Operators who have sufficient planning resources administer the systems. Cell sizes are sufficiently large for the environment, i.e. topology, to change slowly. New buildings, freeways, etc, do not appear overnight. Base stations take time to install, and require contracts with property owners, etc. Furthermore, from a technical point of view, it should be noted that fixed channel assignments at the time were perceived to provide better performance (i.e. lower bit error rates) in wireless systems that experience high loads (Cox & Reudink 1972a; 1972b)[53].

When a public operator does not run a wireless network, for example if a cordless system in an office facility is considered, the conditions change. First of all, the user cannot be expected to have a planning competence. Secondly, the physical environment is prone to change more rapidly, e.g. because offices are rebuilt or remodelled, as is the traffic concentration, e.g. during the coffee break, or during a meeting. This means that a more adaptive assignment of channels becomes relevant.

The concept for adaptive channel assignment that was being researched before, during, and after the development of the DECT standard is often referred to as Dynamic Channel Assignment, DCA. The idea is that base stations and/or terminals monitor the channels of the system, and pick a suitable channel from an interference point of view. The channel assignment is not necessarily constant for the duration of a call. As the radio environment changes, reassignments are possible.

One key aspect of DCA is the design of the assignment algorithm, and thus the choice of parameters to base the assignment on. System level studies of DCA therefore primarily treat the relative performance, and other merits, of different algorithms, often in comparison with a fixed assignment scheme.

A number of feasibility studies of dynamic channel assignment schemes were conducted in the late 1970s and early 1980s (Cox & Reudink 1972a; 1972b; SRA 1982b). These have since then been complemented by continued studies of assignment algorithms (e.g. Beck & Panzer 1989; Frodigh 1992; Goodman, Grandhi & Vijayan 1993), and overviews of system solutions (e.g. Cox 1987; Katzela & Naghshineh 1996).

This brief presentation shows that choice of channel assignment strategy was an issue under scrutiny at the time when the DECT standard was developed. The concept of Dynamic Channel Assignment[54] was considered of special interest for cordless telephony systems.

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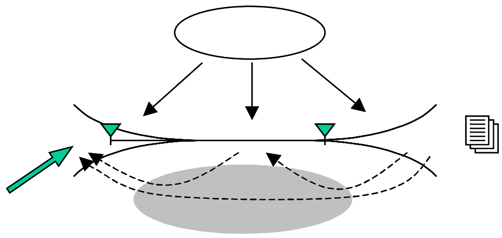
[53] Today the case is not as clear, since more efficient Dynamic Channel Assignment algorithms have been developed. (Dag Åkerberg, interview 2000)

[54] The form of Dynamic Channel Assignment, DCA, used in the DECT standard is sometimes referred to as Dynamic Channel Selection, DCS, or instant Dynamic Channel Selection. This is to differentiate it from the DCA schemes used in mobile telephony systems, where a slow adaptation (i.e. per month, or week, not per call) to average traffic is done by reallocation of channels within the fixed channel allocation plan. (Dag Åkerberg, interview 2000)

7. Preconceptions of market needs



As was noted earlier, Ericsson initiated its investigations into cordless telephony systems after receiving requests from customers for this type of product. Furthermore, I have shown that before digital systems, such as DECT, were developed, there existed at least two generations of analogue systems. In other words, there existed a market for cordless telephony, albeit a market that primarily had experience of simple, analogue products.

I have also shown that several cordless and mobile telephony developments to place more or less concurrently with the development of the DECT standard. They all offered various types of functionality and performance, and thus constitute part of the setting in which DECT systems would be realised. In this chapter, I will explore the perceived market and user needs with respect to cordless telephony when the DECT standard was being developed. I will show how this affected the objectives of the development, and also illustrate how competitive and regulatory aspects influenced the development.

As Clark and Fujimoto (1991) noted in their study of design processes in the auto industry, engineers need to have a good concept of the market for which the products that they are developing is intended. Clark & Fujimoto go as far as stating that engineers simulate the experience of future customers (ibid p. 23). What this chapter shows is how the perceived market requirements were translated to design objectives in the development of the DECT standard.

7.1 Market needs covered by existing systems

The market for cordless telephony devices can broadly be divided into three parts: residential, public and business (Bud 1997; Clancy 1990; 1997). These three subsets of users are perceived to have different needs in terms of applications for, and performance of a cordless system.

Residential users

When the DECT standard was being developed, the residential user was generally believed to need a *cordless extension* of the wired phone. The telephone would typically be used inside the home, or in close proximity to it, e.g. by the pool. It would be used in the same way as a fixed telephone, and major issues for the user would be price, battery life, weight and design of the handset, and speech quality. (CEPT 1985; Ericsson 1981; ESPA 1985b; SRA 1981)

At the time, the proliferation of mobile phones was nowhere near the levels at which it is today (Clancy 1990). As a consequence, most users, especially residential ones, had low expectations in terms of using a telephone while on the move. If a cordless telephone allowed you to bring the phone with you in the garden, or move around the house while talking on the phone, then that itself was an appreciated versatility. Since most conversations dealt with trivialities of everyday life, being overheard was not a catastrophe.

Existing cordless systems, such as the various CT0 solutions, primarily found in the United States, as well as CEPT's CT1 standard, found in Europe, offered functionality to support residential needs. The products came in many varieties. They were simple to use, just plug them in to the wall and start talking, and robust. Once automatic channel selection became the norm, as in CT1 and in later generations of CT0 phones, the risk of being interfered or overheard was reduced.

Cordless telephones of this type were often ample for the small business as well. For such users, however, the security issue was more important.

Public users

Today, the typical public wireless service is mobile telephony. In the late 1980s, however, mobile telephony was still a service available only to few people, predominantly business users, due to its high price. Publicly available telecommunications services, apart from mobile telephony, were payphones and pagers.

When the DECT standard was developed, public applications that combined the convenience of mobile telephony with the low price of payphones were considered to be of interest (CEPT 1985; Clancy 1990). One such application was "telepoint". A telepoint application functions in a way similar to the payphone. It has a number of fixed access locations, in the form of antennas covering small areas. When in such an area, the user can place calls in the same way as from a payphone, but the calls are made from his or her own wireless handset. Calls to the handset are generally not possible, so if the user needs to be accessible, the system can be complemented with a pager.

The cordless systems available in the mid 1980s did not support public applications of this kind. One reason was the need for secure billing procedures. The operator of a telepoint system has to be sure that customers can be billed properly for their use of the system, and that no unlawful use is possible. (Clancy 1990;19p)

Business users

As has been mentioned earlier, simple analogue cordless telephones were useful for small businesses, but hardly suitable for larger enterprises. Existing systems at the time when the DECT standard was developed simply did not measure up to either the functionality, or the performance requirements. For communication outside the company facilities, public applications such as paging and mobile telephony existed. (Clancy 1990; Peter Olanders, interview 970227)

In large office complexes, factories, hospitals, etc, on-site paging was the major business application. It allowed users to be accessible throughout the company facilities, and thus quickly respond to the caller, or to e.g. a company messaging service. While not offering real-time communication, it still reduced the time it took to reach somebody.

In the development of the DECT standard, a potential market was seen among business users who needed the convenience of being able to use a cordless telephone throughout the company facilities. The user would be able to carry a handset with him, and both place and receive calls. In the office domain, the user would thus be truly mobile, even if the phone would not function outside the office. Existing cordless systems did not have the capacity or the functionality needed to provide this type of service. (ESPA 1985b; SRA 1982a)

A further development that was envisaged was that users would increasingly need to be connected to corporate data networks. If such connectivity could be solved through a wireless system, business users ought to demand this.

Market demands for the next generation of cordless systems

In summary, it was apparent when the development of the DECT standard began that existing cordless systems fairly well supported residential applications. However, for public and business users, their functionality would not allow the types of applications envisaged.

7.2 Development objectives

The market needs, as they were perceived when the DECT standardisation started, were presented in the preceding chapter. These preconceptions were translated into objectives for the developing standard.

The market preconceptions indicated that there was a demand for systems with the following qualities (CEPT 1985; 1989; Ericsson 1981; ESPA 1985b):

- A high density of users.

- Placing and receiving calls throughout an entire office complex, factory, hospital, etc.
- Possibility for billing, etc, in public applications.
- Secure calls that cannot be overheard either mistakenly or purposefully.

In addition to these qualities, an important requirement for cordless systems in non-public applications was that they be simple to install. What was especially important was the extent to which radio network planning was needed.

User density

For a typical residential situation, the user density can range from 100 users per sq. km in typical suburban environments (i.e. single family housing), to 10 000 users per sq. km in apartment buildings, and 100 000 users per sq. km in office environments. Public applications, like telepoint, in some cases might have user densities equivalent to that of the office case. (CEPT 1989:15pp; ETSI 1991a:14)

Based on the fact that public and business applications were the areas in which DECT was intended to capture new market opportunities, one important requirement was that the system should be able to handle high user densities.

Handover between cells

If a high user density, e.g. that of an office complex, is to be combined with large area coverage, then multiple cells will be necessary (ESPA 1985b:4). If a single cell is to support both a large number of users, and a large coverage area, it will require a great deal of frequency bandwidth, as well as larger output powers from transmitters in the system.

With the multiple cell solution, i.e. cellular structure, a number of principle problems follow. First of all, there is the question of whether users should be able to move between cells and still place, receive and even carry on telephone calls while moving. Secondly, there is the question of how the coverage of different base stations should be synchronised in order to give good total coverage, without too many gaps, or too much overlap.

The second of these two issues is intimately related to the implementation requirement mentioned above. How much planning was it reasonable to expect the users to do for a DECT system? Should they plan where to place base stations to give good coverage? Should they even plan frequency allocation between cells in order to avoid interference between users in the system? Or, should no planning at all be required of the users? (Peter Olanders, interview 970227; Hulbert & Swain 1997:240p)

Because of how it was expected that systems adhering to the DECT standard would be used, handover capability was conceived to be an important quality (ESPA 1985b:5). Furthermore, business users would probably need networks that could be adapted as offices were remodelled, factories rebuilt, etc, which meant that planning of the cordless telephony system should be simple.

Billing

If a DECT system was to be used for public applications, there had to be some way to accommodate billing of customers. This in turn means that each user must have some sort of identity. Billing functionality in itself does not necessarily have to be part of the radio access system. The information needed to bill customers, however, is generated in the radio access system, and must be communicated to a billing system. Such information includes e.g. duration of calls, to what number calls are placed, and the identity of the user placing the calls. (CEPT 1985; 1989)

One requirement on the DECT standard was thus that there should exist an identity structure, and that it should be possible to gain additional information about calls originating in the system. In addition, such an identity regime would ensure that DECT systems, whether private or public, could not be misused.

Security

As has been noted, early analogue systems of the CT0 and CT1 variety generally did not have secure radio interfaces. Because of this, it was possible to intercept and listen to telephone conversations using fairly simple equipment. For private users, this was not perceived to be a problem, because of the nature of their calls. For business users, however, being able to talk about sensitive matters over the cordless telephone was deemed an essential feature. A more secure connection was therefore required of the new DECT standard. (CEPT 1985; ESPA 1985b; SRA 1982b:17)

Summarising the development objectives

Based on perceptions of what the market opportunities for cordless telephony looked like when the DECT standard was developed, as well as the functionality and performance of current systems, a set of development objectives where articulated. These objectives grew from pre-studies, evaluations, company internal development work, standards meetings, etc.

The key objectives for the development of the DECT standard were:

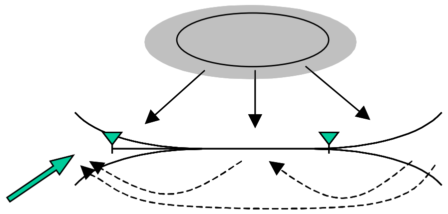
- A high capacity system
- A system supporting handover between cells

- A system with limited planning requirements
- A system prepared to allow billing, e.g. through the design of the identity structure
- A system allowing secure conversations

The system should also be prepared for both speech and data services.

7.3 The impact of competition and regulation

For the individual standardisation effort, as it is perceived in this thesis, competition and regulation become primarily contextual factors that impact, and are impacted by, the technical development of the standard. In this section, these factors are explored briefly.



Regulation of frequency spectrum

The direct way in which regulation affects the development of a wireless standard, is through frequency allocation. In Europe, the EU strives to harmonise frequency plans between member countries, and frequency allocation is coordinated in a CEPT committee called the European Radiocommunications Committee, ERC. The proposals issued by the ERC are adopted by the individual member states, but once they have been adopted, they become mandatory in that country. (Ochsner 1997:109p)

At the time when second generation cordless standards were being developed, a key aspect of frequency allocation had to with whether paired frequency bands were to be allocated. Paired bands were necessary for mobile telephony applications, that were designed with Frequency Division Duplex, and were therefore considered to be short in supply when it came to cordless systems (Hulbert & Swain 1997:235). This obviously affected the developments of both the CT2 and DECT standards, encouraging them to choose a Time Division Duplex solution.

Competitive advantages

Competition between different standardisation efforts, as well as between the participants of a particular effort, is an integral part of the standards-setting process. As has been noted previously, the type of official, open, cooperative standardisation that the development of the DECT standard is an example of, often has the character of “competitive collaboration”. The question is in what way this affects the outcome of the standardisation effort.

It is apparent that the contemporary CT2 development played a catalysing role for Ericsson’s and Televerket’s actions in ESPA and CEPT. The perceived market threat from CT2 triggered the proposals to these organisations of Ericsson’s DCT900 (CT3) system. Here, potential competition played an important role for how the standardisation efforts were shaped at an early stage.

As has been noted, there were a range of differences in the CT2 and CT3 approaches, and consequently in the system solutions advocated by different suppliers. It is reasonable to assume, and has also been demonstrated, that both sides had conducted proprietary research and development before the collaborative (and competitive) standardisation efforts began. This must of course have influenced their ideas of what solutions were beneficial for the own company in terms of a number of factors: competence, existing products and prototypes, patents, market orientation, etc. In this way, their actions in the standards-setting process were affected by their relative competitive advantages, and disadvantages.

8. Key technical problems

In previous chapters, I have described the pre-history of the DECT standard in terms of preceding systems, and what research trends were apparent when the DECT standard was developed. I have also illustrated the functionality and performance of existing cordless systems, and showed what type of applications they were suited for. Finally, I have discussed the preconceptions of user needs that existed during the development.

In this chapter, I intend to show how the above aspects of the development merged, thus creating the actual development tasks in the standardisation of DECT. This identifies some key technical issues that were fundamental for the development of the standard.

8.1 Merging current research with the development objectives

Any technical development activity can be described either as solving a problem based on a market needs, or as a solution searching for a problem to solve. The same is of course true in the case of DECT, and it is impossible to say which comes first: the problems or the solutions, i.e. the market needs or the technical development.

What I believe the DECT case shows is how technological developments, including existing systems and products as well as current research, and preconceptions of market needs (or potential market needs) merge in the standardisation process. The design of the standard is thus a result of both these factors.

When the development objectives meet current research and existing systems, some development issues turn out to be easy to resolve, while others require a serious effort. It is the latter category, in the case of DECT, that is discussed here. By doing so, I wish to identify the key technical problems in the development of the DECT standard in order to thereby illustrate the relationship between the more general technical development in wireless communications, and the standard-setting process. These key technical problems are what Thomas Hughes (1987) refers to as "reverse salients". They were the focus of the development effort, and once they had been solved in essence became determinants of the resulting DECT standard.

8.2 System level solutions

The market needs that were perceived for DECT led to the formulation of fairly comprehensive development objectives. The range of applications that the standard should support was very large. Public applications, such as two-way telepoint and wireless in the local loop, business applications, such as the wireless PABX, and residential applications, were all to be provided by the same system. All these applications should be able to coexist without frequency planning on a frequency band shared by all systems and operators. Furthermore, the standard should support both voice and data applications, and provide means for future evolution.

A system for many applications

At a system level, the standard therefore had to provide extensive functionality, in combination with high performance. This has been discussed previously in terms of system functions such as handover, roaming, billing, etc, and performance requirements regarding e.g. capacity.

The solution chosen for DECT was to develop a standard based on instant Dynamic Channel Selection, a form of Dynamic Channel Assignment, DCA. This meant that a versatile system emerged that could handle very diverse usage situations. It would automatically adapt to changes in traffic concentration, and did not require radio network planning to be installed efficiently (although a certain awareness of radio wave propagation models is obviously beneficial for system performance).

In combination with a high capacity channel structure, with 12 time-slots on each of the 10 carrier frequencies, this resulted in a very flexible system specification. The standard was aimed to provide cost-efficient solutions for the residential market, and at the same time allow very large density, reliable office applications, using the same handset. Of course, simple applications, e.g. the typical wireless extension of a fixed socket intended for residential users, would not have required an as sophisticated solution as the DECT standard offers. For more complex applications, however, especially in high load environments, it is a necessity.

Dynamic Channel Assignment design

The choice of a dynamic assignment and reassignment of channels is, as has been noted, not self-evident for a cordless system. At least not an as refined DCA scheme as found in DECT. I have shown that more simple channel assignment strategies, e.g. automatic assignment of channels, but without reassignment, might well be suitable for simple cordless applications. Fixed channel assignments, in turn, are viable for public applications.

The design of the DCA scheme in the DECT standard is coupled to the air interface design. This is an example of the systemic nature that a technological design generally has and the interdependencies between subsets of the standard that this leads to (compare Hughes 1987; Rosenberg 1982). Irrespective of the DCA algorithm that is implemented, the way in which the handset and base station can gain information about the radio environment on other channels than the ones being used for up- and downlink transmission, is vital.

In the DECT standard, the radio interface is built on a TDMA/FDMA combination. In essence, this means that during the time-slots that a receiver is not transmitting, it can listen to other transmissions. It is therefore possible to estimate the relative interference levels on different channels of the system. Obviously, the channels that use the same time-slot on other frequencies cannot be monitored. It is also reasonable to guess that frequency changes take time, which means that neighbouring time-slots may be difficult to monitor accurately. An additional problem is that the uplink and downlink will experience different interference situations due to the relative locations of other terminals and base stations.

Despite the typical shortcomings of DCA systems, outlined above, it is possible to gain good radio environment information, and thus make qualified judgements in channel assignment and reassignment situations. In general, the more time-slots and fewer carrier frequencies a system has, the better the information on the radio environment will be. The reason for this is that more carrier frequencies will take longer time to scan, thus making the interference data old. As a consequence, the radio environment must change slower than the interference data is updated if meaningful information is to be provided. Once again we see the relation both to the assumptions of user behaviour in a cordless system, and to the design of related components of the standard.

8.3 Radio interface design

The choice of a TDMA/FDMA combination for the radio interface in DECT is hardly surprising, given contemporary wireless developments. Despite the design difficulties that have been mentioned regarding TDMA systems, there seemed to be a prevailing attitude at the time, that this was a reasonable access method for wireless systems with high capacity requirements.

What differs the DECT radio interface from that of contemporary cellular developments is the trade-off between the number of time-slots, and the carrier separation. In GSM, the carriers have a separation of 200 kHz, and there are 8 time-slots (Mouly & Pautet 1992:188). In DECT, the carriers occupy 1 728 kHz, and there are 24 time-slots (12 uplink, and 12 downlink). The trade-off in principle means that DECT has a larger transmission overhead due to the higher number of time-slots.

The main reason for the different trade-offs is that the expectations of what the radio environment that the systems would be used in differed. Here, user behaviour (e.g. speed and range of mobility), the physical environment (e.g. indoor or outdoor), and user densities are important factors.

In the case of DECT the multiple access scheme that was chosen had to fit with the channel assignment ambitions. This essentially ruled out a FDMA solution, and encouraged a solution with many time-slots.

What has also been shown previously, is that the chosen duplex method, Time Division Duplex, results in more simple transceiver designs. Because of the expected applications for DECT systems, this was considered to be important in terms of producing low cost products.

8.4 Identity and security issues

A final note on the design aspects of the DECT standard must deal with the identity and security issues. In order to make possible the great range of applications intended for DECT systems, this was a key element in the design of the standard. It was perceived that secure telephony service was a necessity for the system to have a substantial impact on the business PABX market segment. This was an important design issue, and resulted in a very structured, and well thought through classification scheme (it is documented in ETSI 1992g, and ETSI 1992h).

9. Conclusions and future work

In this chapter, the case study is analysed based on the literature survey and the conceptual framework presented earlier. Conclusions for the thesis as a whole are drawn, and some possible avenues of approach to future research are discussed.

9.1 Summarising the case study

In this section the case study will be summarised. It will be related to the theoretical framework presented in chapter 2.

The latest generation of cordless standards

DECT belongs to the second generation of cordless standards, according to common nomenclature. In fact, more reasonable would probably be to regard this as the third generation of cordless standards, in light of relative development steps from CT0 type systems, via the CT1 standard, to CT2 and DECT. We can thus view DECT as the latest generation of a series of systems and standards in what can loosely be defined as the "family of cordless systems"[55].

When the different product generations are compared, we note that they contain sets of common attributes that relate to the functionality, performance, and use of systems within a generation. For the early analogue systems, CT0, the attributes where: a system offering a cordless extension of the fixed telephone service, low capacity, used around the house. For the CT1 generation, it would be: a cordless system with automatic channel assignment, medium capacity, used in residential and small business applications. For the DECT generation, finally, the attributes were: self-planning, digital cordless system with secure access channels, high capacity, intended for various public, business, and residential applications. The CT2 standard, in this characterisation, falls between the last two generations.

Using James Utterback's (1994) concepts, we can clearly see that there exists a "dominant design" in each generation of cordless telephony systems. The dominant design is, at least to a great extent, articulated in the form of a standard. Utterback defines a dominant design as a product class that both competitors and innovators must adhere to if they want to gain a market following. Utterback uses

[55] Paraphrasing Karlson's (1994) "product family" concept.

the lighting and typewriter industries as his examples, and his presentations show that waves of innovation follow each other, and give rise to successive design solutions, eventually generating a “dominant design”. The same holds true for cordless telephony.

However, what differs a dominant design in Utterback’s model from a cooperative, open standard, is that the market does not exert a direct influence on what the character of the dominant design will be. Instead, the decisions are made in a standardisation process that involves technological development, competition, and regulatory goals. Ultimately, of course, the market decides what impact a product will have, but before this can take place the standardisation process partly determines what types of products will be made available to the market. Therefore, it is reasonable to assess that not only the market can generate a dominant design. The setting of technical standards is an alternative way.

What Utterback’s model furthermore does not capture, is that each standard generation may have its own dominant design. He primarily discusses the emergence of a single dominant design, and stops there. In the case of cordless telephony, as noted previously, we see that generations of standards follow each other. Just as Bo Karlson (1994) showed us with his “wave metaphor”, where generations of products within a family build upon each other, new generations of cordless telephony standards are designed with respect to existing systems. Karlson illustrates that while substantial developments can take place between successive generations of a product family, there is nonetheless a common denominator that defines the products as being part of the family. Similarly, DECT is still a cordless system, even though it in terms of possible applications, functionality, and performance is pretty far from the early CT0 systems. The design of the DECT standard took into account the existing systems, as well as the contemporary developments. A new standard had to offer something different from existing standards, or proprietary product solutions.

For the present study, one drawback of Karlson’s work is that it treats the product design process, rather than a more general process of development, or innovation. The expansion of Utterback’s concepts provided by Andrew Davies (1997) is therefore very interesting. Davies demonstrates that while certain aspects of a dominant design remain unchanged, others will continue to develop from one generation of standards to the next. In the smaller, systemic and component, innovations large changes in the system are possible, but not large enough for it to become a different type of system. In the case of DECT, as mentioned, we still refer to it as a cordless telephony system, although the functionality of the system has increased greatly since its early, analogue predecessors. The advanced, business applications for which the DECT standard can be used, would not have been possible to realise with a CT0 system.

Davies makes a distinction between architectural, systemic, and component innovations – in order of magnitude. If we apply his concepts to the development of cordless standards, we can note that architectural aspects of cordless systems in certain respects have remained unchanged throughout the three generations of standards that have been discussed. This is true of for example aspects relating to how a cordless system is used, i.e. that users move only locally, and at low speeds. Other architectural aspects of the system have changed, especially when the CT0 generation is compared with the DECT generation. Here we note that completely new types of applications, telepoint and large-scale wireless PABX, are introduced with the advent of the DECT and CT2 standards. This required changes in the cordless telephony "product system", and consequently the standards, that were architectural in nature.

Apart from these large changes, there are also a number of systemic innovations that are part of developing the technical standard for DECT. The most apparent example is the allocation of frequency resources within the system, where a Dynamic Channel Assignment (DCA) scheme was designed. As I have shown, the design of the DCA scheme was systemically related to e.g. the choice of multiple access and duplex techniques (compare Hughes 1987; Rosenberg 1982).

Component innovations are also an important part of both the development of the DECT standard, and the development of DECT products. The present study has not primarily focused this level of detail, but to mention some developments that are of this type, we might consider speech coding techniques, or modulation techniques. They obviously affect the performance of products adhering to the standard, but innovations in these areas can take place semi-independently of the rest of the system. Also, there are a great amount of component innovations that relate to the implementation of a standard in products, e.g. dealing with electronics design or manufacturing. Such developments have only entered into the present study in terms of what technological expectations (Rosenberg 1982) they give rise to.

In conclusion, the development of the DECT standard shows us how a dominant design emerges through a standardisation effort. The case demonstrates that primarily systemic innovations are made from one generation of cordless standards to the next. Most architectural aspects remain unchanged, and most component innovations relate to the product implementations of the completed standard.

The DECT standardisation process

If we now shift our focus from the different generations of cordless standards, to the particular aspects of the development of the DECT standard, this process in turn can be analysed.

Pre-history

As discussed previously, the pre-history of the DECT standard in part consisted of the existing cordless systems at the time. However, the standard-setting process was also intimately related to research and development that had taken place in the field of wireless communications prior to the development of the DECT standard. As Kline and Rosenberg (1986) note in their “chain-linked model”, there is an interaction between the individual innovation process, and research and scientific knowledge in related fields. The studies that had been made of channel assignment strategies, for example, were an important input to the development of the DECT standard. How else could the feasibility of such an approach have been tested?

It also important to note that Kline and Rosenberg, in their model, treat research and scientific knowledge as independent of the innovation process. They demonstrate that even though there is an interaction between them, research, and the development of scientific knowledge live a life of their own.

Preconceptions

The case study shows that many design choices of the DECT standard were influenced by the preconceived market needs for a cordless system. The spread in terms of potential applications for DECT put a great demand on designing a flexible radio system, with high capacity, while at the same time making the system simple enough to be an option even for residential applications. As a consequence, the chosen channel allocation scheme, DCA, was perceived to be a viable solution. Similarly, the design of multiple access techniques was influenced heavily.

The process by which perceived, or potential, market needs enter in to the design effort has been illustrated by Kim Clark and Takahiro Fujimoto (1991) in their analysis of the product development process. They describe this as engineers “simulating” the experiences of future users. Parallels to this can be found in the DECT development, where a lot of effort was put into the analysis of the consequences of different usage situations (see e.g. CEPT 1985; 1989; ESPA 1985b; SRA 1982b). The knowledge gained from these studies went into the development process as a sort of feedback from the potential market.

It would of course have been interesting to study whether the actual market impact of DECT ensued in the expected applications, or in what way the assumptions made during the development of the standard proved incorrect. However, such an analysis lies outside the scope of the present thesis.

The analyses, mentioned above, also covered product design and manufacturing issues. Obviously, the participants in the standardisation effort to a large extent had experience of these processes, but studies of developments in these areas were also part of the development of the standard. They shaped the “technological expectations", to use Nathan Rosenberg's (1982) concept, relating to how products adhering to the standard could be realised.

Competition and regulation

For the development of the DECT standard, it has been noted that competition and regulation played a largely contextual role. The reason for this is that they remained largely unchanged over the course of the development. They can be described as part of the institutional environment (Scott 1987) of the standard-setting

Competitive aspects of the standardisation effort were shown to at the very least have had a triggering effect on the entire DECT development. When British manufacturers presented the CT2 proposal, their Swedish counterparts felt action was necessary, and delivered the CT3 counterproposal. In the development of the respective standards, the focuses differed. In part this was due to the fact that they aimed for different market segments, since the participants believed in different competitive strategies.

The regulatory impact on the development of second (or third) generation cordless standards was apparent primarily in terms of the frequency allocations for such systems. Since paired frequency bands were considered to be difficult to obtain, the developments of both the CT2 and DECT standards were encouraged to opt for Time Division Duplex solutions.

Key technical developments

The key technical development that emerged in the DECT standardisation was that of Dynamic Channel Assignment, DCA. DECT was the first radio system standard to implement such channel assignment, at least in its more sophisticated version, where reassignment is also supported.

Thomas Hughes (1987) has coined the expression "reverse salient" as a way of illustrating such components of a development process that have been critical for the path that it has taken. A reverse salient is a key problem in a development effort, where the proposed solutions often are controversial. A great effort is put into solving them since they hold back the development of the entire system because of the systemic ties to other components.

In the development of the DECT standard, the way in which the frequency spectrum should be shared between different users was a "reverse salient". Intimately linked to this was the choice of channel assignment strategy. For a long time, the DCA solution proposed by Ericsson and Televerket for the DECT standard was controversial. It was not until the practical demonstration performed by Ericsson in 1987, that its critics accepted it as a reasonable solution. It was the key, new technology that once it was accepted opened the doors for a very much smoother development process. Once this had happened, the solution advocated by Ericsson gained “momentum”, to use Hughes’ second concept.

The choice of channel assignment strategy is also relevant in that it connects Hughes’ (1987) and Davies’ (1997) concepts with each other. As has been discussed, the design of the channel assignment strategy was part of the systemic innovations in the development of the DECT standard. Since it had this character, it also had the qualities of a reverse salient. It had strong ties to almost all other components of the technical system being standardised, and furthermore would affect how such systems could be used, and the relative competitive advantages of different suppliers of products adhering to the standard.

9.2 The conceptual framework

The case study has shown that the development of the DECT standard had a number of important qualities that determined the design of the standard. From the observations made during the work, the conceptual framework that was presented in chapter three was formulated. Let us recapitulate.

In the conceptual framework, the model of the individual standardisation effort consisted of three phases, in a logical sequence from technological development, through formal standardisation, to market diffusion. Between the phases, besides the sequential delivery of knowledge, documents, etc, there existed a set of relationships. Firstly, the technological development going into the standard-setting had a pre-history. Secondly, the current, and historical, market situation helped determine preconceptions of market, and user, needs for the current standardisation endeavour. The same was true of design and manufacturing aspects. Finally, there was a contextual influence from competition and regulation.

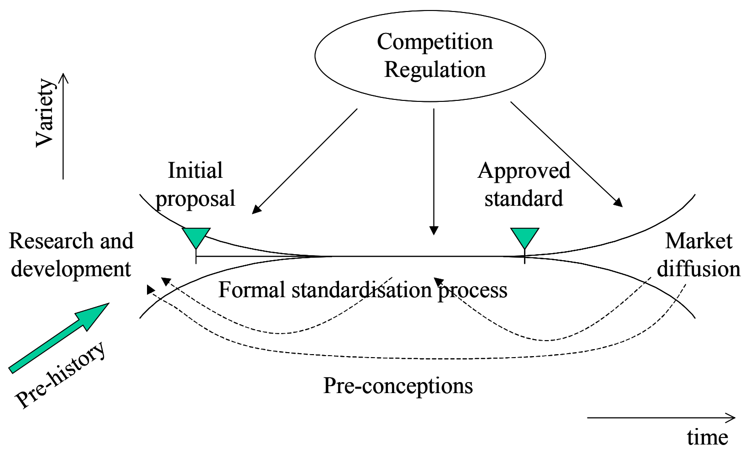


Figure 14: A conceptual model of how the DECT standard was developed.

The conceptual model was also expanded to include several generations of cordless telephony standards, thus demonstrating how the development of a particular standard built upon existing standards and systems.

Conclusions to be drawn from the conceptual model

The conceptual model developed in this thesis demonstrates how the technical standard DECT was developed. It contains a number of elements that are a result of conclusions drawn from the case study. They are:

- The development of the DECT standard was influenced by the pre-history that the standard had. This pre-history consisted of existing standards and systems. Their capabilities, functionality, and performance were important for what requirements were put on the DECT standard.

- The pre-history of the standard also consisted of the technical research and development that were the foundation for the design of the standard. For example, the development of the DECT standard was influenced by research that had been conducted into channel assignment strategies.

- To be able to develop a technical standard, it is necessary to have a clear picture of the needs of the market. However, this picture can only be gained in the form of pre-conceptions of future market needs. By definition, products adhering to the DECT standard could not exist until after the standard had been developed, and consequently there could exist no market for them either.

- Competition between the participants in the standardisation effort does influence how a standard is designed. In the case of the development of the DECT standard, however, this aspect has played a predominantly contextual role. One reason for this is without doubt that both a CT2 and a DECT standard were developed in parallel. There was thus little need for contention within the individual development processes.

- Regulation also plays a part in the design of a technical standard. When the DECT standard was developed, this was apparent through the spectrum allocation. Since DECT was not primarily intended to offer public services, the impact of regulation was not as great as it might have been. In the development of the DECT standard, it had the nature of an external requirement that the standard had to fulfil.

Applicability of the model

As I have noted previously, the conceptual model that is a result of this study was created in order for me to understand the development of the DECT standard. It is based on the case study of this development that is documented in this thesis. Nevertheless, it is of course interesting to consider its applicability to other standardisation efforts.

I believe that several aspects of the model are useful for describing, and understanding, the development of other technical standards. For example, the pre-history that a standard has in the form of existing systems, the way in which research and development affect the design of the standard, and the way in which market pre-conceptions are necessary for the development of a standard.

One important aspect that might not be quite as generic as these is the relative importance of competition and regulation. If the development of a standard intended for public applications were considered, e.g. the GSM system for mobile telephony, the role of competition and regulation would be different. First of all, I believe that competitive aspects were much more a part of the development of the GSM standard simply because its market potential was perceived to be greater than that of a cordless telephony standard. Perhaps not in terms of volume as much as in being a premium service for which people were prepared to pay more. Secondly, since mobile telephony is a public service, regulatory aspects by definition are more important. These two aspects of the model would probably have been more predominant, and not treated in the contextual fashion in which they have been here, if the development of the GSM standard had been studied.

I also want to point out that the model presented here is intended to explain the development of a co-operative, open, de jure standard. The development of a de facto standard would probably require a different type of description, in which the market plays a much more active role as part of the development of the standard.

9.3 Standardisation as technical development

If we want to understand the direction of a technical standardisation effort, we have to view it not only as a political process, but also as a technical development. Today, the development of technical standards is often a form of joint research and development project between several firms.

Standardisation as a bridge between research and market

The characteristics of the development of technical standards have been discussed above. It is a process in which research, scientific knowledge, and existing product solutions, meet preconceptions of market and user needs. From this merger, the standard is shaped. Competitive and regulatory aspects also influence the process.

We can thus, as the expanded picture of generations of standards from the conceptual framework indicates, view the standardisation phase as a bridge between the semi-independent processes of technological development, and market diffusion. It is thus a way of generating products, systems, and services for a market by focusing knowledge from research and development into a joint specification, the standard.

Standardisation efforts thus reduce the uncertainty of the market diffusion process. Path dependencies (Arthur 1994; David 1985) are in part controlled, and regulatory interests can be served as part of the process. The uncertainty for participating firms is thus also reduced, and they either gain a forum through which they can support their own preferred solutions, or closely monitor the leading proposals.

The tension between standardisation and development

The case study in this thesis has given us ample evidence of how the outcome of a standardisation effort is shaped by existing research and knowledge, as well as interpretations of the market and usage situations for which it is intended. However, one question that remains is why companies venture into cooperative standards-setting in the first place.

The reasons for firms to strive for co-operation in this way are several. First of all, they thereby reduce the risk of backing the wrong solution. If the standard turns out to be a failure, competitors are equally affected. Secondly, the magnitude of the development projects needed to define future wireless communications systems is almost too large for the individual corporation. Co-operation has simply become a necessary way of saving resources.

This reasoning illustrates that standardisation in itself has become an objective for the developers of wireless communications technology. It is thus at once a result of technological developments and achievements, and an objective for said developments. In this tension, the standards, that specify the function of so many products and systems that we take for granted, emerge.

Consequences of viewing standardisation as a development activity

I do not want to argue that a technical standard results only from a technical development process. Of course other aspects of standards-setting are important as well. Obviously, political and regulatory objectives play an important part. Companies clearly use standardisation efforts as a way of competing with each other. The company that manages to put as many of their own solutions as possible into the standard “wins”.

Nevertheless, the technical development that takes part in conjunction with a standardisation effort is an essential part of how technical standards come about. The development of the DECT standard clearly demonstrates that many of the design choices in a standard-setting activity are discussed in technical categories, and ultimately contain technical judgements.

From this line of reasoning, a simple conclusion can be drawn. If a company wishes to influence the design of a technical standard, it is imperative that they participate in the technological development related to this standard. By being in the forefront of this development, their say in the standard-setting activity increases. For example, by being able to demonstrate that a DCA solution actually functioned in the way they claimed, Ericsson and Televerket could push this solution through the DECT standardisation. For this to have been possible, they had to do a serious amount of research and development work, even going as far as building a prototype system.

The above conclusion also indicates who should participate in the formal standards meetings, etc. It should obviously be those individuals that have the required technical expertise, i.e. that have participated in research and development in related areas. Not necessarily all participants from a company need to have this profile, but it certainly increases the argumentative power of the company, compared to sending only "standardisation professionals" to the meeting.

It is also important to note that the research and development work that lays the groundwork for a standardisation effort begins long before the formal standardisation process is initiated. This is also clear from the development of the DECT standard, where work on e.g. dynamic channel assignment strategies had begun more than fifteen years before CEPT and ESPA formally initiated their standardisation activities. Therefore, once again, it is important not to view standards-setting simply as a formal process within standard developing organisations, but to also take into account its history and context.

9.4 Future research

I am currently considering three different approaches for future research based on the present thesis. The first option is to expand the time frame of the studies, and thereby capture the relationships between different generations of wireless standards. The second alternative is to study other types of standardisation processes, e.g. in other industries, or de facto instead of official standards-setting, and to make a comparative analysis of them. The third idea is to continue studying the development of technical standards in radio communications, but with a focus on the relationship between standardisation and product design.

Generations of wireless standards

In the conceptual framework developed in this thesis, one of the points I make is how the individual standard-setting effort relates to prior generations of standards. The discussion in the present thesis is only schematic, and might well be expanded.

In the literature review, several concepts focusing similar attributes of technological development were identified. Andrew Davies (1997) discusses different categories of innovations that result in generations of products, or standards within a product system. Bo Karlson (1994) uses the "wave metaphor" to discuss different generations within a product family. In comparison to this object, wireless systems are obviously larger in scope, and do not belong to a single firm, but rather an industry.

The forces influencing the development of new generations of standards can be expressed using the terminology of Rosenberg (1982), "technological expectations", Hughes (1987), "technological momentum" and "reverse salients", and Clark and Fujimoto (1991), "simulations of consumer experience". These concepts point to the underlying movers in the development of standards, seen over a longer time frame.

One way of designing this type of study would be to view DECT as a second generation wireless standard, and thus focus on third generation developments. Currently, the Universal Mobile Telephone System, UMTS, development is underway, and third generation systems are about to be launched throughout the world.

Of further interest would be to study fourth generation systems, to the extent that these have been formulated today. This would complement the historic and contemporary analyses with a forward-looking study, conducted while research efforts are still in early stages, and formal standardisation work has not yet begun. Here, developments that will not lead to standards will appear as well. These can both be "dead ends" in the development process, and be such developments that are not suitable for standardisation, leading instead to e.g. proprietary product solutions.

In this type of study, questions can be asked regarding what changes, and what remains the same between different generations of wireless standards. It would be thus be possible to understand what constitutes a wireless standard, and what differs different families of standards, to paraphrase Karlson above. Furthermore, changes in how wireless standards are perceived over time, could be expressed.

Comparative analysis of standardisation processes

It was noted early in the thesis that the development of the DECT standard is an example of one category of standardisation. It is an open, de jure standard that was developed in an official standards organisation, in co-operation between a number of otherwise competing telecommunications manufacturers. This form of standards-setting is probably far from the norm in the information and communication technologies.

The typical approach used to contrast the DECT style standardisation is de facto standards-setting (ETSI 1996a; Naemura 1995). Here the standard is decided by the market place, leading to a complex, path dependent diffusion of products and systems (David 1985; Shapiro & Varian 1999). Other standardisation approaches are of course also possible.

In a comparative analysis, the relative merits of different approaches to standards-setting could be explored. By keeping the studies within the same industry, and focusing on systems that are similar in terms of scope and complexity, the key differences could be identified. Alternatively, examples from other industries could be considered, thereby allowing the technical characteristics of the standards to be part of the explanatory variables.

As far as my literature studies have shown, typologies of standardisation are common. Harder to find, however, are empirically based studies of the differences between these different standardisation types. In such a study, it would be possible to contribute more than a schematic categorisation. The merits of different processes could be analysed, and the reasons for why a particular approach is chosen might be understood.

Standardisation and product design

The present study focuses the development of a standard for wireless communications. One of the delimitations is that system and product design based on the standard is disregarded, except in terms of preconceptions of feasible design approaches. In the study, the standardisation process has been explored by mirroring it in the broader context of technological development in the radio communications area.

One alternative for future research would be to elaborate the understanding of standards-setting in wireless communications by relating the standardisation process to the product design process. A fuller understanding of standardisation would thereby be accomplished. Also, the differences, and similarities between standardisation and product design could be explored.

The present thesis draws part of its theoretical framework from the area of product design, and there are obvious similarities, as well as couplings, between the two processes. I have not found, however, any analysis of these aspects. Furthermore, a discussion of why standardisation is taken so much for granted in parts of the information and communication industries, whereas other areas go straight for proprietary product development, is warranted.

A study of this kind might entail a case study of how the standard is delivered from standardisers, to product designers. How is this organised? What problems occur? What competencies are needed? How does it affect the design process? How does it affect the products coming out of the design process?

This is the last of the three possible continuations that I see for the present study. What is clear is that whatever route I choose, the study will be most interesting and rewarding.

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Lars Bergenlid, Ericsson Radio Systems, 960419.

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Donald C. Cox, Stanford University (formerly at Bellcore and Bell Labs) 980918, 980925.

Mark Cudak & Roger Peterson, Motorola Laboratories, 990726.

Steinar Dahlin, Ericsson Radio Systems, 960228.

William Dahnke, Ericsson CDMA Systems (formerly Qualcomm), 990706.

Richard Engelman, Federal Communications Commission, 990812.

Lars-Erik Eriksson, Ericsson Telecom, 960828.

Urban Fagerstedt, Ericsson Radio Systems, 960312.

Art Feather, Cisco Systems, 990527.

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Gert Westergren, Teracom, 960829.

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Katarina Vretman, Post- och Telestyrelsen, 960828.

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[56] Dates according to standard Swedish format YYMMDD.

Peter Olanders, Ericsson Radio Systems (formerly at Telia Research), 961127 (telephone), 970227.

David Shively, BellSouth Mobility, 990806.

Johan Siberg, Ericsson Mobile Communications, 980806.

Rolf Wedberg, Ericsson Microwave Systems, 960119, 960126 (telephone).

Dag Åkerberg, Ericsson Radio Systems, 961126, 961218, and 000512 (e-mail).

Erik Örnulf, Ericsson Radio Systems, 960219.

Appendix 1: A typical questionnaire[57]

General

Tell me about your position at Ericsson, work description, etc.

Give a brief description of the operations and organisation of the part of Ericsson that you work at.

Chronology

Describe to me how the DECT standardisation took place.

Why did one start to develop a standard for cordless telephony?

What predecessors did DECT have? (Ericsson products, solutions from other suppliers)

What models were there for how the standard should be designed?

Ericsson's prerequisites and objectives

What were the prerequisites for the DECT standardisation from Ericsson's point of view?

What technical solutions existed?

Did Ericsson have products to start the development work from?

Did the necessary competencies exist within the company?

What were Ericsson's objectives for participation in the standardisation effort?

Why was it relevant to develop an open standard?

Ericsson's internal organisation/work/participants

How did Ericsson organise participation in the DECT standardisation effort?

What parts of the company were active?

What functions influenced the work, and were influenced by it?

[57] Original in Swedish, my translation.

How many people were involved from Ericsson? How many of those involved participated in actual standardisation activities? How many were active “behind the scenes” with development efforts that influenced Ericsson’s actions in the standardisation process?

What individuals participated?

Actors and structures

Who were the most important actors in the standardisation effort?

Give a brief description of their views on the standardisation work.

Did different actors have different objectives? (both small and large differences)

What co-operative organisations were there? What work could be done within these, and what was done outside of them?

Future work on DECT. Market impact.

How is continued, and future, standardisation work relating to DECT carried out?

Have new participants entered the scene?

Is the work different once a functioning, established standard is in place?

What market impact has DECT had?

What competing solutions exist?

Are there other wireless systems that are threatened by DECT? Is e.g. GSM threatened?

Have thoughts concerning this affected the design of the standard?

Additional interviewees

Who should I turn to for additional interviews? (within Ericsson, and other companies)

Is there any literature on the DECT development?

How has the standardisation work been documented? Is it possible to gain access to this material?

Appendix 2: The DECT standards

The presentation of the DECT standards that is given in this chapter is intended to give an introduction to the DECT standards actually contain in terms of the content and structure of the documents they comprise. Although the overview in places is purposefully detailed, in relation to the more than 1000 pages of the standards[58], it is but a brief summary.

The overview will present the two initial standards adopted by ETSI in 1992; the common air interface and the approval test specifications. The continued standardisation work, carried out after 1992, is also discussed.

ETSI standards and standardisation processes

The DECT standards today consist of more than one hundred documents published by the European Telecommunications Standards Institute, ETSI. The documents are named European Telecommunications Standards, abbreviated ETS. The ETS documents are complemented by ETSI Technical Reports, ETR, that are intended to give a more detailed interpretation of the standards and the ideas behind them. In this chapter, an overview of the DECT standards formally approved by ETSI is given. The focus is on the standards adopted in 1992, i.e. the work giving the fundamental design of the system. Since then, the standardisation process has continued, partly by reviewing and updating the original standard, and partly by introducing new parts of the system that were identified but not elaborated on in the early standards (e.g. data services and several interworking units).

Related to the standardisation process of ETSI is the regulation process of the European Union. It is concerned with generating common standards for Europe and harmonising existing national standards. ETSI's role in the regulation process is to produce Technical Basis for Regulation, TBR, documents. These can then be adopted as Common Technical Requirements, CTR, i.e. normative documents that all manufacturers, operators and users are required to comply with by law. The process of going from the technical standards to regulations often takes many years. Also, only certain aspects of the standards need to be regulated, e.g. such

[58] This only includes I–ETS 300 176 (ETSI 1992k) and the 9 documents of ETS 300 175 (ETSI 1992b-j). None of the ETSI reports that treat DECT, and that are highly beneficial to the understanding of the standard, are included.

matters that determine the effect of a system on other public or private systems especially the public telephony system.[59]

The two main documents that determine the original DECT standard are ETS 300 175 ”Common interface” (ETSI 1992b-j) and I–ETS 300 176 ”Approval test specification” (ETSI 1992k). The first one is the system specification, and the second one is the test specification for DECT equipment. Together they constitute the two formal documents that were the outcome of the initial rounds of the DECT standardisation. The system specification document, ETS 300 175, in turn has 9 sub-documents that describe different parts of the system.

The common interface

The ETS 300 175 document specifies the different parts of the DECT system. Together these specifications determine the common air interface, DECT CI, for basic telephony applications. More advanced functionality is standardised in subsequent standards documents.

The first document, ETS 300 175–1, serves as an overview of the standard. In it the basic concepts of DECT are described, as well as the terminology and abbreviations used in the other sub-documents. The objective of the ETS is presented in the following way:

> “The DECT standard has grown out of the need to provide cordless communications, primarily for voice traffic, and also to provide support for a range of data traffic requirements.
>
> The DECT standard is designed to support this versatility of applications at a cost that encourages wide adoption. It is envisaged that DECT will provide personal telecommunication services in residential, neighbourhood and business environments. It is particularly targeted at the following applications:
>
> - residential - domestic cordless telephones;
>
> - public access services;

[59] The acronyms used here for ETSI deliverables are the ones that were in use when the original DECT standards were adopted. Since then the terminology has changed, and there are now five categories of ETSI documents; European Standards (EN), ETSI Standards (ES), ETSI Guides (EG), ETSI Technical Specifications (TS), and ETSI Technical Reports (TR). The European Standards are approved by all national standards bodies of the EU countries, whereas the other documents are approved at various levels within the ETSI organisation. The ETS documents discussed above are approximately equivalent to today’s ES documents, and CTR documents are now EN documents. The intricacies of the ETSI document system are discussed at length in the ETSI Handbook (ETSI 1997:15pp).

- cordless business telephones (PBXs);

- cordless data - Local Area Networks (LANs);

- evolutionary applications (extensions to cellular radio, and extensions of the local public network).

One primary objective of this common interface standard is to provide for inter-operability between equipments of different origin, so offering users a family of telecommunication services for voice or data, either as basic services, or with optional (and compatible) extensions."

(ETSI 1992b:23)

The quote illustrates how a number of different applications were envisioned for the DECT system, which in turn indicates that flexibility and versatility were important foci during the development. The document continues to define the two interfaces that are standardised; the radio interface and the interface between DECT and the network it is connected to:

> "Lastly, this ETS also has the objective of regulating the use of, and interface of, two shared resources:
>
> - the RF spectrum which is allocated to provide for the cordless operation of the communication system; and
>
> - one or more networks for which the DECT network provides cordless connection.
>
> It is the objective of this ETS to ensure that conforming equipments will be able to use the above resources efficiently and with the minimum degree of mutual interference (i.e. avoiding adverse affects to existing, or future, users of those resources ...)."
>
> (ETSI 1992b:23)

These two excerpts from the overview of the DECT standard capture two important features of the standardisation process. The first of these is the aim to create a versatile, multi-service system. The second is a quintessential aspect of all communications standards, to control the interference created by a certain part of the system upon the other parts.

The four sub-documents of the ETS 300 175 that follow the overview give a specification of the lower layers of the communication links. The structure is almost identical to that of the ISO Open Systems Interconnection (OSI) model (see e.g. Stallings 1994:18), which is widely used to describe virtually all communications systems. In the ISO/OSI model, seven generic layers of communication protocols are specified. They represent the different functions that have to be fulfilled in order to establish a communication link.

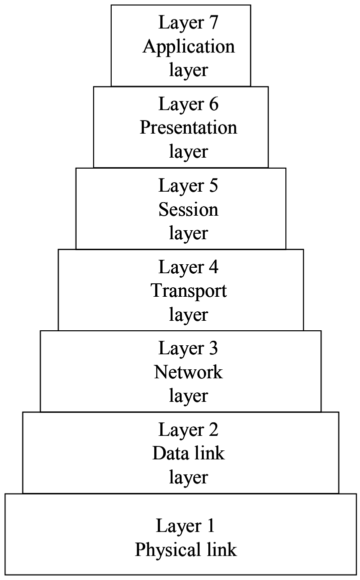

Figure 15: The ISO/OSI model. (Stallings 1994:18)

The DECT protocol layers resemble the ISO/OSI stack. Since the purpose of DECT is to provide an access system to various types of networking infrastructures, the higher protocol levels are handled by the networks that DECT connects to and thus are not standardised within DECT.

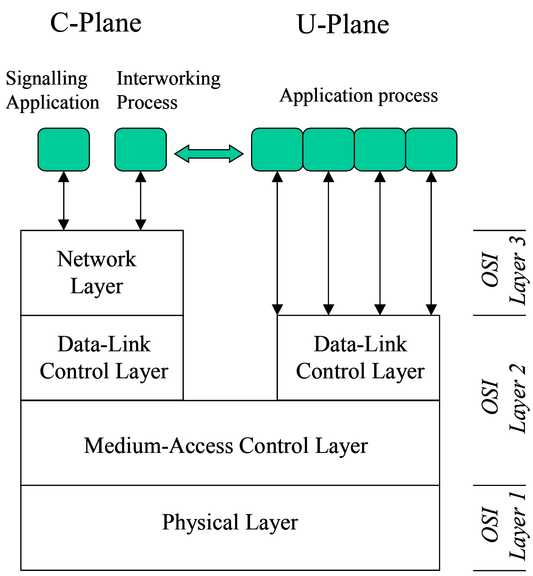

Figure 16: The DECT protocol layers. (ETSI 1991a:17)

<u>The physical layer</u>

The physical layer is the lowest layer of the ISO/OSI model and is concerned with the transmission of a bitstream over a physical link. In the case of DECT, the physical link is of course the radio spectrum used by the system (whether that is a physical entity or not need not be discussed here). Three main areas are specified in sub-document ETS 300 175–2 of the DECT standard (ETSI 1992c):

1. The RF channel.
2. The structure of the bitstream.
3. Procedures governing transceiver behaviour.

The RF channel is determined in terms of the desired electro-magnetic properties. For example frequency, output power, receiver sensitivity and attack and release times for the transmitter (i.e. the time it takes the transmitter to reach or come down from the desired output power level, typically in the order of 10 μs). A typical way that these properties are expressed in the standard is shown in the following passage, where the carrier frequencies of DECT are determined:

> "The radio frequency band allocated to the DECT service shall be 1 880 MHz to 1 900 MHz. Ten RF carriers shall be placed into this band with centre frequencies Fc, given by:
>
> Fc = F0 - c x 1 728 kHz
>
> where F0 = 1 897,344 MHz;
>
> and c = 0, 1, ..., 9.
>
> The frequency band between Fc - 1 728/2 kHz and Fc + 1 728/2 kHz shall be designated RF channel c.
>
> NOTE: A nominal DECT RF carrier is one whose centre frequency is generated by the formula:
>
> Fg = F0 - g x 1 728 kHz, where g is any integer.
>
> All DECT equipment shall be capable of working on all 10 DECT RF channels."
>
> (ETSI 1992c:15)

Apart from giving this type of exact specification of desired values of e.g. the carrier frequency, many parameters also have error margins specified. Since it is clearly impossible to make components, etc, that behave perfectly, it is necessary to state to what degree their imperfections are tolerable.

The second aspect of the physical layer is the structure of the bitstream that is transmitted over the physical link. In DECT, as in any digital communications system, the data being transmitted is divided in to frames of one or several predetermined lengths. To these chunks of data, a number of extra information bits are added to give the intended functionality of the various levels of the communications protocol. In the case of DECT's physical layer, the additions contain fields for e.g. synchronisation between transmitter and receiver, early error detection and guard time between time-slots.

Three different TDMA channel structures are defined in ETS 300 175–2, offering full-slot, half-slot and double-slot transmission. For the full-slot transmission that is typically used for voice services, the channel structure at the physical layer is illustrated below:

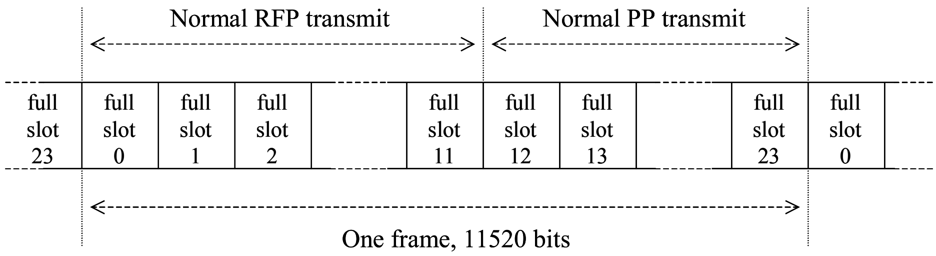

Figure 17: The channel structure for full-slot channels at the physical layer. (ETSI 1992c:16)

The structure is used on each of the 10 available carrier frequencies. The bitstream structure underlying the channel structure is repeated for each of the 240 available channels in the system (120 of which are uplink and 120 of which are downlink).

The third and final aspect of the physical layer, described in ETS 300 175–2, are procedures related to transceiver behaviour. This is specified both in terms of a number of functions that e.g. DECT terminals have to be able to perform, for example signal strength measurement or collision detection, and in terms of how the transceivers should react to instructions from other protocol layers, e.g. requesting it to adjust synchronisation or transmission frequency. Higher protocol layers for radio resource management use some of the functions performed by the DECT terminals. This typically includes the signal strength measurements that provide necessary information for the channel assignment schemes of higher protocol levels.

<u>The medium access control layer</u>

In the medium access (MAC) layer (ETSI 1992d) a number of different logical channels are defined for the DECT system. These channels include both data and control information. The MAC layer determines how these channels are mapped on to the bitstream that is transmitted over the physical link. 13 different control channels are defined in DECT. They have various bit rates and different error correction schemes, as well as automatic repeat request (ARQ) schemes to ensure that control information actually reaches the receiver. In this sense the control information is substantially more protected than user data.

The MAC layer is used to map all the different types of information that has to be transmitted between the base and the terminal, on to a single physical channel. Since a multitude of control information has to be transmitted along with the actual data (i.e. digitised speech), the specification of how the bitmapping is to be carried out, as well as how control information should be generated and what responses it should give, is extensive. The MAC layer specifications comprise the largest part of the DECT standard, approximately one fifth of the total material.

Mapping the data and control bits of a transmission on the physical layer also involves such aspects as error correction, encryption and scrambling. The MAC layer thus defines these procedures for the DECT system.

<u>The data link control layer</u>

The data link control layer (ETSI 1992e) defines two planes within the layer, the C- and the U-plane. The C-plane contains mainly control information, and the U-plane user information (i.e. speech or data). As expressed in the standards document:

> "The C-plane is mostly concerned with the DECT signalling aspects. It provides a reliable point-to-point service that uses a link access protocol to offer error protected transmission of network layer messages. The C-plane also provides a separate point-to-multipoint (broadcast) service (Lb).
>
> The U-plane is only concerned with end-to-end user information. This plane contains most of the application dependent procedures of DECT. Several alternative services (both circuit-mode and packet-mode) are defined as a family of independent entities. Each service provides one or more point-to-point U-plane data links, where the detailed characteristics of those links are determined by the particular needs of each service. The defined services cover a wide range of performance, from 'unprotected with low delay' for speech applications to 'highly protected with variable delay', for local area network applications."
>
> (ETSI 1992e:11)

The data link layer, based on service requests from higher protocol layers, sets up control and user channels, maintains them and terminates them. The type of service request determines the types of channels that are set up. For example there are 6 different types of U-plane channels with different characteristics, as illustrated in the above quote. Setting up and terminating channels is an integral part of handover procedures, which are also controlled in the data link control layer.

The network layer

The network layer (ETSI 1992f) establishes secure connections between transceivers in a DECT system. The connections can either be circuit switched services used for user channels such as speech channels, or connectionless channels for e.g. control messages. The layer defines a number of different network entities governing all the procedures needed to set up a connection, e.g. authentication and location procedures.

Identities and addressing

Identities for both fixed and portable parts are an integral aspect of a functioning DECT system. These aspects are treated in subsection six of the DECT standard (ETSI 1992g).

The standard defines four different categories of identities: fixed part identities, portable part identities, connection related identities, and equipment related identities. The identities are used for access of information from fixed to portable parts, for identification of transceivers in a system, for paging, and for billing. The identities are intended for a number of different usage situations:

> "These identities support:
>
> - different environments, such as residential, public or private;
> - supply to manufacturers, installers, and operators of globally unique identity elements with a minimum of central administration;
> - multiple access rights for the same portable;
> - large freedom for manufacturers, installers, and operators to structure the fixed part identities, e.g. to facilitate provision of access rights to groups of DECT systems;
> - roaming agreements between DECT networks run by the same or different owners/operators;
> - indication of handover domains;
> - indication of location areas, i.e. paging area;
> - indication of subscription areas of a public service."
>
> (ETSI 1992g:7)

Security features

One important aspect of a digital cordless system is that it offers a different level of security than its analogue equivalents. In DECT, the design of the air interface was heavily influenced by the aim to have a secure common interface, which is especially relevant in business applications. This is reflected in subsection ETS 300 175–7 (ETSI 1992h) of the standard. It states the following regarding the scope of the security features in DECT and how they relate to other subsections of the standard:

> "The security architecture is defined in terms of the security services which are to be supported at the common interface, the mechanisms which are to be used to provide the services, and the cryptographic parameters, keys and processes which are associated with these mechanisms.
>
> The security processes specified in this part are each based on one of two cryptographic algorithms: an authentication algorithm and a key stream generator. The architecture is, however, algorithm independent, and either the DECT standard algorithms, or appropriate proprietary algorithms, or indeed a combination of both can, in principle, be employed. The use of the employed algorithm is specified in this part.
>
> Integration of the security features is specified in terms of the protocol elements and processes required at the network and MAC layers of the common interface.
>
> The relationship between the security features and various network elements is described in terms of where the security processes and management functions may be provided."
>
> (ETSI 1992h:12)

The security features of the DECT standard thus affect several levels of the protocol stack.

Speech coding and transmission

The eighth subsection of the DECT standard (ETSI 1992i) defines the speech codec used in DECT. An Adaptive Differential Pulse Code Modulation, ADPCM, is used coding continuous speech on the 32 kbps data channel of DECT. This is one of many possible speech codecs. It allows telephone line speech quality in half the bandwidth used in normal fixed telephone lines. Different codecs vary in how they translate (digitise) an analogue speech signal into a digital bitstream. This process always involves approximating the analogue signal with a digital signal that by definition has a lower granularity since the possible signal interpretations are finite.

Apart from defining the method of speech coding, the subsection also defines a number of restrictions on the performance of speech transmission in a DECT system. For example, the maximum delay tolerated in the system is determined, as well as echo control – a fundamental aspect of telecommunications equipment.

The public access profile

The default access profile used in DECT is called the Public Access Profile (ETSI 1992j). It is intended primarily for public services, but will work with several other types of services as well. Since the development of the original DECT standard, several other access profiles have been developed, e.g. for data services. The general DECT standard contains more functionality than is necessary for each individual type of service, which allows the standard to contain numerous specialised access profiles suited for different types of applications.

In subsection ETS 300 175–9 (ETSI 1992j), the functionality of the portable parts of a DECT system are defined in order for them to comply with the Public Access Profile. The section defines how user (i.e. speech or data) and control information should be transmitted and received by the portable part. It also defines the functionality of the portable part in terms of how calls should be set up and terminated, procedures related to handovers, etc.

The approval test specification

The Approval Test Specification is a separate standards document that defines how DECT equipment should be tested in order to insure that it complies with the ETS 300 175 standard. When the original DECT standard was approved there only existed an interim test specification, I–ETS 300 176 (ETSI 1992k).

The test specification essentially specifies three things. Firstly, what parameters are to be tested on the devices under test, e.g. unwanted RF emission or RF carrier accuracy. Secondly, what values are acceptable for the results of these tests. Thirdly, what the test conditions and test set-up should be in order to insure that test results are comparable both to reference values, and between different pieces of equipment.

Sophisticated measurement equipment is needed to carry out the specified tests. A test bed for the DECT protocol typically costs around USD 200 000. The test specifications are comprehensive, and cover most aspects of interaction between devices in a system, and of interaction between the system and its environment.

> ”Its aims are to ensure the following:
>
> - efficient use of the radio frequency spectrum;
> - no harm is done to any connected network and its services as well as to other radio networks and services;
> - no harm is done to other DECT equipment and its services;
> - inter-operability between DECT equipment intended for public access.”
>
> (ETSI 1992k:13)

Amendments and further development

A number of amendments have been made to the DECT standards since the first version of them were adopted by ETSI in 1992. The amendments for example define:

- A number of access profiles: the Generic Access Profile, the Public Access Profile and the Radio in the local loop Access Profile.
- A number of interworking units to allow interconnection with different network infrastructures: the DECT/GSM IWU, and the DECT/ISDN IWU.
- Data applications.

The standardisation effort did not end with the first version of DECT. It is an ongoing effort within ETSI. As before, meetings are held regularly, and industry participants continue to drive the development.

Appendix 3: Acronyms

AXE	Automatic Exchange. The Ericsson digital switching system.
CDMA	Code Division Multiple Access. A method of allowing multiple users to share the same frequency spectrum. Each user is assigned a unique code that distinguishes his or her signal from those of other users. All users can then transmit simultaneously on the same frequency spectrum. This access technique gives high spectrum utilisation in theory but requires relatively complex systems in operation.
CEN	European Committee for Standardisation.
CENELEC	European Committee for Electrotechnical Standardisation.
CEPT	Conférence Européenne des Administrations des Postes et des Télécommunications. The European standardisation and telecommunications harmonisation body for national telecommunications operators (PTTs). Before 1989 this was the body that determined European telecommunications standards. Today this responsibility rests with ETSI.
CT0	Cordless Telephone 0. A generic name given to all early analogue systems for cordless telephony. Normally these systems operated on frequencies of 46–49 MHz for the uplink, and 1,6 MHz for the downlink. Products generally followed proprietary standards that complied with national requirements for different countries.
CT1	Cordless Telephone 1. The first standardised European cordless telephone system using multiple channels. An analogue system that was not adopted in all European countries (e.g. Great Britain).
CT2	Cordless Telephone 2. The second generation (digital) cordless telephone system for the European market. The system was developed by a

	number of British firms and was first standardised within Great Britain. Later it became an interim ETSI standard.
CT3	Cordless Telephone 3. An early Swedish digital cordless telephone system, based on Ericsson technology. The system was developed as a reaction to the CT2 development and like CT2 was adopted as an interim ETSI standard.
DCT900	Digital Cordless Telephone 900. The early digital cordless telephone product from Ericsson that was subsequently developed into CT3 and DECT.
DECT	Digital Enhanced Cordless Telecommunications. Originally (prior to 1995): Digital European Cordless Telephone. The ETSI standard for second generation digital cordless telephony.
DECT CI	DECT Common Interface. The DECT radio interface. Contains a number of access profiles for different types of usage.
DECT FP	DECT Fixed Part. The complete fixed part, i.e. base stations and base station controller (a switch), of a DECT system.
DECT FT	DECT Fixed radio Termination. The base station network of a DECT system.
DECT PP	DECT Portable Part. The handset used in DECT.
DECT PT	DECT Portable Termination. The radio part of a handset used in a DECT system.
DG IV	EU directorate 4, responsible for trade issues.
DG XIII	EU directorate 13, responsible for telecommunications issues.
ECTEL	European Conference of Telecommunications and Professional Electronic Industries.
EFTA	European Free Trade Association.
ES	End System. The subsystem of DECT that defines the type of terminal being used in all respects except those that involve the radio part of the terminal. Many different terminals are

	possible, ranging from the simple cordless phone to e.g. a small computer.
ESPA	European Selective Paging Association. A standardisation body for European manufacturers of paging equipment.
ETS	European Telecommunications Standard. The acronym that a standard adopted by ETSI receives.
ETSI	European Telecommunications Standards Institute. The European body for telecommunications standardisation. Any operator or manufacturer of telecommunications networks or equipment can be a member. Certain voting restrictions may apply however.
EU	The European Union.
FDD	Frequency Division Duplex. A method of separating up- and downlink transmissions by putting them in separate frequency bands.
FDMA	Frequency Division Multiple Access. A method of allowing multiple users to share the same frequency spectrum by dividing it into smaller partitions, and allowing only one user on each partition. The partitions can be re-used if the users are far enough from each other to not create too much co-channel interference.
GAP	Generic Access Profile. One of the DECT access profiles in the DECT CI. Used for e.g. plain cordless phone operation of DECT products.
GATT	General Agreement on Trade and Tariffs.
GSM	Global System for Mobile communications. The digital cellular mobile telephony system specified by ETSI and adopted throughout Europe and large parts of the world.
I-ETS	Interim ETS. An interim ETSI standard.
IEC	International Electrotechnical Commission.
ISDN	Integrated Services Digital Network. A high-speed method of fixed access to telecommunications networks.
ISO	International Organisation for Standardisation.

ISO/IEC JTC 1	The ISO/IEC Joint Technical Committee on Information Technology.
ITS	Informationstekniska Standardiseringen. The internationally recognised Swedish standards organisation for telecommunications.
ITU	The International Telecommunications Union.
ITU-R	The part of ITU that handles radio issues.
ITU-T	The part of ITU that handles telecommunications issues.
IWU	Interworking Unit. The subsystem of DECT that defines how a DECT system should interface with other types of networks, e.g. PSTN or ISDN.
MoU	Memorandum of Understanding.
PABX	Private Automatic Branch Exchange. A switch used within a corporation, the heart of the corporation's internal telephone network.
PAP	Public Access Profile. One of the DECT access profiles in the DECT CI. Used for public services, e.g. telepoint or Radio in the Local Loop.
PBX	See PABX.
POTS	Plain Old Telephone Service.
PT10	Project Team 10. The ETSI project team that developed the details of the DECT standard from 1989 to 1991.
PTS	Post- och Telestyrelsen. The Swedish regulatory authority for postal and telecommunications services.
PTT	Postal, Telegraph and Telecommunications service provider. Abbreviation normally used with reference to the national monopolies operating such networks.
SIS	Standardiseringen i Sverige. The Swedish Standards Institution.
TDD	Time Division Duplex. A method of separating up- and downlink transmissions by putting them in separate (alternating) time-slots. First the system allows uplink transmissions for a brief instant,

	then downlink, etc. Requires synchronisation to keep users from interfering with each other.
TDMA	Time Division Multiple Access. A method of allowing multiple users to share the same frequency spectrum by dividing it into time-slots, and allowing only one user on each time-slot. The time-slots can be re-used if the users are far enough from each other as to not create too large co-channel interference. This access method is often combined with FDMA.
WTO	World Trade Organisation.

Appendix 4: List of figures

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