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OVERCOMING A TECHNOLOGICAL DISCONTINUITY***

- The case of the Finnish telecom industry and the GSM

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ABSTRACT: The emergence of the Finnish telecom industry is to a significant extent based on the unprecedented success of Nokia. The case of the GSM is interesting in this context because it is at present the most widely diffused telecom standard in the world, and largely accounts for the international breakthrough of Nokia. Moreover, the GSM was discontinuous to the equipment suppliers compared to previous standards, thereby disrupting the industry. The purpose of this paper is to identify the nature and consequences of these discontinuities to the Finnish industry, and to analyses the conditions and processes that contributed to Nokia's ability to develop the competencies necessary to overcome them. The paper applies the framework of technological systems towards this end and concludes with a discussion on the implications of the findings also to present and future developments of the industry.

Keywords: GSM, Finnish telecom, discontinuity, design space, business opportunities

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TIIVISTELMÄ: Suomeen on syntynyt vahva teleala jossa Nokialla on merkittävä asema. GSM-standardi on yleisin telealan standardi, ja se myötävaikutti keskeisesti Nokian menestykseen. Laitevalmistajien kannalta GSM oli osittain epäjatkuva teknologia ja sen syntyminen ja kehittyminen muokkasivat telealan yritysrakenteita. Tämän työpaperin tarkoitus on tarkemmin analysoida GSM:ään liittyviä teknologisia epäjatkuvuuksia ja paneutua näiden epäjatkuvuuksien luomiin haasteisiin ja mahdollisuuksiin Suomen telealan synnyn ja kehityksen sekä Nokian menestymisen näkökulmista. Lähtökohdaksi on otettu kehikko, jossa korostetaan osaamisten, verkostojen ja taloudellisten tekijöiden vuorovaikutusta yritysten ja toimialojen kehityksessä (nk. teknologinen järjestelmä). Tutkimuksen loppuosassa käydään keskustelua myös telealan nykyhetken tilasta ja kehityksestä.

Avainsanat: GSM, Suomen teleala, teknologia, epäjatkuvuus, taloudelliset mahdollisuudet

Contents:

1 INTRODUCTION

1.1 Background

Industries are dynamic and always on the move in terms of changing market positions, the exit and entry of firms. In the telecom industry a primary driver of industrial dynamics is technological change related to standardisation. Specifically, the telecom industry is characterised by the transition between different generations of standards commonly referred to as 1G, 2G, and presently 2,5G and 3G (some commentators also identify 4G as a competitor to 3G). Standardisation achieves coordination between complementary technologies, opens up new mass markets, and contributes to the diffusion of innovations. Accordingly, the transitions between different standards also create new opportunities to the firms and other actors in the industry, and provide scope for differentiation in terms of firm performance. This paper looks at greater detail on one such transition in the context of the Finnish telecom industry, namely the transition from the analogue NMT standard of 1G to the digital GSM standard of 2G.

Characterising the Finnish telecom industry is the unprecedented success of Nokia with an approximate 40 percent global market share in the mobile terminals market, and a strong position in the cellular network systems market as well. Apart from being the largest Finnish company by the number of employees and the size of turnover, Nokia also contributes significantly to the Finnish GDP growth (in the peak year of 2001 Nokia accounted for roughly one third of GDP growth). Moreover, the contribution of Nokia to the renewal of Finnish industries is noteworthy as the industrial base has diversified from the traditional forestry and engineering industries towards high-technology industries, spearheaded by the growth of the electronics and ICT-related industries. According to estimates, in 2001 Nokia accounted for some 40 percent of the total sales and as much as 80 percent of total exports of the ICT-related industries. (Ali-Yrkkö & Hermans 2002).

The transition from the NMT to the GSM standard is interesting from a Finnish viewpoint for various reasons. The GSM standard is the most widely diffused standard in the world till present with a 69 percent share of all wireless telecom subscriber in the world, and largely accounts for the international breakthrough of Nokia in the mid 1990s (Pulkkinen 1997; GSM world 2003). The widespread diffusion and further extensions of the GSM also introduced a range of new technological and business opportunities, and largely accounts for the changing market position and composition of firms in the industry as these sought to master the technologies underlying the standard. This is illustrated in table 1 below, according to which Nokia's strong position in the NMT market has been accentuated further in the GSM market, while other important firms clearly have lost ground (most notably Ericsson, Siemens and Panasonic), or exited the market (Storno, Dancall, Spectronik).

	NMT/1985	GSM/2000
Nokia*	26%	31%
Motorola	6%	14%
Ericsson**	15%	10%
Siemens	9%	5%
Panasonic	9%	5%

* Mobira in 1985
**Sony-Ericsson in 2002

Table 1. The market share of the major equipment suppliers in the NMT/1985 and GSM/2002 markets (source: Häikiö 2001b, p.134; www.3g-generation.com)

By the face of it, the technologies underlying the GSM might thus classify as discontinuous as they are widely diffused and have offered a springboard to growth for such firms as Nokia, while others have been in a less advantageous position (Tushman & Anderson 1986). An understanding of the degree to which the GSM was discontinuous compared to the NMT - and how the underlying technologies and competences were developed in the Finnish context - is therefore important in order to properly account for the international breakthrough and growth of Nokia, as well as the emergence of the competence base and present strength the Finnish wireless telecom industry in a broader sense.

1.2 Purpose and structure of the paper

The transition to 2G and the GSM is often portrayed as a continuation of the regulatory regime established during 1G, although new firms and other actors were involved. Likewise, the transitions from 1G to 2G, and further to 2.5G and to 3G have recently been studied at greater length, among others by Gaffard & Krafft (2000), Fransman (2002), and Steinbock (2002) from the viewpoint of the organisation of the industry. This paper contributes to the extant literature by recapitulating the history of the GSM from the viewpoint of how the necessary technologies and competence related to this standard were developed in Finland. It offers a background account of the evolution of the competence base upon which the global breakthrough of Nokia was based. More precisely, the paper deals with the following two research questions:

1. Which were the crucial GSM-related technologies and competence fields that enabled Nokia to achieve a first mover advantage and strong position in the GSM market?
2. To what degree could these technologies be characterised as discontinuous, when, where and how were the related competences developed?

The paper draws on the literature on technological discontinuities for the identification and definition of technological change in relation to the GSM, and discusses the development of the related competencies from the viewpoint of the emergence of the underlying technological system (Tushman & Anderson 1986; Carlsson & Eliasson 2001). Hence, it is more focused on the emergence of technologies and related competencies than the realisation of business opportunities, which subsequently turned Nokia into a major player in the industry.

This paper is structured as follows. Section 2 defines the concept of technological discontinuity, and relates it to a discussion of technological systems as a conceptual organiser to be applied to the case study. Sections 3 and 4 constitute the empirical part of the paper. In section 3, the principal technologies and related competence fields of cellular systems and the GSM are identified, while section 4 analyses the case material. Section 5 concludes the paper by synthesising the main results and discussing implications for the present development of the industry.

2 A CONCEPTUAL FRAMEWORK

2.1 A typology of technological change – the concept of technological discontinuity

The idea that technology progresses through alternating phases of incremental and discontinuous change relates to the contributions of the Austrian economist Joseph Schumpeter, writing in the early 20th century (Schumpeter 1911, 1942). Schumpeter identified discontinuous technological change and related innovations as the sources of the 'creative destruction' of industries. Subsequently economists working in this tradition have sought to characterise different types of technological change into more detailed typologies by their nature and effects (see Freeman 1994 for a review of this literature). Such typologies are useful conceptual devices for focusing attention on important phases in the development of an industry, and for separating out 'major' types of technological change from minor ones.

One such typology, referred to throughout in this paper, makes a distinction between incremental improvements of existing technologies, and technological discontinuities that mark a break from incremental improvements (Tushman & Anderson 1986; Anderson & Tushman 1997). A technological discontinuity might be defined as a *"breakthrough innovations that advances by an order of magnitude the technological state-of-art, which characterise an industry. They are based on new technologies whose technical limits are inherently greater than those of the previous dominant technology, along economically relevant dimensions of merit"* (Anderson & Tushman 1997). They also make the distinction between competence enhancing and competence destroying discontinuities. A competence enhancing discontinuity is based on the introduction of innovations and new technologies that push forward the state-of-art in a field, but nonetheless complements existing competences. A competence destroying discontinuity is based on innovations and new technologies so fundamentally different that previous competencies become obsolete, and are substituted for new one's.

Tushman & Anderson (1986) established the relationships between technological discontinuities and industrial dynamics through empirical analysis of the minicomputer, cement and airline industries. The distinction between competence enhancing and destroying discontinuities is based on qualitative material on the innovations in the industries included.

Their discontinuous nature was measured as percentage improvements in price/performance ratios within the three product classes. Measures of uncertainty, demand growth, the entry and exit of firms, as well as early adopters were also included. The findings essentially confirmed that technologies in all three industries evolve through periods of incremental change punctuated by technological breakthroughs and innovations. Moreover, competence enhancing discontinuities were initiated by the large incumbents in the industry. Competence destroying discontinuities were initiated by new entrants, and caused greater inter-firm variability in sales and market shares.

Following these seminal findings, there exists a burgeoning literature that has, by and large, confirmed and elaborated on these relationships between discontinuous technological change and industrial dynamics (see Ehrnberg 1996 for a review). The concept of technological discontinuity has subsequently become integrated in the analysis of industry life cycles (Utterback 1994). Industries are considered to evolve through successions of technology cycles, each inaugurated by a technological discontinuity. Following a discontinuity is an era of substitution and design competition, as new entrants compete through innovations. This competition gradually leads to what Abernathy & Utterback (1978) call a dominant design, or an agreed upon benchmark synthesising previous achievements to direct future directions within R&D. The rate of substitution and design competition drops, small firms are often over taken by the incumbents, and incremental innovation continues until the next discontinuity.

Another relevant contribution in this context is Christensen (1997). He distinguishes between sustaining and disruptive technological change. Sustaining technological change improves the performance of established products along the dimensions of performance that existing customers in major markets have historically valued. In contrast, disruptive technological change introduces features to products that initially only attracts customers at the fringe, while they subsequently also overtake the mainstream market. Accordingly, disruptive technological change requires the mastery of both the new technologies and the new markets at the fringe, since they disrupt the customer's value perception of products. Hence, the point to be made here is that the speed of diffusion of technologies is an additional dimension of discontinuous change. If new technologies diffuse quickly to new markets, first movers can gain volume related advantages if they are able to attract customers at the fringe of the mainstream market. If diffusion is slower, a larger share of the firms will have more time to overcome a discontinuity and enter new markets.

2.2 Discontinuities and evolving design spaces in the telecom industry

Ehrnberg (1996) argues that there is substantial variety surrounding the definition and identification of technological discontinuities in the literature following the seminal paper by Tushman & Anderson (1986). There are two points of ambiguity to this issue. First of all, whatever the concepts used, the question of 'what' it is that changes appears to vary from one study to the next. Put differently, at which level of analysis should one identify changes that mount to a technological discontinuity? Secondly, the question of 'how large' this change should be to classify as a technological discontinuity likewise varies significantly. In addition, it seems clear that both of these points of ambiguity will depend on the type of industry that is analysed.

On the first point, Ehrnberg (1996) concludes that three dimensions of the unit of analysis in identifying technological discontinuities have been used. Common to all dimensions is that they focus on the product (or process) affected by the discontinuity.[1] The first dimension focuses on the underlying competences for developing the product. The second dimension focuses on physical changes in the product itself. The third dimension focuses on the changes in the price/performance ratio embodied in the new product, and thereby relates a technological discontinuity to the speed of diffusion in so far as superior price/performance ratios are import to customers in the market. While these dimensions add some clarifications, they also add new ambiguities. For example, 'competences' is a broad term to describe different types of knowledge and tangible assets underlying different types of products. Competencies are often considered as firm specific, but do typically also span organisational and institutional boundaries due to the importance of complementarities during the exchange of knowledge between firms (Foss 1999).

In this paper, the focus on the development of GSM cellular systems in Finland, extends the conceptual framework to cover the role played by the broader network of actors involved in developing the required competencies (compare with McKelvey & Texier (2000) for the case of the Swedish wireless telecom industry). A relevant concept for this purpose is that of technological systems. A technological system can be defined in three dimensions. The *cognitive dimension* defines the clustering of technologies that together make up the

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[1] Product and process innovations are often related. However, product innovations are more significant in this context since they have greater potential to renew industries by creating new markets.

competence base, or design space to paraphrase Stankewicz (2002), which scientific and engineering communities draw upon within a technological system. The *organisational and institutional dimension* defines the network of actors embodying the design space, and provides the social context of its emergence and development. These networks are typically made up of a variety of actors, ranging from firms, universities, research institutes and other private and public sector actors (see also Rappa & Debackere (1992)). Finally, the *economic dimension* refers to those specific actors and their functional competencies that turn technological opportunities embedded in design spaces into business opportunities. (Carlsson & Eliasson 2001).

This definition of technological systems is here used as an overall conceptual framework for anchoring the development of GSM-related competencies to the cognitive, organisational, and institutional setting in which it took place. In this context, the idea of *design space* seems to be relevant to capture 'what' changes in a discontinuous sense in the underlying technologies and related competencies needed to develop a GSM cellular system (see section 3.1 for a detailed discussion). The organisational and institutional setting constitutes of those university groups, research institutes, firms and other actors in Finland that contributed to the emergence and development of the required competencies embodied in the design space. The *economic dimension* refers to forceful actors and their functional competencies that turn technological opportunities into business opportunities. It essentially refers to the role played by Nokia, and various related firms, in translating technological opportunities into business opportunities, and vice versa, in the GSM terminals and network equipment market.

On the second point of ambiguity in terms of 'how large' a technological change should be in order to classify as discontinuity, Ehrnberg (1996) suggests an analytical framework that appears to be useful also in this context. She focuses on how much the old and new technologies overlap in terms of the competencies required. If the new technology is within the same generic technology field it is easier to master compared with when the new technology marks a shift towards another generic field. Furthermore, Ehrnberg (1996) differentiates between whether the new technology complements or substitutes competencies within an old or new generic technology field. With reference to Carlsson & Eliasson (2001), it seems more relevant to talk about evolving design spaces, as equivalent to the transition from different cellular standards, rather than shifting generic technologies. Thus, one way to trace the evolution of a design space is to identify those clusters of technologies that either complement or substitute existing ones as determinants for this evolution. This overall framework, as applied to the case of the GSM, is illustrated in figure 1.

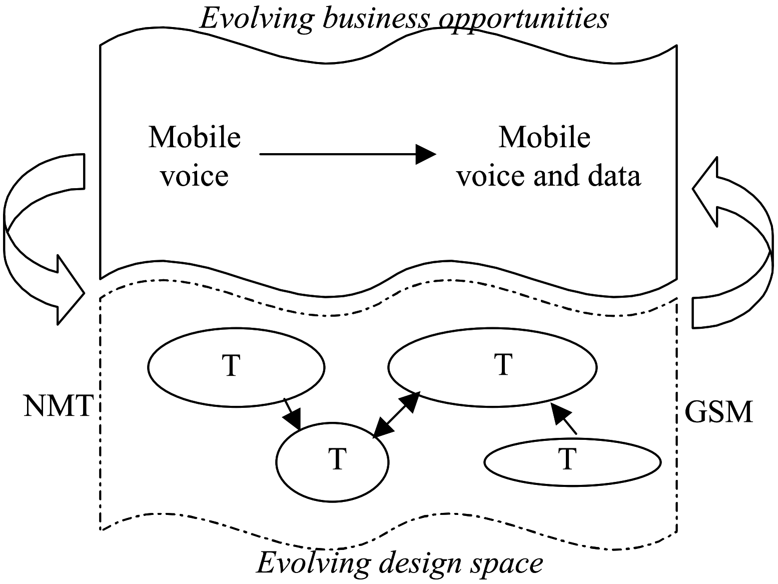

Figure 1. A conceptual framework - the evolution of the cellular network system design space from NMT to GSM (T=cluster of technologies)

In the figure the economic dimension of a technological system is illustrated in terms of the different business opportunities that the NMT and GSM standards (including the GSM extensions through GPRS and EDGE) have created for the equipment producers and service operators. These different business opportunities draw on specific clusters of technologies embodied in the evolving design space of cellular systems, as these have been specified by the different standards. Hence, business opportunities related to mobile voice were associated with clusters of technologies related to the NMT while business opportunities related to the integration of mobile voice and data were associated with those of the GSM standard (the letters T in figure 1 denote such technologies, while the arrows denote their relationships). Thus, this evolution was to a great extent spurred by standardisation and the addition of new technologies and competencies – some of which were incremental while others were discontinuously complementary or outright substitutes - as well as the integration and restructuring of existing one's. Furthermore, this evolution of the design space is also paralleled by the changing composition of the related network of actors, or the organisational and institutional dimension, contributing to the development and application of cellular systems technologies to the GSM in Finland.

2.3 A note on the methodology

The methodology chosen towards achieving the aims of this paper is a single case study approach. Stake (1995) makes a distinction between intrinsic and instrumental case studies. An intrinsic case study seeks an understanding of the uniqueness of a specific case as a goal by itself while an instrumental case study uses a specific case as an instrument towards understanding a broader issue. The case of the development of competencies related to the GSM in Finland in this paper is primarily describable as an intrinsic one, due to the importance of the case to the international breakthrough and growth of Nokia. Nonetheless, this paper also contributes to a broader discussion about the nature of technological and industrial dynamics in the telecom industry, as well as to an understanding of how firms master technological discontinuities.

The case study builds on qualitative semi-structured interviews with 21 interviewees well vested in the case due to their own participation in the development of technologies related to the first GSM cellular system commercialized in Finland (see appendix 3). The interviews had two purposes, apart from establishing the broader background context of the case study. The first purpose was to identify the key competence areas underlying the development and commercialization of the first GSM cellular system, aand to characterize the nature of these competence fields according to the distinction between complementing versus substituted competencies – or competence-enhancing versus competence-destroying discontinuities. This characterization relied on the 'discontinuity chart' discussed in section 3.3, based on the degree to which the interviewees perceived clusters of technologies as complementary or substituting during the evolution of the design space from the NMT towards the GSM. The second purpose of the interviews was to map the case chronology as well as to interrogate in depth how the necessary competencies were built to overcome the discontinuities. By way of clarification, it should be noticed that our understanding of 'competences' is here relatively narrow and confined to the knowledge of specific technologies that individuals draw upon during invention and innovation.

The issue of generalization of the results is of lesser concern given our interest in the uniqueness of the case of the GSM. Nonetheless, the conceptual framework developed above is reflected in the interview structure, as well as in the description of the case study, and thereby functions as a conceptual organizer and facilitator for a general discussion of technological and industrial dynamics in the telecom industry. The analysis of the interviews was based on their literal notes. An important aspect of the validation of the case study description and the results was that of data and research triangulation (Yin 1989). Data triangulation refers to the combination of different data sources to bear on the same case study. In this paper, reference is made to the interviews as well as numerous publicly available technical documentation, journals, previous research publications, and presentations. Research triangulation refers to the formation of multidisciplinary research groups to deal with the same case study. This type of triangulation is especially evident in this paper due to the different disciplinary background of the authors combining technology and economic analysis. Furthermore, preliminary drafts of the paper have been circulated amongst interviewees and another commentators knowledgeable about the case to secure consistency of the description and validity of the conclusions.

3 CELLULAR SYSTEMS AND GSM STANDARDARDISATION[2]

3.1 Cellular systems and the underlying design space

The emergence of the design space underlying cellular systems is largely attributable to research undertaken at the Bell Laboratories in the 1940s, and the subsequent introduction of the cellular concept in 1947. In brief, the main idea was to use low power in radio transmission and to divide the area to be covered into smaller areas, or cells, each being formed by a transceiver station using several radio frequency channels depending on the anticipated traffic volume. In adjacent cells other frequencies are used to avoid interference, while the same radio frequencies in cells still further away could be reused. A core technique is that of handover, whereby the switch over from one cell to the next is facilitated even though a communication is in progress.

The cellular concept resolved various technological problems related to the advancement of wireless telecommunication at the time, of which the most significant one was the fact that communications capacity now was codetermined by the size of the cells instead of just by the available frequency spectrum. (Bekkers & Smith 1999). By the early 1980s further developments in complementary technologies (mainly in microprocessor capacity) allowed for the commercialisation of the first complete cellular system. The first analogous cellular systems were based on national standards such as NMT in Scandinavia, TACS in the UK, AMPS in the US, Netz-C in Germany and RTS in Italy. Since ISDN was the platform in the fixed network standardization, the digital access for users was seen to become important also in cellular networks after 1980s. Pan-European mobility was another goal, which motivated the development of the common digital cellular standard, later called as the GSM system.

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[2] The terminology used here is based on GSM and the abbreviations can be found in (GSM 01.02 and 01.04).

The basic building blocs of a cellular system included the mobile and base station subsystem (BSS), the switching subsystem (NSS), and the operations support system (OSS), as illustrated in figure 2. These basic subsystems, the components and technologies that they embody, thus defines the design space of the clusters of technologies, the evolution of which is the focus of this paper.

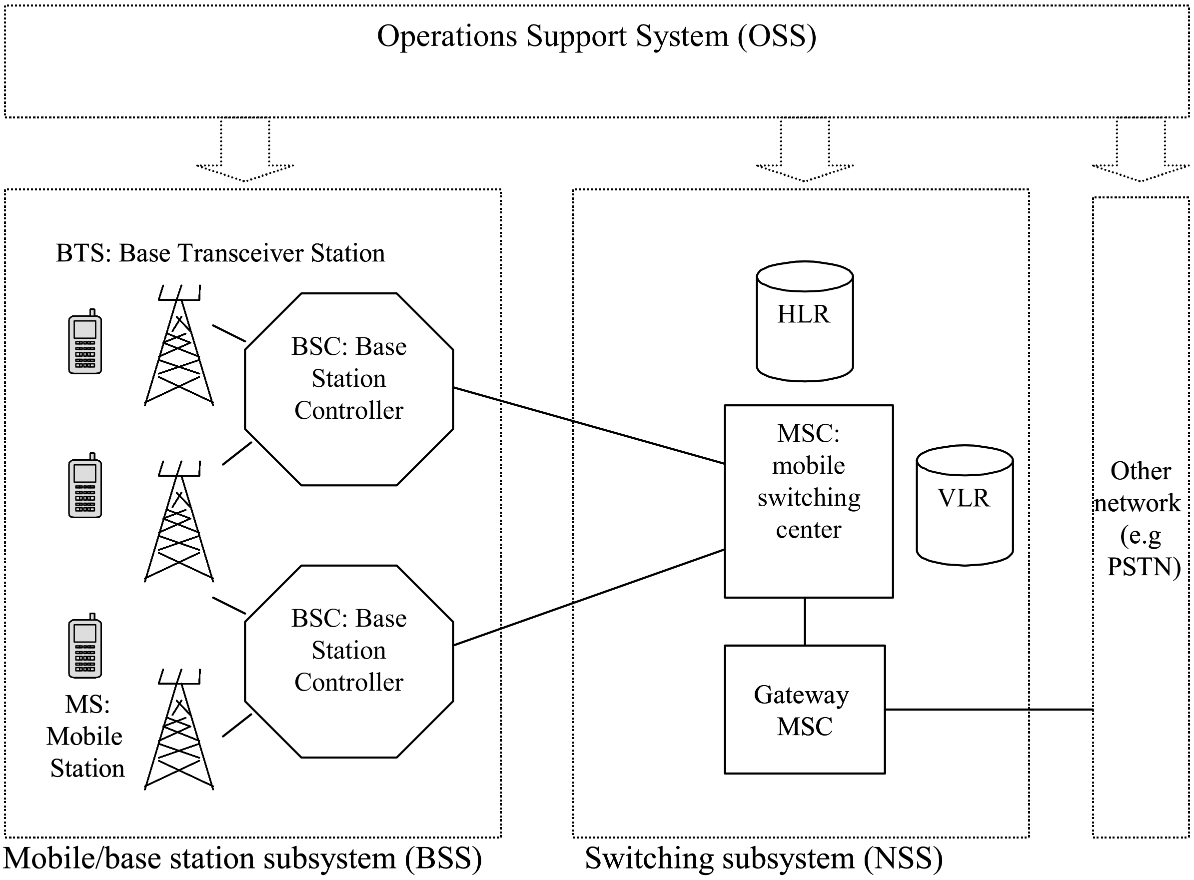

Figure 2. The basic building blocs of a cellular system (adapted from Bekkers & Smith 1999, p. 113)

The mobile subscriber access is based on the cellular radio coverage that is provided by several components constituting the mobile and base station subsystem (BSS). *The mobile station* (MS) is the mobile terminal equipment – or the mobile phone - used by the subscriber to access the telecommunications services offered by the network. The *Base Transceiver Station (BTS)* is the physical equipment used to give radio coverage to a determined geographical zone called a cell, and contains the equipment needed to communicate with the MS. The *Base Station Controller (BSC)* controls the various functions involved in the communication between the BTS and MS.

Roaming and handover, as well as the location databases, is managed in the *Switching Subsystem (NSS)*. *The Mobile Service Switching Centre* (MSC) is a digital switching center that facilitates all the switching functions needed for mobile stations located in an associated geographical area, called an MSC area. Furthermore, the MSC facilitates the switch-over from one MSC area to another, as well as from the cellular networks to other networks, such as the PSTN. This switch over is handled in the *Visitors Location Register (VLR)* and *Home Location register (HLR).* The VLR is the functional unit that dynamically stores subscriber information, such as location area, when the subscriber is located in the corresponding MSC area. The VLR also contains other information needed to handle incoming and outgoing calls. The HLR is a database used for the management of mobile subscribers.

Finally, the *Operations Support System (OSS)* enables the operation and maintenance of the cellular network. The mobile operator connects new customers, provides the services they need and collects charging information from the services with the help of OSS. The purpose of network maintenance is to prevent and correct faults and other disturbances in the operative network. In the GSM network the operation and management is centralized and modelled using the Telecommunications Management Network (TMN) standards. The *Operation and Maintenance Centre (OMC)* is the functional entity through which the Network Operator can monitor and control the GSM system. Furthermore, in the GSM subscriber and terminal security were separated from each other by adding to new management elements. *The authentication center* (AUC) is in charge of providing the authentication key used for authorizing the subscriber access to the associated GSM network. *The Equipment Identity Register* (EIR) is in charge of handling Mobile Station Equipment Identity included with each Mobile Station.

3.2 The standardization process from NMT to GSM

Standardisation essentially strikes at the interfaces of the MS, BTS and BSC (the base station subsystem), and MSC, HLR and VLR (the switching subsystem), by specifying interoperability, or how the different components of cellular systems communicate with each other during a call between to mobile terminals. Standards have also successively added a range of new services to the users. They have thereby also complemented or substituted the basic components and related technologies of the cellular systems design space. Even though it is outside the focus of this paper to discuss the various phases of standardisation in the wireless telecom industry in greater detail, it makes sense to briefly describe the standardisation process underlying the transition between 1G and 2G standards (standardisation in the wireless telecom industry has recently been analysed in greater depth by Lindmark (1995), Bach (2000), Manninen (2002) as well as by Edquist (2003).

In fact, the standardisation process leading up to the GSM might be interpreted as an extension of the work undertaken during the standardisation of the NMT by the Nordic PTTs. The opportunities associated with an extension of the NMT were already discussed in 1979 prior to the inauguration of the NMT service, when the World Administrative Radio Conference (WARC) reserved frequencies in the 900 MHz band for cellular systems. Nonetheless, the first concrete steps on the path towards the GSM standardardisation was taken by the French PPT in 1980, who invited several other PTT's from Western European countries for a meeting to be held in October that same year. Subsequently the German, Austrian, Swiss, Dutch, UK, Danish, Finnish and Swedish PTTs met several times during 1980-1982 in the preparation a proposal for a pan-European mobile system. The next concrete steps were taken by the Dutch and Nordic PTTs, who put forward the initiative in the form of a working group under the CEPT (Conférence Européenne des Administrations des Postes et des Télécommunications), which subsequently was institutionalised in June 1982 as the Groupe Spéciale Mobile (GSM). This institutionalisation of the collaboration was decisive since it dedicated the PTTs to achieving the same goal. The unexpected popularity of the NMT service, inaugurated in 1981, provided further impetus to the work of the GSM group. (Manninen 2002).

The ambitious aim of the GSM group became to develop a new mobile system in the 900 MHz radio frequency, which could coexist with the existing national systems but also provide pan-European roaming of both speech and non-speech value-added services. The decision that the GSM system would be a digital one was a natural step to support the Integrated Service Digital Network (ISDN), the digital standard for a fixed digital telecommunications network. This decision also added a range of new components and technologies to the NMT cellular system, of which digitalisation of the radio transmissions was the most significant one and restructured the design space accordingly. Moreover, digitalisation also implied that the GSM system was specified to support the OSI (Open Systems Interconnection) reference model, which was expected to become mainstream for data communications. The OSI model and the corresponding protocol stacks, in turn, increased the complexity of the system and required application of software tools to develop, test and simulate the system functionality and data communication across different subsystems.

Due to the envisioned compatibility of the GSM with the ISDN, a primary effort during standardisation was the objective to bring transmissions in digital form from the network down to the mobile terminal of the user. The advantages of digital radio transmissions related to improved spectrum efficiency, extensive security facilities, and realisation of new value added services and facilities such as SMS and data transfer (developed further in the GPRS standard), caller identification and call-transfer facilities. (Bekkers & Smith 1999). The digital radio transmission also facilitated the use of highly integrated circuits (ICs and VLSI modification of these) in mobile terminals, which contributed to reducing their size, weight and gradually also their price on the market (GSM Association 2003).

By 1985 the basic features of the GSM were specified, including radio frequency bands, security, roaming and services compatible with the ISDN and the fixed networks, such as the PSTN, while standardisation continued to finalize recommendations for each subtopic. At this point there was differences in opinion whether to apply broadband or narrowband radio transmission technology. A constellation of the French and German PTT's, Alcatel, SEL, Siemens and AEG favored the former solution, while a constellation of the Nordic PTTs, Nokia and Ericsson favoured the latter. This competition was subsequently resolved in favour of the narrowband solution and the 'Nordic camp', following extensive evaluation tests and experimental implementations of prototype systems in collaboration with the suppliers during 1986-1987 (the so called 'Paris competition' (Bekkers & Smith 1999; Hommén & Manninen 2003). This decision was also underpinned by high-level political commitment at the inter-governmental level of the European Commission and coincided with the establishment of the European Telecommunications Standard Institute (ETSI), to take over standardisation from the CEPT (Bach 2000).

The decision to opt for narrowband TDMA transmission was cemented at the Madeira meeting of the GSM group in February 1987. Some months later the same year at their next meeting in Copenhagen the 13 participating European PTTs signed the GSM Memorandum of Understanding (MoU) to support the rapid deployment of the GSM standard. This MoU established common guidelines for the procurement and deployment of GSM cellular systems, compatible routing and numbering plans to support pan-European roaming, as well as concerted service introduction, harmonization of tariffing principles and definition of accounting principles. The signatories of the MoU also committed themselves to the opening of commercial service in 1991.

Nonetheless, the decision to opt for the narrowband TDMA transmission also concealed a technological compromise, whereby further standardisation was to be based on several non-proprietary technologies according to a 'basket-model'. In practice, this meant that the protocol interfaces between the BSS and NSS were tightly specified, while the internal interfaces and the component technologies included in the MS, BTS, BSC, as well as MSC, HLR and VLR, were loosely standardised and made open for competing technological choices and associated R&D alliances. Alliance formation was also a response to the tight timetable of rollout of the services laid down in the MoU, which provided incentives to the firms to work together in different constellations. One such alliance was the ECR900 alliance, discussed at greater length below.[3] (Bach 2000). The downside of the basket model was that complexity increased significantly in the component technologies, which also increased the complexity of the system as a whole. Uncertainties and risks likewise increased for the equipment suppliers, which now were formally incorporated into the further standardisation of the GSM. These risks foremost related to the uncoordinated application of VLSI technology, the exponential increase in component software, and possible inconsistency in the overall system definition (Manninen 2002).

The choice of digital technology, the basket model approach to further standardisation, and the related increase in complexity of the system, amounted to a significant restructuring of the underlying cellular system design space and introduced different types of discontinuities from the viewpoint of the equipment suppliers. With reference to Ehrnberg (1996), the underlying competence base that firms needed to master broadened, while the price/performance ratio of the mobile terminals eventually increased in the denominator. The increasing complexity, related risks and uncertainties, also carried implications to the practical organisation of continued standardisation. Hence, the GSM group decided in 1989 to freeze the standardisation work and the further specifications of the GSM were divided into Phase 1, Phase 2 and Phase 2+. The later phases of standardization would complement the design

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[3] Three competing alliances were formed amongst European equipment supplier, of which the ECR900 is discussed in greater length below (see also Manninen (2002)).

space further, even though the business opportunities remain similar, more or less (see appendix 1).

3.3 Continuous and discontinuous GSM competence areas

Recalling the discussion on identifying technological discontinuities above, the focus of this paper is on discontinuous competence areas that the networks of actors in Finland hade to overcome in order to manage the transition from the NMT to GSM. Furthermore, the point of departure in the concept of design space suggests that these competence areas might be identified as those clusters of technologies, which appeared to complement or substitute the design space prevailing in the NMT era. Put differently, we suggest that substituting clusters of technologies introduced competence-destroying discontinuities, while complementing clusters of technologies introduced competence-enhancing discontinuities (Tushman & Anderson 1986). Clusters of technologies that neither substituted, nor complemented, the design space are of lesser interest in this context. Accordingly, table 2 identifies such complemented or substituted competence areas associated with this transition (bulleted in the table) in terms of the new technologies and services introduced through the GSM. They will be our focus in subsequent sections of this paper.

It is clear from the table that the most discontinuous consequences of the GSM concerned the BSS subsystem, while the NSS and OSS subsystems essentially could be upgraded by complementing NMT related competencies. This was a direct consequence of the fact that the BSS components had to become ‘smarter’ due to digitalization and the requirements of pan-European roaming, as parts of the software content of the system was transferred from the NSS to this subsystem (Hommén & Manninen 2003). In the BSS the digitalization of the radio transmissions substituted analogue RF filters for digital one’s, and introduced A/D and D/A converters. This implied an increasing demand for DSP hardware and software competencies both in the MS and BTS. Likewise, the integration of voice and data through the ISDN demanded competencies in integrating digital signaling stacks and the associated software into the MS and BTS, thereby also increasing the complexity of the software at the MS-BTS interfaces many fold. In addition, the BSC was disintegrated from the NSS in order to relieve the MSC of the handling of the radio medium and terminal mobility functions, and in so doing to increase the network performance in heavy load. Accordingly, the BSC was a new component in the BSS, requiring new competencies.

Table 2. Complemented and substituted competence areas associated with the transition from the NMT to the GSM standard.

	Complemented competence areas	**Substituted competence areas**
Mobile and base station subsystem (BSS)		
MS		
Digital RF filters, A/D and D/A converters		
• DSP and software		√
Signaling and control software		
• Application/user interface software	√	
Integration of voice and data services		
• Digital signaling stacks		√
• Signaling software complexity		√
BTS		
Digital RF filters		
• DSP and software		√
Signaling and control software		
Integration of voice and data services		
• Digital signaling stacks		√
• Signaling software complexity		√
BSC		
Mobility and roaming functionalities		
• Location area roaming and mobility		√
ISDN for integration of voice and data		
• Digital signaling stacks		√
• Signaling software complexity		√
Switching subsystem (NSS)		
MSC		
Mobility and roaming functionalities		
• Pan European roaming and mobility	√	
• Service software	√	
ISDN for integration of voice and data		
• Digital signaling stacks (SS#7 and OSI)	√	
• Signaling software complexity	√	
HLR/VLR		
Location data	√	
ISDN for integration of voice and data		
• Digital signaling stacks (SS#7 and OSI)		√
• Signaling software complexity		√
Operations Support System (OSS)		
Centralized operation and maintenance		
• Operations and Management Centre (OMC)	√	
• Protocol stacks and databases (TMN)		√
• Authentication Center (AUC)		√
• Equipment Identity Register (EIR)		√

The digitalization of the radio transmissions had lesser consequences to the NSS subsystem, since the MSC could be developed on top of a digital switching system, specified in accordance with the ISDN already in the NMT. The primary competence requirements related to integration of the GSM signaling in the MSC, HLR and VLR components of this subsystem, as well as to the necessary application of modern software development, testing and simulation tools introduced in the 1980s. In practice, this integration implied the fitting of HLR and VLR with solutions that enabled pan-European roaming. Furthermore, the increasing complexity of the software in the BSS also spilled over to the NSS, whereby the management of this complexity constituted a major challenge, even though the related technologies essentially complemented previous ones.

The challenges related to the increasing complexity of the software in the BSS and the NSS can be illustrated in the growth of lines of software code during the transition from the NMT to the GSM, as an indicator of the increasing demand for software specialists. By rough estimation, the lines of software code (LOC) in the MS grew from 20 000 in the NMT to 500 000 in the GSM. In the BTS the growth was approximately from 100 000 to 1 000 000, while in the MSC the growth was from 1 000 000 to 6 000 000. Moreover, the TMN parts included 1 500 000 new lines of software code. Thus, the acronym of GSM might rightfully be spelled out as ‘Global Software Monster’, at least from the viewpoint of the community of software engineers at the time.

4 OVERCOMING THE GSM IN FINLAND – DEVELOPING COMPETENCES[4]

4.1 The organisational and institutional setting

As suggested above, the cellular system design space evolved from the NMT to the GSM through the addition of clusters of both complementary and substituting technologies. Accordingly, a prime interest of this paper is on the emergence of the related networks of actors that facilitated the development of competencies in the fields characterised by the greatest discontinuity. With reference to Stankiewicz (2002) and Rappa & Debackere (1992), these networks of actors make up the organisational and institutional context of this competence development. They contributed to the subsequent commercialisation of Nokia's first GSM cellular system, as well as the further consolidation of the digital cellular system design space in Finland. A relevant point of departure to approach this organisational and institutional context is to identify the main contributors to total R&D in the telecom industry in the mid 1970s, prior to the start of the GSM standardisation. This is illustrated in table 3 below.

Table 3. Distribution of total R&D performed in the telecommunications sector in 1975 (Ekberg 1985, p.98)

Telecom firms	**60 %**
PTT	**20 %**
Technical Universities	**8 %**
Private telecom operators	**6 %**
Technical Research center of Finland	**6 %**

A noteworthy observation is the concentration of R&D to the industry at the time. Of the firms active in the industry, Nokia Electronics, Salora, and the state-owned firm Televa were the most significant ones in this context. Nokia Electronics had grown out of the cable works firm Suomen Kaapelitehdas, which merged in 1966 with the rubber works firm Suomen Kumitehdas, and the forestry firm Nokia to form the Nokia Group (Nokia for short). Nokia Electronics was an early mover in the field of digital technology, and had already in the 1960s and 1970s gathered competencies in the field of early large scale computers and related

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[4] The case chronology and major contributors of GSM-related competencies is illustrated in appendix 2. This section is to a significant extent based on the interviews referred to in appendix 3, while the interview guide is attached in appendix 4.

equipment, radio transmission technologies, and industry automation. Nokia Electronics was also involved in the development of radiotelephones and switching systems.

The further development of radiotelephones and switching systems at Nokia Electronics was intertwined with similar developments at Televa. Converging R&D projects, especially in the field of switching, lead to the founding in 1977 of Telefenno as a joint R&D venture between Nokia Electronics and Televa. (Häikiö 2001b). Based on a research consortium on the application of the emerging ISDN standard, Telefenno soon came to focus on the application of digital technology and the ISDN standard in switching systems for fixed networks. The first generation of a completely digital switching system for fixed networks was commercialised in 1982, and named the DX200. Subsequently, this joint venture was institutionalised in 1981 through the establishment of Telenokia, as Nokia acquired the remaining shares of Televa. (Palmberg 2002).

Turning to Salora, this firm was involved in miscellaneous fields within electronics, of which radiotelephone was a gradually expanding business starting from the early 1970s when the first nation-wide radiotelephone network was inaugurated in Finland (the so-called ARP network as the forerunner to the NMT). By the mid 1970s, the radiotelephone department also became involved in exports of radiotelephones to the various local networks in the other Nordic countries, apart from deliveries to the ARP network and various other local public networks in Finland. In the meanwhile, Nokia Electronics and Salora had started to coordinate their production and marketing efforts. In 1981 this coordination led to the founding of Mobira based on 50-50% ownership between the two firms. Hence, prior to the start of the GSM standardisation in the early 1980s, the lions share of R&D related to radiotelephones had been concentrated to Mobira. Mobira was also developing BTS base transceiver stations intended for the NMT. (Koivusalo 1995).

On the operator’s side of the market, the PTT was the other significant contributor to total R&D in the telecommunications industry in the mid 1970s, while the role of the private telcos was of lesser importance (the Helsinki and Tampere telcos were exceptions).[5] The PTT was a participator in the pre-competitive research consortia on the ISDN standard, with an interest in digitalizing the fixed networks. The PTT was also a fist mover in the field of cellular networks technologies through participation in the construction of the ARP network (which incorporated a rudimentary cellular architecture), as well as participation in the NMT standardisation since the late 1960s in collaboration with the other Nordic PTTs. The PTT had established a small, but likewise expanding, radiotelephone department and associated R&D laboratory to coordinate this work. Subsequently, this department became a key carrier of competences related to NMT and GSM specifications for cellular systems, as well disseminator of the business opportunities related to these standards. (Palmberg 1998). The mobile market success become clear to the Finnish PTT already in 1982 when the NMT subscriber growth clearly outperformed the subscriber growth of the previous mobile radio service ARP in Scandinavia.

On the university side, Helsinki University of Technology in Espoo had developed education and research in transmission and radio technology from 1960s onwards, complemented with cellular and digital radio technology starting from the late 1970s and early 1980s. This education and research was foremost focused on the digitalization efforts of the PTT during the modernization of the fixed networks. At the University of Oulu activities in the field of electronics was started in the late 1960s and early 1970s, as new microprocessor technology and systems software development methodologies were included in the education and research. At the Helsinki University research in compiler theory had been conducted since 1970s and research in protocol design languages and concurrency models in 1980s.

At the Technical Research Center of Finland (VTT) the early application of digital technology was related to collaboration during the 1970s between the VTT Telecommunications Laboratory, the Helsinki University of Technology, Nokia Electronics, and some of the private telcos. This collaboration had an origin in the pre-competitive research consortium related to the ISDN standard, but subsequently evolved towards the fields of PCM transmission technologies and fixed switching systems, for corporate users as well as video telematics. Subsequently, the telecommunications laboratory became involved in European collaboration for the application of the OSI model in a transmission and switching environment, whereby the development of OSI-compatible protocols, gateways between public networks and LANs (today called 'routers') and related prototype and simulation tools became a primary interest. Another important initiative was the founding of the VTT

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[5] The Finnish system of operators was decentralised, with the PTT operating the trunk networks and long-distance calls while numerous private operators operated local networks (see Paija (2001)).

Electronics Laboratory in 1972 in the city of Oulu to strengthen the local education and research milieu in the region. The laboratory came to specialize in embedded computer control and software design and contracted projects to industry. The competences in low power consumption microprocessor software were also widely taught out to firms in the region (Mikroprosessori käsikirja 1977). Moreover, the laboratory succeeded in establishing several major industrial R&D programs. One was the Computer Aided Design (CAD) and printed circuit design project, involving Nokia, Salora, as well as the engineering firm Strömberg, among others. Another important program was the Software Engineering Environment (SEE) program for embedded software, which included Telenokia, Kone and Valmet as two other major engineering firms in Finland (Taramaa et al. 1985).

It should also be acknowledged that the Ministry of Trade and Industry played an important role in consolidating the networks of actors through public R&D funding. Nonetheless, the role of public funding grew in importance somewhat later, in 1983, as research on digital technology started to generate industrial application. This coincided with the founding in 1983 of the National Technology Agency of Finland (Tekes). Tekes overtook the operative responsibility of R&D funding from the Ministry, a development that was underlined by the initiation in 1984 of the first large four-year research program on ICT named FINPRIT. Tekes funded 70 percent of the costs of this program, while the remaining shares was provided by the research institutes and industry. The main goal of the program was to raise the competence level in the fields of ICT hardware and software applications and to integrate the different ICT subsystems with respect to their data content and communication capabilities. The FINPRIT program was subdivided into four project modules, namely Integration of IT-systems, Computer Aided Design and Manufacturing, Software Engineering, Applications of Pattern Recognition. The continuation of the OSI-related research of VTT Espoo was included in the Integration of IT-systems and in the SEE program engaging VTT at Oulu and Espoo.

4.2 The BSS subsystem – digitalizing radio transmissions

4.2.1 Nokia as an early mover in the field of digital transmission

An important prerequisite for Nokia's entry to the GSM market related to the fact that Nokia Electronics, the forerunner to Nokia Telecommunications and Nokia Cellular System, was an early mover in the field of digital transmission and related pulse-code-modulation techniques (PCM techniques). The PCM technique modulates analogue speech signals into digital ones, prior to the further transmission of these signals within fixed networks. PCM techniques thereby also cover digital signal processing (DSP). Furthermore, cost-effective PCM techniques entered switching already before the implementation of the ISDN standard, whereby switching systems gradually were fully digitalised. (Volontinen 1999). PCM techniques thus contributed to both the application of DSP in the wireless GSM environment, as well as to the mobile extensions of Nokia's digital DX200 switching system, first to the NMT and later to the GSM.

The accumulation of competencies in the field of PCM extended back to the 1960s, when the R&D projects related to PCM modulation were initiated. These projects had their origin in a conscious attempt to diversify from cable works to electronics, as a new and promising industry. In 1969 Nokia Electronics delivered their first digital 30-channel data transmission system to the PTT, based on PCM in accordance with standards set by the CEPT. This system was the first of it's kind in the world and underlines the dedication that Nokia Electronics gave to digital transmission technology already in the 1960s. Nokia Electronics had also initiated collaboration with the Helsinki Telephone Company, and the State Railways, which resulted in further deliveries. The first exports of PCM based digital transmission systems were directed to the Soviet Union, which subsequently emerged as an important market in the field. In the meanwhile, Nokia Electronics had also become involved in the development of minicomputers and data modems based on PCM techniques. (Häikiö 2001a; Palmberg 1998).

The first R&D projects related to DSP based modem designs drew on research undertaken in the US during 1970s. Nokia Electronics accessed this knowledge through a Finnish entrepreneur in the US named Karl Nordling - a 'self-made man' from the Aland Islands in the Finnish archipelago - who took employment at a pioneering firm in the field of DSP data modems named Paradyne and subsequently founded the spin-off firm named Kinex (acronym for Karl Ingmar Nordling Excellent). Evidently, Kinex had attracted funding both from some US firms and venture capitalists, and Nokia in Finland. Gradually, the collaboration between Kinex and Nokia Electronics extended to cover subcontracting and technology transfer related to the experimental application of DSP in data modems. By the early 1980s, Nokia engagement in Kinex went one step further through the acquisition of this firm, whereby the competencies were transferred from the US to industrial applications at Nokia Electronics.

> *" In the 1970s we knew about Paradyne and their competencies in fast speed DSP-based modems, although research in Finland at the time was highly theoretical.* […] *The first DSP-based data modem, commercialized in 1979, was based on collaboration with Kinex…"*

Following these early experimental applications of DSP to data modems Nokia Electronics was subdivided into various units, of which Nokia Information System came to focused on further applications of DSP to data modems as one of their core businesses. These competencies in DSP and fast speed modems subsequently laid the foundations for a successful business, elevating Nokia to one of the largest European manufacturers of data modems and microcomputers in the 1980s, especially in the corporate customer market.[6] As data speeds increased, Nokia Electronics became increasingly dependent on commercially available DSP-based IC subcontracted from Texas Instruments, which became available starting from 1983. Nonetheless, Nokia Electronics early competencies in the field were a crucial prerequisite for this subcontracting – it also turned out to be of crucial importance to later developments related to the GSM.

The connections between data modems and the GSM went through the importance played by DSP in both fields. As it turned out, the software logic of the DSP was very similar to the one specified in the GSM standard, whereby these competences found direct applicability in the design of the first BSS prototypes. Hence, the radiotelephone pioneer Mobira started to probe various possibilities to collaborate with Nokia Information System during the mid 1980s. These probes resulted in a small scale collaborative R&D project in 1985.

> *"Mobira's GSM radio team contacted us* [Nokia Information System] *with a request to write the DSP software for the GSM radio signalling channel. We took the job and used a lot of our free time for it. This was before the GSM radio transmission design competition in Paris 1986…"*

Following this first R&D project, the technological complementarities between these were nurtured further through informal consultations, masters thesis, as well a the hiring of engineers to the expanding activities of Mobira. Hence, in hindsight it seems clear that the early Finnish connection to research and industrial applications related to DSP, and the strong position in the 1980s of Nokia Information Systems in the data modem business paved the

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[6] The Nordic banking sector was a key customer during the development in 1980s of the data modem business (see Hernesniemi (1999))

way for the subsequent entry to the GSM. Nonetheless, the role played by Mobira during these early phases of the GSM relates back to developments already in the 1960s and 1970s.

4.2.2 The identification of business opportunities – Mobira's entry to the GSM

With reference to Carlsson & Eliasson (2001), the identification and realization of business opportunities is a crucial prerequisite for the evolution of design spaces, for the commercialisation of the related technological opportunities, and for the emergence of technological systems. As suggested above, in Finland the role of Mobira cannot be overemphasised in identifying the business opportunities, and formulating these into various R&D projects within Nokia and amongst the network of research groups at the technical universities and the VTT. This important role of Mobira related to the strong market position that it had acquired, first in the Nordic radiotelephone market, and subsequently in the market for mobile terminals and base stations for the NMT.

Mobira's entry to the mobile telephone industry dates back to the 1960s when the Finnish State railways and the Finnish Defence Forces upgraded their radio systems, and placed orders for portable radiotelephones as the forerunners to mobile phones as we know them today (Palmberg 1997). By the mid 1970s Salora-Mobira had become the largest supplier of radiotelephones to the various public networks in Scandinavia. Meanwhile, as demand and production volumes started to grow, Salora-Mobira could take increasing advantage of the synergies between the development and production of television equipment and radiotelephones.

> *"In 1972 I caught one of our sales managers in the very act of stuffing a radiotelephone into a briefcase - antennas, batteries, headphones, and all – since somebody had asked for such a device. This was the forerunner to our first mobile phones."*

The strong position of Mobira is illustrated through growth and market share figures at the time. In 1979 Mobira had 270 employees, was the market leader in the Nordic countries, and had a turnover 8 MEURO. In 1983, after the inauguration of the NMT network and the start of the GSM standardization process, Mobira had 631 employees, was the global market leader, and had a turnover of 38 MEURO (market leadership was lost to Motorola in 1984 after the inauguration of the AMPS service in the US). Moreover, Mobira had developed efficient production facilities in Finland and retailing chains abroad. Against this background, the identification of business opportunities related to the emerging GSM market was a logical next step for further expansion of activities. Similarly, Mobira also decided to enter the TACS market in the UK, the AMPS market in the US, as well as the Netz-C market in Germany, and RTS market in Italy (Koivusalo 1995).

> *"In practice we had no alternative but to enter the GSM. We were the market leaders in the field of analogue mobile phone and foresaw the business potential of the GSM. The efforts that we put into mastering the complexity of digital technology were merely a necessary consequence of our commitment."*

The first initiatives towards developing competencies for the GSM were taken by Mobira in 1982, as the rough contours of the GSM standard specifications became visible. This initiative was very modest resource-wise since it involved the hiring of one full time researcher from the Helsinki University of Technology with the purpose of getting acquainted with the rudimentary specifications of the GSM standard. The Finnish PTT also funded this research due to their growing interest in the field. In the early 1980s the R&D activities of Mobira started to expand significantly in response to the inauguration of new networks all over the world. After 1985 this expansion also related to the growing complexity of the GSM standard, especially in terms of the embedded and DSP software requirements. Hence, engineers vested in the field of embedded software were hired, primarily from the Helsinki Technical University, but gradually also from the VTT and the University in Oulu, and also Nokia Information Systems as discussed above.

Initially, R&D was divided between the two units of Mobira. The first unit was situated in the city of Oulu, and focused on the BTS hardware and the BSS subsystem software. The second unit was situated in the city of Salo, at the headquarters of Mobira, and focused on the MS software and hardware. Nonetheless, due to the increasingly demanding embedded software requirements more and more of the R&D related to software was delegated from Salo to Oulu, while the focus also started to shift from NMT, TACS, AMPS and other standards towards the GSM.

4.2.3 The clustering of embedded software and DSP competencies to Oulu

The increased importance of R&D undertaken in Oulu involved a regional dimension since the demand for embedded software competencies coincided with initiatives in the early 1970s to locate the VTT Electronics laboratory to Oulu, in close vicinity of the Oulu University. The growth of VTT Electronics lead to its division into two laboratories in 1983; VTT Electronics with 80 people focusing on hardware and embedded software, and VTT Computer laboratory with 20 people concentrating on software. The involvement of Mobira in collaboration with the VTT in Oulu was largely facilitated through the SEE program related to the development of embedded software methodologies. This program was financed by industrial partners with activities in the region, most significantly by Telenokia, Kone and Valmet. The program applied so-called Structured Analysis methodology to embedded software design (DeMarco 1979; Ward & Mellor 1985).

The importance of the SEE program was foremost to consolidate the latest competencies in the field to networks of researchers at the Oulu University and various laboratories of VTT. Specifically, these competencies concerned techniques enabling formalized and disciplined development, simulation and testing of embedded software, including real time features and DSP algorithms, for various industrial applications of microprocessors and integrated circuits. One such application was the MS and BTS components – a competence field that turned out to be of key importance in the transition from the NMT to GSM. (Alanko 1990).

> *”The formal SEE approach based on specifications of several abstraction levels developed in parallel, verification of specifications by simulation, or formally, and then automated code generation, created a software process that was applied by Nokia.”*

As suggested above, the formation of the network of engineers emerging in the mid-1980s in Oulu – in the field of embedded and DSP software – constituted a crucial organizational prerequisite for overcoming the discontinuities related to the GSM. A noteworthy aspect of this network was the close collaboration that was achieved between the VTT, the Oulu University and the R&D unit of Mobira. Apparently, the density of the networks, rather than their size, contributed to the subsequent success of the GSM-related projects. This density enabled the rapid absorption of relevant knowledge in the field.

To paraphrase Allen (1977), the role of a handful of ‘technological gatekeepers’ was crucial in this context. These gatekeepers changed affiliations and contributed to the dissemination of knowledge throughout the networks, as well as the achievement of complementarities between R&D undertaken by teams at the different locations of Mobira and Nokia in Oulu, Salo, Espoo, Helsinki, and later also in Tampere. Examples of such complementarities were the dissemination of early microprocessor technology and embedded software competences from Oulu, the application of OSI-related protocols in the development of real-time embedded software, and the application of the IC-architecture of DSP-based data modems, originally developed by Nokia Electronics in Espoo and Helsinki already in the 1970s.

> *"When I moved from VTT Espoo to VTT Oulu I identified complementarities between the OSI data communication reference model, and the approaches to embedded real-time software applied to industrial projects in Oulu.* […] *Three engineers moved from the VTT and Oulu University to Mobira, they played a key role in the further development of the embedded software methodology."*

Developments in Oulu were rapid from the mid 1980s onwards, following this first phase of the consolidation of embedded software competencies. The increasingly large share of Mobira's R&D that was outsourced to research groups led, in 1985, to the founding of a separate R&D unit with a focus on MS software in Oulu, alongside production facilities. The new R&D unit continued to subcontract projects from VTT and from local software SMEs in Oulu. Subsequently, there were reorganizations, first under Nokia-Mobira, and subsequently under the corporate umbrella of Nokia Mobile Phones, founded in 1988 to focus Nokia's MS business. Through these reorganizations Nokia also internalized the lion share of the R&D projects by recruiting engineers from the VTT and the Oulu University. These recruitments increased the R&D staff of Mobira Oulu from approximately 10 in the early 1980s to approximately 100 in the late 1980s.

> *"The software development process was the most important thing we learnt from the SEE program. In Mobira we created our own software architecture and tools closely tied to the software process. We were able to simulate all developed MS software modules against each other in our VAX minicomputer."*

Apart from this quantitative upgrading of R&D, this unit also, to an increasing extent, became involve in designing the DSP software. The co-ordination of the R&D as well as the MS hardware development remained in Salo. Even though Nokia relied on commercially available ICs, arm's length subcontracting with AT&T and Texas Instruments gradually evolved into R&D collaboration as DSP was applied to the first GSM mobile terminals. Nokia also collaborated with Hewleth-Packard with the purpose of testing digital RF filters prior to commercialisation.

> *"We looked for DSP IC components around the world. AT&T was our main subcontractor partner* [in the 1980s]*, but we took an active part in the specification of these IC's. This was a significant achievement - our partners knew nothing about Finland and expected to be confronted only with ice bears."*

The next significant changes in the organisation of R&D related to the founding in 1985 of the Nokia Research Center (NRC) based on the R&D department of Nokia Electronics, as well as the founding in 1987 of the Nokia Cellular Systems (NCS) based on Telenokia. This reorganization pooled R&D related to the GSM standards, the OSI model and their simulation to the research center, whereby the R&D and production related to the BTS and BSC was the responsibility of NCS. The research center also collaborated with Nokia Cellular Systems, related to the protocol and simulation tools used in the development of the BSS and NSS subsystems.

A year later, in 1988, Nokia Mobile Phones was founded, based on Nokia-Mobira. Nokia Mobile Phones came to focus on the MS component of the BSS. R&D related to the MS software was concentrated to Oulu, while R&D related to the MS hardware remained in Salo. Nokia Mobile Phones also founded a new R&D unit in the City of Tampere. This unit collaborated with Nokia Research Center, the Tampere Technical University and the Cheerbroke University in Canada in the fields of DSP-based speech codec, upgraded algorithms, as well as image processing during Phase 1, Phase 2, and Phase 2+ of the further standardization of the GSM in the 1990s. (Koivusalo 1995).

4.3 The NSS subsystem - switching and mobility management software

4.3.1 From the ISDN to DX200 towards cellular system extensions

Interestingly, Telenokia was heavily involved in shaping the design space underlying cellular systems already in the early 1980s, even though Telenokia was focused on the business opportunities related to the fixed networks rather than the NMT and GSM. All resources were delegated to finalising and upgrading the first digital switch to the fixed networks, while the standardisation process leading to the inauguration of the first NMT 450 service in 1981 largely passed unnoticed.

> *"Our first deal for the series production version of DX200 digital switch was struck in 1980 with the Tampere telco, with delivery in 1983* […]*. We had also made some preliminary block diagrams of the switch intended for a cellular network already in the 1970s as an exotic experiment… the DX200 was a very flexible switching platform in this respect."*

As suggested above, the upgrading of the DX 200 system to a MSC cellular system environment primarily required competences in complementary, rather than substituted, technologies. Telenokia had already developed a digitalised switching system through the DX200 project. The DX200 had originally been designed based on a modular architecture with decentralised processing power to incorporate the easy upgrading of commercially acquired IC's and the related software. Nonetheless, the move towards developing cellular switch applications was set in motion by Mobira, in collaboration with the PTT – hence the role of Mobira was crucial also with regard to translating business opportunities into R&D projects in the field of the GSM NSS subsystem. (Palmberg 1998).

In the early 1980's, Mobira had a strong interest to integrate sales of the BSS and NSS subsystems due to the fact that turnkey cellular systems deliveries had become a necessary prerequisite for new market openings abroad. This was the situation already during the inauguration of the NMT in various countries starting from 1981. The PTT, in turn, had a strong incentive to promote domestic development and production of MSC switches due to the overly dominance of Ericsson in the NMT 450 market. Thus, in 1982 a first serious attempt was made by Mobira and the PTT to involve Telenokia in the upgrading of the DX 200 to the cellular NMT environment. The reluctant position of Telenokia is best illustrated with the quotation:

> *"Our main focus was in the fixed networks.* […] *In 1982 the first proposal for developing an NMT switch was lobbied to Telenokia by Mobira, but we laughed them out of the office at that time due to the strong position of Ericsson in the MTX market in Finland."*

This first unsuccessful attempt was followed by other ones, and in 1984 Telenokia finally dedicated itself also to cellular switching, after successful deliveries and the finalisation of the DX200 for fixed networks. This dedication concerned an MSC, developed during 1984-1986 for the NMT market. The first delivery was to Ankara, in Turkey, followed by deliveries to the Finnish NMT networks upheld by the PTT, and also to France and China. By 1986, prior to the signing of the MoU on the GSM, Telenokia had thereby committed itself to collaboration with Mobira in the NSS market. (Palmberg 1998).

The involvement of Telenokia in the GSM was actualized during collaboration with Mobira – the perceived business opportunities had already been formulated into R&D projects in the field of DSP and the related software for the MS. These business opportunities also started to become evident at Telenokia due to the successful delivery and inauguration of the NMT network in Ankara, as well as other NMT deliveries.

> *"When the Turkish NMT system was inaugurated in 1986, we left for lunch in a kleinbus. I had a Talkman in my lap, which suddenly started to ring* […]. *It became clear to me that this mobile phone business really might become a big thing."*

The official decision to engage in the GSM was taken in 1987 at the managerial level of Nokia, four years after Mobira's first R&D projects in the field. In hindsight, it seems that this late entry foremost related to the fact that all resources were dedicated to adjusting the DX200 to a business opportunity in the fixed network market. The NMT and GSM 'adventures' were outside the focus areas of Telenokia, as the largest share of turnover originated from exports of PCM digital transmission systems and the DX200, especially to the Soviet market.

The additional services features related to the GSM implied that the software embedded in the MSC, HLR and VLR had to be complemented with signaling stacks, compatible with the OSI model and the SS#7 standard. The operation and management requirements also included the development of the TMN in the OSS susbsyste,. There was also the requirement for pan-European roaming, substituting pan-Nordic roaming in the NMT. In terms of competencies, the BSC was disintegrated from the MSC as the local terminal mobility was partly delegated to the BSS. Taken together, these complementing and substituting technologies were felt in the tenfold increase in the complexity of the software, and implied a significant increase in the required R&D resources at Telenokia. This increase was unexpected at the time, although the dedication given to the GSM was made explicit. Likewise unexpected was the decline of the Soviet market, starting from 1989, whereby Telenokia could shift over resources to the GSM at a time when they were needed the most

> *"In 1989 we were lucky, since the end of the bilateral trade to Soviet Union collapsed Telenokia's fixed network switch business, and a large*

> *number of R&D people could be relocated from there to the development of the first switch intended for the GSM."*

As suggested above, the late entry of Telenokia into the GSM was partly compensated by the unexpected compatibility of the DX200 with the cellular network design space. Apart from the decentralized processing power, the early competences in PCM digital transmission and data modem technologies found direct application in the subscriber and transmission part of the switch. Accordingly, the roots of the first GSM NSS in fact extend back to the 1970s and 1980s to the time when Nokia Electronics participated in the pre-competitive research consortia on the ISDN, and subsequent R&D collaboration with the Helsinki Technical University, the private telcos and the VTT Telecommunications laboratory. In this context, collaboration with the VTT was especially noteworthy.

In the early 1980s, the collaboration with the VTT came to focus on the architectural level of the MSC and NSS, whereby the software development methodologies were made compatible with the standards prevailing at the time. Subsequently, as software development methodologies became increasingly critical to Nokia due to the ECR900 consortium requirements and the complexity of the GSM, many of these R&D projects were internalised to the Nokia Research Center, along with recruitments of engineers from the VTT. Later on, Telenokia also extended collaboration with Nokia Research Center to cover the complementation of the DX200 with signaling stacks compatible with the OSI model and OSS subsystem.

4.3.2 Process innovativeness – developing prototype and simulation tools

By 1987, Nokia had reorganized R&D in line with the requirements of the emerging GSM standard and the structure of the underlying design space. Competencies related to the ISDN and digital signaling interfaces between the BSS and NSS subsystems were consolidated to Nokia Cellular Systems, while R&D projects of more generic nature were outsourced to the newly founded Nokia Research Center. Competencies related to the hardware and software developments of the MS component of the BSS were consolidated to Nokia Mobile Phones at the Salo and Oulu locations. Furthermore, formal decisions had been taken to prioritize the GSM over the other markets and emerging standards.

These reorganizations and dedications also coincided with the 'basket-model' compromise amongst the European PTT's, providing the equipment suppliers with greater room of manoeuvre with respect to technological choices related to the internal interfaces of the BSS and NSS components. Hence, the prototyping and simulation of these internal interfaces of the different subsystems became a crucial issue, prior to the commercialisation of the first GSM cellular system. Put differently, product innovations had to be coupled with process innovativeness, the importance of which was accentuated further due to the unprecedented complexity of the GSM-related software. In hindsight it seems that Nokia's approach to prototyping and simulating was highly successful, and contributed, in important ways, to the timely commercialisation and further upgrading of the first GSM cellular system.

Again it seems justified to highlight the density of networks of engineers and the role of technological gatekeepers in disseminating the relevant knowledge. Specifically, Nokia's competencies in various important prototyping and simulation tools had their roots in the above-mentioned Integrated Office Systems module of the FINPRIT research program, initiated in 1984 by the newly founded National Technology Agency (Tekes). The FINPRIT program covered various R&D projects, enabling the collaboration between researchers at the VTT and technical universities, as well as Nokia. Subsequently, some of these researchers were hired to the Nokia Research Center, founded at the same time.

> *"We had learnt to use prototype and simulation tools at VTT. As a result, we managed to harness these tools efficiently during the simulation of the GSM NSS subsystem even though our team was small at the time* […]*. Similar in-house tools were reused in subsequent projects."*

The Integrated Office Systems module of FINPRIT was the most significant in this context since it's explicit aim was to develop and apply new prototype and simulation tools in a risk-minimizing way, by allowing parallel product and process innovation development, or concurrent engineering. Furthermore, the idea was to use powerful VAX minicomputers and LANs as platforms to emulate future personal terminals, networking and new protocols. This type of basic research oriented R&D was undertaken at the VTT Telecommunications laboratory during 1983-1986. The resulting prototype and simulation tools were developed first in Pascal, and later in C programming languages. This prototype and simulation tool was named the CVOPS, as an acronym for C-language Virtual Operating System.

> *"We wanted to simulate future workstations and network architectures with present day minicomputers, LANs and self built*

> *gateways in order to learn to develop network software and to simulate the behavior of such complex systems."*

Starting from 1986, the CVOPS tool was taken into use at the Nokia Research Center, whereby a first priority was the secure the compatibility between the specifications of the BSS and NSS interfaces in the GSM standard. Thereafter various protocol libraries for Nokia's GSM solutions were developed, in parallel with requirements emerging from joint R&D within the ECR900 consortium that had been established together with Alcatel and AEG. Starting from the early 1990s, during the further specification of the GSM standard during Phase 1, Phase 2, and Phase 2+, the CVOPS was complemented with GPRS and 3G protocol stacks. (Inside Mita 2002).

Other important tools are so-called compilers used to encode and decode abstract data structures and formal specifications. Examples of such tools are the CASN and BUILD, both of which also originated in collaborative R&D projects in the early 1980s and involved the VTT, Helsinki University and the technical universities. The early application, the requirement for interoperability between the different tools, and their further upgrading at the Nokia Research Center was a major challenge.

> *"It was so time consuming work to type all the protocol IN, IF and AUT specification files of CVOPS by hand that we developed a tool at VTT to automate the typing of larger protocol stacks. Because of the large amount of specification data for big systems we called the tool first as ARGH..."*

Still further examples of prototype, simulation, and related tools, developed in the late 1980s at the Nokia Research Centre include SIMUCVOPS as well as the TTCN tools. The development of many of these tools has also involved collaboration with various technical universities and other partners, both in Finland and abroad. Some of the tools have also been designed as 'stand-alone' versions, disconnected from other in-house technologies, thereby enabling out-licensing and independent commercialisation (Beginner's guide 1992).

4.4 Pulling it all together - the commercialisation of Nokia's first GSM cellular system

4.4.1 The basket model and the ECR 900 alliance

Apart from the reorganization of R&D in line with the structure of the emerging GSM design space in 1987 and 1988, Nokia was also faced with various options related to translating competencies and technological opportunities into business opportunities, to paraphrase Carlsson & Eliasson (2001). As suggested above, the 'basket-model' compromise to standardization was the crucial device whereby technological opportunities could be tailored to firm-specific business opportunities in the GSM markets, which were set to open in 1991 throughout Europe.

In practical terms, this implied that the various equipment suppliers came under increasing pressure to achieve interoperability of the signaling and control interfaces of the BSS, NSS and TMN subsystems and components ahead of this deadline, as well as to find channels to commercialize the first GSM systems in the various European markets. Likewise, the GSM introduced intellectual property rights (IPR) issues to the forefront, since interoperability also implied that patents of different firms had to be pooled to secure the openness of the standard – an issue of lesser concern in the case of the wholly publicly standardized NMT. Hence, the GSM promoted collaboration between competing constellations of firms in the form of strategic alliances. (Bekkers et al. 2002).

Apart from Nokia the major equipment supplier firms dedicated to the GSM included Ericsson, Matra, Orbitel and Alcatel, Bosch, Siemens, AEG, and Motorola. Around 1987, these firms reorganized themselves into three principal alliances. The first alliance consisted of Orbitel, Matra and Ericsson, while the second so-called DCMS900 alliance consisted of Bosch, ANT, Phillips and Siemens. Nokia entered the third alliance, called ECR900, together with Alcatel and AEG. (Manninen 2002). From the viewpoint of Nokia, it seems that that the incentives to join the ECR900 alliance foremost related to seeking access to protectionistic European markets in which incumbent PTT's had an upper hand. Alcatel was a logical partner also due to broader arrangements between the two firms in the consumer electronics market, into which Nokia had entered during the late 1980s (Routtu 1996). Nonetheless, this alliance also bridged complementary clusters of technologies underlying the design space due to a division of labor in R&D.

> *"The ECR900 alliance was also related to broader business arrangements between Nokia and Alcatel, we divided target customers…these were complex arrangements* […]. *The alliance was also considered as a means to gain access to complementary technologies and competencies."*

The alliance covered two separate projects. The first one was a collaborative R&D project concerning the BSS, whereby Alcatel focused on the BTS and the BSC, while Nokia contributed with their RF, PCM and DSP software expertise. The participation of AEG was based on competences that this German supplier had developed in the field of DSP. The second project involved the construction of a GSM simulator in the city of Stuttgart, enabling the testing of the GSM software in order to secure the timely commercialisation of the first GSM system of the alliance.

Nokia's prerequisite to participate in collaborative R&D in the ECR900 originated in the early digital radio and software projects undertaken in the mid 1980s in Salo and Oulu. The GSM simulator was originally designed to cover all components of the BSS and NSS subsystems, but in the summer of 1988 the HLR and OSS/OMC components were withdrawn due to problems in sharing proprietary technologies. Hence, Nokia Cellular Systems developed their own MSC solutions and the ECR900 work was undertaken by NMP Oulu and NRC using their prototype and simulation tools – most significantly the CVOPS and CASN – which they had developed in-house. The MS software was developed by Nokia Mobile Phones in Oulu, and the GSM protocol stacks were developed by the Nokia Research Center for both the ECR900 GSM simulator in Stuttgart and Nokia's own simulator system in Oulu. In this sense, the ECR900 alliance did not contribute decisively to competence developments, although it did provide complementary competencies, especially related to the BSC component, to some reference orders in Europe, as well as to general insights into problems and potentials of international collaboration.

> *"The BTS could have been developed in-house, while the ECR900 was more decisive for the timely development of the BSC. Alcatel provided some DSP competences* […]. *We also got some deals as a subcontractor to Alcatel, although these were of lesser significance […]. Maybe the biggest lesson learnt was how to participate in, and manage, the complexities of international alliances."*

Competence-wise, the GSM simulator developed in the ECR900 alliance also provided opportunities to cross-test equipment prior to the finalisation of the standard and commercialisation of the first systems. In fact, the BTS and BSC components of Nokia's first GSM cellular system had their origin in this consortium. In the meanwhile, starting from 1989, efforts had been made to complement these ECR900 components with Nokia's own components in order to become self-reliant in the turnkey cellular network business. These own BTS and BSC components were finalized in 1992 and delivered to the first customers the same year. Similarly, the Nokia developed an own GSM simulator, in parallel with the development of the ECR900 simulator.

4.4.2 From crisis to Nokia's first 'just on time' delivery in July 1991

The 'basket-model' secured the intermediate completion of the GSM standard in 1989, and provided scope for differentiation in the business strategy of firms. However, it also introduced additional problems in the interoperability of the various internal and external interfaces of the BSS and NSS, discussed above, which caused delays in the commercialisation of the GSM service. This delay was especially problematic in the case of the MS due to the requirements of international roaming and handover, whereby the different mobile phone types of the different equipment suppliers were subject to rigorous approval tests in order to avoid rogue terminals. As interoperability of the GSM cellular systems was of primary concern to ETSI, an interim type approval procedure (ITA) was established, whereby only a subset of the approval parameters were tested to ensure minimum performance criteria for mobile terminals. The development of simulators – a complex piece of equipment that simulated the entire GSM cellular system - was the bottleneck for inauguration of the service and became crucial for the timely commercialisation (Manninen 2002; GSM Association 2003).

During participation in the ECR900 alliance, Nokia Cellular Systems had managed to upgrade the NSS subsystem to a GSM environment, based on the DX200 architecture had been tested against the BSS subsystem developed by the ECR900 alliance. Hence, already in 1990 Nokia Cellular Systems possessed a prototype GSM system, which was compliant to the ECR900 simulator, and to Nokia's own simulator located in Oulu. Nokia's only missing component ahead of inauguration of the GSM service was the MS product prototype, which had suffered the most from the uncertainties associated with the basket-model, and the delay in standardization. This phase also coincided with times of crises for Nokia due to problems in the consumer electronics businesses, that accounted for close to 50 percent of the electronics-related businesses at the time, as well as the tragic suicide of the GEO in 1988 (Ruottu 1996). Hence, the successful commercialisation of the first GSM cellular system also crucially depended on higher-level commitment that was given to the whole project in times of crises.

> *"The years 1988-90 were critical times for the GSM, but they were also times of crises at Nokia. Nonetheless, despite these crises somebody at the managerial level had the wisdom to safeguard the project not matter what…"*

The final moments in the commercialisation of Nokia's first GSM cellular systems were experienced in the Autumn of 1990, Spring and Summer of 1991, prior to the opening of the service in Finland by Radiolinja as Nokia's first GSM customer. (Helsingin Sanomat 1991/7). The tight timetable for the finalisation of the MS required the reorganization of R&D teams, whereby software experts from the Oulu unit of Nokia Mobile Phones were summoned with the very specific task of customizing the various technologies into the first commercially available GSM mobile phone. This team undertook a fundamental review of the project in order to ties loose ends and narrow down the tasks to the bare essentials. These tasks included the scaling down of the detailed specification to a minimum, the fine-tuning of DSP and the related algorithms, and the development of testing equipment in line with the interim type approval procedure of the ETSI.

> *"The project was in small pieces and there was an enormous hurry to close the detailed specifications and process model, develop measurement equipment etc. as soon as possible during 1990."*

As the deadline drew closer the cross testing of the different components and subsystems intensified. An anecdote in the subsequent successful inauguration of the GSM service in the cities of Helsinki, Turku, and Tampere on Monday, the first of July 1991, was the fact that the MS software still was incompatible with the latest version of the MSC software on Saturday. Nonetheless, in hindsight it appears to be the case the public GSM calls made that day in Finland were the first one's to the world. Hence, Nokia's strong commitment to being the first supplier of a GSM cellular system was realized, despite the crises, reorganizations of R&D projects, and problems of interoperability experienced in the final phases of the project. This first GSM cellular system was based on Nokia's NSS and OSS subsystems, as well as the MS components. The BSS subsystem was complemented with the BTS and BSC developed jointly in the ECR900 alliance.

Even though Nokia survived the deadline, work remained to fine-tune the specifications in line with the requirements of the ITA. In May 1992 the GSM group had decided to allow the suppliers to self-approve their MS, in line with the ITA, whereby Nokia became involved in extensive field-trial testing of the system. In the meanwhile development work for the MS hardware had been completed, and the first batch of some 10 000 prototypes entered production and the markets that same summer. These prototypes facilitated the collaboration with customers, as the first users of the service, and thereby feed back on the fine-tuning of the software specifications. A month later, in June 1992, Nokia introduced the first fully specified GSM mobile phone to the markets. This first truly commercialized mobile phone was named the GSM 1011, and paved the way for subsequent upgrading of both the MS software and hardware during Phase1, Phase 2 and Phase 2+ standardization.

> *"There was an enormous amount of work left related to handover and the rescaling of the MS for production* […]. *Our goal was to receive the ITA approval in February 1992…in June a batch of 10 000 were distributed to users."*

Nonetheless, from the viewpoint of the GSM group the coordinated inauguration of the GSM service was a failure, since only eight European countries – namely Finland, the UK, Denmark, Germany, France, Sweden, Portugal and Italy - achieved this during 1992. The second wave of the inauguration of GSM networks started in 1993, through the addition of Norway, Greece, Ireland, Switzerland and Luxembourg. This second phase also marked the inauguration of GSM networks in a number of countries in the Asia-Pacific area. However, it took until 1997 before the growth in the number of subscribers started to increase exponentially, from 50 million subscribers. Gradually, the inauguration of the first systems, the commercialisation of the related equipment, diffusion and growth in the number of subscribers also started to restructure the industry. As illustrated in table 1 in the introduction, US and Asian suppliers entered the market, while established alliances – such as the ECR900 – were dissolved or restructured. (Manninen 2002).

5 A CONCLUDING DISCUSSION

5.1 Overcoming the GSM discontinuities – incumbency, collaboration and serendipity

The point of departure of this paper was in the casual observation that the transition from the NMT to the GSM introduced technological discontinuities to the evolution of the telecommunications industry due the widespread diffusion of the GSM standard, the subsequent rapid growth for firms such as Nokia, and the restructuring of the industry. Accordingly, the paper set out to identify the crucial technologies and competencies introduced through the GSM, characterize their discontinuous nature to the equipment suppliers, as well where and how the related competencies were developed in the context of the emergence of a technological system of interrelated GSM technologies, organizations and institutions in Finland (Carlsson & Eliasson 2001). With reference to this overall analytical framework, the foregoing qualitative case study analysis gives rise to the following conclusions.

For starters, it seems safe to confirm our casual observation and conclude that the GSM indeed introduced technological discontinuities to the cellular systems design space underlying the NMT, and all previous analogue standards. In this paper we have identified two such major discontinuities from the viewpoint of equipment suppliers. The first discontinuity concerned the digitalization of radio transmissions, which substituted the analogue component parts in the BSS subsystem and required the development of new competencies towards that end. The second one concerned the manifold increase in the complexity of the signaling and control software – an increase that essentially substituted previous software in all subsystems and components of the NMT cellular system. To paraphrase Tushman & Anderson (1986, p.46), these discontinuities *"…advanced by an order of magnitude the technological state-of-art* [in cellular systems, and were] *based on new technologies whose technical limits are inherently greater than those of the previous dominant technology…"*. Moreover, they contributed directly to improved price/performance ratios of the mobile phone and the related services, as well as to the broader restructuring of the industry, although these causalities were set in motion with a lag after the inauguration of the first networks in 1991.[7]

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[7] An formal analysis of the relationships between technological discontinuities related to the GSM, diffusion and industrial dynamics was outside the scope of this paper (compare with Ehrnberg (1996)).

In the case of the Finnish telecom industry, the key role of Nokia in the development of competencies to overcome these discontinuities is quite clear. It seems unquestionable that the case of the GSM represents a success story of the entry of an expanding firm in a country at the outskirts of Europe into a hugely successful high-growth industry (until quite recently). Nonetheless, this entry was not based on coordinated control of all risks and contingencies involved, nor was it based on a clear vision of the business opportunities at the managerial level, at least initially. In fact, the standardization process underlying the GSM as a whole was characterized by a high degree of uncertainty of technological and business opportunities, the mitigation of conflicts and risks combined with collaboration and political compromise at the EU level, that was bound to spill over to the equipment suppliers. In this sense, the transition from the NMT to the GSM is well captured in the overall framework of the co-evolution of complex design spaces and business opportunities, requiring forceful actors and functional competencies for their fulfillment (Carlsson & Eliasson 2001).

In Finland, a notable point of departure was that Nokia was a new entrant to the telecom industry when compared to the other significantly larger players, such as Ericsson, Siemens and Alcatel, who had decades of experiences in the technologies on a much broader basis. Nonetheless, the roots to Nokia's competencies in telecom technologies extend back to the 1960s and 1970s when Nokia was a first mover in the field of PCM digital transmission – later on these competencies proved essential to the GSM. Thereby Nokia was unintentionally involved in the emerging GSM design space far sooner than the business opportunities were disseminated throughout the firm. A further important prerequisite for the realization of these business opportunities was the entrepreneurial role played by Mobira, based on the strong position that this small but expanding firm had gained in the early radiotelephone and analogue mobile telephone market.

Mobira's entry into the GSM market shared two characteristics of interest in this context. First, these perceptions of business opportunities were based on developments at the 'wireless fringes' of the mainstream telecom markets, in which the PTT's placed voluminous orders for equipment for the fixed networks prior to the breakthrough of the cellular standards. Thus, a peculiarity of the Finnish case was the early exposure of Nokia to progressive customers in a new market. This interaction with customers in a fringe market - which subsequently also overtook the mainstream market – is reminiscent of Christensen's (1997) discussion of the mastery of what he refers to as disruptive technological change. Secondly, the active role of the Finnish PTT in disseminating the business opportunities throughout the industry was pivotal, already during the NMT era. This active role of the Finnish PTT derived directly from fears of becoming overly dependant on the pricing policies of an oligopoly of a few foreign incumbents, most notably Ericsson and Siemens (Palmberg 2002).

An important dimension in the emergence of technological systems, such as the GSM in Finland, is the organizational and institutional dimension – complex innovation processes are typically embedded in their organizational and institutional context of collaboration amongst networks of actors. It is quite clear from the foregoing case study that the ability of Nokia to overcome the discontinuities associated with the GSM is no exception to this insight. In fact, this paper demonstrates the intertwined emergence of an ICT research infrastructure and GSM related competencies during the 1980s in Finland. This research infrastructure has subsequently constituted the core of the Finnish system of innovation, with Nokia at it's center (Ali-Yrkkö & Hermans 2002). Hence, policy initiatives and developments in the public sector have played an important part in overcoming the discontinuities. However, it should be strongly stressed that these initiatives and developments did not amount to a coordinated 'grand plan', or an outspoken policy vision, of the development of the ICT industry at the time.

A striking feature of competence developments in the early and mid-1980s was the small scale of activities. Mobira confronted the discontinuities in the BSS by hiring a handful of engineers. As the complexity of the software started to increase beyond limits, R&D expenditures likewise started to increase, while more and more projects were outsourced to research groups at the technical universities in the cities of Espoo and Oulu, as well as to the Technical Research Center of Finland (VTT). An important aspect of this outsourcing of R&D was the early interest that research groups at the universities and the VTT had shown towards embedded software and related IC and DSP applications, prototype and simulation tools. Moreover, the clustering of competencies in the field to Oulu was well timed, since both the founding of VTT Electronics and the SEE research program activated communities of researchers in the late 1980s, when they were needed the most at times of crises and tight deadlines. With reference to Allen (1977), we repeatedly stressed the importance of dense networks and gatekeepers in absorbing and disseminating the relevant knowledge, as well as in identifying technological complementarities – these contributed to spillovers in the emerging telecom technological system related to the GSM.

Starting from the mid-1980s, the further hiring of R&D personnel was facilitated through the founding of the Nokia Research Center and Nokia Cellular Systems to coordinate the turnkey GSM business. These organizational changes were likewise important. They illustrate the organic growth of Nokia, from being a dispersed group of smaller entrepreneurial firms to becoming a significant player in telecom. In hindsight, it seems that this growth – from small to large – was well-timed vis-à-vis the inauguration of the GSM service and the diffusion of the standard. The Nokia Research Center contributed to the development of important prototyping and simulation tools, or various process innovations required to finalize the software and secure interoperability and the timely commercialisation of the first cellular system. Moreover, the founding of Nokia Cellular Systems in 1987, and Nokia Mobile Phone in 1988, were the result of a strong commitment that Nokia showed towards being a first mover in the GSM. With reference to Carlsson & Eliasson (2001), this reorganization created the critical mass necessary to turn technological opportunities in the design space into business opportunities in the market. The basket model compromise during standardization, and the participation of Nokia in the ECR900 alliance, should also be highlighted. While the ECR900 alliance appears to have been of limited significance competence-wise, it did provide Nokia with a necessary 'entry ticket' into the oligopoly of a few larger firms controlling the markets at the time.

Furthermore, the role of serendipity should not be ignored. As Dosi (1988) forcefully argues, the role of serendipity and various unforeseeable contingencies are an inherent property of innovation processes. In the case of the GSM, these were present at various levels. The standardization process took many turns favorable to Nokia. One such turn was the selection of the narrowband solution as a basis for the GSM – a selection that evidently favoured both Nokia and Ericsson (Hommen & Manninen 2003). Another one was the basket model compromise, which opened standardization of the internal interfaces of the BSS and NSS subsystems to the equipment suppliers, and thereby provided entry opportunities to Nokia as a new entrant. In Finland, the critical moments of the GSM in the late 1980s and early 1990s also coincided with the collapse of the Soviet trade, whereby resources could be relocated from mainstream to the 'wireless fringe' markets. Risk taking and the presence of guardians of the GSM venture at the managerial level, during times of severe crises due to problems in the consumer electronics businesses, should also be highlighted.

5.2 Innovation and the GSM as a break in the regulatory regime – reflections of present developments and policy

Even though this paper has focused on competence developments from a historical perspective, it does raise some important conclusions of relevance for present and possible future developments in the telecom industry. In this context we wish to abstract from some of the specific insights emerging from the case of the development of Nokia's first GSM system – or the innovation processes described above – to discuss broader policy issues related to standardization, the present and future development of the industry.

A first important conclusion along these lines relates to the cumulativeness of technological change and innovation discussed in the literature (see Dosi (1982) for a seminal paper), which is illustrated very clearly also in this paper. As suggested also above, important competencies related to the first GSM system were already in place in the 1970s, prior to the founding of the GSM group. Examples of such competence areas include PCM digital transmission and data modems, both of which could be used in the subsequent digitalization of the BSS subsystem. Moreover, Nokia's DX200 digital platform technology, developed during the 1970s, provided a surprisingly flexible platform also in a cellular environment due to certain technological choices taken during the pre-history of digital switching in Finland (see Palmberg (1998) for a detailed discussion of the DX200 case). Accordingly, the case highlights the importance of unforeseeable complementarities, combinatorial and incremental innovations, rather than radical one's. From a policy viewpoint, a key lesson could be that intended outcomes tend to be constrained by paths taken in the past. The identification and analysis of these paths in the past is therefore of great importance in the design of future policy and definition of priorities, irrespective of whether an industry faces technological discontinuities or not.

Despite the fact that the role of public sector involvement should not be overemphasized, the case study indicates that public R&D programs, as well as R&D funding, played their role in the development. Apart from the SEE program, the first ICT orientated research programs commissioned by Tekes were largely tailored to the needs of Nokia (Lemola 1996). According to Ali-Yrkkö & Hermans (2002), in the 1980s up to 25 percent of Nokia's R&D expenditures was financed by Tekes. On the basis of this paper, the conclusion to be made is that this involvement mattered especially in the early phases of competence developments, at a time when Nokia consisted of a dispersed group of firms and smaller R&D teams, outlocated to different units and cities. The interviewees also stressed the 'leverage effect' of public funding, as it complemented in-house funding by giving more degrees of freedom in terms of risks and deadlines. Hence, the precise targeting and content of this funding appear to have been far more important than the volume, even when highly complex technologies are at stake. However, the most significant contribution of the public sector to the development of GSM in Finland was in the form of the supply of skilled engineers, well vested in the relevant fields of technology. In hindsight it seems that the adaptability of the technical universities to the GSM related discontinuities was on par with that of the industry in this respect, especially in Oulu and Helsinki, and later on also in Tampere.

From a more distant viewpoint the standardization of the GSM also appears to have introduced important organizational and institutional frameworks - and codes of conduct – to the industry at large which are worth briefly reflecting on in this context (the GSM standardization process has recently been studied at greater depth by, among others, Bach (2002) and Hommen & Manninen (2002)). Due to pan-European ambitions, the GSM contributed to the establishment of ETSI in 1988 to coordinate future standardization. The GSM departed from the NMT by partly opening up standardization to the equipment suppliers through the introduction in 1987 of the basket model to further standardization. As suggested, the basket model resulted in competing technological choices and the differentiation of firm strategies, thereby stimulating the formation of strategic alliances. Subsequently, the openness of the standard also implied the entry of a range of new players and the setting up of an essential patents procedure at ETSI, whereby firms are obliged to make patents at the core of standards public under the principle of non-exclusive compulsory licensing to other ETSI members, while retaining their rights to claim licensing revenues (Hommen & Manninen 2003).[8] In summation, the transition from the NMT to the GSM thus also represents a major break in the regulatory regime of standardization of cellular systems with important ramifications to the nature of competition and industrial dynamics way beyond the period in time that has been the focus of this paper.

Finally, a discussion on the envisioned transition from 2G and the GSM forward to 3G and the UMTS standard is warranted. The historical case study of this paper advances two points

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[8] According to ETSI, in 2002 as many as 31 firms hold essential patents in the GSM. This number should increase manifold in the UMTS.

on this issue worthy of highlighting. First, one should be recognizant of the fact that the UMTS essentially should be interpreted as a continuation of the regulatory regime and technological paths set in motion through the GSM, rather than a radical break in this regime. In effect, GSM standardization defined a path of progress through GPRS and EDGE towards the UMTS as the major standard of 3G, while the transition from 1G and the NMT to 2G and the GSM appears to have been more discontinuous competence wise. Secondly, the present uncertainties surrounding the transition – or rather evolution – from 2G to 3G appear less dramatic once the initial conditions prevailing prior to the inauguration of the GSM service in the early 1990s are kept in mind. Specifically, both the telecom operators and the equipment suppliers grossly underestimated the popularity of the GSM service and the prospects of such value added applications as SMS – a tendency running through the case of the NMT as well. Furthermore, the technological risks associated with standardization were high and the whole standardization process was endangered at various points in time. Hence, in the light of history, it seems too early to doom 3G, as some commentators have been inclined to do.

The delays in GSM service openings in 1991-1992, the public suspects of the future popularity of the GSM and the unavailability of mobile terminals at that time resemble the situation of 3G in 2003. Similarly, competing short-range wireless telephone services such as CR2 and DECT were under development and gave an alternative to GSM, but failed later in challenging it. However, at present the situation is much more complex. The vast progress in personal computing, Internet and wireless local area networks (WLANs) – creating a platform for 4G – overrun these technologies in the design space. Internet based messaging and access to business applications rely already on personal computing platforms, but voice telephony and multimedia messaging are increasingly dominated by mobile phone platforms. ‘Wireless fringes’ integrating messaging, business applications and voice may emerge and it is difficult to forecast the design spaces underlying these business opportunities. The worst case with 3G could be, if its growth is delayed much beyond the year 2005, whereby competing technologies gradually begin to cannibalise the potentials, forcing 2.5G and 3G to become lower level transmission channels.

Another success related to the GSM was the coordinated standardization and the establishment of the MoU, and political will, that pushed the standardization process onwards through various compromises (Bach 2000). The mobile operators fixed the time schedules for the commercialisation of the GSM, and the radio licence fees were quite reasonable. In 3G the standardization is driven by an even greater number of actors and industry partners in the 3G partnership project (3GPP). Moreover, the inauguration of the service is based on individual decisions by different national and local mobile operators, whereby a coordinated inauguration is hampered by financial barriers to entry due to high license fees that have taken many operators to the brink of bankruptcy. In Europe the 3G licenses were approximately to 156 Billion Euro in 2000. This sum is equivalent to roughly one year of the total investments of the whole telecom operator industry in Europe (Helsingin Sanomat 2000/6). If 20% of the sum is taken from investments each year since 2001, the investment blockage caused by the 3G license fees will be over only in the year 2005.

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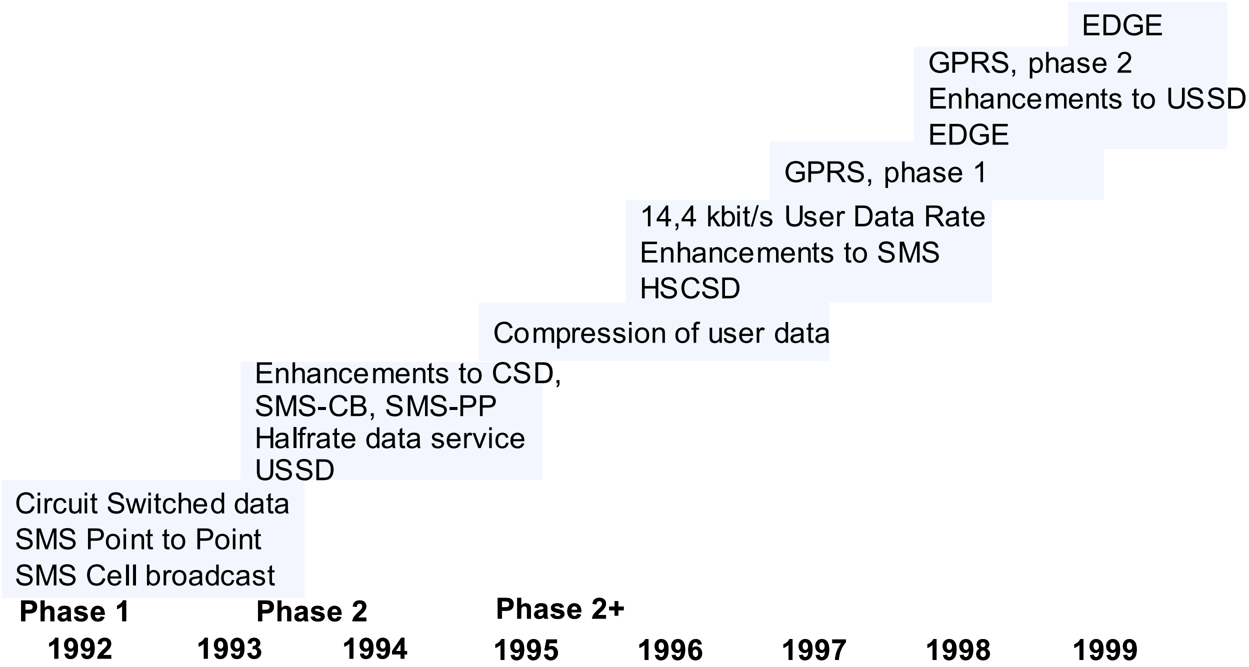
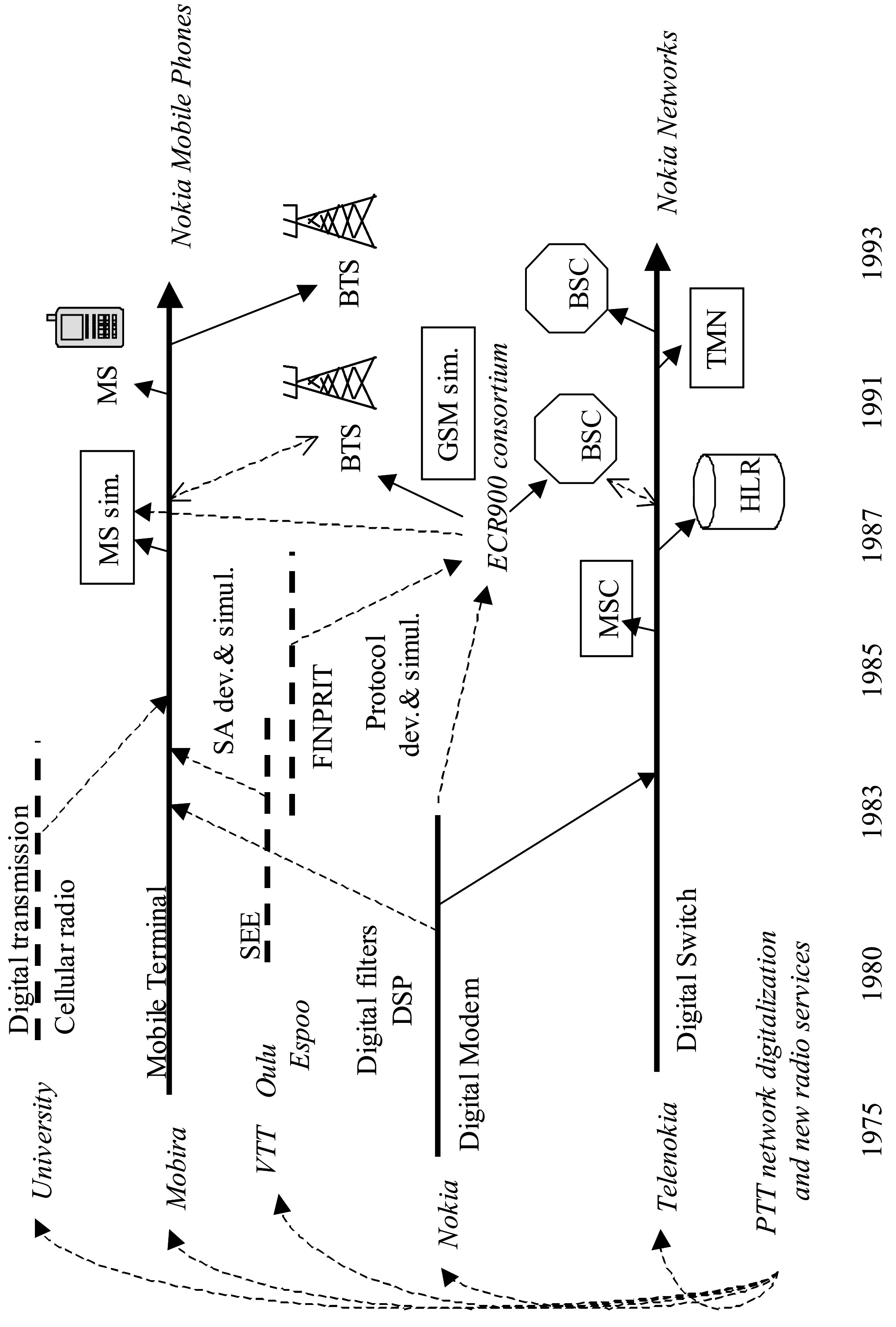
Appendix 1 – Further phases of GSM standardisation



Appendix 2 – The case chronology and competence flows



Appendix 3 – Interviewees

Ahava Heikki, Nokia, 2002

Ahtiainen Ari (details), Nokia, 2003

Ali-Vehmas Timo, Nokia, 2003

Halme Lauri (details), Sonera – retired, 2003

Hintikka Pekka, Nokia, 2003

Huttunen Timo, Nokia, 2003

Hovi Matti, Nokia, 2002

Kari Risto, Tellabs, 2003

Karila Arto (details), Helsinki University of Technology, 2003

Koski Aimo, Sonera – retired, 2002

Karppinen Martti, 2003

Laamanen Heikki, Tellabs, 2003

Makkonen Matti, Finnet Group, 2002

Melamies Lauri, Nokia – retired, 2002

Nieminen Jorma, Benefon, 2002

Paajanen Reijo, Minutor, 2003

Pulli Petri, University of Oulu, 2003

Saukkonen Samuli (details), University of Oulu, 2003

Soikkeli Jukka, Nokia, 2002

Vatjus-Anttila Lauri, 2003

Veikkolainen Erkki, Elektrobit, 2003

Appendix 4 – Interview guide

1. Personal history of interviewee

2. The perceived business opportunities and competitive set-up related to the GSM in the 1980s

Perception of the market, dedication given to GSM?
Competitors?
The Finnish competitive advantage, alternatives routes?

3. The origin of GSM competencies

Complementing versus substituting competencies ('discontinuity chart')?
Alternative technological choices?
Background of choices actually taken?

4. The development of GSM competencies

When and where?
How, collaborative partners?
Role of key persons and gatekeepers?
Role of public sector initiatives?
Strategic alliances, EU programs?

7. Who else should be interviewed, available written material etc.

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