Technological Life-Cycles

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TECHNOLOGICAL LIFE CYCLES: LESSONS FROM A CLUSTER FACING DISRUPTION

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Abstract.

New disruptive technological life cycles may initiate the emergence of new regional industrial clusters or create opportunities for further development of existing ones. They may, however, also result in stagnation and decline. For clusters in many of the fast developing technologies, the evolution is closely related to shifts in technological life cycles. During the 1980s and 1990s new mobile communications technologies have emerged as a series of distinct life cycles, which have caused major disruptions in the industry. The paper examines the key features of a cluster in wireless communications technologies, where the economic evolution has been quite closely related to the emergence of new key technologies. The analysis is focused on the strategy and policy issues involved in the specific phase where one technological life cycle may (or may not?) be succeeded by the next. When facing disruption the actors in the cluster have discussed various strategies for how to cope with shifts in the technological life cycles. We find that there is room and need for policy and collective action in periods of uncertainty created by new disruptive technological life cycles.

Keywords: Technological life cycles, regional clusters, communication technology

JEL – O31, O38, R12, R58

1 Introduction

This paper is focused on how regional clusters may react on the emergence of new disruptive technological life cycles. During the 1980s and 1990s new mobile communications technologies have emerged as a series of distinct 'generations'. The introduction and diffusion of each of these life cycles have caused major disruptions in the industry, but also opened opportunities for new entrants. The shifts from one generation to the next have also involved some major policy issues, such as choice of regulation and standardisation set-up and the need for large investments in university R&D.

For detailed analysis of clusters in many rapid developing technologies, the theories of technological life cycles seem to fit, because a given cluster often experiences the passing of several life cycles. The capability of a cluster to adapt to these sequential 'shocks' of new technologies is the core field of the study. This paper intends to further develop the analysis of sequential disruptions by using the concept of technological life cycles and apply this on a single case over an extended period of time, including several cycles. The term disruptive refers to such significant changes in the basic technologies that may change the industrial landscape. Tushman and Anderson (1986) describes disruption as a technological discontinuity that is so significant that no increase in scale, efficiency, or design can make the older technologies competitive with the new one.

The case to be studied in detail is a cluster of high technology based wireless communications firms in the region of North Jutland, Denmark. A special emphasis is given to the study of whether and how a 'collective spirit' may be formed and turned into collective action in periods of major threats and challenges. This again leads to a discussion of the interaction between privately and publicly initiated efforts and policy initiatives. Ideally, the paper aims at pointing at some features and mechanisms of a more general relevance for evolution of regional clusters based on fast developing technologies and the opportunities and potential necessities for developing policy measures in periods of major disruptions.

The term cluster is applied as "geographic concentrations of interconnected companies…. linked by commonalities and complementarities" (Porter 1998, p. 199). It is important how precisely these commonalities and complementarities are conceived and defined. Martin and Sunley (2003) has surveyed the wide array of cluster definitions applied in the literature more recently. The cluster concept appears to be very elastic and imprecise in academic as well as in policy circles. The present paper faces this problem by using a concise and operational definition. The object of this analysis is a rather precisely specified regional cluster, NorCOM, consisting of approximately 50 firms, a science park, and Aalborg University. The delimitation of the cluster has deliberately been narrow, i.e. a common knowledge base focused on radio waves as an information carrier. The size has made it possible to base the paper on extensive interviews and interaction with a large share of the major players in the cluster as well as to be rather specific in the discussions of policy issues.

The following Section 2 highlights the general theoretical background of the paper, which is the re-born interaction between geography and economics since the early 1990s. Section 3 focuses on the concepts of technological life cycles and the role of disruption. Section 4 analyses the technological life cycles in the mobile communication technology industry. The cluster in its regional context is introduced in Section 5, while Section 6 contains the analysis of the interaction of various generations of mobile communications technologies and the evolution of the cluster. Section 7 focuses on the future challenges for the cluster and the role of policy and privately initiated collective efforts. The conclusion is presented in Section 8.

2 The interaction between geography and economics

Since the early 1990s, the literature on the importance of geography for economic development has been revitalized. Inside the economics profession Krugman (1991; 1995) has engaged in a 'crusade' aiming at integrating the spatial dimension into mainstream economic theory. This has borne fruit in such theoretical work as Fujita et al. (1999) as well as influenced e.g. the discussion on income convergence versus divergence among European regions. Krugman's

writings also caused a comprehensive, but rather hostile, reaction from the community of economic geographers during the 1990s, surveyed by Martin and Sunley (1996) and Martin (1999).

In 1990 another stream of literature dealing with the geographical dimension of economics emerged from research rooted in a strategic management perspective, in terms of Porter's (1990) highly influential reinterpretation of Dahmén's (1970; 1988) development blocks as regionally based *industrial clusters*. Also emerging in the early 1990s was the literature on *innovations systems*, whether national (Lundvall, 1992; Nelson, 1993), regional (Cooke, 1992) or based on specific technologies (Carlsson and Stankiewicz, 1991) or broader sectors (Breschi and Malerba, 1997). Technical change and its diffusion has been a core driver of the innovation systems literature as well as in Porter's work. They share the view that the traditional linear model, where scientific discovery and invention move on to industrial innovation in a fairly simple manner, cannot explain the dynamics of industrial development, neither at present nor historically. On the contrary, they share an emphasis on the systemic character of technical innovation - the institutional set-up matters as do interaction among a great deal of actors, such as firms, universities, industry associations, standardisation bodies, government regulators (at the national as well as regional level), science parks etc. While the innovation system literature has emphasized the role of inter-firm cooperative networks, Porter on the other hand emphasized local competition as a main dynamic force in the development of clusters.

Recently, major attempts to synthesize and integrate these various lines of work have been presented. *The Oxford Handbook of Economic Geography* (Clark et al., 2000) represents a great effort to bring together the various contributions, although without necessarily solving the differences between the various approaches; there is still a rather large gap between mainstream economics and the other approaches. Edquist's (1997) presents the various contributions to the innovations system literature, which to a large extent appear to have been integrated through that effort. Porter (1998; 2000) contains an effort of further integration of the strategic management perspective with the emerging research tradition in economic geography and innovation systems.

The various lines of research on the interaction between territory and industrial development have, thus, somehow tended to converge. Major efforts to do empirical comparisons of regional innovation systems have been performed in several European projects during in the second half of the 1990s with an early proponent of the concept of regional innovation systems as a central node, see e.g. Braczyk et al. (1997), Cooke et al. (2000), and Cooke (2001).

The present paper is focused on a particular line of research in this context, that of high technology based regional clusters. Many of the available cluster studies have been focused on more static descriptions of their characteristics at a given point in time, although flavoured with evidence of some of the main features of their history. A more systematic focus on the role of technology and the development of specific clusters over longer time spans has somehow been given less priority. This may be due to the great variety of regional clusters. Generalisations across this variety may seem difficult, especially concerning different patterns of evolution over time. This paper intends to further develop the analysis of sequential disruptions by using the concept of technological life cycles and apply this on a single case over an extended period of time, including several cycles.

In the theory of the patterns of technical innovation the concepts of product, industry, and technological life cycles seem fit to a more dynamic analysis of the development of regional clusters. Klepper's (2002) analysis of the early concentration of the automobile industry in Detroit is an example of the merit of the industry life cycle approach. For detailed analysis of clusters in electronics, the theories of technological life cycles seems fit because a given cluster often experiences the passing of several life cycles. It is the capability of a cluster to adapt to these recurrent disruptions caused by new technologies, which is the core field of the study. Saxenian's (1994) account of the history of Silicon Valley is closely related to the emergence of radical new technologies, as is her analysis of how the Route 128 region got stuck in one, at the time highly successful, technology – i.e. minicomputers. Two new technological life cycles (Unix based 'workstation' computers and the PC) were at the heart of the Silicon Valley resurgence in

the 1980s, when the Boston area, according to Saxenian, was left behind in the computer industry.

Thus radical technological change may cause disruptions for existing clusters as well as form the foundation for the emergence of new ones.

3 Theory of technological life cycles and disruptive technologies

The transformation and change of sectors, industries, and products are in the literature on industry life cycles (Vernon, 1966; Klepper, 1996) and product life cycles (Abernathy and Utterback, 1975) shown to follow a life cycle from birth to maturity. Abernathy and Utterback (1975) focused on technological innovation, where product and process innovations were integrated into a single model explaining the evolution of a product life cycle.

In the beginning (the fluid phase), there is a lot of experimentation with different designs etc., resulting in a high number of product innovations. The early stage then turns into a phase dominated by incremental innovations, when a dominant design emerges. As the rate of product innovations drops and technological uncertainty is lowered, the rate of process innovations increases. Consequently productivity increases and the scale of production grows (Utterback, 1994). The focus shifts from product performance maximisation to cost minimisation (the transitional phase). In the following mature phase, the overall rate of innovation fades, the products become standardised and the production processes become more efficient and closely integrated with the products.

The industry life cycle and the product life cycle are closely linked. Entry, exit, and growth are added to the product life cycle to form the industry life cycle. In addition, the fluid phase of an industry is characterised by a high number of entrants. But as the industry enters the transitional phase and the number of firms peak, a shakeout occurs resulting in concentration. The prices decline during the cycle and while the market size initially is small, it grows rapidly in the transitional phase.

The organization of the firm and the character of its innovative activity also change during the cycle (Utterback, 1994). In the early phase there is high innovative activity among smaller firms and new entrants, while in the mature stage, with less product innovation, there tends to be an advantage in the innovative activity of large and established firms (Audretsch and Feldman, 1996; Klepper, 1996). In Cainarca et al. (1992) the industry life cycle is split into (different) life cycles of sub-industries defined by their technology. This technological life cycle is more than a product but less than an industry life cycle. It is also important to note that each technological life cycle has different features i.e. competition, user needs, applications etc. can be different.

Utterback uses an S-curve model where the evolution of technology, industry or product follows an S–curve over time. The performance is usually either measured by technological performance or market penetration. Utterback uses the American ice industry as an example, but finds a similar pattern in others, such as the computer industry.

[FIGURE 1 ABOUT HERE]

However, the coexistence and shifts from one technological life cycle to the next is not straightforward. The life cycle of an established technology may be prolonged by 'sustaining innovations' or may be disrupted by the emergence of a new technology. Sustaining innovations are not necessarily incremental, but may be quite radical.

Initially the disrupter under-performs the established technology, but it enables new applications for new customers, presents new benefits, and the performance improves rapidly. The disruptive technology may initially have a lower performance than the established and may also serve different customers and applications. For a long period the established technology may continue to perform better and the disrupter may not be seen as a threat. Because the disrupter has a different improvement trajectory, it can eventually outperform the old technology, although the latter may fight back for a prolonged period.

The evolution paths of the cycles are, obviously, not as deterministic and predictable as indicated in Figure 1. Many potential disruptive technologies will not win or outperform the old technology due to technological lock in, de facto standards, sustaining innovations, timing etc. A possible cause can be different types of disruption. Tushman and Anderson (1986) categorizes these as product (new product class, substitution, or fundamental improvement) or process disruption (substitution or radical improvement), which are either competence destroying or enhancing. Bower and Christensen (1995) and Lewis et al. (2001) have emphasized that the causes of disruption usually are new business models, applications, or customers, but not necessarily the technology itself.

The disruptive technology often comes from outsiders and not the industry leaders (see Utterback (1994) and Bower and Christensen (1995)) and is therefore very hard to predict. Even disrupters may be disrupted. But when a new technological life cycle successfully takes off, the outcome is often a shift of market leaders and location. Likewise, a new technological life cycle may offer new opportunities for existing or emerging regional clusters. Audretsch and Feldman (1996) shows that there is a tendency in the early stages of an industry life cycle for innovative activity to cluster, whereas it is more dispersed in the mature stages. Also Storper and Walker (1989) and Thompson (1975) have studied the industrial transformation process with special emphasis on regional instability and dynamism in these different phases.

4 Technological life cycles in the mobile communications industry

The concept of technological life cycles fits neatly the evolution of mobile communications technologies. The significant changes in the basic technology from the first generation (1G) technology to the second (2G) constitute a shift of technological life cycles. Likewise the emerging third generation system (3G) represents a new potential cycle. The pattern for the European mobile communications industry is shown in Figure 2, which also contains an 'envelope curve' in order to illustrate that there may be a life cycle pattern of the entire industry moving towards

the mature stage already at present, due to (temporary?) market saturation of mobile phones in the most dominant markets.

The 1G cycle consisted of analogue mobile systems, of which the Nordic NMT - the first international system operating from 1981 - became very successful. The disrupter and subsequent new technological life cycle was the pan-European GSM, which was a shift to digital technology and required a new infrastructure. The disruption caused by GSM did not only lead to replacement of NMT; GSM even became the de facto dominant world standard. GSM also became a disrupter to the fixed telephones and satellite cell phones networks as well as in the telecom service provision industry. (Mannings and Cosier, 2001; Dalum, 2003).

[FIGURE 2 ABOUT HERE]

Within each of the generations different systems have been competing worldwide. The NMT system became adopted in several, mostly European, countries as well. But technically inferior and internationally incompatible systems were implemented in the dominant European markets of Germany and France, while the UK adopted an adjusted version of the US (1G) AMPS system, called TACS. During the 1G cycle the US and Latin American markets were dominated by the AMPS system. Although the highly successful GSM has emerged as the dominant world standard within the 2G technologies, the equivalent US digital technologies have caused fierce competition between these rivalling systems, especially in the US and Korea. Also within the 3G technologies, no universal standard could be established. The European-Japanese UMTS system competes with the US CDMA2000 and a potential Chinese rival standard, TD-SCDMA, has not been decided on yet. For detailed historical accounts on the various generations of mobile communications systems, see Funk (2002), King and West (2002), Hommen (2003) and Dalum et al. (2002).

At present the industry is in the transition phase between 2G and 3G. However, the 2G technologies are 'fighting back' with the sustaining innovation EDGE (or 2.5G) that offers the data transmission speed of the same magnitude as the first 3G networks. The latter is still in the pro-

cess of being rolled-out and has been hit by various delays, such as lack of sufficiently attractive terminals. A situation quite similar to what happened a decade ago during the early implementation of the first GSM networks. But the open question is will the smooth pattern indicated in Figure 2 be realised? Or said differently will history to a certain extent repeat itself? The outcome is not easy to predict. The recent history of the industry indicates that an exaggerated optimism concerning the transition from 2G to 3G has led to a technology push dominated approach where customer needs have played a too minor role.

The UMTS variant of 3G requires a completely new infrastructure. The order of magnitude of the estimated costs are reported to be around $150bn, while the costs for the major European operators to acquire 3G licenses during the spectrum auction processes during 2000-1 were around $120bn. The operators have vested interests in the rollout of 3G in Europe, but it is nonetheless not straightforward to which extent 3G will cause radical disruption, partly because of the sustaining innovations, such as EDGE, and other potentially disruptive technologies. Especially Wireless Local Area Networks (WLAN), which are providing low cost, high-speed short distance wireless Internet access, may be considered a potential disrupter to the emerging 3G networks.

5 North Jutland – the emergence of ICT

The region of the North Jutland County is located at the northern tip of the peninsula of Jutland at the top the Central European continent. The population is around half a million people, slightly less than one tenth of the Danish total. Total employment was 245,800 persons in 2001, of which the private sector share was 161,700. The largest municipality is Aalborg, the fourth largest city in Denmark, with 163,000 inhabitants. The region is 'specialised' (i.e. has an above national average employment share) in the primary sector and in metal products, but also in mechanical engineering and electronics. This industrial structure is in line with the average Danish 'non-metropolitan' counties. The two 'metropolitan' regions are Copenhagen (including its suburbs) and Aarhus.

The presence of a fairly visible segment of the ICT sector is a rather recent feature. Total ICT employment was almost 8,450 in 2001 of which 30% was in manufacturing compared to 22% for Denmark. Specialisation in ICT manufacturing increased to 1.1 during the 1990s concentrated on two segments, telecommunications and components. Especially telecom hardware has been outstanding with an increase from a three to nearly five times larger employment share compared to the national average.

6 The NorCOM history – the interaction of cluster evolution with technological life cycles and disruption

These statistical patterns cover a wireless communications cluster, NorCOM, in North Jutland consisting of two related fields, mobile telephony (development and production of hardware and telecom services) and equipment for maritime communications and navigation. The cluster originates back to the mid 1960s when the 'mother' company SP Radio switched from being a consumer electronics producer for the domestic market to radio telephones for small ships. This firm quickly became one of the world leaders in its field. During the 1970s a few maritime communications firms emerged as spinoffs from SP Radio. An important trigger for further industrial development was the start of Aalborg University (AAU) in 1974, which integrated two previous undergraduate level engineering schools both with departments in electronic engineering.

6.1 The NMT (1G) life cycle – an embryo of a cluster formed

From 1981 the Nordic mobile telephony operators (incumbent government owned monopolies) launched the first cross national public mobile telephony system ever seen, the NMT.[1] The system became an enormous – and unexpected - commercial success in term of user penetration, which called for significant attention internationally. The main producers of the equipment were Swedish Ericsson, which was the unchallenged leader in infrastructure equipment, and Danish Storno, located in Copenhagen, being strong in terminals.

A new technological life cycle had emerged and barriers to entry were lower at the early stage, at least within the terminals market. Among the new entrants were the North Jutland firm, Dancall, which started as a maritime communications spinoff from SP Radio and the Finish Nokia, who acquired the Mobira start up. The 1980s became the decade of the 1G life cycle. Growth was very rapid for Ericsson, Nokia, Dancall, and Storno. The business opportunities appeared very promising, but competition increased. Prices and size of the terminals decreased, while technological performance increased rapidly. While the next generation of systems could be seen in the horizon, Storno was sold to the dominant US terminal producer Motorola in 1986. In North Jutland another maritime communications start up from the 1970s Shipmate also entered the NMT field in 1985 as Cetelco.

At the end of the 1980s North Jutland had become internationally visible as an NMT region. Several of the large telecommunications multinationals had entered the NMT terminals market, such as Siemens and Alcatel. The first Alcatel terminals were developed in North Jutland by T-Com in 1986 - a spinoff from Dancall to become acquired by Korean Maxon in 1991. The coincidence of the take off of NMT from 1981, the first vintage of M.Sc.'s finishing their degree in electrical engineering at AAU in 1979, and the close industry-university interaction in the emerging mobile telephony industry paved the way for this early development. It was not an outcome of a deliberate industrial policy effort, although it could not have happened without the result of a deliberate outcome of a public policy effort, the start of Aalborg University in 1974.

6.2 The GSM (2G) life cycle – the regional cluster consolidated

During the last half of the 1980s a new life cycle was emerging. The tremendous success of NMT inspired the European telecommunications operators to create a Pan-European system, entirely based on digital technology. This process was given strong political backing by becoming a Europe 1992 'flagship project'. The standardisation process of the GSM system was taken over by a new EU organisation, the European Telecommunications Standards Institute (ETSI).

The GSM system was planned to become operational in 1992 and a large amount of prestige and political momentum was embedded in the entire process.

GSM – and its competing 2G technologies in the US and Korea - represented an entire new technological life cycle. The infrastructure had to be rebuilt in terms of antennas and base stations in the landscape. The technological challenges for developing this new infrastructure as well as the GSM terminals were huge. A veritable race began because many of the incumbent telecommunications hardware producers saw the commercial opportunities already harvested by Ericsson, Storno/Motorola, and not least Nokia in the second half of the 1980s.

The challenges were of such a magnitude, that some of the major multinationals formed pre-competitive alliances for developing parts of the equipment. Nokia, until the 2G cycle not active in infrastructure equipment, formed with Alcatel and AEG the ECR900 consortium to develop GSM infrastructure technology (Dalum, 1993). Ericsson cooperated with Siemens at some stage during the 1988-92 period as part of the contract of building the Deutsche Telekom 2G infrastructure.

In the North Jutland context the advent of GSM was a major challenge and also seen by many as a major threat, given the character of the small and medium sized firms. GSM was no doubt seen as a major disruptive phenomenon in the horizon. However, local university research had flourished during the NMT boom and the interaction with the local industry thrived. The knowledge infrastructure of the region began to become internationally visible. The two local producers and competitors, Dancall and Cetelco, announced in 1988 a pre-competitive joint venture, DC Development, to develop the basic technology for GSM terminals - located on neutral ground at the newly founded Aalborg University science park, NOVI. The two firms explicitly planned to close the joint venture when the mission was accomplished and compete based on different features of the terminals, such as design. Close interaction with AAU and the National Telecom Agency in testing of the new terminal equipment were among the 'outside' factors of importance for the project.

The DC Development team peaked at approximately 30 persons in 1992 and managed to develop a GSM terminal presented at the CEBIT fair in Hanover, Germany in 1992. At the time terminals were presented by only a handful of companies, including Ericsson, Motorola, Nokia, and Dancall-Cetelco (in various disguises such as Philips, Hagenuk, and Dancall). Although a new technological life cycle could be envisaged, the NMT market was still growing and it coexisted with the emergence of the 2G cycle. The competition in the NMT market had changed during the 1G life cycle, the many entrants and the success in terms of a rapid diffusion of the mobile phone and (at the time) high user penetration had led to falling prices and fast technological change. The innovative effort in GSM by the small North Jutland firms basically drained them financially, because the competition was fierce in NMT market. Both were taken over by foreign companies. Dancall was acquired by UK Amstrad, then by Bosch, and later again by Flextronics and Siemens. Cetelco was taken over by German Hagenuk, to be sold later on to Italian Telital.

At this stage, the first private GSM operator Sonofon[2] decided to build its main operations in Aalborg and the AAU research profile was consolidated by a new research Centre for Personal Communication (CPK), which became an important international actor at the research scene in wireless technologies. But there was a widespread fear at the time, that the (planned) closing down of DC Development would be the end for the region in mobile telecom hardware development and production. However, instead of dying this group of industrial development engineers managed to start a 'cloning' process – through existing firms or via spinoffs - which resulted in the region becoming a development hub for GSM terminals with six-seven firms developing GSM equipment, mainly for foreign companies.

The shift from the 1G cycle to 2G had caused a significant amount of disruption. The advent of a new cycle had created uncertainty and a major technological challenge for the firms in the NorCOM cluster. The 'solution' was thought to be the joint venture model for developing the basics of a GSM phone between the two largest firms. The strategies of other firms in the cluster were less coordinated and more diverse. The local affiliate of Maxon continued to develop NMT

phones since this market still was growing and Maxon had a deliberate strategy of postponing its entrance into GSM technology for some years. The emerging cluster thus consisted of firms with radically different strategies, from early movers to late entrants who followed a more opportunistic wait-and-see strategy. In the first half of the 1990s the cluster consisted of somehow fragmented small and medium sized players with rather different strategies.

The latter half of the 1990s became a period of very rapid growth. To some extent the events of the late 1980s were replicated but on a larger scale. And what became more and more evident already from the early 1990s were the contours of a wireless communications cluster, to a certain extent based on close personal interaction between engineers (Dahl and Pedersen, 2004).

During the 1990s this cluster was widened horizontally[3]. Several firms entered the cluster as spinoffs or as inexperienced entrants. Many of these started working in other wireless communication technologies than the dominant mobile and maritime communications technologies e.g. a group of engineers left Dancall and were joined by a group from Maxon to found RTX, which during a decade became a world leader in developing cordless phones for big companies on OEM terms. In the second half of the decade RTX entered mobile communications as well. A new collaborative activity was initiated between some of the firms in the cluster and some 'outside' firms in the field of cordless phones. A standardisation project involving a group of Danish firms founded Dansk DECT Udvikling focusing on further specification of the European standard for cordless phones, DECT. The main idea was that the European standard was too loosely defined and would not necessarily allow for seamless compatibility of equipment or parts from different producers. By making a more detailed specification of the DECT standard and getting it approved at the European level they went for creating a Danish advantage within the cordless segment of the industry inspired by the success of NMT. The cordless phone technology was, however, disrupted by the rapid diffusion of mobile phones, but survived as an add-on to the fixed line telephony system. In 1995 the consortium was taken over by Ericsson that continued working on cordless technology, but soon diversified into other technologies.

Parallel to the horizontal proliferation, a vertical deepening was also seen. The first significant event was the decision to locate the major activities of the first private mobile phone operator Sonofon in Aalborg from 1991, which resulted in nearly 1,000 jobs at the end of the decade. This deepening was matched later on by upstream entrance of specialised component developers, especially marked when one of the US leaders in chipsets for mobile phones Analog Devices opened an affiliate in Aalborg in 1997. Analog delivered chipsets for two of the local terminal developers and wanted to be present at the now thriving GSM development hub. This deepening was brought further by the Texas Instruments acquisition of a GSM developer ATL in 1999, and Infineon, which founded DWD a small GSM developer in 1999.

University R&D and education thrived further in the late 1990s, when CPK at AAU was prolonged with a second major research council grant 1998-2002. All over Europe there was a general lack of electronic engineers in the late 1990s. Any region that could offer qualified engineers and an innovative research environment in the wireless field could attract multinational companies – and North Jutland indeed did.

At the end of the decade the GSM developers moved into 'sustaining' solutions, such as GPRS and EDGE, who are able to speed up the data communication performance of GSM solutions. This indicated the early beginning of the next major technological life cycle 3G. In general major players in the industry were attracted by the viability of NorCOM and saw opportunities as using the region as also a development hub for 3G technology. This was the explicit aim by Nokia and Ericsson when they founded 3G development units in North Jutland in 1999.

In 1999 and the first half of 2000 the NorCOM cluster, thus, became clearly visible on the international scene, but dark clouds appeared in the horizon.

6.3 Is UMTS (3G) a major threat?

The emergence of 3G as a new technological life cycle is also expected to create disruption, but the telecommunications turmoil began long before the roll out of 3G networks. The turmoil

was caused by the global crisis in the ICT sector that started in 2000, as well as the characteristics of the spectrum auctions in Europe and the emergence of other potentially disruptive wireless technologies. Complexity and convergence are two central issues. The increased complexity of the technology creates disruption, because development of UMTS technology requires huge resources, while the convergence between wireless technologies and the fixed net has potentially created even more disrupters.

The complexity and costs of making a mobile phone have increased 20-30 fold in each cycle. The increased complexity from the 1G to 2G required a large R&D effort, which mainly could be managed by the large firms. Multinational companies entered the promising market and other firms formed alliances and cooperated in the early stages of the technology. Development of 3G handsets – let alone the equipment for 3G infrastructure - requires huge R&D resources, which has led the big players to form joint development consortia and joint production activities have emerged. Sony and Ericsson founded a joint venture developing 3G handsets; Toshiba and Mitsubishi formed an alliance, which also has been the case for NEC and Matsushita (Panasonic).

In North Jutland the density of firms in the cluster increased and at the end of 2000 there was 40 firms employing 4,200 persons, which was about half of the total ICT employment in the region, see Table A1. Several firms were doing GSM development and the cluster became significantly denser compared to the peak of the 1G cycle. But compared to the most outstanding regional concentrations or clusters in the ICT sector, such as Silicon Valley, Southern Sweden, Southern Finland, Munich, and Cambridge, it was still sparse. The following firms performed R&D in UMTS in 2000: L.M. Ericsson (125 employees), Siemens (350), Maxon (105), Shima (60), and Condat (20). In 2004 the pattern had changed; Maxon is focused on sustaining innovations, while Shima has been closed down. Ericsson has closed its 3G development in North Jutland and Siemens has downsized its R&D staff from 350 to 200 during 2001-2003, but has increased employment again in 2004 to 270. Development of the basic 3G technologies does not appear to take place in the cluster to the same extent (in relative terms), as was the case in the initial GSM

phase a decade earlier. The crisis in the telecommunication industry and the increased complexity has enforced many of the players to focus their R&D in larger units and form alliances. However, the high complexity and the demand for an increased number of functionalities of the 3G handsets open new opportunities for specialisation.

The evolution of the mobile communications technology has lead to convergence between the mobile devices and wireless networks with the fixed net. Although there is convergence, there are still differences between the mobile Internet and wireless access to the fixed Internet.

One of the major driving forces behind 3G is the 'killer' demand for data access on the move. There seems to be a demand for the combination of mobility and communication, which provides access to data and other corporate, commercial, and communications services. However, other technologies capable of creating wireless access to the Internet are also available, and they may cause serious disruption to 3G.

The character of the firms in the NorCOM cluster had changed during the latter part of the 2G cycle, basically caused by the (grossly exaggerated) commercial potential seen at the time in the emerging 3G cycle. While the cluster in the transition phase between 1G and 2G still mainly consisted of small and medium sized Danish owned firms, the ownership structure changed significantly during the second half of the 1990s. Then very fast growth of the GSM market and the perspectives for the coming 3G led to an expansion process among all the major large multinationals in the industry. Ericsson, Nokia, and Siemens set up UMTS development units in the region and Motorola acquired a local development firm. And the big players in the chipset technologies for 2G and 3G also established or acquired development units in the region.

The outcome for the cluster was that these large players did not go for local collaborative strategies, such as especially the joint GSM effort, DC Development, which became crucial for the vitality of the cluster during the 2G cycle. An initiative was, however, taken among the small players in the region - such as Maxon, Telital, Shima, and RTX - to discuss the establishment of precompetitive collaborative ventures in 3G technologies. The lesson from the initial

stage of the 2G cycle concerning the potential benefits of collaboration was clearly understood within the cluster, but the companies could not agree on common goals and joint strategies.

6.4 Is 'beyond 3G' or '4G' a major opportunity?

The massive investments required to build the coming 3G infrastructure paired with deep financial problems of the telecommunications sector in general in the early 2000s has increased the focus on what is coming next in the horizon. 4G has loosely been defined as the complete integration between the wired and the wireless spheres of telecommunications with speeds of data communications of 100-150 Mb/s. But there is a certain amount of ambivalence prevalent in the terminology at present. 'Premature' versions of 4G are much closer – in fact already available - consisting of a combination of 2G and WLAN technologies.

This potential disrupter to 3G is WLAN, a technology that makes short distance high-speed wireless Internet access possible. The access device is mainly a laptop or PDA, but the speed is much higher than 3G and WLAN based solutions seem very attractive even in the short run. The users will have to move to 'hotspots', such as hotels, airports, railway stations, cafés, and petrol stations, to be able to reach the Internet. Instead of waiting until the 3G networks have been completely rolled out, users may demand a kind of 'surrogate 4G' solution where they will have to move around in the terrain with their laptop PCs or PDAs *and* mobile phones. This kind of solution requires an infrastructure of hotspots.

Given that the US is lagging seriously behind the European mobile telecom infrastructure – with severe implications for the US mobile hardware industry - there are strong incentives in the US market to promote a decentralised WLAN based wireless Internet access approach. The latter should be conceived as a supplement to the ordinary wired telecom infrastructure. On this background there is a rapid process of technological change in this segment of telecommunications going on at present.

WLAN is, opposite to UMTS, using unlicensed spectrum and is highly deregulated. One of the attractions is the possibility to build up small range high-speed wireless networks for low cost and avoiding some of the problems of carriers controlling the 'last mile'. But there are advantages and disadvantages with 3G as well as WLAN solutions. To summon a few, WLAN has higher speed, but has a limited reach, while the mobile networks are significantly slower but have much better coverage.

The potential disruptive effects of the WLAN technology vis-à-vis 3G may turn out to be a potential opportunity for the NorCOM cluster. Given that development of 3G handsets has been organised by the large telecom multinational companies in pair wise alliances, this is a field very difficult to enter for small firms – at least in the initial phase of the 3G technology life cycle. However, the risk of 3G becoming a major failure cannot be neglected in light of the heavy financial burden the 3G infrastructure is causing for the mobile operators. Also the demand for full mobility (3G) versus high-speed data transmission (WLAN) is subject to uncertainty. This is the basic background for the present true uncertainty about the future infrastructure: will 3G or WLAN solutions win? Or will they co-exist as true complements?

7 What are the opportunities for public policy and collective efforts?

The uncertainties analysed above are of a global character. Although the institutional setups differ between the main group of players in Europe, the US, and Japan, the present situation can be characterised as very open ended, where quite different outcomes all may have some degree of probability.

The relevance of policy measures and/or coordination between groups of actors at the *national level* may be of most relevance in exactly the very uncertain transition phase between two technological life cycles. The emergence and very fast growth of the 1G and 2G mobile telephone industry in initially the Nordic countries followed by several continental European coun-

tries may to a considerable extent be attributed to the standardisation initiatives performed by first the Nordic PTTs followed by the EU created ETSI standardisation body (Gessler, 2002). Both efforts were due to visionary telecom regulators and (initially) incumbent monopoly wireless operators.

This path to standardisation is often nicknamed the Nordic or continental European way, as opposed to the US approach, often characterised by a decentralised, if not anarchistic, bottom-up dominated procedure. The latter has been very successfully applied in the case of the Internet, where the process has been dominated by US actors, which has led to a US lead in the equipment industry as well as the e-business industry, as analysed by Mowery and Simcoe (2001) and Kenney (2002). The Nordic and European experience, so far at least, have fostered a common understanding of the significance of international coordination efforts ex ante. But the general crisis in the telecom service industry as well as among the equipment vendors from 2001 coupled with the huge rents that some of the major European governments have extracted from the coming 3G service providers in the auctions for licences have caused a significantly higher degree of uncertainty in the transfer from the 2G life cycle to 3G. The outcomes are very difficult to predict, but they are on the other hand deeply dependent on actions taken by the major actors.

The outer poles of the future scenarios in a medium term perspective may be represented by:

1. 3G systems may dominate the mobile communications networks with WLAN solutions as a complementary service basically controlled by the incumbent mobile carriers.
2. 3G may prove to be a new 'Titanic' in Europe, if not Japan, because the US telecom industry may strike back by not adopting a 3G system at any large scale, but exploit the sustaining innovations in 2G and combine them with the evolving opportunities offered by more decentralised WLAN experiments.

At the *regional level* there is also room for policy and collective efforts. Given such fundamental uncertainties it may prove relevant for a region involved in these technologies to put forward field experiments with the patterns of telecommunications services seen from a user perspective, including firms, government agencies at all levels as well as private consumers. The aim can be to be prepared for different future trajectories, if not to influence these outright. Even small regions may eventually influence the future development abroad if they use their potential institutional advantages in organising field experiments that may be visible internationally.

In the case of North Jutland such options may be argued to be present, if the necessary consensus could be established. This region was in 1999 appointed as one of two Danish 'IT Lighthouses', or as the so-called Digital North Denmark (DDN). The national government allocated approximately €25m and another €50m has been added by local government organisations as well as private firms, not restricted to be local. In one of the DDN projects an Aalborg University group has collaborated with the largest IT service firm in the region and a small group of municipalities in order to design local optical fibre based network solutions, which will bring 'true broadband' to local government organisations, private firms, and consumers – i.e. a Fibre-To-The-Home vision. Given that how to organise this infrastructure – and not least the 'last mile' problem - still is one of the fundamental barriers for diffusion of IT in general, such experiments could be of considerable importance in their own right. The infrastructure project opened unique opportunities of creating field experiments with an optical fibre based local infrastructure that *also* contained extensive possibilities for WLAN access.

Taking into account that a considerable competence has been developed in the NorCOM cluster in developing 2G, sustaining innovations and – at least among some of the firms – competence in various parts of 3G technology as well as a significant competence has been developed in other fields e.g. in data transmission over very short distances, there are several important points of departure, which may form an ideal background for coming at the forefront in the wireless-to-wired data communications field – i.e. to become involved as a visible player in

the early stages of a new technological life cycle. Not necessarily because of major technological breakthroughs, but *through the capability as a region* to combine unique field experiments in the area of wired and wireless telecom convergence with competence among several NorCOM firms to find various footholds in the field in the early stage, and especially to be placed as a 'core player' in the international standardisation efforts through documented user experiments. If some of the field experiments may prove successful rumours could spread internationally, create visibility, and attract some of the big global players. Echoes of the implementation of this vision may be heard internationally – as happened successfully concerning the capacity of the region to become an international hub (although at a fairly small scale) during the GSM cycle.

The policy challenge is to perform the act of (i) combining efforts at experimenting with the consumption structure - i.e. the telecom infrastructure, (ii) supporting the basic university research in the field of convergence between wireless and wired telecom, and (iii) interacting with the local as well as the global industry.

At the cluster level the NorCOM firms realised that there was a need for collective efforts, given the fundamental uncertainties and the more peripheral role that these companies were approaching in the field of 3G technologies. Aalborg University and the cluster organisation have jointly invested considerable efforts in gaining new ground in the basic R&D background needed to become visible players in the market for solutions for the future ICT infrastructure as well as in the international academic community in this field. A significant outcome has been the establishment of Centre for Teleinfrastructure, CTIF, at AAU in 2004 consisting of more than 100 researchers. Among the foreign contributors to CTIF is the large EU 6th Framework Programme project MAGNET, where AAU is the coordinator, as well as grants from Samsung, Siemens, and Nokia. The establishment of CTIF has been an outcome of a prolonged battle to get support at the national level. The Danish government has been fairly hesitant, but finally gave support through a specific innovation consortium scheme. What probably has been a decisive catalyst for the final establishment of the centre is support and commitment from national and not least local industry and three local foundations, which have allocated money for free

basic research. The support and commitment from the local players - firms as well as foundations – has been an outcome of a 'collective spirit' accumulated among the network of regional players over nearly two decades. In this specific case the public policy authorities at the national as well as regional level has been somehow reluctant. The final outcome has more been a result of efforts from local firms, foundations, and university paired with significant contributions from large multinational telecom companies.

8 Conclusion

This paper has analysed features and mechanism of a general relevance for evolution of regional clusters based on fast developing technologies and the opportunities and potential necessities for developing policy measures when facing disruption. The growth of the wireless communications industry has been among the fastest of all industries in the 1980s and 1990s. Technological innovation has been radical and very fast, not least in the dominant segment of mobile telephony. The new mobile communications technologies have emerged as a series of distinct technological life cycles. These have caused disruption in the industry and have involved major policy issues in terms of regulation and standardisation.

This systemic character of innovation has been emphasised by the innovation system literature in which the institutional set-up matters as well as interaction among actors. In the studies of high technology based regional clusters the role of technology and the development of specific clusters over longer time spans have been given less priority. However, for analysis of the evolution of technology driven clusters the concept of technological life cycles has proved to be useful in a more dynamic analysis of the development since a cluster often experiences the passing of several life cycles.

The paper adds to the analysis of sequential disruptions by applying the theories of technological life cycles on a single case over an extended period of time, including several cycles. The focus has been on the capability of a cluster to adapt to these continuous 'bombardments' of new technologies. The NorCOM case revealed a close relation between the evolution of the

cluster and technological life cycles. The cluster emerged during the first cycle, succeeded in growing during the second cycle, and is now facing the third cycle. A special emphasis has been given to the study of whether and how a 'collective spirit' could be formed and turned into collective action.

Policies at the regional level, and in the Danish case at the national level, cannot by their very nature *create* competitiveness among local high tech firms. The firms in the NorCOM cluster are not the outcome of any 'grand plan' designed ex ante. However, some of the components behind the emergence of this cluster were definitely the outcome of deliberate policy efforts and long-term struggles, such as the establishment and further consolidation of Aalborg University in 1974 and the science park NOVI in 1989. A 'grand design' of the future cannot be planned for the same reasons. New technological life cycles may make local competences obsolete, but even when disruptions occur there are often elements of cumulativeness in innovation processes. As in the NorCOM case, the task is to enhance the present competences to be better placed to grasp the new opportunities created by new technological life cycles. Social experiments based on the competences in the regional cluster consisting of firms and university will increase the probability of success. This is one of the 'rules of the game' for policy experiments in an evolutionary setting

Acknowledgements

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10 Appendix

[TABLE A1 ABOUT HERE]

Figure 1 S-curves for the established and disruptive technology

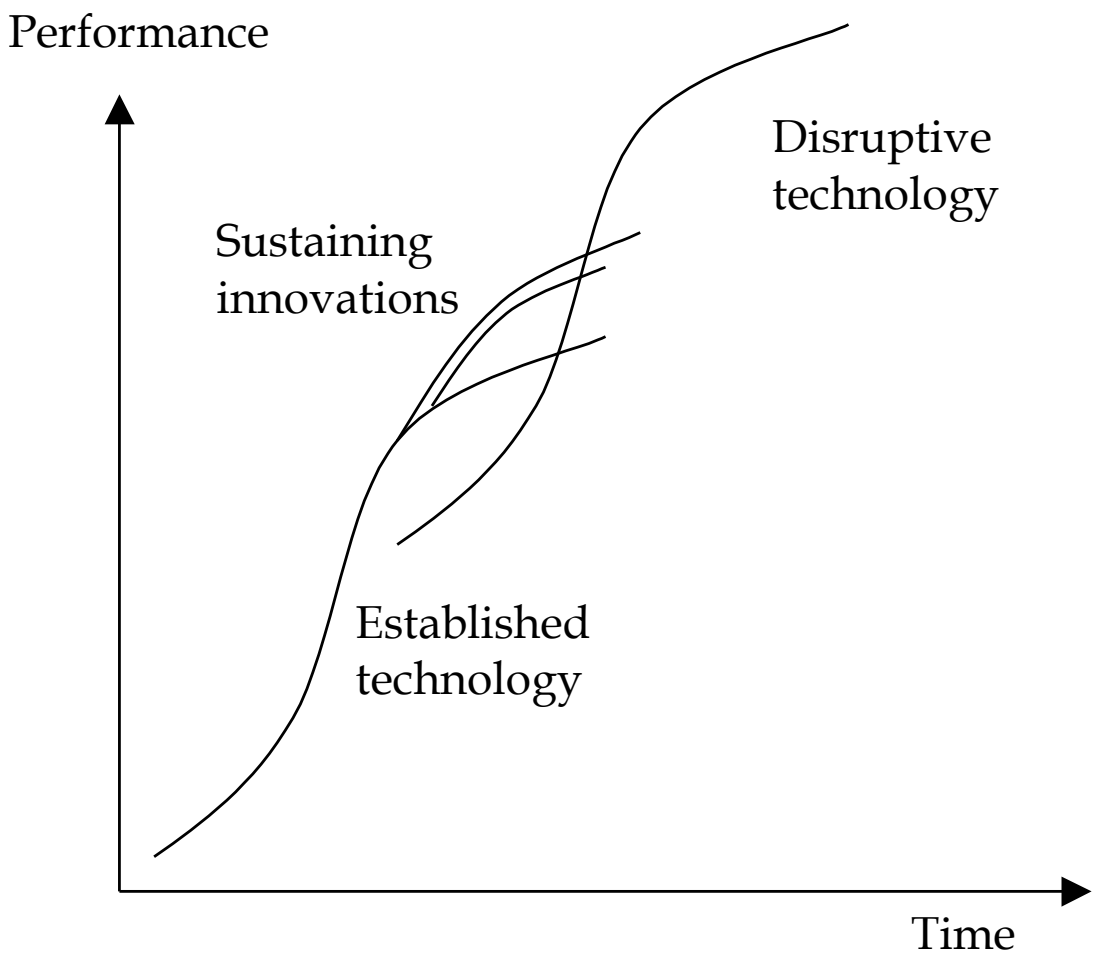

Figure 2 The technological life cycles of the European mobile communications industry

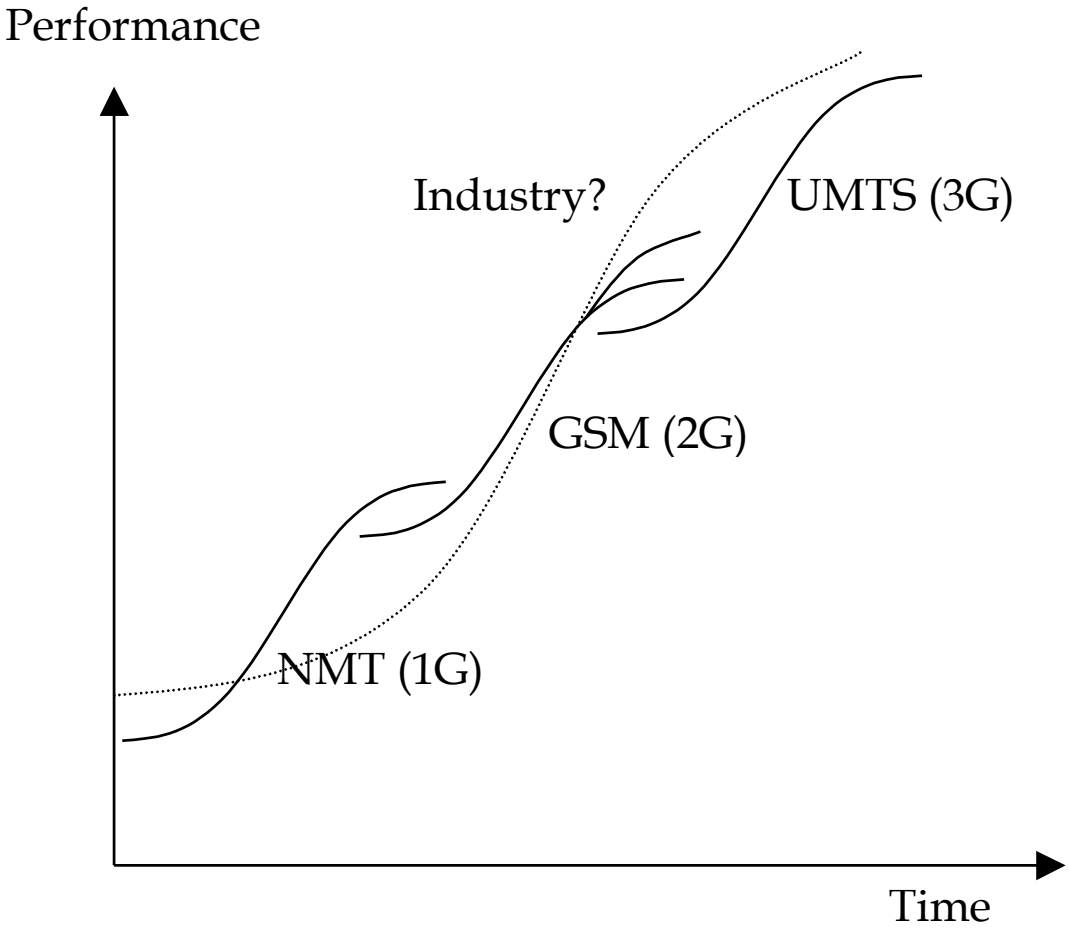

Table A1 Companies in the North Jutland wireless communications cluster 2003

Firm	Activity	Employees	Established	Owner
Analog Devices	Wireless systems applications (chipsets for mobile communications)	35	1997	Analog Devices (Boston, US)
BD-Consult	Production & development of specialised mobile comm. equip.	16	1988	Founder (DK)
Bluetags	Bluetooth applications	8	2000	Founder (DK)
CPK	Research centre	60	1993	Sponsored by Aalborg University, research councils, EU and industry
Cambridge Silicon Radio	Design of single-chip radio devices. Applications for Bluetooth.	9	2001	CSR, (Cambridge, UK)
Danphone Communications Systems	Development of land mobile (closed) radio communication systems	21	1990	Eltomatic (DK)
Digianswer	Development of Bluetooth technology	83	1986	Motorola (US) majority. Founder (DK) 1/6
Danish Wireless Design A/S (DWD)	Development of GSM/GPRS equipment	48	1999	Infineon (Munich, GER)
Eurocom Industries (SP Radio)	Production & development of maritime comm. & navigation equipment (GMDSS/VHF) & satcom. equipment	250	1992 (1948)	SAIT-Radio Holland (BEL-NLD) & STN Atlas (GER)
End2End	Wire free Application Infrastructure Provider (WAIP).	42	2000	Pre-tel Wireless (London, UK)
ETI	Telecommunication analysis equipment	86	1985	Private owned
Flextronics	Production of mobile terminals and DVD equipment	1,700	2000	Flextronics (US)
Force Electronics	Development, marketing and distribution of satellite TV receiver equipment	40	1989	Satellit Kompaniet (Oslo, NO)
Futarque	Development of satellite TV receivers	25	2001	NOVI A/S, Erhvervsinvest Nord (DK)
GateHouse	System software and data protocols for satellite and radio communications	35	1992	Founders and employees
GlobeSat	Production & development of satellite disks	3	1993	Founder (DK)
LH Technologies Denmark ApS (LH Agro)	Development, manufacturing and marketing of electronics for agriculture	80	1992 (1976)	Spraying Systems Co. (Illinois, US)
LH COMLOG A/S	Systems for communication and logistics in the transport business	32	1998	Founder (DK)
Maxon (T-Com)	Development of GSM/GPRS equipment	130	1991 (1987)	Maxon Telecom Co. (KOR)
M-tec	Equipment for GPS based road pricing	20	1998	Founder (DK)
Niros Telecommunications	Development of professional land mobile radio equipment (LMR)	8	1985	Private owned
Nokia	Software for WAP and UMTS	20	1999	Nokia (FIN)
NOVI	Science Park at Aalborg University	43 firms (8 from this table)	1989	Major Danish institutional investors and as minor shareholders regional authorities
On-Air	Software for real-time end-to-end video streaming solutions to cellular and wireless products	11	2000	A/S Dansk Erhvervsinvestering, IPM Management A/S, Erhvervs Invest Nord, HC Projects, Vaekstfonden

Note: The firm names in brackets are the former name of the firm.
Source: The homepage of the NorCOM cluster (www.norcom.dk)

Table A1 Companies in the North Jutland communications cluster 2003 (continued.)

Firm	Activity	Employees	Established	Owner
Penell	Bluetooth. GSM-modems.	20	1991	RTX Telecom A/S
RF Micro Devices, Design Centre Denmark	Design of radio frequency chips	7	2000	RF Micro Devices, North Carolina (US)
Rohde & Schwarz Technology Centre A/S	Development of test equipment for UMTS and Bluetooth	40	1993	Rohde & Schwarz GmbH & Co. KG (Munich, GER)
RTX Telecom A/S	Development of DECT, Bluetooth, CDMA, and UMTS equipment	210	1993	Founders (DK) 46%, National Semiconductors (US)
S-Card	Production of chip cards for telecom (e.g. SIM cards)	20	1991	Founder (DK)
Siemens Mobile Phones A/S	Development of GSM/GPRS and UMTS equipment	225	2000	Siemens (GER)
Simrad (Shipmate)	Production & development of maritime navigation and communication equip. (GPS/VHF)	120	1994 (1977)	Simrad (NOR)
Sonofon	Mobile communications. Service provider	1,000	1991	Bell South (USA) 47,5% and Telenor (NOR) 52,5%
SpaceCom	Production & development of satellite communications equipment	16	1989	Founder (DK)
STMicroelectronics	Development of protocol software for GSM/GPRS and UMTS chips	10	2001	STMicroelectronics (FRA, ITA)
TDC	Service provider. Mobile and fixed net	45 (Total TDC employment 17,000)	1990	Ameritech (US)
Texas Instruments	Development of GSM and UMTS equipment	105	1996	Texas Instruments (US)
TTPCom	Software for GSM/GPRS and UMTS	18	2001	TTPCom (Cambridge, UK)
WirTek	Wireless software technologies	15	2001	Founders
Aalborg University (AAU)	Technical, social science & humanities faculties	13,000 students and 1,700 staff	1974	Government

Note: The firm names in brackets are the former name of the firm.
Source: The homepage of the NorCOM cluster (www.norcom.dk)

[1] AT&T in the US developed the first cellular wireless system. The basic idea was demonstrated at Bell Labs already in 1947. A prototype of the AT&T's 1G AMPS system was tested in 1978 in Chicago, but due to a series of complications, mainly rooted in the ongoing antitrust case against AT&T, a 1G analogue system was first launched commercially in the US in 1983.

[2] The European telecom regulation set-up required from the beginning of the GSM phase at least two operators with nationwide coverage in each country. The result was heavy competition not least in the 'lead user' Nordic countries. Their previous monopolies, the government controlled incumbents, were broken leading to fierce competition, even in the early stage with only two operators. Sweden became the first country in the world with four nationwide GSM operators. Competition in the service industry appeared to be strongest in the Nordic countries, although the character of regulation was very different from the US system. The key feature was the requirement of nationwide coverage, which led to very fast diffusion of 2G technology in these countries. They maintained their lead from the 1G cycle in terms of the highest per capita penetration ratios.

[3] For a discussion of cluster dimensions, see Enright (2001).