# The Finnish Telecom Sector Facing Next Generation Standards - Indigenous Capabilities versus R&D Alliances

Christopher Palmberg[1], Tarmo Lemola[2] and Olli Martikainen[3]
[1]*The Research Institute of the Finnish Economy (ETLA),* [2]*Advansis Ltd.,* [3]*ETLA/Oulu University*

## 1 INTRODUCTION

### 1.1 Background

The Finnish telecom sector has come to the crossroads and now faces various possible paths to follow and challenges to master. The 1990s witnessed the emergence, internationalisation and rapid growth of Nokia, which, today, has a very strong position globally (and indeed in the Finnish economy as a whole). Nokia has also contributed to an outgrowth of a broader ICT cluster of related and supporting industries especially in the field of embedded software, mobile network equipment and operation, multimedia and components. A pivotal event in this context was the early focus given to the GSM standard in the late 1980s in Finland and the capabilities which were developed to overcome the related technological and market discontinuities (Palmberg and Martikainen, 2003).

After the successful global inauguration of the GSM service, the Finnish telecom sector has set out on a development path towards the commercialisation of technologies related to third generation (3G) wireless standards, and especially the UMTS (the UMTS is a European incarnation of the W-CDMA standard). This is a logical path, given that the UMTS standard often is considered as a linear European outgrowth of the GSM standard. Nonetheless, it is as of yet unclear whether the UMTS standard will achieve the same momentum as the GSM. At present there is technological and market competition between different 3G standards, where the US- and Korean-backed CDMA2000, and possible also the Chinese TD-SCDMA are serious contenders to the W-CDMA. Some commentators also identify wireless VoIP and especially WLAN/WiMax as dire competitors to 3G standards with the potential to disrupt the ICT sector as a whole. Common to these competitors to the linear GSM-UMTS path is their origin in the datacom industry following the development of the Internet Protocol (IP) that underlies the Internet (Tan et al., 2004).

The Finnish telecom sector has broadened significantly both technology- and product-wise, and developed into a coherent cluster of related and supporting industries.

However, one might suspect that a degree of path-dependency is observable in so far as the UMTS standard is a logical extension of the GSM standard, so successfully mastered in the past. Further, Nokia is now a global firm with lesser domestic ties. A key question is therefore if, and to what degree, the Finnish telecom sector indeed is overly focused within GSM based telecom technologies, especially at the expense of Internet-related ‘new’ technologies that hold disruptive potential. One way to differentiate between these two technology fields is by referring to the former as the linear 3G scenario, while referring to the latter as the extreme 4G scenario. In between these scenarios we might also locate the hybrid 3G/4G scenario combining elements of both.

### 1.2 Aim and structure of paper

In this paper we provide a preliminary assessment of the position of the Finnish telecom industry with respect to the above mentioned scenarios, while leaving the debate on the competition between different 3G standards aside. We do not intend to provide a definitive viewpoint of whether the Finnish telecom sector has greater possibilities to success in one or the other of these two scenarios. Rather, we wish to highlight and discuss the breadth and depth of recent patterns of technological diversification of the cluster from the perspective of technology fields related to traditional GSM- and new Internet- related telecom fields. As such, this paper is ‘insightfully speculative’ in so far as past developments are reliable indicators of the future.

More precisely, we provide empirical insights and, at least partial, answers to the following two questions that we tackle in this paper:

1. Have patterns of internal/indigenous diversification of the Finnish telecom sector differed from those of external diversification in terms of technological breadth and depth? If so, how?
2. Which have been the characteristics of external diversification through R&D alliances in terms of their nature?

Taken together, these questions and the related discussion also go some way towards assessing the characteristic of Finland’s entry into Internet-related telecom, although a full-fledged analysis of the organisational, institutional and competitive restructuring of the broader Finnish ICT cluster is outside the scope of this paper.

The point of departure of this paper is in the discussion on technological diversification and convergence at the industry and firm level. The theoretical literature is discussed in section 2 of this paper, along with a brief account on the emergence and development of the Finnish telecom sector, and the differences between the 3G and 4G scenarios. The empirical part of the paper uses a combination of patent data to measure internal/indigenous diversification and a database of R&D alliances of prominent Finnish telecom firms to measure external diversification. Data limitations and the methodology is discussed in the third section, followed by a presentation of the results of the statistical analysis. Section 4 contains a synthesising analysis of the main findings, while section 5 concludes the paper.

# 2 CONTEXTUAL FRAMEWORK

## 2.1 Technological diversification and strategic R&D alliances

The diversification of industries is facilitated through two main processes. Industries might diversify through the entry of new firms or through the diversification of existing firms. For practical reasons, this paper mainly focuses on the latter processes as viewed through the diversification of the firms included in the sample.

In the literature, a seminal contribution is Penrose (1959). She focused on product and market diversification of firms as an intrinsic outcome of firm growth. In various elaborations firms are understood as organizations engaged in continuous learning processes through experimental adaptation and creation of technologies and competencies. Two important insights emerge from this so-called resource-based view of the firm. First, given the centrality and locally constrained nature of learning processes, diversification exhibit strong path-dependency phenomena. Firms tend learn close to zones of their existing activities and competencies. Second, and partly as a consequence, related diversification tends to be more economically successful than unrelated diversification since the latter is managerially much more demanding (see Foss (1997) for a reader).

More recently increasing attention has been given to technological rather than product and market diversification both at the firm and industry level (see special issue in Research Policy from 1998). This is due to pioneering research drawing on patent databases. Among others Kodama (1986), Pavitt et al. (1989), Patel and Pavitt (1994), and Cantwell and Piscitello (2000) show that the technological profiles of large multinational firms show diversifying patterns over times, even though the same firms typically have remained relatively coherent on the product side. This also appears to hold at the industry level as shown, among others, by Fai and Tunzelman (1999). Various explanations have been put forth to explain this path-dependent and diversifying patterns of technological diversification at the firm and industry levels (Granstrand et al., 1997). Some of these explanations seem to be particularly relevant in the context of the telecom sector.

There is agreement that products are becoming increasingly complex and multi-technology due to rapid scientific and technological advances, especially during the last decades. Indeed, this tendency is very clear in the telecom sector, characterised by strong technological complementarities, systematic innovations and network externalities. For example, switching technologies fused with digital technologies in the 1970s, and further with radio transmission technologies in the 1980s. Present wireless telecom standards cover a very broad and complex set of technologies, whereby firms also have to become multi-tech even though they might focus on the commercialisation of niche products (Granstrand et al., 1997).

A salient feature is also an ongoing process of technological convergence between the telecom and datacom technologies (Kogut, 2003). This convergence is largely due to the digitalisation of telecommunications, combined with the development of the Internet Protocol (IP) that facilitates interoperability across heterogeneous networks. Telecom equipment producers have not yet become major players in the datacom industry. But this ongoing process of convergence does imply that telecom firms are under strong pressure to develop non-core technologies through diversifying towards datacom, and vice versa.

The diversification towards non-core – sometimes unrelated – technologies might be interpreted with reference to the discussion on absorptive capabilities and complementary assets (Cohen and Levinthal, 1990; Teece, 1986). Firms, especially in the telecom sector, have to develop in-house capabilities in non-core technologies in order to be able to absorb and exploit new emerging technologies. Further, since firms seldom manage to commercialise and benefit economically from innovations alone, complementary assets in R&D, production, marketing and retailing often become essential. Diversification towards unrelated technologies might therefore also be essential in order to either build, or collaborate for access to, complementary technological assets.

However, technological diversification in the telecom sector is also induced upon firms due to the present uncertainties surrounding the choice of next generation standards and the potentially disruptive effects of Internet-related technologies. On the one hand firms have to develop technologies and IPRs in standards which they deem relevant for their businesses in order to secure access to related licensing fees and markets (Shapiro, 2003). On the other hand, the co-existence and competition between many standards incentive firms to diversify and place their bets on many alternatives. In the end, those firms with the strongest technological and IPR position in the ‘winning’ next generation standards will also be set to gain the most businesswise.

The received literature has foremost focused on the internal diversification of firms as measured by the distribution of patents across technological fields. But internal diversification based on in-house R&D is not the only means that firms can use to diversify their technological base. In the ICT sector, and especially in telecom, the number and importance of strategic R&D alliances have been growing significantly since the mid 1980s, not least due to the active stance that firms have taken vis-à-vis standardisation (Hagedoorn, 2002; Palmberg and Martikainen, 2003). In this context, strategic R&D alliances offer an additional mean for firms to diversify to related or unrelated, non-core, technologies and thereby complement their internally developed technology base.

While strategic R&D alliances might contribute to the technological diversification of firms, it should be stressed that this type of external diversification should only be considered as complementary to the internal diversification of the core technological base of firms. R&D alliances are commonly considered most beneficial in unrelated diversification towards complementary, non-core, fields in order to exploit economies of scale and scope in R&D and to share risks (Teece, 1986; Hagedoorn, 1993). Risk sharing also implies that benefits and liabilities are shared, whereby external diversification does not secure a long term technological and IPR position. As a consequence, we suggest that in-house diversification is more akin to capture indigenous developments and longer-term competitiveness of firms or an industry in a specific technology field. Strategic R&D alliances capture collaborative diversification, where the risks and benefits are shared between all partners to the alliance. They are thus more relevant for developing short-run competitiveness in a specific technology field.

## 2.2 The emergence and development of the Finnish telecom sector

In Finland, the 1990s was both an era of re-industrialization and rapid structural change towards a knowledge-driven economy. In 1990 wood, pulp and paper accounted for 40% of Finnish exports, slightly above the share of metal and machinery products at close to one third. During the 1990s Finland became a major exporter of ICT and other electronics products, which, by the year 2000, accounted for 30% of exports (Rouvinen and Ylä-Anttila, 2003). Even though this restructuring of the 1990s was wide-ranging and covered practically all sectors in the economy, it was very much driven by the ICT sector and mobile telecom in particular. In the beginning of the 1990s Finland was one of least ICT specialized countries, today the most specialized.

The rapid recovery from the recession and the growth of industrial output has been very much explained by the success of Nokia, which has been the main driver of the change. In the 1990s, Nokia became one of the world's leading firms in telecom. Since the mid-1990s, Nokia has contributed significantly to the economic growth of Finland. Nokia's share in the country's exports is one fifth, and the share of industrial research and development about 60%. However, Nokia's direct impact on employment in Finland is actually relatively small. Nokia has slightly over 25 000, or one third, of its employees in Finland. This implies that Nokia accounts for 1.1 percent of total employment in Finland and for 5 percent of employment in industry (Ali-Yrkkö, 2001).

Nokia's diversification into electronics was very much a process of trials and errors. In the 1980s telecommunications was not yet at the core of new businesses of Nokia Corporation. The time to telecommunications came not until in the late 1980s after the collapse or low profitability of the actual core businesses of the electronics sector, above all consumer electronics and the computer business. This means that Nokia's focus on telecommunications in the beginning of 1990s was not only a consequence of a good vision of Nokia's top management. As well it was a consequence of a bad vision of the early 1980s. Somewhat later in the early 1990s Nokia decided to withdraw even from rubber and paper industries. Nokia started the diversification process as a conglomerate and ended it as a coherent if not a specialist firm.

At the beginning of the 1980s Nokia was the market leader in the production of mobile telephones in the Nordic countries. In mobile phones, a very significant step was the introduction of the Nordic standard NMT (Nordic Mobile Telephone) in 1981-1982. The standard was jointly developed by Nordic operators in more or less close co-operation with the industry. This opened a fairly big and advanced market not only to Nordic but to international competition as well.

The Nordic companies (Ericsson, Nokia, Dancall, Simonsen) were better prepared than their foreign competitors to take full advantage of the new business opportunities. This gave the firms, and particularly Ericsson and Nokia, a head-start which was of great help to them in the formation of the dominant design. Based on their earlier experience, the Nordic operators played an active role in initiating the Groupe Special Mobile (GSM) in 1982, which in ten years lead to designing the pan-European digital mobile network (Palmberg and Martikainen, 2004). With the breakthrough of digital telephones in 1993, Nokia was exceptionally well prepared for the growing markets and intensifying competition.

Nokia is not a lone star, although it does occupy an exceptionally strong position in the Finnish telecom sector. During the 1990s, as an outcome of mutually enforcing dynamic relations between actors there a broader ICT cluster has evolved in Finland into (Paija and Rouvinen, 2004). A cluster connects the whole production value chain, i.e. ICT equipment manufacturing, components and contract manufacturing (suppliers), and telecom services via market and co-operative relationships. A more detailed definition of clusters is found in Porter (1990), based on which the Finnish ICT cluster also has been identified (Hernesniemi et al., 1996). Nonetheless, a peculiarity of the development of the Finnish telecom sector, compared to many other countries, is the decentralized system of *operators*. The public telecom operator (PTO) has operated the trunk network while the local networks have been operated by a large number of smaller and privately own local operators. From the late 1980s, the tendency has been to liberate telecom further. In 1990 the PTO was transferred from a state-owned monopoly into a state-controlled commercial enterprise, in 1994 into the limited company Telecom Finland, and in 1999 into a stock company named Sonera. Later it has been merged with the Swedish PTO Telia.

Within the field of mobile telecom the monopoly position of the PTO prevailed up until 1990 as the local private operators received a license to operate GSM networks. In 1997 the position of entrants was improved further. In an open competition, Finland granted in 1999 UMTS or 3G licences for four operators as the first country in the world. Nonetheless, in the actual roll-out of these networks Finland lags behind other ICT-specialised countries, such as Sweden.

### 2.3 The 3G and 4G scenarios

Before proceeding to the empirical part of this paper, a more detailed discussion of our definition of the 3G and 4G scenarios in the telecom sector is warranted. Even though the literature has identified many different scenarios in this context, we will focus on three of these for the sake of analytical clarity. We chose to call these the *linear 3G scenario*, the *extreme 4G scenario*, and the *hybrid 3G/4G scenario*. This third scenario might, in fact, be the most realistic even though it is outside the scope of this paper to provide any robust assessments of the realization of these scenarios (see e.g. Bohlin et al. (2004) for a discussion).

The first linear 3G scenario started to unfold when stored program controlled digital switches enabled the development of roaming and handover functionalities for cellular radio. After several analogue cellular standards, the first commercial digital services started in the early 1990s through the inauguration of the GSM service on a global scale. Since then GSM has become the most popular digital mobile network standard. The GSM thus very much represents the 2nd generation (2G) digital mobile network standard. The development of the cellular systems from GSM eventually to 3G is often referred as the GSM-continuum, and hence we call this *the linear 3G scenario*. The basic idea in this development is to add data packet network functionality to the switched GSM network, including both core-network capabilities and radio access network capabilities. This first step with enhanced GSM-radio access is called General Packet Radio Service (GPRS). When broadband WCDMA or CDMA2000 radio access is included in this service, the first phase 3G network is available. The next phase of 3G also includes broadband, high speed, data transmission. So, the packed data system is included on top of the GSM switched system as an overlay enabling the combination of voice and data services.

The global standardization of 3rd Generation (3G) mobile systems has been done at the standardization bodies ITU-T and ITU-R under the name IMT-2000. In Europe 3G is called UMTS and it is based on WCDMA standards. In Japan there is an own version of WCDMA and in the USA the CDMA2000 standards is the prevailing one, while the Chinese version in the TD-SCDMA. It should be noted that these different incarnations of 3G essentially are competing standards, as suggested in the introduction. However, in this paper we cannot differentiate between different technology fields underlying each of these, whereby our definition of the linear 3G vision of necessity is broad (Henten and Saugstrup, 2004). It is indicative of technological diversification within the broader fields of ISDN-based switching and transmission technologies which are common to all 3G standards.

The second scenario is labelled *the extreme 4G scenario*. It is based on Wireless LAN (WLAN), which is a cost-efficient wireless data access technology based on the Local Area Network architecture, optimized for indoor office environments. WLAN provides today much faster data speeds than those available in 3G. Building outdoor public WLAN coverage has proved to be a difficult task. WLAN hotspots are small and a large number of them are needed for extensive coverage. Unlike WLAN, WMAN (Wireless Metropolitan Area Access) is a technology that has been designed for outdoor coverage.

The most important WMAN standard is the IEEE 802.16a, also called WiMax. The next major step will be the IEEE 802.16e, which adds mobility to the concept.

These 4G networks are commonly considered to be based on broadband wireless technologies such as WLAN and WiMax. A critical part of our definition of this extreme 4G scenario is that its relevant core technologies have developed independently from the fields of ISDN-based switching and transmission technologies underlying the linear 3G scenario, and have their origin in the datacom industry. The core technologies are instead Internet-related, as they are compatible with Internet architecture and the Internet Protocol (IP). Nonetheless, vested interests amongst incumbent equipment suppliers and operators, as well as problems with security issues makes this extreme 4G scenario unlikely as a 'stand-alone' scenario, although WLANs already have experienced a breakthrough in corporate networks and business applications.

Finally, *the hybrid 3G/4G scenario* is based on intelligent terminals which are capable of roaming between the existing cellular networks and the developing wireless broadband networks. Both broadband wireless technologies, such as WLAN and WiMax in the extreme 4G scenario, switching and transmission systems in the linear 3G scenario, will be supported. This implies the possibility of using the so called multichannel access to several wireless networks and vertical roaming between cellular and broadband wireless access networks. Depending on the user location and current service needs, the best available wireless access can be chosen. However, this hybrid scenario may be biased towards Internet type of applications and services due to technical problems.

# 3 INTERNAL VERSUS EXTERNAL DIVERSIFICATION OF THE FINNISH TELECOM SECTOR

## 3.1 A note on the data used

In the selection of firms to include in our analysis we sought to narrow down the list to those firms which have actively patented in core telecom technology fields. These core fields were identified through a combination of expert opinion and the patenting profiles of firms which we know are prominent in the Finnish telecom sector. The result was the list of 15 firms in table 1, all of which hold a minimum of at least ten patents.

Table 1. Description of firm sample

| Name | Employees in 2002 | Description |
|---|---|---|
| Nokia | 52 700 | Telecom equipment producer |
| Tecnomen | 249 | Telecom equipment producer |
| Benefon | 129 | Telecom equipment producer |
| TeliaSonera (Sonera) | 8 170 | Operator (used to be PTT) |
| Elisa | 8 120 | Operator |
| Aspocomp | 3 080 | Circuitry and mechanics supplier |
| Perlos | 3 640 | Precision component supplier |
| Eimo | 1 940 | Plastic component supplier |
| Elektrobit | 1 400 | R&D services and automation supplier |
| Okmetic | 515 | Circuitry and component supplier |
| Micro Analog Systems | 167 | Circuitry and component supplier |
| Scanfil | 362 | Electromechanical component supplier |
| SSH Communications security | 127 | Security solutions supplier |
| First Hop | 67 | Mobile middleware supplier |
| Netseal | 50 | Embedded software supplier |

As expected, the list includes prominent firms in the telecom sector in terms of size and/or importance. Hence, the major telecom equipment (terminals and network systems) providers are included, along with the two biggest operators, and key component suppliers. These firms also constitute the core of the broader Finnish ICT cluster (Rouvinen and Ylä-Anttila, 2003).

One problem in this context is the fact that software is not easily patentable in Europe, as compared e.g. to the US. This is because a patentable invention must have a technical character in the sense that it has industrial application. Hence, the patent system in Europe (including Finland) mainly tends to cover embedded software that is linked to hardware, for example to a switching system or mobile terminal. There is indication that embedded software indeed is increasingly being patented, especially in the core telecom technology fields (McQueen and Olsson, 2003). The poor patentability of software implies that pure software firms or inventions might not be included in our analysis, even though firms developing embedded software are included. This should be kept in mind when interpreting the results, given that Internet-related technologies are software-intensive.

The logic behind defining the firm sample through patenting was to secure the inclusion of the most innovative and R&D-intensive firms of the Finnish telecom sector. Further, it could be expected that these firms have been the most active ones in terms of strategic R&D alliances. The next step was to identify the R&D alliances of the firms. Whereas the patent data extends back to 1990s, we only have reliable data on their R&D alliances since 1995. We defined a R&D alliance as *'a formal/contractual longer-term relationship characterised by the commitment of two or more partners to develop joint tech-*

*nologies/innovations'* (for a more extensive discussion and typology of R&D alliances see Palmberg and Martikainen (2003)). This definition was then used to identify R&D alliances that the firms had been involved in through reviews of their annual reports and articles in the most important business newspaper in Finland – this so-called literature-based alliance counting methodology is commonly used in research on alliances (see e.g. de la Mothe and Link (2002))[1].

As suggested in the introduction we use the patent data to capture internal, or indigenous, technological diversification, while the data on R&D alliances captures the external technological diversification of the firms. In addition to the poor coverage of software, patent data also has other well-know limitations. They might disguise both inter-industry and inter-firm differences in the propensity to patent, as well as differing levels of significance of individual patents in relation to technological advances (Griliches, 1990). Here a specific issue is the degree to which one can delineate the relative cognitive closeness of different patentable technology fields. In other words, relatively arbitrary assumptions have to be made with respect to which technology field (or IPC class to relate to the patent classification nomenclature employed by the European patent offices) are sufficiently different than others to count as diversification proper as this is discussed in the theoretical literature. In this paper we stick to relatively detailed 3-digit technology classes as defined by the International Patent Convention (see http://classifications.wipo.int).

With regard to the data on R&D alliances, these have also been classified to the 3-digit technology classes using the same IPC nomenclature. This classification thereby enables the comparisons of patterns of diversification across patents and R&D alliances by their content. There are two limitations to this exercise that should be mentioned. First, data collection is of necessity only limited to publicized R&D alliances through the firms own reporting or through reporting by the chosen business journal – this under-coverage is a common problem of literature-based alliance counting methodologies. Second, an R&D alliance might often be somewhat broader in scope than patents as described at a 3-digit technology class level. We have attempted to minimize this limitation through careful consideration of the technical content of the included R&D alliances by an expert in the field.[2]

[1] The business newspaper is Kauppalehti, the largest one in Finland by the number of subscribers.

[2] The R&D alliances were classified to the most important primary IPC class to define their primary content and to secondary classes in cases where an alliance clearly covered diverse contents.

The final step in our methodology was to produce a concordance table linking the 3-digit technology classes to broader technology categories which are more informative in terms of recent developments in the telecom sector. In table 2 we hence distinguish between traditional telecom technologies, Internet-related telecom and various application areas of relevance to next generation standards. It should be stressed that the resulting concordance table is based on a subjective inspection of all patents and R&D alliances included, and might hence not be relevant to other firms or countries.

Table 2. Concordance table between 3-digit technology classes and broader categories

| Technology categories | IPC-classes |
|---|---|
| *Traditional telecom* | |
| Transmission | H04B, H01Q,H01P,H04J,G01R |
| Switching | H04Q,H01H |
| Voice applications and equipment (incl. Handsets) | H04M,H04R,G10L |
| *Internet-related telecom* | |
| Data and Internet applications (incl. SW tools and OS) | G06F,H04L,G06N |
| Encrypting and security | H04K |
| User authentication and access control (incl. SIM) | G09F |
| *Applications* | |
| Pictoral communication | H04N |
| Positioning | G01S |
| Games | A63F |
| Electronic payment | G07G |
| Mechanical technologies | B23K,B29C,G06N,H05K,H01B,H01R,H02B,H02 |
| Codecs and algorithms | H03M,H03L |
| Machine to machine | G08C |
| Photography | G03B |
| *Others* | Remaining ICT-relevant classes… |

In the table the traditional telecom categories include transmission technologies, which specify the physical layer of electrical and radio interfaces, and link layer protocols in telecom systems. Switching includes technologies and algorithms for naming users and services, addressing them with numbering and algorithms and technologies for connecting users and services by using names and addresses in the switching layers. In the linear 3G scenario roaming and handover algorithms are based on switching technologies and signaling protocols controlling the switching. Hence, these technology fields to a significant extent also underlie the linear 3G scenario. We have also included voice related algorithms such as speech analysis and synthesis, voice reproduction and voice terminal equipment such as mobile phones in voice applications class.

Internet related categories include data and internet applications for digital datacom. Specific areas such as encrypting and security and user authentication and access control are important in data, since they must be built as separate functionalities or applications. In traditional telecom, switching authentication, access control and security are based on fixed switched connections and they are inherent in the system architecture as covered by the categories ‘Switching’. Thus, these Internet-related categories are essential in the extreme 4G scenario, and the hybrid 3G/4G scenario.

Application categories include pictoral, video and voice applications and corresponding codecs and algorithms, photography, games, positioning and payment technologies. Electronic payment and machine to machine applications are also included. All of these categories are of primary importance to smart phones to be used in 3G and 4G network environments, and thus relate to all three of our scenarios. Mechanical technologies relevant to manufacturing of telecom equipment and terminals are complementary areas also included in application categories.

### 3.2 Trends and structure of patenting and R&D alliance activity

The indigenous nature of technological diversification as viewed through patenting might also be judged by the country, or patent office, where the patent was applied for (this application is also called the priority application). Inventions are typically patented in those countries where firms intend to commercialize and compete with their inventions. However, the R&D activities of firms are also often highly international, whereby a significant share of inventions might originate at their foreign affiliates through expatriate R&D (Palmberg and Pajarinen, 2004). In this paper we have chosen to limit the analysis of internal diversification to patents applied for at the Finnish Patent Office in order the underline our interest in the indigenous nature of internal technological diversification. Further, through this chose we secure the broadest possible coverage of patent applications, also of the smaller firms included in the sample.

As we limit the analysis to patents applied for at the Finnish Patent Office, our treatment will undoubtedly be somewhat biased against firms heavily engaged in expatriate R&D and operating on global markets. This is especially true in the case of Nokia as a global firm with extensive R&D activities abroad. We should therefore stress that our analysis only covers Nokia partially since a growing share of the patents are applied for at foreign patent offices (most notably the European and US patent offices). Although other firms included in our sample also patent abroad, the Finnish context is relatively much more important to these firms when compared with Nokia.

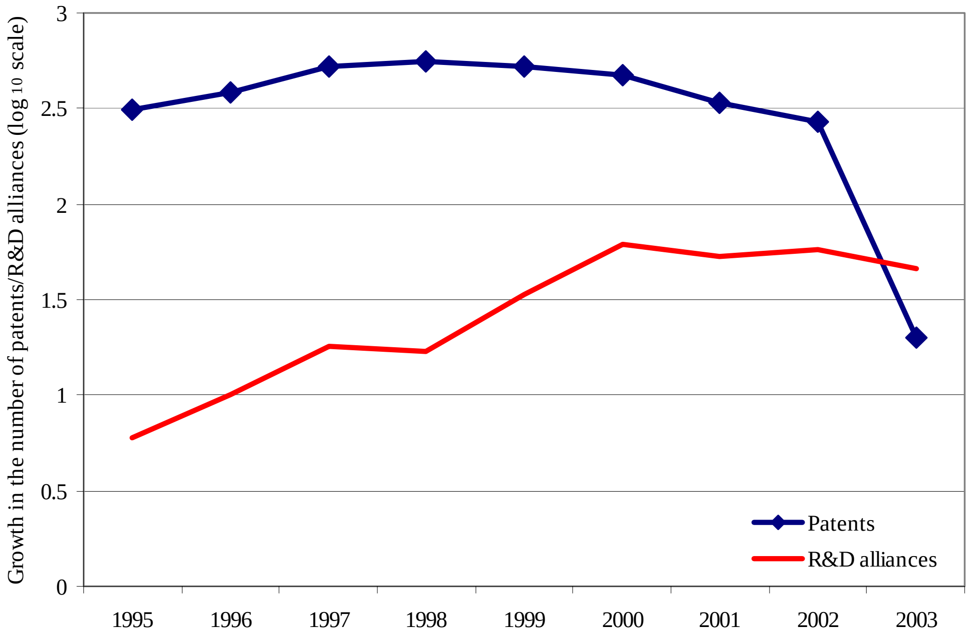


Figure 1. Trends in patenting and R&D alliance activity of firm sample

The dominant position of Nokia in Finland also strikes through the data on trends in patenting, as illustrated on a $\log_{10}$ scale in figure 1. Patenting picked up in the early 1990s and continued at an increasing rate throughout the mid 1990s, after which there has been a relative decline and rapid drop since 2002. This trend reflects, above all, the GSM breakthrough and subsequent internationalization of Nokia as the focus on patenting shifted toward US and European markets (Palmberg and Martikainen, 2004).[3] The rapid drop since 2002 is a statistical artifact due to an approximate1.5 year time lag in publicizing patent applications at the Finnish Patent Office. According to the logarithmic scale, the R&D alliance activity picks up later than patenting, but shows relatively faster growth than patenting towards the late 1990s.

[3] We also analyzed patent data drawn from the European Patent Office (EPO) and could essentially confirm that the decline in Nokia's patenting at the Finnish Patent Office is compensated by a significant increase in patenting at the EPO, especially since 1999. However, we have not had the possibility to compare with patenting at the US patent office.

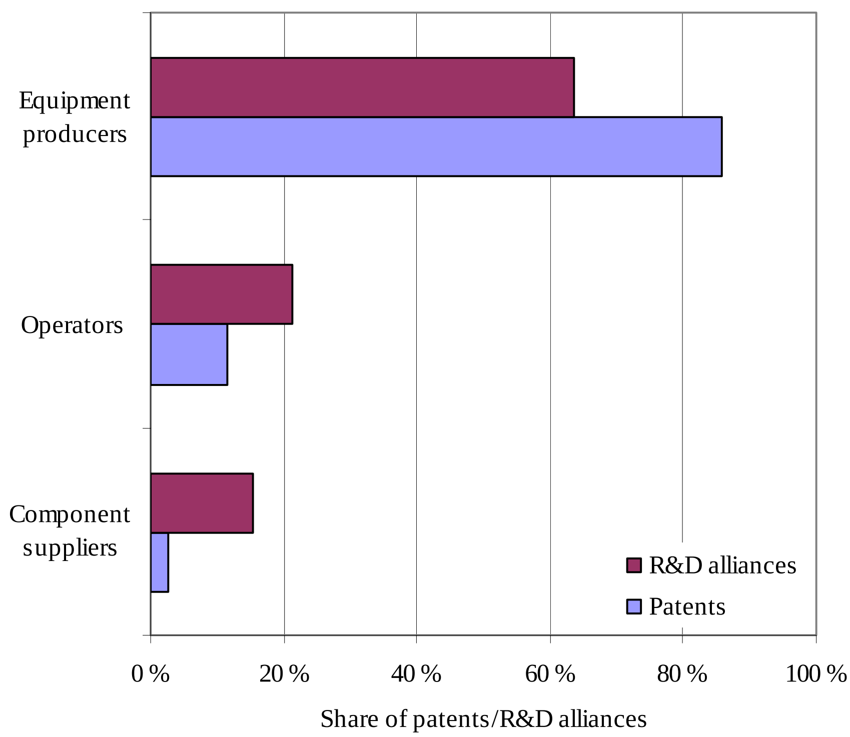


Figure 2. Distribution of patents and R&D alliances across firm sample

On closer inspection of the distribution of patenting and R&D alliances across the firm sample, the dominance of Nokia in patenting is especially clear. Altogether the sample includes 4 439 patent applications at the Finnish Patent Office. Equipment producers account for 85 percent of these (3 810 applications), with Nokia alone contributing to this share with 86 percent, as illustrated in figure 2. Nonetheless, the two main Finnish operators do also account for a significant 12 percent share of the applications (516 applications). The remaining 3 percent share (113 applications) is accounted for by the component suppliers, and these applications are relatively evenly spread out across the firms included in the sample.

Our literature-based alliance counting methodology identified 364 R&D alliances involving firms in the sample. Of these the equipment producers accounted for 63 percent (231 R&D alliances), while operators accounted for 21 percent (77 R&D alliances) and component suppliers accounted for 15 percent (55 R&D alliances). Even though the share of Nokia of all alliances involving the equipment producers is 96 percent, it seems that the dominance of Nokia is lesser when compared to patenting. Especially component suppliers appear to have a higher R&D alliance intensity than their share of patenting would predict. This is also true for the operators, and especially well-documented in the case of Sonera due to aggressive internationalization in the late 1990s (Annual Reports 2000-2002). In this context it should be noted that only 8 percent of all these 364

R&D alliance are between the firms included in the sample (informal R&D collaboration, not captured by our definition of R&D alliances, is probably much more widespread).

### 3.3 **Breadth of technological diversification**

We approach the issue at hand through indicators of the breadth and depth of internal and external technological diversification of our prominent Finnish telecom firms. Of indicators capturing the breadth of diversification, the Herfindahl index is a commonly used one (see e.g. Giuri et al., 2002). The Herfindahl index is conventionally used to approximate industry concentration. In this paper we use it to derive a measure of the dispersion of patents and R&D alliance across the 3-digit IPC technology classes of the sample firms. Accordingly, a high value of the Herfindahl index indicates that the firms have concentrated their patenting to a few classes, and hence that their degree of internal/external technological diversification is low. A low value of the index indicates that the firms have spread out their patenting across a wider range of technology classes, and hence that they have a greater breadth in their internal/external technological diversification.

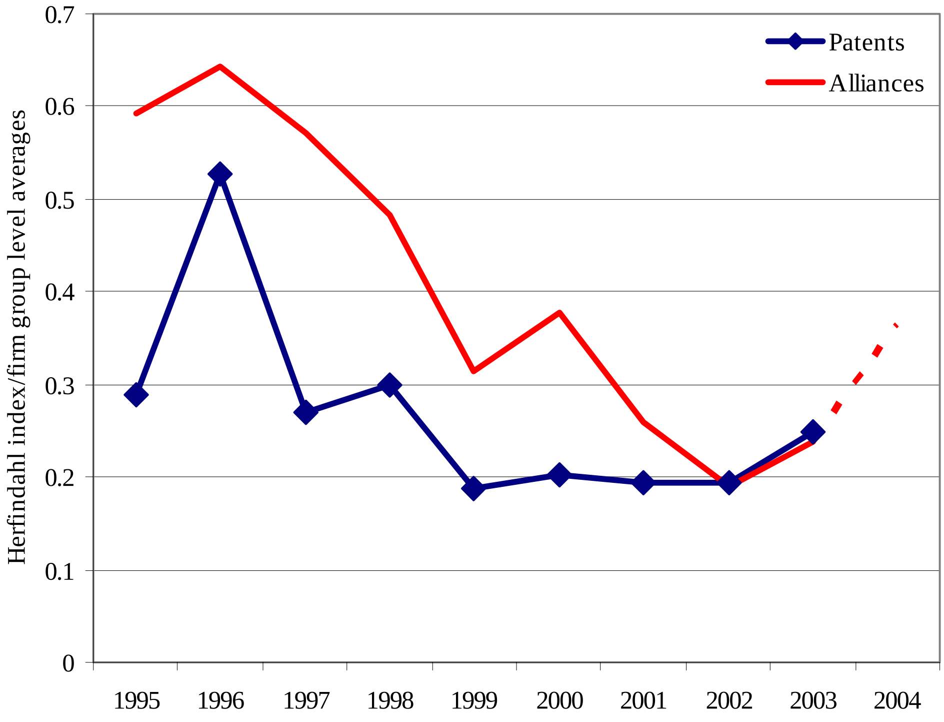


Figure 3. Degree of internal/external diversification by Herfindahl: all firms in sample

Broader patterns of diversification across all groups of firms in the sample are illustrated in figure 3. It is clear that internal diversification, as measured through patenting, is broader in scope than external diversification as measured by R&D alliances (although the indexes are converging during recent years). This is compatible with theoretical insights and empirical research discussed above, in so far as R&D alliances might be considered to better cover R&D of the more market-oriented and applied type when compared with patents (Giuri et al., 2002). Thus, these Finnish firms at the core of the ICT cluster appear to be multi-technology especially in their internal activities, while a greater degree of concentration within specific technology fields is evident in their external diversification patterns.

When looking at the overall trend over time, there appears to be an increase in the breadth of external diversification over time, especially when discounting observations from 2004 as an ongoing year. This result is probably explainable by the heightened uncertainty surrounding the future choice of standards in the telecom sector, as suggested above. It might also reflect the search for 'killer applications' in future 3G or 4G markets. In these circumstances, R&D alliances might be a viable option to diversify into uncertain non-core technologies, exploit economics of scale and scope in R&D, and share risks (compare with the discussion in Teece (1986)).

In order to cater for differences across the equipment producers (mainly Nokia), operators and component suppliers, Herfindahl indexes were also calculated at the firm group level although these are not reported here. From this viewpoint it is clear that especially the equipment producers account for the higher average degree of internal diversification of the firm sample, when compared with external diversification. This is intuitive since especially Nokia is a large multinational firm with extensive R&D resources. However, the diversification of the operators is characterised by the opposite pattern. They appear as more diversified externally when compared to their internal diversification.

Finally, a distinct pattern emerges in the case of the component suppliers. These firms are characterised by lesser breadth both in their internal and external diversification patter. This is also intuitive, since these firms are significantly smaller and more specialised than the equipment suppliers and operators – they are suppliers of specific network equipment, mobile phone components or embedded software. When the Herfindahl is calculated as an average across all firms in this group rather than as averages at the firm level, we notice that these firms are focusing on different technology fields. Hence, the component suppliers are technologically diversified as a group, even though they are highly focused at the firm level.

## 3.4 Depth of technological diversification

Turning to the depth of internal and external technological diversification, this can be approximated by ranking the distribution of patent applications and R&D alliances of the firms across the broader technology categories presented in table 2. This will suggest whether patterns of internal diversification are similar or different to patterns of external diversification also in terms of content. In other words, we can assess whether Finnish telecom firms have diversified towards similar or different technology fields through collaborative R&D alliances when compared with their indigenous diversification in core fields. We thereby also divided the data into the two time periods. The ranked distribution of patents by technology fields is illustrated in figure 4.

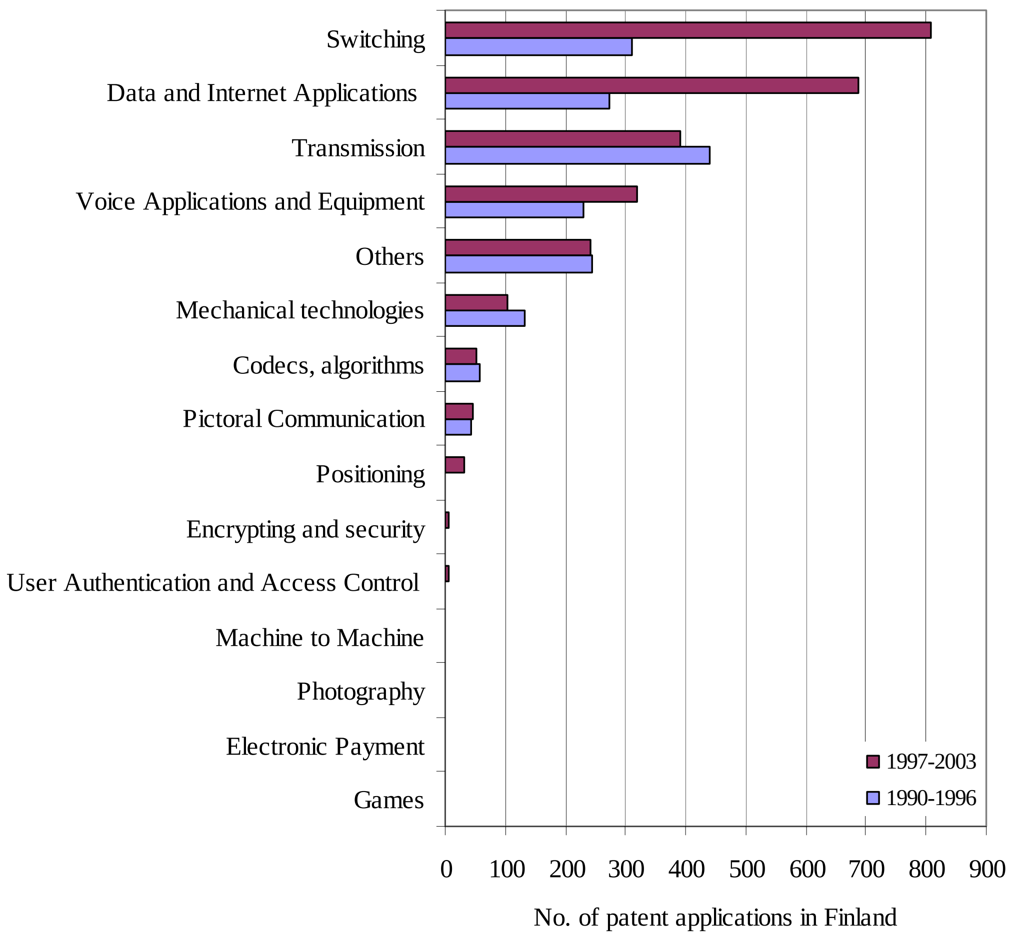


Figure 4. Ranked distribution of patents by technology fields

With reference to the concordance table between IPC classes and broader technology categories, the following observations are immediately clear from the figure.[4]

First, the traditional telecom field of ‘Switching’ has grown relatively most, followed by ‘Data and Internet Applications’ representing internet-related telecom. These two fields are also the most important ones in the internal diversification patterns of the firms, especially in recent years. The other fields show lesser changes in importance over time. We register a slight decrease in patenting in the field of ‘Transmission’, and an increase in the field of ‘Voice Applications and Equipment’. Both of these fields might also be classified to the traditional telecom category as the majority of these patents relate to both fixed and mobile telephony.

A second observation is the very low number of patent applications in the various applicaton fields of relevance to smart phones in 3G or 4G network environments. Patenting in ‘Pictoral communications’ has remained at low levels throughout, while an entry into the field of ‘Positioning’ is evident during recent years. Nonetheless, the application fields ‘Electronic payment’, ‘Games’ and ‘Photography’ are not covered by patent applications at the Finnish Patent Office.

These two observations hold true across both the equipment producers and the operators, for which the top of the ranking list is dominated by traditional telecom fields. However, the component suppliers are characterised by a slightly different pattern since ‘Data and Internet Applications’ clearly tops the ranking list. As a group, it thus seems that the smaller and more focused component suppliers have been earlier entrants to Internet-related telecom fields.

---

[4] Again we also analyzed patent data drawn from the EPO and could essentially confirm that the ranked distribution of patenting is similar, by and large, when compared with figure 4. Even though there has been accelerating growth in patent applications of the firm sample at EPO, the ranking in recent years is topped by the category ‘Switching’ followed by ‘Data and Internet applications’, ‘Voice applications and equipment’ and ‘Transmission’. However, again we have not had the possibility to compare with patenting at the US patent office.

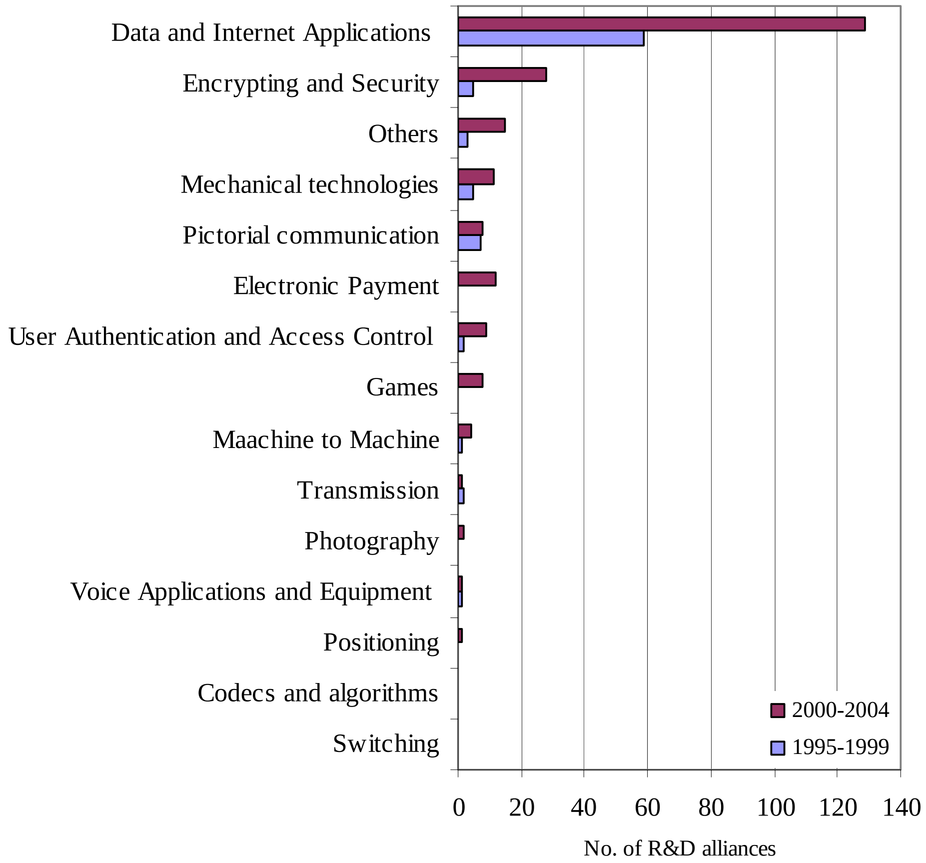


Figure 5. Ranked distribution of R&D alliances by technology fields

The ranked distribution of R&D alliances across technology fields, in figure 5, is very different. R&D alliances categorized to the traditional telecom fields of 'Switching', 'Transmission' and 'Voice applications and equipment' are particularly non-existent, especially in recent years. Instead a large majority of all R&D alliances fall within the field of 'Data and Internet Applications', followed by 'Encrypting and Security' and the various application fields. Moreover, the number of alliances in these categories have increased manifold in recent years – this is especially evident in the case of 'Encrypting and security', 'Electronic payment' and 'Games' as important application fields in 3G or 4G.

By and large these observations again hold true across all three firm groups, although the share of R&D alliances in the various application fields is relatively higher for the equipment producers (especially Nokia) when compared with the operators and component suppliers. This is intuitive, since the equipment producers are 'systems integrators' of operator services and telecom components, which serve end-users of telecom equipment, and hence also need to be more involved in developing and supporting various application functionalities that add value to their hardware.

Thus, based on these ranked distribution measuring the depth of technological diversification, the general impression is that the Finnish telecom sector has pursued a dual path in technological diversification towards next generation standards. Internal, indigenous, capabilities have diversified in the traditional telecom fields in parallel with partial entry to Internet-related technology fields. Nonetheless, the relatively larger increase in patenting in the traditional telecom fields suggests that indigenous capabilities of the telecom sector to a relatively larger extent is focused on traditional telecom technologies with strong ties to the GSM-UMTS continuity of the linear 3G scenario, rather then with the extreme 4G scenario. Further, the very low number of patent applications in the various application fields of relevance to smart phones in 3G or 4G network environments suggests that the Finnish telecom sector is indigenously weak in application fields.

Judged by the content of external diversification, the R&D alliances that the firms have been engaged in appear as highly complementary due to the dominance of Internet-related technologies and also due to the rapid growth of alliances in the various application fields. On the one hand, this overall pattern in the diversification of the core Finnish ICT cluster appears quite viable as judged by the theoretical literature. Specifically, non-core, unrelated or complementary technologies have been accessed through collaborative R&D alliances, where the uncertainties, risks but also liabilities are shared amongst the partners (compare with the discussion in Palmberg and Martikainen (2003)). This might also be a viable way forward in the both the linear 3G and hybrid 3G/4G scenarios. On the other hand, the seemingly over-reliance on external diversification through R&D alliances in these fields might also constitute a threat to the Finnish ICT cluster, especially if further developments in Internet-related fields mounts to a disruption of the whole ICT sector in line with what we labelled the extreme, albeit also more unlikely, 4G scenario.

### 3.5 **The nature of external diversification**

A complementary viewpoint is to analyse, in greater detail, the nature of the external diversification. The data on R&D alliances contains information on the collaborative partners involved. We propose two additional dimensions to our analysis, namely the regional distribution of R&D alliance partners and the ranking list of the actual partner firms. These dimensions provide possible further indications of the position of the Finnish telecom sector with respect to the 3G and 4G scenarios. Specifically, the strong European backing of the W-CDMA standard that underlines the UMTS would suggest that European firms are the most viable partners in the linear 3G scenario. In contrast, the hybrid 3G/4G scenario, and especially the Internet-related WLAN/WiMax path underlying the extreme 4G, is strongly US-backed and hence also better approached through R&D alliances with US partners (see e.g. Kogut (2003); Henten and Saugstrup (2004)).

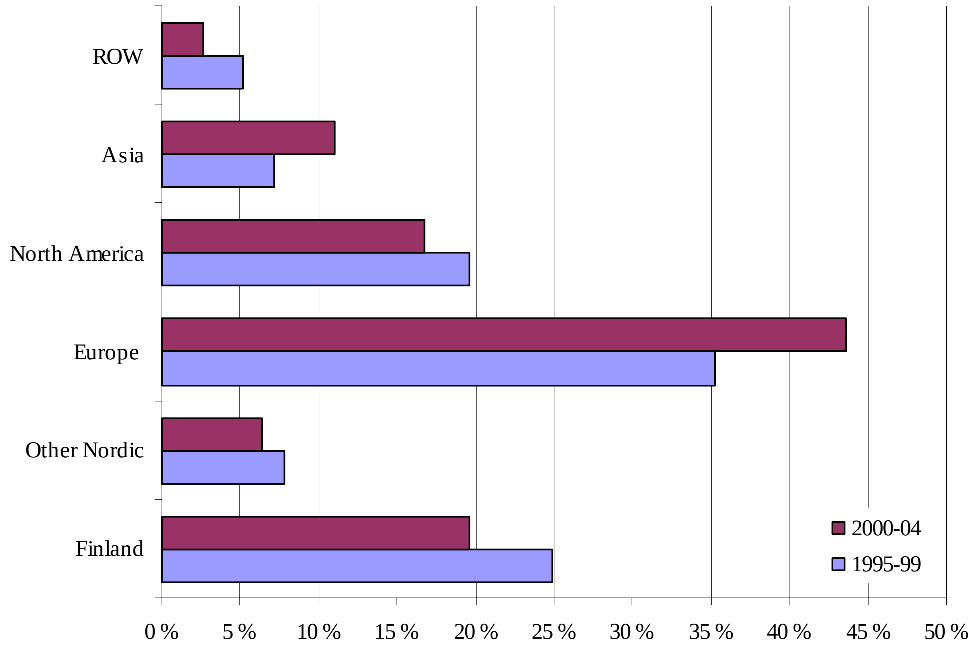


Figure 6. Regional distribution of R&D alliance partners

The regional distribution of R&D alliances by the country of origin of firms, displayed in figure 6, has undergone relatively significant changes during the time period studied. The most indicative change is the relative decline in the share of domestic R&D alliances in recent years when compared with developments in the late 1990s. This relative decline is reflected in a corresponding increase in the share of Asian and especially European R&D alliance partners, which presently accounts for the majority of all partners. Meanwhile the relative share of Nordic R&D alliances and those including US (North American) firms has declined slightly.

These regional shifts are to be interpreted from various viewpoints. What appears clear is that the decreasing relative importance of Finnish partners points towards an increasing internationalisation of the R&D of these firms. Cross-border R&D alliances is one mechanism, alongside FDI, mergers and acquisitions, through which firms might become engaged in expatriate R&D (Serapio and Hayashi, 2004). This interpretation is also in line with what we know about the trends in internationalisation of R&D of Finnish firms in general and multinational firms in particular (Ali-Yrkkö et al., 2004; Palmberg and Pajarinen, 2004).

On closer inspection of the data, at the firm group level, some interesting differences nonetheless emerge. Most noteworthy of these is the increase, rather than decrease, in the share of domestic partners to R&D alliances involving the operators. It thus seems that the Finnish context is becoming increasingly important in the external technological diversification patterns of the Finnish operators, at least from the viewpoint of formal collaboration through publicized R&D alliances. This is an interesting observation worthy of further investigation in terms of the exact content of these alliances.

The regional shifts in the nature of alliances can also be taken as further confirmation of the relative specialisation of the Finnish telecom sector within 3G technologies and related standards. As suggested, the strong European backing especially of the UMTS standard would imply that firms which pursue this path would be inclined to collaborate with other European firms possessing the necessary capabilities. The increasing share of European partners to the R&D alliances suggests that this indeed is the path being pursued. In part, these R&D alliances cover collaboration within well-known European 3G forums and standardization bodies, such as the 3GPP forum, the WAP forum and Symbian developing operating software for smart phones. However, especially Nokia is also involved in a range of other global forums and standardization bodies, such as the IEEE that are more focused on IP- and WLAN/WiMax-related technologies of the extreme 4G scenario.

Table 3. Top 25 ranking list of partners to R&D alliances

| | 1995-1999 | 2000-2004 | Total |
|---|---|---|---|
| ERICSSON | 8 | 7 | 15 |
| IBM | 5 | 9 | 14 |
| MOTOROLA | 4 | 9 | 13 |
| HEWLETT-PACKARD | 3 | 9 | 12 |
| SIEMENS | 0 | 8 | 8 |
| TEXAS INSTRUMENTS | 2 | 6 | 8 |
| INTEL | 4 | 2 | 6 |
| CHECK POINT SOFTWARE | 1 | 4 | 5 |
| OSUUSPANKKI | 2 | 3 | 5 |
| SONY ERICSSON | 0 | 5 | 5 |
| SAMSUNG | 0 | 4 | 4 |
| TEKES | 2 | 2 | 4 |
| VTT | 2 | 2 | 4 |
| ACCENTURE | 0 | 3 | 3 |
| ALCATEL | 2 | 1 | 3 |
| AT&T | 1 | 2 | 3 |
| CAP GEMINI | 0 | 3 | 3 |
| FUJITSU | 0 | 3 | 3 |
| INTERNET SECURITY SYS | 0 | 3 | 3 |
| NTT DOCOMO | 1 | 2 | 3 |
| PHILIPS | 1 | 2 | 3 |
| SUN MICROSYSTEMS | 0 | 3 | 3 |
| SYMBIAN | 0 | 3 | 3 |
| TOSHIBA | 2 | 1 | 3 |
| BMC SOFTWARE | 0 | 2 | 2 |

Our final viewpoint is the ranking of the actual partner firms to the R&D alliances in table 3. This table partly confirms the discussion above in the sense that the most frequent partner has been the Swedish firm Ericsson (including the recent joint venture Sony-Ericsson). Ericsson has been an outspoken supporter of W-CDMA technologies in the context of the linear 3G scenario, especially in the 3GPP forum (Leiponen, 2004). The German telecom giant Siemens is also high on the list. US datacom firms such as IBM and Hewlett-Packard, as well as the telecom equipment and component firm Motorola and the security software producer Check Point Software are also well represented. Nonetheless, these firms are second-tier incumbents in the field of Internet-related telecom when compared to such new entrants originating in the 1990s from Silicon Valley in the US such as Cisco, Sun Microsystems, Oracle, as well as Lucent, 3 Com and the US media giant AOL Time Warner Networks (Kenney, 2003). These firms do also appear as R&D alliances partners, but much less sporadically. Hence, at least in terms of publicized formal collaboration, ties to first-tier Internet telecom carriers appear as relatively weak.

## 4 A SUMMARISING DISCUSSION

In this paper we have taken as point of departure the ongoing convergence between telecom and datacom, and present uncertainties characterising the telecom sector due to competition between next generation standards. We identified three possible scenarios in this context, which we labelled the linear 3G scenario, the extreme 4G scenario and the hybrid 3G/4G scenario. Our basic aim was then to analyse recent patterns of internal and external technological diversification of the Finnish telecom sector vis-à-vis these three scenarios in order to provide some insights into possible future developments. The frame of reference was the literature on technological diversification and strategic R&D alliances, and its emphasis on path-dependency phenomena, multi-technology firms, and complementary assets during innovation, all issue of which are relevant to analysis of diversification in the ICT sector and telecom in particular.

At the outset, it should be stressed that it has been outside the scope of this paper to assess which of the three above mentioned scenarios actually will prevail. Likewise, we do not propose a definite viewpoint on the strengths and weaknesses of the Finnish telecom sector vis-à-vis these scenarios. Our data is limited to patentable technologies, whereby especially software-related Internet technologies might be underrepresented. The focus on patent applications at the Finnish patent office is motivated by our interest in the diversification of indigenous technological capabilities, but does bias against the larger firms (especially Nokia) in the sample which are heavily engaged in expatriate R&D and operating on global markets. Our literature-based alliance-counting methodology might also be subject to under-coverage of R&D alliances depending on the publication policies of the firms included. With these limitations in mind, the following conclusions nonetheless emerge from our empirical analysis.

*First*, the emergence of the Finnish telecom sector and the, breakthrough of Nokia following the inauguration of the GSM service globally, is apparent both in the growth of patent applications and R&D alliances. The dominating position of Nokia is especially clear in patenting. The internationalisation of Nokia also implies that the focus of patenting has shifted towards European and especially US markets starting from the late 1990s, the patents of which fall outside the scope of our analysis. However, in R&D alliances Nokia's domination is lesser and especially the operators appear as relatively much more active than their patenting would suggest – this is largely due to the aggressive internationalization of Sonera as the major operator in Finland. The R&D alliance activities of the firms included in the sample has also increased at a faster rate than their patenting. These patterns are compatible with previous empirical research of other firms and countries, and also fit the broader picture of trends in the R&D alliance activities of firms globally in the ICT sector (see e.g. Palmberg and Martikainen, 2003).

*Second*, a more substantial conclusion concerns the breadth and depth of technological diversification. The Herfindahl indexes that we employed to measure the breadth of diversification suggests that the degree of diversification of the Finnish telecom sector has increased over time, even though this diversification is lesser in terms of external diversification through R&D alliances when compared to internal/indigenous diversification as captured by patenting. This diversification was interpreted as a natural consequence of ongoing convergence between the telecom and datacom sectors, the emergence of, and competition between, multiple standards after the GSM era, as well as by the search for 'killer applications' in future 3G or 4G markets. However, it probably also reflects the emergence and broadening of the ICT cluster in Finland, even though Nokia still is the dominating firm.

In the literature, special emphasis is given to the pervasiveness of path-dependency during technological diversification at the firm and industry level due to the localised nature of learning processes (Foss, 1997). Our results concerning the depth of diversification also highlights path dependency, especially in the case of the internal/indigenous diversification patterns of the firms included. The strong early focus given to the GSM standard, so successfully mastered by Finnish firms in the past, seems to prevail due to the significant, and growing, number of patent applications in traditional telecom fields such as switching and transmission. These technologies underlie the linear 3G scenario, and hence we suggest that the indigenous capabilities of the telecom industry appear as especially strong in this scenario.

But these traditional telecom fields are also increasingly complemented with new Internet-related technologies internally, but especially in external diversification through R&D alliances. The received literature suggests that R&D alliances are especially viable in diversification towards non-core, unrelated or complementary technologies where the uncertainties, but also risks and liabilities, are shared (see especially Caloghirou et al. (2003)). Thus, if the scenario that we labelled the hybrid 3G/4G scenario becomes a reality, this mode of diversifications appears fruitful. However, if the extreme 4G scenario will be the dominating one, and disrupt the ICT sector as a whole, our analysis provides indication that this over-reliance on external diversification might constitute a threat to the Finnish telecom sector. However, most commentators, including ourselves, deem the extreme ‘stand-alone’ 4G scenario as an unlikely one.

A related *third* conclusion is the indigenously weak position of the Finnish telecom sector within various application fields of relevance in 3G and 4G network environments that our results suggest, even though these fields increasingly have been covered by R&D alliances. This might be a reflection of the ongoing uncertainty and search for ‘killer applications’ in the telecom sector through collaborative diversification. Many of these applications might emerge within firms and sectors not directly covered in our analysis, such as media, banking and health-care. A bigger question, beyond the scope of this paper, is to what degree such sectors in Finland manage to become integrated with the ICT cluster as a whole. This is relevant both in the extreme 4G scenario and in the hybrid 3G/4G scenario, where Internet-related ‘all-IP’ applications most probably will dominate. Hence, interactions between the telecom core of the ICT cluster, and advances users within these sectors, are of crucial importance to the future of the broader Finnish ICT cluster, especially if we discount Nokia as a global firm with lesser ties to Finland than previously.

*Fourth*, our analysis also provides observations on the nature of external diversification through data on the actual collaborative partners within the R&D alliances. Judged by the decreasing share of domestic partners to R&D alliances, the internationalisation of R&D of the Finnish telecom sector is evident and in line with what is known about the internationalisation patterns of Finnish firms more generally (Ali-Yrkkö et al., 2004). International R&D alliances provide a complementary path of internationalisation of R&D along with FDI, mergers and acquisitions, and these types of alliances become increasingly important in developing globally applicable Internet-related applications. However, more to the point, the large and increasing share of European partners strengthens further the impression that a path-dependency along the GSM-UMTS continuum in the linear 3G scenario is detectable. R&D alliance ties to US firms, and especially those prominent in Internet-related technology fields, are more sporadic and hence appear much weaker.

Finally, we wish to point out once more that this paper does not adequately capture Nokia’s diversification due to the various data limitations discussed above, and should therefore primarily be read as an analysis of the domestically-based Finnish telecom sector. Nokia is now a global firm with extensive R&D activities abroad and engaged in a broad range of R&D alliances covering most aspects of the 3G and 4G scenarios that we identified in this paper. Further, the patenting of this firm is increasingly internationalized to foreign patent offices not covered here, most notably the US patent office.

## References:


1. Ali-Yrkkö, J. 2001. Nokia's Network – Gaining Competitiveness from Co-Operation. Helsinki: Taloustieto (Etla B 174).
2. Ali-Yrkkö, J., L. Paija, C. Reilly, and P. Ylä-Anttila. 2000. Nokia – A Big Company in a Small Country. Helsinki: Taloustieto (Etla B 162).
3. Ali-Yrkkö, J, Lovio, R and Ylä-Anttila, P (eds.). 2004. *Multinational enterprises in the Finnish innovation system*. Helsinki: Taloustieto Oy.
4. Bohlin, E et al. 2004. *The future of mobile technologies in EU: assessing 4G developments*. Final report forthcoming in the ESTO Network publication series.
5. Caloghirou, Y, Ioannides, S and Vonortas, N. 2003. Research joint ventures. *Journal of Economic Surveys* vol. 17, no.4, 541-570.
6. Hernesniemi, H., M. Lammi, and P. Ylä-Anttila. 1996. Advantage Finland: The Future of Finnish Industries. Helsinki: Taloustieto (Etla B 113, Sitra 149).
7. Cantwell, J and Pisicitello, L. 2000. Accumulating technological competence: its changing impact on corporate diversification and internationalisation. *Industrial and Corporate Change*., vol.9, no.1.
8. Cohen,W and Levinthal, D. 1990. Absorptive capability: a new perspective on learning and innovation. *Administrative Science Quarterly*, vol.35,issue 1,128-152.
9. Foss, N. 1997. *Resources, firms and strategies – A reader in the resource-based perspective.* Oxford: Oxford University Press.
10. Fai, F and von Tunzelman, N. 1999. Industry-specific competencies and converging technological systems: evidence from patents. *Structural Change and economic Dynamics* 12, 141-170.
11. Giuri, P; Hagedoorn, J and Myriam, M. 2002. Technological diversification and strategic alliances. *LEM Working Paper Series* 2002/04.
12. Granstrand, O; Patel, P and Pavitt, K. 1997. Multi-technology corporations: why they have "distributed" rather than "distinctive core" competencies. *California Management Review*, vol.39, no.4.
13. Griliches, Z. Patent statistics as economic indicators: a survey. *Journal of Economic Literature* 28, 1661-1707.
14. Hagedoorn, J. 1993. Understanding the rationale of strategic technology partnering: interorganizational modes of cooperation and sectoral differences. *Strategic Management Journal*, vol. 14, 371-385.
15. Hagedoorn, J. 2002. Inter-firm partnerships: an overview of major trends and patterns since 1960. *Research Policy* 31, 477-492.
16. Henten, A and Saugstrup, D. 2004.3G standard: the battle between WCDMA and cdma2000. Paper presented at the *Nordic ICT Workshop* 'Past developments and future challenges of the Nordic ICT sectors, 19-20 August, Helsinki
17. Kodama, F. 1986. Technological diversification of Japanese industry. Science, 233, 291.296.
18. Kenney, M. 2003. The growth and development of the Internet in the United States. In Kogut, B (ed.) *The global Internet economy*. Cambridge MA: The MIT Press.
19. Kogut, B (ed.). 2003. *The global Internet economy*. Cambridge MA: The MIT Press.
20. Leiponen, A. 2004. Standardization strategies: a comparison of wireless telecommunications firms from Asia, Europe, and North America. Forthcoming in Zysman, J (ed.) *The digital era: national responses, market transition, and global technology*.
21. Malerba, F; Breschi, S; Lissoni, F. 1998. *Knowledge proximity and technological diversification*. Paper submitted to the Commission: March, 1998.

22. McQueen, D and Olsson, H. 2003. Growth of embedded software related patents. *Technovation* 23, 533-544.

23. de la Mothe, J and link, A (eds.). 2002. *Networks, alliances and partnerships in the innovation processs*. Boston: Kluwer Academic Publishers.

24. Paija, L, Rouvinen, p. 2004. The evolution of the Finnish ICT cluster. In Schienstock, G (ed.) *Embracing the knowledge economy – the dynamic transformation of the Finnish innovation system*. Cheltenham: Edward Elgar.

25. Palmberg, C and Martikainen, O. 2003. The economics of R&D alliances - A review with focus on the ICT sector. *ETLA Discussion papers* No. 881.

26. Palmberg, C and Martikainen, O. 2004. The GSM standard and Nokia as an incubating entrant. Forthcoming in *Innovation: Management, Policy & Practice*.

27. Palmberg, C and Pajarinen, M. 2004. The global dispersion of innovative activities – the case of Finnish multinationals. *ETLA Discussion papers* no. 916.

28. Penrose, E. 1959. *The theory of the growth of the firm*. Oxford: Oxford University Press.

29. Porter, M. 1990. *The competitive advantage of nations*. New York: The MacMillan Press.

30. Research Policy. 1998. Special Issue: Technology and the Firm. *Research Policy* 27, no.5.

31. Rouvinen, P. and Ylä-Anttila, P. 2003. Case Study: Little Finland's Transformation to a Wireless Giant. In S. Dutta, B. Lanvin, and F. Paua (Eds.), The Global Information Technology Report 2003-2004. New York: Oxford University Press, pp. 87-108.

32. Shapiro, C. 2003. Navigating the patent thicket: cross licenses, patent pools, and standard-setting. In Jaffe, A, Lerner, J and Stern, S (eds.) *Innovation policy and the economy*, vol. 1. Boston: MIT Press.

33. Serapio, M and Hayashi, T (eds.). 2004. *Internationalization of research and development and the emergence of global R&D networks*. Amsterdam: Elsevier JAI.

34. Tan, S-E, Saugstrup, D and Olesen, H. 2004. WLAN vs. UMTS – the European Scene. *Paper presented at the World Wireless Congress*, May 2004, San Francisco, California.

35. Teece, D. 1986. Profiting from technological innovation: implications for integration, collaboration, licensing and public policy. *Research Policy* 15, 285-305.

36. Ali-Yrkkö, J, Lovio, R and Ylä-Anttila, P (eds.). 2004. *Multinational enterprises in the Finnish innovation system*. Vantaa: Printed in Dark Oy.

**Authour Information:**

Christopher Palmberg
The Research Institute of the Finnish Economy (ETLA)
christopher.palmberg@etla.fi

Tarmo Lemola
Advansis Ltd.
tarmo.lemola@advansis.fi

Olli Martikainen
ETLA/Oulu University
olli.martikainen@etla.fi