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The Innovation Landscape in the Telecommunications Industry – the paradigm shifts –

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Abstract

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1. Introduction

The wish by humans to communicate over longer distances is of all time and all places. Starting with the spoken language, the reach of the human voice was extended through, e.g., smoke signals, which required a 'code' to be agreed between senders and receivers to make the message intelligible. The development of the written language can be considered as the most significant step forward in the field of communication. From writings on the wall to stone tablets, the communication of messages was made easy by the development and the use of ink on paper (Papyrus), as the messages could be carried on horseback. Hence, the Roman *cursus publicus* can be considered one of the early infrastructures facilitating speedy communications.

In late 1700, we see a major increase in the speed of message transfer through the development of the semaphore or optical telegraph. Inventions in the mid and late 1800s will lead to the beginning of a new era, the era of electronic communications; starting with the invention of the electrical telegraph to be followed by the telephone. These inventions start off an innovation process that will shape the telecommunications industry structure for the major part of the twentieth century. Around 1960, the need for communication among computers starts to challenge the hegemony of the telephony driven paradigm. Starting around 2000, the new paradigm will subsume the old, and in the process it is changing the industry structure fundamentally.

Innovation dynamics and industry structure are considered to be strongly related. Highly vertically integrated industries exhibit a different innovation pattern than industries that are characterized by a horizontal open networked structure. In the utility industries the reform process has a major impact on industry structure and, hence, changes in the innovation pattern can be observed. As innovation is important for the continuous development of utility industries and their ability to meet public value objectives, it is important to understand the relationship between innovation, industry structure, and reform. Important in this analysis is to recognize the role of the underlying technological paradigm in guiding the development of an industry. This contribution explores these relationships for the telecommunications industry. The exploration is based on a longitudinal analysis.

2. Framing the analysis[1]

Although, innovation is of all times, in the twentieth century it has become recognized as the essential driver for continued economic growth and social development. In the words of Schumpeter: "The fundamental impulse that sets and keeps the capitalist engine in motion comes from the consumer's goods, the new methods of production or transportation, the new markets, the new forms of industrial organisation that capitalist enterprise creates" (1942). For this reason researchers have been interested in identifying the reasons how innovation occurs and under what conditions. Innovation is considered as knowledge put into practice to solve a perceived need or problem. How the innovation is perceived depends on the knowledge-base of the onlooker. Rogers defines innovation as: "…an idea, practice, or object that is perceived as new to an individual or another unit of adoption" (2003). Even if the innovation can not be classified as 'new-new' it may have considerable value to the individual or organisation involved. Of importance in our context is the innovation-development process which Rogers defines as: "…all the decisions, activities, and their impacts that occur from recognition of a need or problem, through research, development, and commercialisation of an innovation by users, to its consequences." This definition suggests an underlying sequential process: a perceived need or problem that triggers an action by an entrepreneur, who allocates R&D resources to create a solution for the need or problem perceived, which is subsequently commercialized. See Figure 1 for an illustration of the flow.

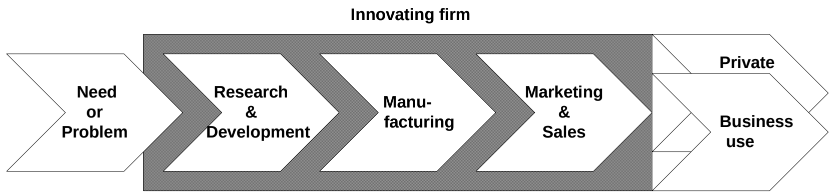

Figure 1. Sequential innovation process

While this may be the dominant form of innovation in our industrialised economy, it is certainly not the only form. Based on his empirical research Von Hippel replaces this manufacturer-as-innovator assumption by four functional categories of innovators: (1) the users, (2) the manufacturers, (3) the suppliers, and a (4) category 'others' (1988). See Figure 2 for the relationship between these categories.

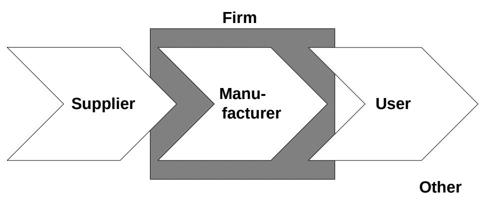

Figure 2. Sources of innovation

In the case studies supporting his research, Von Hippel demonstrates that the innovators appear to be the actors that are best positioned to capture the temporary profits, or economic rents, from the innovative activities being undertaken. He observed for instance that in the case of scientific instruments the users are the main source of innovation; in engineering thermoplastics the manufacturers are the source; in process equipment involving industrial gases, the gas suppliers are the innovators.

In our analysis we consider innovation, the innovation process and the resulting technological developments as the cumulative result of intentional behaviour of actors. We consider the innovation process thereby as an integral part of the overall organisational process of a firm, aimed at the production of goods and/or the delivery of services. As such the innovation process is closely linked to the processes of manufacturing, sales and marketing, and it forms an integral part of the business model being deployed by the firms involved. Collective the firms, theirs buyers and suppliers constitute the industry, that is shaped by the environment, the technological, the economic, social, and the political-regulatory forces, as conceptualized by Porter in his Five Forces model (1980) and Wheelen, in capturing the Four Forces in the environment (Wheelen and Hunger, 1983). See also Figure 3.

2.1. Innovation landscape metaphor, technological trajectories and paradigms

The perceived needs and problems that are being addressed through the innovation process are of course determined by time and place. Our needs and problems reflect progress and the accumulation of knowledge. Hence, the available knowledge, technologies and tools that may be applied in the innovation-development process provide the context within which solutions are being pursued. In this respect the past, in the form of path dependency, and in the form of paradigms, i.e. the way we tend to solve our problems, plays an important role.

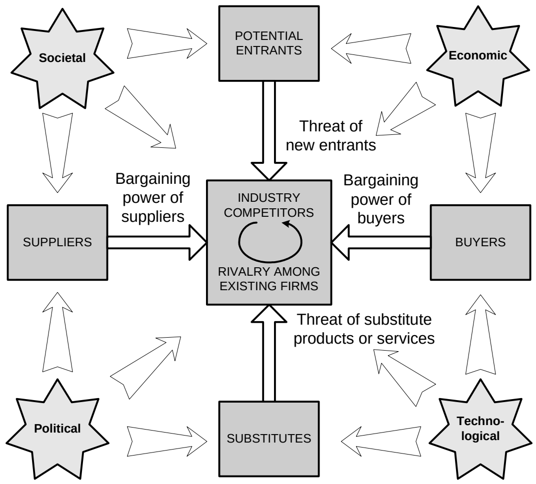

Figure 3. Framework for industry analysis (Porter-Wheelen)

Innovations may appear coincidental, they are often a next step on a trajectory of technological development. A trajectory that is not necessarily continuous and certainly not linear. It may show turns and shifts, as well as discontinuations as paradigm shifts may occur. It may show trajectories coming together or branching off. The term of "innovation journey" as used by Van de Ven c.s. to describe the dynamics of the innovation process within and among firms (Van de Ven et al., 1999) and the 'landscape' metaphor, as introduced by Waddington in biology and applied by Sahal to describe the process of technological innovation, are appropriate ways to describe the development in the telecommunications industry (Sahal, 1981; 1985). See also Figure 4.

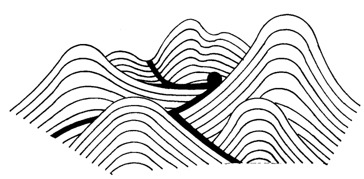

Figure 4. Topography of technological evolution

According to Sahal, in the landscape metaphor or topographical representation,: "…a developing object such as an infant technology is shown here as a ball. Starting in a low basin, the ball may roll along any one of the two valleys. It is chance that determines the specific valley chosen. Once a specific valley has been opted for, the ball can keep rolling on its own momentum until the next branch point is encountered at which stage chance once again predominates over necessity… …Beyond a certain stage, quantitative changes in the scale of an object are invariably transformed into certain qualitative changes with profound implications for its morphological, functional, and structural properties… ..[T]he developing object can only ascend through the various slopes if its form is progressively modified. Eventually, it may reach one of the several hilltops if its form is perfected through a process of constant refinement. The higher the peak, the greater the perfection… …The overall topography itself can be altered by a wide variety of socio-economic forces… ..The process of technological evolution is characterized not only by *specific innovation avenues* that concern individual industries… …but *generic innovation avenues* as well that cut across several industries… .. [I]t is apparent that the emergence of a new innovation avenue through *fusion* of two or more avenues or through *fission* of an existing avenue can give rise to sudden changes in the mode and tempo of technical progress" (italics in original, Sahal, 1985).

The term 'necessity' in following a certain innovation avenue can be interpreted in the terminology of Dosi as a technological trajectory or technological paradigm that guides the process of technological development (1982). The latter emphasising the cognitive dimension, similar to the way scientific paradigms guide the process of scientific discovery as elaborated by Kuhn (1962). Nelson and Winter use in this context the term technological regime (1977). A term that is also used by Rip, Kemp and Geels to emphasise the social embeddedness of technological development (Geels, 2002; Rip and Kemp, 1998). The term 'chance' can be further elaborated, e.g., by drawing a parallel with *speciation* in biology, whereby geographical separation may give rise to a new technological niche, as explained by Levinthal in an attempt to bridge incremental and radical views of technological change, see the illustration in Figure 5 (Based on Levinthal 1998 in Geels, 2002).[2]

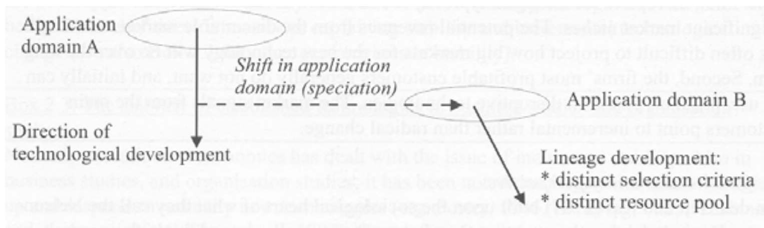

Figure 5. Speciation in technological development

In describing innovation in the telecom industry, we will discuss the relevant aspects of the innovation process and use the 'landscape metaphor' and the concept of 'innovation avenues', 'technological trajectories' and 'technological paradigms' to interpret the developments.

3. Early inventions and innovation in the communications industry

3.1. The optical telegraph – Claude Chappe, in France

In the innovation of telecommunications the optical telegraph can be considered the precursor of modern communications: the electrical telegraph. In 1792 in France, Claude and Ignace Chappe developed the optical telegraph or semaphore, which was first operated between Lille and Paris, a distance of 230 km requiring 17 telegraph stations. The construction was financed by the "Assemblée Législative" to facilitate a faster transfer of intelligence messages and military orders; it was the time of the revolution – Marseilles and Lyon were in revolt and France was surrounded by allied forces of Britain, Holland, Prussia, Austria and Spain. The network would ultimately include 556 stations and cover 4800 km. However, the operation of the network being totally manual was very cumbersome and brought Chappe in financial difficulties, which was probably the cause of taking his own life in 1805. The cost of the network and the maintenance of a large staff was a extremely costly affair and could only be afforded by the State, the network being used primarily for conveying military or naval messages.

The example set by Chappe was followed across the European continent; Czar Nicolai would inaugurate the line between Moscow and Warsaw. But, at the borders the lines stopped, due to different systems employed, each having its own code vocabulary, and for the obvious secrecy of all military and political messages. The semaphore idea ‘travelled’ and reached also England in 1794 and subsequently a system of ‘visual telegraphy’ was build for the British Admiralty. In the USA an optical telegraph was built in 1800 connecting Martha’s Vineyard with Boston to transfer information about shipping (ITU, 1965).

3.2. Electrical telegraph – Cook and Wheatstone, in Britain, and Morse, in the USA

Around the 1750s in a parallel development, a long period of experiments started using static electricity to convey messages, to be followed by more successful experiments using an electrical current influencing the needle of a compass, a phenomenon first observed by Oersted, a professor of physics at the University of Copenhagen in 1820. A first practical electromagnetic needle telegraph was build by Professors Gauss and Weber in Göttingen. In 1837 in Britain, Cook and Wheatstone receive a patent for a five needle telegraph, to be deployed in a simplified version by the Great Western Railway. This example was followed by other Railway Companies and royalties started to flow to the pioneers. In 1846 they formed the Electric Telegraph Company and it was estimated that by 1852 there were 6500 km of telegraph lines in Britain (ITU, 1965).

During a trip to Europe in 1832, Samuel Morse a Professor of the Literature of Arts and Design at the New University of New York, had become interested in the properties of electro-magnets. His idea was “to use the passage of an electric current through an electromagnet to deflect a pen or pencil in such a way that they could mark a strip of paper passing underneath them.” This facilitated for the first time the permanent recording of messages. The Morse code of dots and dashes was developed to convey the letters of the alphabet. In 1843 the US Congress allocates US$ 30,000 to build an experimental cable connection between Washington and Baltimore. The line was sold to private interests in 1847 and many other private telegraph companies emerged. The “Pacific Telegraph Act” of 1860 facilitated the building of the first transcontinental telegraph line. The early telegraph industry was consolidated by Sibley to form the Western Union Telegraph Company in 1865. By 1866 Western Union owned 2250 offices and the network expanded to 120,000 km; a development which was stimulated by one major application: the telegraphic news service for the New York newspapers, led by Associated Press (ITU, 1965).

The invention of the electrical telegraph can be considered the start of the first major innovation avenue in telecommunications industry. As the Morse code had to be translated to plain language for the general public to read, the focus of the innovation effort became aimed at plain language telegraphy. A first step was the patent granted to David Hughes in 1855 for a system using a rotating wheel with the letters of the alphabet activated by an electromagnet. In 1874 Emile Baudot, an officer of the French Telegraph Service, introduced a five-unit code for the letters of the alphabet, which he combined with a time division multiplex system, allowing several communications in parallel. It was Edison who obtained patents for duplex circuits and in 1874 for quadruplex circuits increasing the capacity of the telegraph lines manifold (ITU, 1965).

3.3. Telephone – Reis, in Germany, and Gray and Bell, in the USA

Again in a parallel development, it is Philipp Reis who demonstrates the transmission of a musical melody electrically over a distance in Friedrichtsdorff, near Frankfurt-am-Main in 1860. He was using rapid interruptions of the electrical current and magnetisations and demagnetisation to reproduce the sound. On February 14, 1876, Elisha Grey, inventor and manufacturer in Chicago, filed a caveat to prevent others from patenting his idea for the telephone for the period of a year. However, on the same day, a few hours earlier, Alexander Graham Bell had applied in Boston for a patent for a similar type of instrument. Bell was a Professor of vocal physiology at Boston University, devoted to educating the deaf. But he also spent time to develop a system for sending multiple transmission of telegrams over the same wire. It is his experimentation in this area that has led to invention of the telephone and the granting of US Patent 174,465 on March 3, 1876 (Fagan, 1975; ITU, 1965).

In the invention of the telephone we see a first branching of the innovation avenue related to the telegraph.

4. AT&T and the shaping of the telephone industry

The funding of Bell' work on the telephone is made possible by funding from direct friends Sanders, a leather merchant, and Hubbard, a Boston attorney, which they formalize in a "Patent Association" in 1875. In 1876, Watson, Bell's assistant, joins as an associate to make the inventions "pecuniary successful". He receives a 10% stake in the "Association". In the absence of Bell, who marries and spends a year in Europe demonstrating and lecturing on the topic of the telephone, Watson improved the operation of the telephone and in the process obtains 60 patents. To obtain additional funding for the development, the Patent is offered to Western Union for US$ 100,000. The offer is declined, the view being "that the telephone was a toy and would never be of practical use" (Fagan, 1975).

In 1877 the Bell Telephone Company is established to develop and manufacture telephone equipment. The first production was 'outsourced' to Williams Jr, a maker of telegraph instruments. Clearly the skill sets required for the production of telegraph and telephone instruments have much in common: electrical and mechanical engineering. The first application of the telephone is in 1997 as E.T. Holmes & Co. expands its wire line based burglar alarm service to include a Telephone Despatch Service. The first telephone service is provided by George W. Coy, who operates the District Telephone Company of New Haven, serving 21 subscribers through a manual switchboard. In 1878, New England Telephone Co. is established to provide telephone service in the Massachusetts and Rhode Island area, based on leasing the telephone equipment and being exclusively licensed by Bell to operate the telephone service. This business model, that would become leading for rendering telephone service across the world, was established by Hubbard as part of the "Association" (1975):

> "The business of manufacturing telephones and licensing parties to use the same for a royalty, shall be carried on and managed by the Trustee, under the name of the Bell Telephone Company, under and in accord with such general directions, rules and regulations as may be made for that purpose by the Board of Managers"

The success of the New England Telephone Co. suggested the establishment of a similar organization for the rest of the country. To that purpose all Bell interests were united in the National Bell Telephone Company established in 1879. The success of the telephone made evident that the mere leasing was not sufficient for effective coordination with the parent unit. Competition was becoming strong, with many rival companies starting up. Hence, it was considered necessary to license local companies on an exclusive basis and to gain control of these companies by buying a sufficient portion of their stock. This required more capital than for which the National Bell Telephone Co. was authorized. An issue that became more pressing with the settling of the dispute with Western Union in 1881.

Although Western Union had denied the importance of the telephone in 1876, it recognized its potential by 1877, as Bell had 3,000 telephones in use. The company took a two-third stake in establishing American Speaking Telephone Company and started to make telephones in violation with the Bell patents and leasing the instruments in competition with Bell. In 1878, the Bell Co. brought a suit against Western Union and its subsidiaries. Negotiations resulted in a settlement whereby Western Union agreed to withdraw from the telephone business and the National Bell Telephone Co. was granted a license to the telephone inventions that Western Union had acquired or might acquire during the 17 year term of the agreement. The Bell Co. was to buy the telephones which Western Union or its subsidiaries had made, totalling 50,000, and the telephone exchanges that they had established. In return, the Bell Co. agreed not to compete with Western Union in the public message-telegraph field. The agreement reached in 1879 was approved as decree by Judge Lowell on April 4, 1881. The increase in business required huge amounts of capital and made it necessary to consider another reorganization. This was facilitated by the Massachusetts Legislature passing a special Act, to permit the "manufacturing, owning, selling, using and licensing others to use electric speaking telephones and other apparatus and appliances pertaining to the transmission of intelligence by electricity, and for that purpose constructing and maintaining by itself and its licensees public and private lines and district exchange." In accordance with the Act the American Bell Telephone Company was formed in 1880 (Fagan, 1975).

Just four years after the invention of the telephone the structure of the US telecom industry structure was established and firmly anchored in the legislate of the state of Massachusetts.

In 1880 the International Bell Telephone Company (IBTC) is established with the sole right to sell or lease the Bell telephones abroad.[3] Also in 1880, the first long-distance telephone line is opened between Boston and Providence, followed by Boston to New York in 1885, and New York Chicago in 1892. Much of the expansion came through the efforts of Theodore Vail, former Superintendent of the Railway Mail Service, who had joined the Bell Telephone Co. as General Manager in 1878. The building of these connections marked the beginning of the Long Lines System. The capital required exceeded the level allowed for the American Bell Telephone Co. and hence a new company was established the American Telephone and Telegraph Company in 1885. In 1899, AT&T became the central organization of the Bell System through a transfer of all assets of the American Bell Telephone Co. (Fagan, 1975; ITU, 1965).

4.1. The appropriation of value through products

Following the settlement with Western Union, the Western Electric Manufacturing Co. of Chicago was licensed to manufacture telephones for the Bell organization. In 1881 the Bell Co. purchased a controlling interest in the company and by 1882 the Western Electric Company officially became the manufacturing unit of the Bell System (Fagan, 1975).

4.2. First Antitrust action by the US government – the Kingsbury Commitment

In 1910 AT&T acquires Western Union, which operated the nation-wide telegraph system. This leads in 1913, under the Presidency of Wilson, to the first Antitrust action against the Bell System by the Department of Justice (DoJ). This action was averted when AT&T committed the Bell System to relinquish its Western Union stock, stop further acquisitions of competing independent telephone companies (except when in the public interest, and with approval of the ICC)[4], and interconnect the Bell operating companies and independent telephone companies with its long distance lines, the so-called 'Kingsbury Commitment'. In 1921 the Graham-Willis Act affirms "the Bell System had become a national resource and allowed the existence as a natural monopoly because it provided a unique technology" (Falk, 1983). Note that AT&T remains a private corporation albeit under close regulatory supervision by the Federal Communications Commission.[5] The position of AT&T in the market remains a concern to the US government and in 1940 the DoJ considers again an Antitrust Suit, to be postponed due to WorldWar II to 1949. This Suit is settled in the 1956 Consent Decree. Again in 1974, the DoJ files an Antitrust Suit to be settled in the 1982 Modification of Final Judgement (1983). This leads to the break-up of the Bell System whereby seven Regional Holding Companies are spun off to assume the local and regional telecommunications services.

5. Invention and innovation at AT&T – Bell Telephone Laboratories

Until 1883, the technical work within the American Bell Telephone Co. had been carried out by the Electrical and Patent Department, performing all engineering functions, and the Stock Testing Department. In that year an Experimental Shop was added. By the end of 1885, the Company had 29 employees denoted as Headquarters Technical Staff; to grow to 81 in 1985 and 195 in 1905. In the same year, a Traffic Division was added as part of the AT&T Engineering Department. Western Electric had its own Engineering department with development and design engineers. In 1925 the Bell Telephone Laboratories started operation as a central R&D organisation incorporated with a dual ownership and dual responsibility: to the AT&T Co. for fundamental research and to Western Electric Co. for "the embodiment of the results of these researches in designs suitable for manufacture" (Fagan, 1975).

In the decades to follow the fundamental research at Bell Labs will lead to a number of Nobel Prizes in Physics: in 1937 Davisson shared the Prize for demonstrating the wave nature of matter; in 1956 Bardeen, Brattain and Shockley received the Prize for inventing the transistor in 1947; in 1977 Anderson shared the Prize for developing an improved understanding of the electronic structure of glass and magnetic materials; in 1978 Penzias and Wilson receive the Prize for their discovery of cosmic background radiation; in 1997 Chu shared the Prize for developing methods to cool and trap atoms with laser light; in 1998 Stormer, Laughlin and Tsui were awarded the Nobel Prize in

Physics for the discovery and explanation of the fractional quantum Hall effect. Moreover, Bell Labs research culminated in, e.g., the UNIX operating system, the C programming language, and “A Mathematical Theory of Communication” by Shannon. (Alcatel-Lucent, 2009; Wikipedia, 2009).

In terms of inventions and innovation in communications Bell Labs demonstrated the first facsimile connection in 1925; in 1947 the cellular concept was proposed; the invention of the laser dates back to 1958; the launch of the first communications satellite that amplified the received signal was launched in 1962; in 1963 the touch tone key pad was introduced; the first mobile network was cut in service in 1970; and the first single chip digital signal processor was manufactured in 1979.

The Bell Labs development efforts were focussed on turning inventions into innovations trough communications equipment. Initially the focus is on telephone instruments; the switching and signalling systems, from manual to fully automatic; the cable system and later multiplexing equipment (Fagan, 1975; Joel Jr. and Schindler Jr., 1982).

5.1. Communications inventions and innovations elsewhere

It should be noted that also important inventions in communications came from outside the Bell System. For instance, automatic switching originated with Strowger, in New Haven, Connecticut, as a result of experiment triggered by perceived ‘unfair’ treatment by the local switch board operator, who happened to be the sister of an undertaker, being his major competitor (ITU, 1965).

In Europe, with the telephone service being provided by a government entity, the research and development efforts occurred in the labs of the incumbent operator as well as the labs of the main providers of communications equipment. Examples are CNET in France, the Martelsham Laboratory of the BPO in Great Britain, as well as the R&D Labs of L.M. Ericsson in Sweden, of Siemens in Germany, and the Nat Lab of Philips in The Netherlands,

In the early days the model of ‘one country – one operator – one supplier’ leads to close cooperation between the labs of the operator and the labs of the main supplier. In the USA the vertical integration is the most extreme, whereby the Bell System develops and manufactures the communication products that it uses in its communication services business, whereby the equipment is leased to the users. In Europe there is no vertical integration between the supplier and the operator, but the principle of leasing is applied. As an illustration of the close cooperation, the Swedish operator Televerket and the supplier L.M.Ericsson would collaborate in the development of mobile telephone system NMT. In The Netherlands, the PTT received royalties for its contribution to the development of the PRX system, a semi-electronic switching system introduced by Philips in the early 1970s.

6. Technological trajectories and paradigms

It has been Schumpeter who introduced the concept of innovation as the central explaining variable of economic progress, arguing that business cycles are caused by the occurrence of innovations and in particular through the process of ‘creative destruction’ (Schumpeter, 1911; 1942). In his earlier work Schumpeter emphasizes the importance of the entrepreneur in the process of innovation. In our case the early period of the development of the telegraph and the telephone. In his later work Schumpeter shifted the emphasis to the role of the larger corporation, having the means to engage in capital and resource intensive processes of innovation. In our case the establishment of the Bell Telephone Laboratories and its contribution to inventions and innovations in the following decades.

Nelson and Winter have modelled the so-called Schumpeterian competition. Their modelling is aimed at exploring the relationship between innovation and imitation policies, industry structure and industry output (Nelson and Winter, 1982).[6] Industry structure relates in this context to concentration, the number and size distribution of firms, including entries and exits. From their modelling efforts they conclude that: "Schumpeterian competition is, like most processes we call competitive, a process that tends to produce winners and losers. Some firms track emerging technological opportunities with greater success than other firms; the former tend to prosper and grow, the latter to suffer losses and decline. Growth confers advantages that make further success more likely, while decline breeds technological obsolescence and further decline. As these processes operate over time, there is a tendency for concentration to develop even in an industry initially composed of many equal-sized firms." Following Van der Steen, it has been Winter who in subsequent work has extended the model with endogenous entry and adaptive R&D strategies of firms (Van der Steen, 1999). Thereby Winter linked the role of the entrepreneur, in the early Schumpeter view on innovation, to industry entry and the later view, emphasizing the role of corporate R&D in innovation, to a change in the behavioural rules within larger corporations, whereby the 'routine-search' mode becomes the prevailing model of innovation, as part of the normal business practice. In the work of Malerba and Orsenigo the differences in innovation regime have been elaborated based on the combination of four factors: (1) opportunity conditions; (2) appropriability conditions; (3) knowledge diffusion; and (4) cumulativeness of innovation (Malerba and Orsenigo, 1993; 1994; 1997).

In addressing innovation management and the development of innovation strategies, Tidd, Bessant & Pavitt state, with reference to Teece & Pisano, that: "[f]irm's [innovation] strategies are strongly constrained by their current position and by the specific opportunities open to them in future: in other words, they are path dependent. At any point in time, two sets of constraints make path-dependency in corporate innovation strategy inevitable: those of the present and likely future state of technological knowledge, and those of the limits of corporate competence." (Tidd et al., 1997, 2001). From the notion of path dependence, they argue, comes the notion of technological trajectories (Nelson and Winter, 1977). A technological trajectory is defined by Dosi as: "the pattern of 'normal' problem solving activity [in the Kuhnean sense] on the ground of a technological paradigm." A technological paradigm is being defined as: "a 'model' and a 'pattern' of solution of *selected* technological problems, based on *selected* principles derived from natural sciences and on *selected* material technologies." (italics in original, Dosi, 1982). As such the paradigm determines broadly the trajectory in which a firm or an industry is developing.

6.1. Shaping of the circuit-mode paradigm

From its inception, telephony or the telephone service has been concerned with establishing a connection – a circuit or two-way communication path – between the originating party and the terminating party in a telephone call. The main issue became the efficient connection of a 'pair wires'. First this connection was realised manually, later automatically – through circuit switching. In setting up the connection automatically, dialling information from the calling party had to be obtained to control the switching fabric. This was called signalling. Initially the realisation of the switching fabric, the control of the fabric, and the signalling were all integrated and accomplished using electro-mechanical technology. Improvements in the switching fabric resulted from a transition from step-by-step switches, to larger capacity rotary switches, to crossbar switches. A process that was facilitated by introducing a register or translator, based on relay technology, to translate the 10-digit based dialling information into signals appropriate for controlling the set-up of the connection through the switching fabric, and from one exchange to the other.

Based on traffic studies and equipment costs, the optimum number of connections between exchange nodes is established. Moreover, given the topology of (potential) subscribers to a telephone network, optimization of cable costs against the cost of switching determines the location of subscriber exchanges.

From audibility test it became apparent that for intelligible speech the transfer of the audio spectrum from 300 Hz to 3400 Hz is sufficient. This enabled the multiplexing of multiple speech signals on a single cable to significantly reduce the costs of long-distance transmission, based on Frequency Division. In following stage of development the 3 kHz analogue signal is sampled and digitally encoded into a 64 kbit/s data stream for subsequent digital multiplexing, based on Time Division.

The above principles characterize the technological dimension of the emerging voice-driven circuit-mode paradigm. Additional attributes are derived from the prevailing business model in telephone service provision, i.e., the subscriber equipment beng leased and the charging for the telephone call being determined by the duration, distance, and time of day.

The innovation dimension is characterized by large corporate research laboratories, closely related with the incumbent operator. The institutional dimension is characterized by cooperation and standardization of equipment and practices on a regional level (e.g. CEPT in Europe) and on an international level (ITU), through the National Administrations.

This circuit-mode paradigm becomes associated with the ‘Bell Heads’.

It should be noted that from the early 1900 to the 1970s, very little is changing with respect to the end-user service. All innovation is aimed at improving the capacity of the network and the efficiency of its operation, as the teledensity steadily increases. This changes as Stored Program Control (SPC) is applied for the control of the switching fabric in the beginning of the 1970s. SPC is related to computer technology specially developed and applied for the purpose of real-time switching. SPC allows for flexibility in the interpretation of signalling information and allows features, such as, call waiting, and ‘free’ phone numbers to be introduced (800-numbers in the USA; 06-numbers in The Netherlands). Initially, SPC is used to control a switching fabric composed of matrices of reed contacts. In the 1980s, the switching fabric becomes fully digitalized and the control is based on microprocessors and general computers.

7. Introducing mobile communications[7]

In parallel to the development from wired telegraphy to wired telephony we see a development from wireless telegraphy to wireless telephony. In 1906 Fessenden transmitted for the first time the human voice using radio technology. In the 1920s and

1930s this has led to radio broadcasting and to radio receivers appearing in most homes.[8] In 1946, mobile telephony service is introduced when AT&T, with the permission of the FCC, provided the first commercial car-borne service in St. Louis, Missouri, which quickly expanded to cover the major cities in the USA (Manninen, 2002; Meurling and Jeans, 1994). In 1947 Bell Labs introduced the concept of cellular communications to resolve capacity constraints of these systems through the geographical re-use of frequencies. To make the concept work the principle of 'switch-over' between cells had to be realized, a functionality for which the technology was not yet available.[9]

In the Netherlands plans for a public mobile phone service were developed in 1947 and have led to the introduction of service in 1949, a first in Europe; the connections were set-up by an operator. The service proved its value during the flooding in 1953, when the fixed infrastructure was out of service (Schuilenga et al., 1981).

In 1968 – 21 years after the concept was introduced – the FCC initiated proceedings for the deployment of cellular communications. In 1970 it sets aside 75 MHz of spectrum for cellular systems. In 1977 the building of two so-called developmental systems was authorized, which led in 1981 to the decision to allow two systems in each market (Meurling and Jeans, 1994). In 1982 the FCC started to accept application for licenses. They received 140 applications for the first round of 30 designated markets, each market attracting two to twelve applicants. The selection was to be based on 'comparative hearings' using the requested information on marketing, engineering, and roll-out plans, cash-flow projections, etc. For practical reasons this model was quickly abandoned and replaced by an evaluation based on 'population covered'. The first commercial license was granted in 1983 and the first analogue cellular service based on the AMPS (Advanced Mobile Phone System) specification by Bell Labs was introduced by Illinois Bell in Chicago in the same year. Like earlier systems AMPS uses Frequency Division Multiple Access (FDMA) and operates in the 800-900 MHz band (Botto, 2002; Manninen, 2002; Mock, 2005; Rey, 1983).

In Sweden mobile developments started with a trial system becoming operational in 1950 to be followed by two commercial systems in 1956, in Stockholm and in Gothenburg. In 1965 a newer car-borne system was introduced (Manninen, 2002; Meurling and Jeans, 1994). In 1970, in the context of Pan-Nordic cooperation, the internal study commissioned by Televerket[10] on mobile communication would form the basis for a working party that subsequently recommended the construction of a new, pan-Nordic automatic mobile telephone system (NMT), to be based on the cellular concept. The NMT Group decided upon a standardized approach to be applied across the Nordic countries, including quality of service and 'roaming', to be completed in 1975, and to be made available to the industry, essentially as an open standard – free of charge. In 1978 a trial was successfully concluded. In 1977 manufacturers were invited to bid for the supply of the base stations and the mobile switching equipment with the cut over date to be October 1st, 1981. Ericsson was to become the supplier of choice for the switching part and SRA for the base stations.[11] The targeted in-service date was met, but, the world's first cellular system would be inaugurated one month earlier on September, 1st, 1981 in the Kingdom of Saudi Arabia; also based on NMT.[12]

With this initial success other countries followed to introduce mobile telephone service. In the Netherlands the incumbent operator adopted the NMT 450[13] standard, as did the operators in Belgium and Luxemburg. In the UK the duopoly concept had been introduced and the first licence was awarded to Cellnet, an independent subsidiary of the incumbent operator BT. The second license was open to competition and awarded in 1983 to a new entrant, a joint venture of Racal and Milicom (later Vodafone). Subsequently Cellnet and Vodafone had to negotiate the standard to be used, which became known as TACS (Total Access Communication System), a version of the US AMPS[14], heavily pushed by Vodafone, intending to leverage the larger US market volume. Motorola would become supplier to Cellnet and Ericsson to Vodafone. The in service date was January, 1st 1985. National cellular standards were applied in Germany: Netz-C (in service in 1986), in France: Radiocomm 2000 (1986), and in Italy: RTMI/RTMS (1985), which later introduced TACS (Botto, 2002; GSM Association, 2004; Manninen, 2002; Meurling and Jeans, 1994).

7.1. Mobile communications – an extension of the circuit-mode paradigm

In virtually all dimensions, except the use of radio waves rather than wires for network access, mobile telephony developed in the tradition of the circuit-mode paradigm. With a rapid take-up of the mobile service it enforces the success of the telephony paradigm.

The first generation of analogue systems would be followed by a second generation of digital systems (GSM in Europe, D-AMPS in the USA), to be launched in the early 1990s.

8. The shaping of another communications paradigm

From the early days computers had operated in stand-alone mode. An example of an early large-scale data network was the SAGE system installed by the US Air Force in 1958. This system used telephone lines to link radar stations and other devices across the USA to mainframe computers to provide centralized command and control. One of the first civilian wide area networks, installed in 1964 by American Airlines, was the SABRE system to coordinate airline seat reservations. It connected over 1,200 terminals to the mainframe computer via 12,000 miles of telephone lines, making it a large-scale Wide Area Network (WAN) application. The sharing of computer power through time sharing became the prevalent mode of operation in the early and mid 1970s, leading to extensive use of wide-area terminal networks based on (dial-up) telephone lines (Von Burg, 2001).

In 1960, packet switching is invented by Baran at Rand, and independently by Davies at the UK National Physics Laboratory. The principle applied is that information is transferred in packets, each being provided with the destination address. At the switching node the address is analysed and the packet is forwarded over a link to the next node on its way toward the destination. If a node fails or is unavailable alternate route(s) will be used to reach the destination.[15] By adding links and nodes, the survivability of the network and its ability to transfer information increases. This approach is in stark contrast with the prevailing paradigm of circuit switching as used for telephony, whereby the calls are completed in a hierarchical network structure, and connections are set-up and retained for the duration of the call. Packet switching is much more suited to computer communications, with large variations in message size and large difference in message volume in the up and down link.

The invention of packet switching leads to two innovation trajectories, one in the development of large distance or wide area networks leading to the Internet, and one in the area of short distance communication within company premises or local area networks, leading to Ethernet.

8.1. Development of Ethernet

The introduction of the minicomputer in the late 1960s meant that it was becoming cost effective for research departments within universities to own their computers rather than time sharing a mainframe. At the University of California, Farber became interested in linking these minicomputers to create a local distributed computing system. In 1971 this first LAN became operational and by 1975 it connected computers, terminals, printers and a magnetic tape unit. The network operated on twisted-pair and on coaxial cable, at speeds of up to 2.3 Mbit/s (Von Burg, 2001).

In a parallel development, the ARPA program had also set off research into the use of packet switching in land-based radio and satellite radio applications. As the noisy telephone lines on Hawaii appeared ill suited for data transmission, Abrahamson at the University of Hawaii decided to try packet radio as an alternative for wire-based local area networking across the seven campuses and many research institutes; resulting in the Aloha net (Abbate, 1999).

The Aloha wireless-LAN would play an unexpected role in the development of the wired-LAN, as Metcalfe, who was completing his PhD on packet switching networks at Harvard University, was drawn into the ARPANET developments at the Massachusetts Institute of Technology (MIT). In pursuing the theoretical contribution of his PhD he was introduced to the Aloha network protocol for which he would devise a new waiting algorithm that would radically improve the throughput of the network under heavy load conditions.[16] In 1972, Metcalfe accepted a job at Xerox Palo Alto Research Centre and was asked to design a system to connect the newly developed Alto workstations. Based on his dissertation work Metcalfe created a random-access broadcast system dubbed the Alto Aloha network, soon to be renamed Ethernet. The first version of Ethernet introduced in 1973 would cover a distance of 1 kilometer, connect a maximum of 256 stations and operate at a speed of 2.94 Mbit/s (Abbate, 1999; Von Burg, 2001).

In 1979 DEC, Intel and Xerox formed the DIX alliance with the goal of establishing an industry-wide *de facto* LAN standard. In 1985, this effort would lead to the release of the IEEE 802.3 standard.

8.2. Development of Internet

In 1959 the Advanced Research Projects Agency (ARPA) was initiated and funded by the US government.[17] The sharing of computer power as part of the US Defense ARPA program led to the development of the ARPANET, which linked mainframe computers at university research centres, thereby creating the first wide area computer-to-computer network, using leased telephone lines and mini computers as the front-end. In 1970, the first five nodes would be connected using packet switching.

ARPA's efforts to link computers through packet switching is generally considered as the start of what is now called the Internet, the term to be introduced in 1984 (Slater, 2002). From 1972 the ARPANET and later the NSFNET formed the backbone network, run on behalf of the US government to connect regional networks and supercomputer sites for research and education purposes. In 1989 Performance Systems International (later PSINet) started to provide TCP/IP network services to business customers, soon followed by other 'regional' and long-distance operators (Abbate, 1999). In 1991 the non-profit organisation Commercial Internet Exchange (CIX) is created to interconnect networks. RIPE, established in 1989, provided a similar function in Europe. In 1995 the

NSFNET backbone, that connected by that time to 22,000 international networks, was retired and the Internet 'transitioned' from the public to the private sector (1999).

Four major innovations are considered instrumental for the Internet to develop towards its current day popularity (Cassidy, 2002): (1) the creation of the TCP/IP protocols in 1974 resp. 1978 under the leadership of Cerf at Stanford and Kahn at ARPA, to be used universally across the Internet for information exchange; effectively decoupling applications from the underlying communications network and the transmission medium deployed (copper or optical cable, radio waves); (2) the creation of the world-wide-web (www) using the principle of hypertext developed in 1989 by Berners-Lee at CERN in Geneva, the application (html+http+url) that would unlock information stored in computers on a world wide basis; (3) the introduction of the first popular browser Mosaic by Andreesen at the University of Illinois in 1993; and (4) the transition of the Internet in 1995 from the research and educational domain to the private domain. To this we may add a fifth element, the invention of email by Tomlinson, at Bolt Beranek and Newman in 1971.

It should be noted that fundamental to the development of the Internet has been the popularisation of computing through the invention of the microprocessor in 1971 and the introduction of the PC, notably the Apple in 1977, followed by the IBM PC in 1981. (Ceruzzi, 1998).

What has captured the imagination of the public at large, and the financial industry in particular, has been the initial public offering (IPO) of Netscape on August 9, 1995. Within one year from its introduction the Netscape Navigator had become the most popular browser, with 5 million users and 60% market share. This popularity was reflected in the development of its stock price. Morgan Stanley had priced the shares of the start-up at US$ 28, but demand was so high that the listing opened at $71 and the company was worth $ 4.4 billion by the end of the first day of trading (Quittner and Slatalla, 1998). Netscape's founders James Clark and Marc Andreesen became overnight millionaires, with resp. $ 583 mln and $ 59 mln.

These lofty proceeds attracted many venture capitalists and in 1999 at least 50% of the total investments went to Internet related start-ups. Total VC funding rose to a peak of US$ 102 bln. for the year 2000, enabling invention and innovation at an expanded scale.

8.3. Shaping of the packet-mode paradigm

In the early days, for the transmission over the telephone network the computer signals were encoded to fit within the 3 kHz voice band. In this way the circuit-mode paradigm was imposed on computer communication. An obvious mismatch, as data communication between computers is totally different in character from voice, being very bursty, and widely varying in message size. The telephony call set-up time, of hundreds of milli-seconds, is often far exceeding the data connection time required.

Packet switching is a more appropriate way for handling computer communication. In packet mode each message is cut in fixed length packets, and to each packet addressing information is added that facilitates the routing of the packet through the network, consisting of transmission links and switching nodes. Using a fully interconnected (mesh) network, multiple routes are available between any combination of source and destination. The packet mode of communication would become the prevailing mode for data communication; sharing the transmission infrastructure of the public telephone network and providing in the exchange nodes its own switching and routing functions.

The packet-mode paradigm also changes the business model through the principle of 'all ways on' connectivity between appliances and the Internet. The tariff system changes dramatically, a flat access fee is charged, based on the data rates being provided in the uplink and downlink.

The innovation dimension is initially characterized by an important role for government research centres and university laboratories; during the deployment phase product innovations are achieved through a multitude of start-up companies – new entrants in the equipment industry, such as Cisco, Ascend Communications, Cascade, StrataCom and Bay Networks. These companies focussed on the development of packet switching, routers and access equipment. In an attempt to bootstrap the in-house capabilities in this new field, incumbent telecom equipment suppliers acquired new start-up data communications companies paying top dollar, albeit mostly in (inflated) shares. In the heat of the battle for supply to the construction of the Internet, Nortel and Lucent Technologies went into an acquisition frenzy. Nortel acquired between 1996 and 2000 18 companies for a total value of US$ 30 bln.. The most significant acquisition for Nortel was Bay Networks in 1998 for US$ 9.1 bln. Between 1996 and 2000 Lucent Technologies acquired 38 networking companies for approx. US$ 43 bln.. Lucent' most significant acquisition was in 1999 when it bought Ascend Communications for US$ 24 bln (Malik, 2003),

Cisco, established in 1984 as a spin-out of the development of the router at Stanford University by Lerner and Bosack, applied a growth strategy through acquisitions. The most significant acquisitions were StrataCom in 1996 for US$ 4.7 bln, Cerent in 1999 for US$ 6.9 bln[18], and ArrowPoint communication in 2000 for US$ 5.7 bln. (Bunnell, 2000). In the period September 1993 through July 2001, Cisco spends US$ 34.6 bln to acquire 69 companies (Paulson, 2001). Although firmly positioned as provider of routers c.a. for the Internet, initially with a focus on the enterprise market and later the telecom market, optical kit was missing in the Cisco portfolio. Therefore it acquired StratumOne to boost its hardware expertise, followed by Monterey and Cerent (Bunnell, 2000).

The success of Cisco, as an independent provider to the Internet, and the amounts paid at the time for acquisition targets, led to a wave of start-ups in the field of optical and packet switching and routing equipment. In 1999 followed a wave of IPOs: Extreme Networks, Juniper Networks, Redback Networks, Copper Mountain Networks, Foundry Networks. These companies averaged returns of 240%. Thereafter a wave of start-ups in the field of components followed, e.g., E-Tek Dynamics, SDL, NetOptix. And subsequently in 2000 a wave of IPOs: Corvis, Agility Communications, CyOptics, Lantern Communications, Yipes Communications, Chiaro Networks (Malik, 2003). In 1999 also the merger of component makers JDS-Fitel and Uniphase into JDS-Uniphase took place. Upon which also this company went on a buying spree of US$ 61 bln in 3 years, paying hefty premiums of up to 50%.

Through the application of TCP/IP protocol stack as the standard for the internet, the applications are now decoupled from the underlying communications infrastructure. This provides a new degree of freedom for innovation. As a consequence the industry is adopting a much more horizontal structure, reflected in the innovation pattern. Moreover, the application layer with a low barrier of entry provides for a much wider innovation community.

The innovation related to the packet-mode paradigm is also characterized by a more open environment in terms of standardization; on the one hand the IEEE, the Institute of

Electrical and Electronic Engineers, and on the other the IETF, the Internet Engineering Task Force. The ITU does not play a role in the international coordination. Regional coordination takes place for instance through RIPE, ARIN, APNIC, the entities that are coordinating the use of the Internet domain name system, essential to the routing function within the Internet. With the success of the Internet, the packet-mode paradigm becomes associated with the 'Net Heads'.

The attributes of the circuit-mode paradigm are summarized inTable 1, left-hand column, and packet-mode paradigm in the right-hand column.

	Paradigm attributes	
Determinants:	The existing voice communication paradigm: **Circuit mode**	The emerging computer communication paradigm: **Packet mode**
Service focus:	Voice telephony	Data communication between computers
Principle:	Two way symmetrical and synchronous connection for the duration of the call	Two way asymmetrical and asynchronous communication - Always On
Technology:		
Principle:	Circuit switched	Packet switched – store & forward
Bandwidth:	Analogue – 3 kHz	Bandwidth/throughput time determined by capacity of the transmission links and the capacity of the routers
Digital encoding:	8 bit voice sample every 125 μs generating a 64 kb/s digital stream (USA: 7 bits in 64 kb/s)	
Primary multiplex:	30x64 kbit/s + overhead: 2Mb/s (USA 24x64: 1.5 Mb/s)	
Higher order multiplexing:	Typical data rates in Mb/s: 8, 34 (45), 140 (155), 565 (622); in Gb/s: 2.5, 10, 40	
Connection control:	PSTN: Call set-up through in-band signalling in the access network	Routing information in the packet header
	Trunk signalling out-of-band or through common channel signalling	No link or end-to-end signalling
Network design:		
Design assumption:	Bandwidth is expensive	Bandwidth is cheap
Principle:	Hierarchical, static routing	Non-hierarchical; dynamic routing;
Intelligence:	In the network	In the equipment at the periphery of the network
Business model:		
Principle:	Usage based	Capacity based
	Tariff based on: time, duration and distance	Flat fee based. Inspired by the LAN model: driven by infrastructure cost.
Network interconnection:	Volume based; bilateral arrangements based on 'half-circuit'	Based on peering; sender-keeps-all, with transit payment for backbone traffic
Innovation:	Corporate labs drive the research agenda; agreements based on (ex-ante) negotiations and patenting	University labs drive the research agenda; agreements based on rough consensus and functional code; wide publishing and peer review. Start-up companies commercialize innovations.
Institutions:	Associations of telecom operators or government representatives; voting based on membership	Open conventions; voting based on participation
Standardization:	CEPT (later ETSI)	IEEE, IETF
Industry coordination:	ITU, CEPT (Europe) / ANSI (USA)	RIPE, ARIN, APNIC
Frame of mind:	"Bell Heads"	"Net Heads"

Table 1. Paradigm attributes - circuit and packet mode

9. Acceleration of innovation – Telecom Reform

In the late 1960's and early 1970's the development of new equipment such as microwave, satellites, switching and computer terminal equipment and their applications presented major challenges to the boundaries of the telecom industry monopoly, represented the USA by AT&T and GTE. This did not lead to a "…fundamental restructuring of the sector, but rather the gradual removal of specific monopoly restrictions that prevented other firms from participating in the marketplace." (Melody, 1999). After World War II the FCC had granted permission for leasing private microwave systems on a case-by-case basis to serve areas where there were no common carriers. By 1951, 13,000 route miles of private microwave systems were in place or had been approved. In 1959 the FCC decided in favour of licensing private intercity microwave systems for voice and data transmission (Falk, 1983).[19] In 1968 through the Carterfone decision the entry policy for the customer terminal market was formalised, based on compatibility and safety standards. In 1969 the FCC allowed the competition to enter the long distance services market, through the famous MCI decision (Melody, 2002). Further liberalization of the telecom services market would follow with the Telecom Act of 1996, liberalising the local access.

In Europe telecommunications services had remained firmly in the hands of the national operators, but this would change with the 1987 landmark document "Green Paper on the development of the common market for telecommunications services and equipment" (Cawley, 2001). The first and politically acceptable step in the process of liberalization was aimed at introducing competition in terminal equipment and at the services level, while the infrastructure could remain under monopoly control. A series of directives followed that would provide the legislative framework for the implementation of this first phase of liberalization on the national level (Cawley, 2001)[20]:

1988: Competition in the markets in telecommunication terminal equipment,

1990: Competition in the markets for telecommunication services,

1990: Establishment of the internal market for telecommunications services through the implementation of open network provisioning.

1995: CATV Services liberalization, allowing the provision of Internet and voice services,

1996: Mobile telecom liberalization.

But, "[t]he Commission recognised that the gains in innovation, productivity improvements and price re-structuring would only come about through competitive entry in infrastructure, be it at a local level by up-grading cable networks or building new ones, or more immediately through alternative backbone investments." (Bangeman Group, 1994). Following the publication of the *Bangeman Report* addressing the implications of the 'information society' in early 1994, the European Council by the end of 1994 officially recognized the principle that telecommunications infrastructures should be liberalised and it set January 1st, 1998 as the date "by which all remaining restrictions on services competition would be lifted" (Cawley, 2001).

By 1998 all formal legal barriers to enter the telecom services market had been removed and many new players did emerge. Regulation was put in place to assure a 'level playing field' for new entrants, i.e., an *ex-ante* regime to prevent the use of the 'significant market power' that incumbents had obtained during the monopoly period. The principle of 'unbundling' was introduced to open up network access to new entrants, to allow business models to develop based on a 'mix and match' of own and leased infrastructure elements.

CATV networks were considered as one of the few if not the only alternative infrastructure that would provide for 'infrastructure based' competition. In the EU in general the CATV networks remained local monopolies, with a strong linkage between network operation and content provisioning.[21]

The process of reform furthermore resulted in a break with the tradition of tight links between the national incumbent operator and the domestic supplier of telecommunications equipment. This opened new opportunities for existing and new suppliers to enter the lucrative market represented by the domestic operators as well as the opportunities offered by the new entrants; creating a broader base for innovation in the sector.

10. The paradigm shifts

In the words of Baden-Fuller and Stopford: "The crucial battles amongst firms in an industry are often centered around differing approaches to the market. Even in the so-called mature industries, where incumbent strategies have evolved and been honed over long time periods, it is new ideas that displace existing leaders. Traditional wisdom has overstated the power of the generic approach and underplayed the role of innovation." (Baden-Fuller and Stopford, 1992 as summarized in De Wit & Meyer 2004). This notion is contrasted by Tidd *et al*: "Like many mainstream industrial economics, Porter's framework underestimates the power of technological change to transform industrial structures, and over-estimates the power of managers to decide and implement innovation strategies. Or, to put it another way, it underestimates the importance of *technological trajectories*, and of the firm-specific *technological and organizational competencies* to exploit them." (Tidd et al., 1997, 2001).

These observations directly relate to our analysis of innovation in the telecommunications industry, where we observe that two very distinct innovation avenues, with different origins and following different technological trajectories come together in the late 1990s. One avenue is related to voice communication, the other to data communication. During decades of development each avenue has become characterized by a specific paradigm, the circuit-mode paradigm resp. the packet-mode paradigm. Each paradigm his distinct features with respect to the innovation pattern, the business model, and the institutional environment.

As the packet-mode paradigm is supporting a multitude of services, including voice, it is more generic than the circuit-mode paradigm that has been optimized for voice. And as the packet-mode paradigm exploits in a more efficient manner the latest transmission and switching technologies, the packet-mode paradigm is subsuming the circuit-mode paradigm, as telecom operators transition their fixed and mobile networks to All-IP.

In this paradigm shift the battle between the Bell Heads, defending the concept of 'intelligence in the network', against the Net Heads, promoting 'intelligence in the periphery', is won by the latter; enabled by ever increasing computing power being embedded in the devices connected to the network. Hence, the locus of innovation is shifting to the devices and the services and application platforms employed. The network is becoming a 'bit pipe' and network operators are becoming 'bit pipe providers'. Nonetheless, innovation in the network is unabated, to cater to an ever increasing need for capacity in support of the growing Internet.

As a consequence the firms that have become extremely successful as part of the circuit-mode paradigm are struggling to survive; consolidation in the infrastructure equipment business has taken place at a grand scale, see the mergers of e.g. Alcatel-

Lucent and Siemens-Nokia. Telecom operators are revisiting their business models and are assessing their opportunities under the new ‘rules of the game’. In the process national innovation icons such as Bell Labs are disappearing as major sources of inventions and innovations.

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Notes

[1] This framing of the innovation process was first applied for the "Innovation journey of Wi-Fi – the road to global success" to be published by Cambridge University Press in 2010.

[2] The notion of market niches in explaining and categorising radical technical change has been further elaborated by Schot and Geels along the dimensions of low and high protection/isolation and low and high stability of rules (Schot and Geels, 2007).

[3] In the Netherlands the provision of a telephone service to the general public was left to private initiative. As an example, the City of Amsterdam selected from a number of applicants IBTC, whereby the Nederlandsche Bell Telephoon Maatschappij (NBTM) was to build a telephone network under license from IBTC. NBTM was for 40% owned by IBTC, the remainder was provided by financiers from Amsterdam, including the NBTM director-to-be Hubrecht, who would invest close to 25% of private equity.

[4] ICC: the Interstate Commerce Commission, regulating the interstate telecom services preceding the establishment of the Federal Communications Commission in 1934.

[5] The Federal Communications Commission is an independent United States government agency, directly responsible to Congress. The FCC was established by the Communications Act of 1934 and is charged with regulating interstate and international communications by radio, television, wire, satellite and cable. The FCC's jurisdiction covers the 50 states, the District of Columbia, and U.S. possessions (FCC, 2007).

[6] The model is based on the following main characteristics: a number of firms produce a single homogeneous product, the industry faces a downward sloping demand curve, each firm operates a single technique – the best it knows, all techniques are characterized by constant returns to scale and fixed input coefficients, a firm will use its best technique to the maximum level permitted by its existing stock of capital, purchasing needed complementary inputs on factor markets, factor supplies are perfectly elastic and factor prices are constant over the period. The technique used by each firm thus determines the unit costs. Given each firm's capital stock and its technique, industry output and product prices are determined (Nelson and Winter, 1982).

[7] The information in this Section is based on (Lemstra and Hayes, 2009).

[8] Critical to the development of radio communication and broadcasting has been the invention of the vacuum tube by Fleming in 1915.

[9] This functionality would be developed in the 1960s – 1970's.

[10] Televerket: the Swedish Telecommunication Administration, a state organization having provided the country with telephone service. In 1993 it would become a stock company called Telia AB, still state owned,

[11] The mobile switching system MTX was of the AXE type, the first fully digital switch developed by Ellemtel, a joint company of Swedish Telecom and Ericsson. SRA – Svenska Radio Aktiebolaget– was founded in 1919 by ASEA, AGA and Ericsson. In 1982 it would become a fully owned subsidiary of Ericsson (Meurling and Jeans, 1994).

[12] In 1978 the Joint Venture between Ericsson and Philips of the Netherlands had been awarded the contract to build a new fixed telephone network for the Kingdom. In 1979 this contract was extended to include a mobile telephone system.

[13] NMT 450 referred to the 450 MHz frequency band being used.

[14] The main difference is the channel spacing: 25 kHz in Europe and 30 kHz in the USA.

[15] Within the packet network a special signaling protocol is used to inform the routers in the nodes on the availability of the transmission links.

[16] Metcalfe proposed to increase the re-transmission intervals with increasing traffic loads. For a more extensive discussion of the technical features see Chapter 8 on Polling and random access in data networks in Schwartz (1987) and Chapter 4 the Medium access sublayer in Tanenbaum (1996).

[17] The launch of Sputnik by the USSR in 1957 had made the USA aware of a ‘science gap’ and triggered the creation of ARPA.

[18] Cerent had US$ 10 mln in sales in the first half of 1999, expecting $ 300 mln. in the next 12 month (Bunnell, 2000).

[19] The so-called Ábove-890’Ruling, referring to frequencies above 890 MHz being available.

[20] Additional directives were issued on: satellite communications and broadcasting, Pan European cellular communications.

[21] In some countries the CATV networks were owned and operated by the incumbent telecom operator, for instance in Germany and the Netherlands (in part). This would require divestment before infrastructure competition could evolve.