Chapter 6

Technology Trends and their Implications for Telecom Regulation

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1.0 Introduction

The relative importance of technological innovation and government policy reform as drivers of successful development of public services has been a subject of constant debate for many years. Recall the anecdotal minister who tasked his legal staff to write a White Paper on airline regulation just after the Second World War. In the spirit of international co-operation in those days, the legal experts' draft set out as follows: "Civil aviation is based on international law established by modern nations in order to regulate international traffic." However, when the ministry's technical staff got wind of this, a counter-proposal was tabled with the following opening statement: "Civil aviation is based on the aerodynamic laws of nature which permit man to fly in vessels heavier than air."

This chapter does not defend a purely engineering approach to public telecom arrangements. Such approaches have prevailed in virtually all of the monopolistic telecom operating companies in Europe and former European colonies, as well as the common carriers in North America. Still, neither makers of telecom policy nor new independent regulators of the behaviour of national network operators and service providers can neglect the (im-)potencies of different modern technologies when considering the rights and obligations of telecom operators and their customers. Novel transmission and switching technologies presently change the economy of networks entirely from inside, even if gradually. When new technology shifts traditional benefits and costs to different user communities, or to other parts of communication networks, changes to regulated tariff structures and entirely new arrangements for public control of telecom firms become necessary.

Recently, advanced computer and network technologies have also created new types of business users with special commercial requirements. Such users do not accept to be treated as standard subscribers to a national universal service; they wish to have a choice of the most recent and cost-effective communications technology to reach their particular markets at home or abroad. They stir up political discussion about market entry of specialised telecom providers and about the appropriate legal and institutional frameworks, and also force regulators to consider more detailed technical choices of standards, frequency bands and service-quality grades than in the past.

Thus, technological (r)evolution constantly challenges the classical civilised policy objective of a single universal service to everyone, everywhere. Many governments appear to waver between their desire to create adequate industrial and labour policies to foster more knowledge-based employment and higher economic welfare, and their adherence to vested arrangements for distributing welfare in a fair and equitable manner. The national and international discussions of appropriate regulatory frameworks for the so-called "information society" reflect several dilemmas in appropriately (re-)allocating the benefits and costs of telecom. What remains constant, is new information and communication technology (ICT) as a prime mover of telecom firms, and of their customers: both network (infrastructure) evolution and service (market) developments are affected.

This review of ICT focuses on a few major technological driving forces in modern telecom:

- the generic impact of microelectronics, due to the rapidly changing price/performance ratio of Very Large Scale Integrated (VLSI) circuits, both on the common network infrastructure and on customer equipment;
- the role of optical techniques in *bulk* information transmission over long distances;
- the increasing role of radio technologies in reaching *individual* users over shorter distances ('wireless local loop', cellular systems); and
- the intrusion of special computer platforms and networks into the infrastructure for the plain old telephone service (POTS), in order to create and manage more advanced services ('intelligent networking').

It is not the aim to go into any engineering detail in these areas, or to cover ongoing major system developments. For instance, digital switching based on the Asynchronous Transfer Mode (ATM) or multiplexing of digital circuits based on the Synchronous Digital Hierarchy (SDH) will not be discussed, since the purpose here is not to assist in systems engineering of modern telecom. What is intended in this survey, are illustrations of the inherent dynamics of modern enabling ICT, and how this appears to affect some of our most cherished traditions of public telecom policy. An attempt to (re)design such policy purely on the basis of the legal and political conventions of, say, public administration, would face the considerable economic and cultural risk of neglecting the empirical evidence of modern ICT as a radical and permanent change agent inside telecom – and in the society to be served by telecom.

2.0 Microeletronics: An Economic Catalyst

2.1 Capabilities of VLSI Technology

Powerful communication and computing functions and terminal devices have become economically viable thanks to the electronic revolution of integrated-circuit (IC) technology. This enabling technology allows a large number of electronic components to be etched into a minute 'chip' cut from semiconductor material. The vast majority of VLSI circuits use silicon chips. When the author studied engineering some 25 years ago, the opinion of leading semiconductor experts was that much more sophisticated and costly compound materials (e.g., gallium arsenide) would soon become necessary for high-frequency circuits, e.g. to meet the demands for smaller radio sets. However, the ongoing development of silicon technology since then has allowed extension of its practical frequency ranges by orders of magnitude. Today's hand-held mobile telephones are based on cheap silicon VLSI chips working in the 900 or 1800 MHz bands (or even in both bands, in new 'dual mode' terminals required for roaming between different mobile networks based on different technical standards such as GSM, DCS1800 and DECT). This is one of the chief reasons for the spectacular drop in the prices of mobile radio handsets, which has stimulated the mass market for mobile telephony.

VLSI technology appears to evolve in accordance with a rule of thumb postulated in 1965 by Gordon Moore, one of the founders of the leading US chip maker Intel. Standard chips come in families with the generations separated by a couple of years, in order to reap the major economies of scale in industrial mass production[2]. Broadly stated, 'Moore's law' predicts that the maximum number of transistors or other minute components on a state-of-the-art VLSI chip doubles in 18 months, so the cost per component halves between successive mass-produced generations of chips. In retrospect, the component number on state-of-the-art chips has indeed increased by a factor of 100 in less than 10 years! This has shown up in both prices and improved storage capacity of random access memory (RAM), for instance in personal computers. The maximum operating frequencies of silicon chips continued to break perceived barriers, too. This benefited not only the output signal frequency of electronic systems, but also the internal 'clock' frequency by which transistors are switched on and off, when working in the binary mode used in digital telephone exchanges and other computers. In 10 years, the clock frequency of typical PC microprocessors has gone up by a factor of about 40. As a result, the total processing power of a standard microprocessor chip has increased by some 100 x 40 = 4000 times per decade! Sometimes this is restated as a growth rate of 1.5 percent per week, but this can be misinterpreted in view of the longer lives of chip generations.

2.2 Consequences of VLSI for Telecom

Consider the different performance trajectories sketched in Figure 1 for three main sectors of the electronic manufacturing industry, namely, for consumer products, computers, and telecom equipment. Clearly, the cost benefits of mass production are far larger in consumer electronics than in the professional sector of telecom equipment (switches; multiplexers, etc.). Telecom subsystems come in much smaller series and must also be more reliable over a longer operational life. Hence they are more expensive – though not necessarily more complex – than the standard electronic products bought by consumers, such as video recorders, televisions and radio sets. The industry performance/price ratio for mainframe and large mini-computers also lies well below that of the consumer electronics industry, but above that of telecom manufacturing. A digital telephone switch is essentially a special-purpose computer, with exigent requirements for nearly permanent availability. For a central computer used for financial bookkeeping or other off-line purposes, an hour of weekly servicing every Monday morning might be routine, whereas a telephone exchange could not be allowed any comparable downtime[3].

Between these evolutionary "beaten tracks" of industrial VLSI development, three significant new revolutionary cross-over branches between these trajectories are included in Figure 1. Two of these branches represent the advent of the personal computer and of the hand-held mobile telephone, respectively. These innovations have become the most important new telecom terminals in the last ten years. Both the PC and the digital mobile telephone illustrate cost-effective confluence of the powerful tradition of information processing developed in the computer industry, with the scale benefits and global price competition found in the consumer electronics industry[4]. These two powerful low-cost terminals have engendered some of the most impressive traffic growth rates ever in telecom, as enjoyed by Internet service providers and digital mobile network operators (GSM and PCS), respectively.

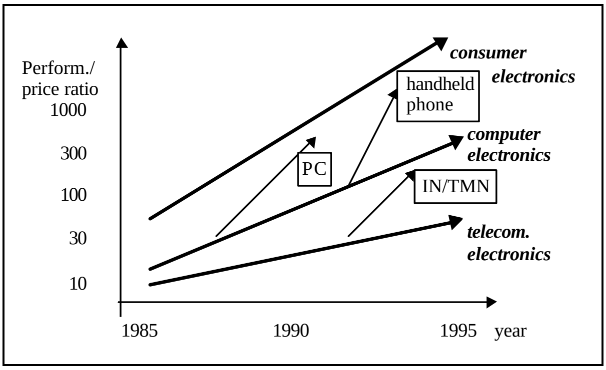

Figure 1 – **Electronic product performance trajectories and branches, 1985-1995**

(*reference:* O. Martikainen, April 1994)

The third cross-over branch shown in Figure 1, that between telecom and computer electronics, arose from a need felt by many network operators to deliver new or improved telecom services to increasingly demanding professional users. Better services can be introduced using the two concepts of the intelligent network (IN) and the telecom management network (TMN), which are based on implanting entirely new computer platforms into the nervous system of the classical public network, its signalling system. In this way, much lower equipment costs are incurred than if the expensive central switch equipment itself were to undergo upgrading or complete replacement. Moreover, inevitable software risks (see Sect. 5) can be kept separate from the standard switch software.

Innovative telecom operators are invoking the IN to support delivery of new services (whether offered by themselves or by third parties) and the appropriate flexible billing schemes for such services. The TMN, on the other hand, can be used to reconfigure the existing network capacity more flexibly in response to the rapidly changing user needs, e.g., due to user mobility or other less foreseeable shifts in traffic patterns. In both cases, the introduction of computer platforms enhances the capabilities of the more expensive telecom equipment, at the much lower cost of computer hardware suggested by Figure 1.

2.3 Limits to Growth of the VLSI Impact on Telecom Markets

Will Moore's law continue to apply indefinitely, and so produce ever increasing dynamic changes – if not turbulence – in the markets for telecom terminals and services? Two probable limitations should be mentioned briefly.

The principal limit to further growth of VLSI capacity and functional capabilities arises from the fact that the transistors on present generations of silicon chips are already very closely packed. In the near future, the spacing between transistors on one chip will become so minute that the effects of quantum physics will start to affect individual electrons. These will probably then 'tunnel' through the walls separating individual transistors or be disturbed by individual atoms or impurities in the semiconductor material. In either event, the result will be unreliable transistor performance. With millions of even slightly unreliable transistors on a single chip, this would become useless. Avoiding such problems already now leads to exponentially increasing costs of factories for new chip generation; this affects the manufacturing paradigm of the benefits of mass production, unless production volumes in each successive generation would also increase exponentially. Probably, the cost of a VLSI chip will, in the future, no longer be dominated by its marginal cost, but by the tremendous fixed capital costs of each new chip factory (at present, several billion USD). This problem could be mitigated by co-operative teams (cartels?) of competitors, or by accepting longer lifetimes of each chip generation, but the assumptions underlying Moore's law would cease to apply.

A second economic problem of the present microelectronics chip supply in distinct generations is the inherent creation of a commodity market, with cyclical fluctuations in price and demand, resulting in mercantilist pleas for import regulations and protection of national producers (*The Economist,* March 23rd, 1996). As experienced with agricultural policy, this may lead to less efficient markets and, consequently, yet another perturbation of Moore's law.

Despite such changing climates of microelectronics, its revolutionary crops are far from completely harvested by new systems and service sectors. For instance, many observers and investors believe that storage and individual delivery of compressed multimedia information, such as digital video on demand, will soon receive an impetus from low-cost VLSI-based platforms and consumer terminals. Systems based on microelectronics will continue to be agents for change in public and private telecom for years

3.0 Progress and Prospects of Optical Transmission

3.1 Capabilities and Limitations of Photonic Technology

The (re)invention of optical fibre technology in the 1960s[5] and the development of solid-state lasers generating infrared light have, in combination, probably already had a greater impact on telecom networks than the electronic revolution discussed above. Specifically, this 'photonic' technology has enabled broadband transmission systems. In the area of long-distance high-capacity transmission, optical systems have completely outperformed coaxial cables and permanent satellite links[6] within one decade.

A standard performance figure-of-merit for an optical fibre link is the product of its data transmission capacity (in megabits per second) and the transmission distance bridged (in kilometres). The first commercial systems in 1976 had figures-of-merit of about 20 (Mbit/s km), corresponding to conveyance of 30 digital voice channels over a distance of 10 km. Since then, the performance figure of state-of-the-art optical links has continued to grow exponentially at a rate of some 75 percent per annum, passing 2000 Mbit/s km in 1984, and reaching 2 million Mbit/s km in 1992.

The cumulative transport capacity of transatlantic submarine cable systems went up from 24 voice channels in 1956 (coaxial cable) to well above 100,000 channels in 1992, thanks to the shift to optical technology in about 1987. This indicates why satellite links can no longer compete on such high-density routes. By 1996, considerable spare capacity on the Atlantic cable routes between Western Europe and North America has built up. More significantly, the transatlantic cable cost dropped from seven million USD per deployed voice channel in 1956 to some 6000 USD per voice channel in the TAT-9 optical cable deployed in 1992 (USD 1992 level).

Just as for VLSI chips, a quantum limit would seem to curse future performance jumps of photonic transmission links. This theoretical limit of the performance figure lies at about one billion Mbit/s km per optical fibre and may be approached a few years after the turn of the century. However, the total transmission capacity can still be increased beyond the single-fibre limit, simply by including more fibres into one cable. This hardly increases the laying costs of the cable.

3.2 Implications for Long-distance Transmission Costs

To understand the impact of optoelectronic transmission on telecom, consider the following case of transatlantic conveyance costs.

> *Problem*: A submarine transatlantic (optical) cable was deployed by an international consortium in 1992 at a cost of USD 6000 per channel. How much does the corresponding transatlantic transmission cost contribute to the national tariff for a telephone call between Europe and North America?
>
> To estimate the cost of transatlantic conveyance, we assume the following:
>
> a) call minutes/year for a two-way circuit corresponding to 5 busy hours/day;
>
> b) the operational life time of the cable is 10 years (1993-2002);
>
> c) the cable investment was financed by a debt with an interest rate of 12 percent in 1992;
>
> d) the annual operation and maintenance costs are 25 percent of the initial capital;
>
> e) the consortium wishes a return on investment of 15 percent p.a.
>
> A 10-year annuity with present value 1 and interest rate 12 percent has equal instalments of 0,173. Hence, the total annual turn-over of the system must be at least (17,3+25+15) % = 57.3% of the initial investment. Assume that this turn-over would be earned during the busy hours only, i.e. during 100,000 fully-loaded minutes per year. The initial investment per (two-way) voice circuit being 2 x 6,000 $, the required turn-over per transatlantic telephone circuit would be

12,000 $ x 0,573/100,000 minutes = 6,88 cents/minute (1)

A crude estimate of seven cents per minute does not take some real risks of operators into account, such as inflation and unused capacity during the busy hours. On the other hand, capacity will be reserved and/or used outside the peak hours, for instance for lines leased by multinational customers and call-back service providers. Also, some new transatlantic traffic, notably using Internet (World Wide Web browsing), is not constrained by the narrow time slots of joint business hours in North America and Europe.

Present transatlantic telephone tariffs are obviously much higher than the circuit revenue indicated in (1), plus the mark-up for national delivery costs at both sides of the Atlantic Ocean. In other words, despite major recent international tariff cuts, very high profit margins are still earned on such long-distance routes. This would explain why excess cable capacity can exist or even be further expanded without dropping below a reasonable financial return (say, the 15 percent p.a. assumed above). International competition, however fierce-looking, is not yet effective for consumers, even on the most contested high-capacity routes. Generally, long-distance telecom services still seem far away from the risks of commodity pricing, which have started to affect the microelectronics sector.

4.0 Wireless Technologies: The End of the (Local) Line?

4.1 Cellular Technology: Avoiding Natural Barriers and Natural Monopolies.

Like most other technologies, wireless communication was initially developed in our classical human endeavour to overcome *natural* barriers. When Guglielmo Marconi bridged the distance between Cornwall and New Foundland in 1901 by dispatches of telegrams – so-called “cables” in American English – without using any physical cables or wires, it caused a sensation. Eight years later, he was awarded the Nobel Prize in Physics, a telling testimony of the public appreciation of an achievement then seen as falling under the Natural Sciences.

Marconi’s innovative skills were indeed based on his perception of the physics of electromagnetic waves and electrons. However, it should not be forgotten that his British patent No. 7777, filed in 1900, was the first milestone on the important road to *shared* use of the radio spectrum. Frequency tuning was proposed as a way to allow several users to share the radio spectrum, without causing unacceptable interference to each other. This was the first step towards a novel cultural discipline required for wireless networking, namely, multiple-access air interfacing of several local users. By exploiting this discipline, modern local radio networks are seldom limited in performance by the random natural noise on individual links. Rather, the effectiveness of the user culture (Arnbak 1993, 74-82), as embodied in joint multiple-access protocols and other public standards, in general determines the overall network performance and capacity.

In a young wireless technology, evolving since the 1970s under the name ‘cellular radio’, our engineering ambition to overcome nature’s noise limits by brute-force increases of transmission power has been deliberately reversed, simply to reduce the mutual interference between many users located in fictitious cells inside a service area. With less transmission power used on each individual link, the cumulative traffic capacity in the area can be increased. Reduced transmission power (and, hence, smaller coverage area for each *single* cell) makes it possible to increase the total number of users over all the cells in the service area of a network operator. Cellular networks interconnected to fixed networks offer us the perspective of personal communications services (PCS) for a virtually unlimited community of mobile users, each linked to the fixed network infrastructure by a wireless link, granted to active subscribers only for the duration of their call. As soon as a call ends, the frequency of the supporting wireless subscriber loop must be surrendered for use by somebody else in the cell.

Obviously, temporarily assigned wireless local loops have variable costs and so differ fundamentally from the fixed cost of the twisted pair of wires which has permanently connects each telephone subscriber, irrespective of actual use, since the days of Alexander Graham Bell. Apart from the radio terminals (which, as we have seen in Section III, also happens to become cheaper due to VLSI technology), the access network and notably its cost can be dynamically shared by all users in a cell. Moreover, except for the radio base station centrally located in each cell, the wireless access link is intangible and seemingly gratis.[7] It does not have to be entrenched in ducts or mounted on poles. These factors entirely change the cost structure of a public network. The dominant investment is no longer required for static transmission plant to all individual subscribers, but in automatic equipment to handle the dynamic procedures for:

- activity management, to support (only) users calling or moving between cells; and
- dynamic transmit power control, to prevent harmful mutual interference between active users.

Accordingly, standard economic and policy arguments for the need to subsidise fixed local loops by (monopoly) profits made elsewhere within the public telephone network are invalid in cellular networks. Cellular technologies reverse the costs of providing user access, which become proportional to the actual individual use, and to the number of users in a given area. In particular, access networks are cheaper in thinly populated areas than where higher network revenues can be collected by an operator[8]. Due to this cost structure, cellular networks are not natural monopolies, and thus they can be developed and sustained under competition. It is hardly accidental that telecom network liberalisation in most European nations was introduced by admitting a duopoly of public mobile networks, using the GSM standard.

An appropriate (inter)national context of regulation and standardisation of public cellular systems and a suitable choice of spectrum policy[9] increases the market size for candidate network technologies. Establishing the proper collective 'radio culture' maximises the public utility of mobile systems, notably in terms of system capacity, cost reduction and unhindered user roaming across the borders between different operators and/or countries.

4.2 Mobile Services – A Functional System Model

Figure 2 suggests a generic model of the market provision of telecom. It is divided into four layers of service facilities, in a way similar – but not identical (Sapniol, et al. 1995, 20-33) – to the well-known Open Systems Interconnection (OSI) model. The bottom layer is where radio engineers find their challenges: the provision of the wireless link between a customer terminal moving in a cell and the base station covering that cell in which different numbers of terminals will be located from time to time. Moreover, Layer

1 includes the (generally fixed) transmission links connecting base stations (BS) to their corresponding controllers (BSC) and the mobile switching centres (MSC).

Layer 2 comprises the BSCs and MSCs with the associated network intelligence required to control, route and tariff the traffic to and from the appropriate radio terminal. Mobility management is exercised by the network operator at this layer, both for his own subscribers moving across the cells in his service area, and for roaming customers paying temporary visits from other network operators' service areas.

Most public network operators offer access to specialised communication services at Layer 3, provided by themselves or by service providers, as selected by the user. Typical examples in the area of mobile networks are voice-mail boxes, mobile computing, and fax gateways. Finally, Layer 4 provides content services, such as travel information, news, and other on-line data services. On average, mobile users are more likely to demand such value-added services than are subscribers to the classical public switched telephone network (PSTN). This is not merely caused by the early adoption of wireless services by the most demanding and affluent ('leading-edge') customers. Generally, the typical circumstances of users on the move, away from their office facilities and from home, generate requirements for more advanced features. Accordingly, the technological ability allowed for supporting services in the upper layers is instrumental in commercial and regulatory plans for introducing public wireless networks.

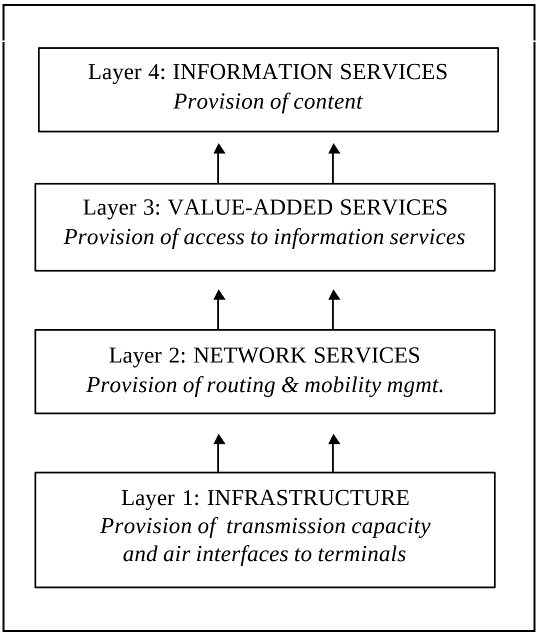

Figure 2 – **A generic telecommunications model for the provision of transmission capacity and services to mobile customers**

Note that the mobile terminals themselves are absent in the service model in Figure 2. An alternative layered model, which better reflects the engineering disciplines and the manufacturing industry supply of mobile communications products, would contain the following four levels:

- Intelligent network level (service/network control);
- Transport network level (transmission and switching in fixed networks, within the mobile system itself or interconnecting this to PSTN or ISDN);
- Wireless access level (air interface equipment); and
- Terminal level (user transmit/receive interface).

However, from a regulatory viewpoint, this layering according to system technology appears less useful than that in Figure 2.

5.0 Telecom Software: A Major Concern

Compared with VLSI and optical technology, the progress of software technologies is considerably slower. This is an important shortcoming, since the programming cost of software dominates the cost of all major network facilities with the exception of fixed subscriber loops. Especially, the cost of switch software has now risen to a substantial fraction of new telephone exchanges, typically 75-80 percent of the overall cost of a switch. Obviously, this lag is partly emphasised by the rapid performance/price improvements of hardware discussed above (see Figure 1), but it nevertheless reminds us of the general fact that broad human creativity and total systems understanding are more difficult to muster than greater production efficiency and expertise at the physical level of components and subsystems.

One of the consequences of the key role of software in modern telecom systems is the increasing impact of inadvertent programming errors, occurring in rare operational situations almost never accounted for or discovered in acceptance testing of public switches. Even the type approvals of the first digital handsets for the GSM mobile networks in Europe in 1992 became a protracted affair, leading to delays in the market supply of user equipment and, hence, loss of operator revenues in countries which had implemented GSM networks early. In fact, formal testing of a few of the GSM conformance requirements was waived, until the problems were resolved.

A modern intelligent nodal switch requires far more complicated software than does GSM-terminals. Testing a switch under all feasible operational conditions is well-nigh impossible; test programmes tend to concentrate on vital functions, plus the more commonly observed error risks. Hence seemingly minor, but undiscovered software ‘bugs’ or viruses in telephone exchanges can lead to serious errors. If such errors propagate through the signalling system and its associated TMN or IN networks, their impact may be catastrophic. Such an error propagation occurred some years ago in New York, leaving all of Manhattan and Newark airport without telephone service for a considerable period.

Conceivably, such problems and security ‘firewalls’ form two reasons why strictly separated, dedicated computer platforms are increasingly introduced in support of intelligent networks. In this way, IN or TMN software problems and the proper switch software problems may become easier to distinguish, identify and resolve.

6.0 Some New Regulatory (Pre-)Occupations

Successful introduction and operation of new network technologies require adequate public policies, e.g. for granting frequencies and the right to interconnect with the fixed telephone network(s) to mobile operators on fair terms. Comparison of the evolution of mobile networks in different parts of the World suggests that there is a public interest involved in ensuring common standards, in order to allow mobile users to roam between operators and to purchase their terminals from the largest possible mass market. Last, but not least, there is strong international evidence to suggest that competitive provision of network and value-added-services (Figure 2, Layers 2 and 3) and terminals is beneficial, in terms of more rapid introduction and lower pricing. Nevertheless, regulators should oversee the new competitive markets. There is a need to maximise network externalities by stimulating interconnection between competitors, but also to prevent dominant suppliers from abusing their market power in interconnection arrangements.

To illustrate the significance of regulation in the event of mobile interconnection under the European Open Network Provision (ONP) rules, the layered model in Figure 2 can be expanded into three dimensions (Arnbak, et al. 1994) (see Figure 3). Thus, competitive facilities offered at a given layer can be shown as duplicated symbols in that service plane. The (potential or real) competitors are spaced apart in one direction; the hierarchical delivery chain in networks is shown in the other direction of the resulting ‘interconnection space’. Selecting the best path through this space is a classical technical and economic problem faced by all telecom operators when procuring equipment and (re-)configuring their network in response to market needs.

With monopolistic supply of network resources in the past, a single national firm (typically a PTT) supplied all facilities between the international gateway (at the far right in Figure 3) and down to – and often even including – the user terminal at the extreme left. Such ‘external’ network points were generally the only interfaces accepted for interconnection, and hence also the most widely standardised. Between these extreme interfaces, the classical PTT as the sole provider of PSTN facilities and services was both vertically and horizontally integrated, and used its own proprietary internal interfaces.

In a regulatory regime allowing interconnection by a mobile operator (shaded in Figure 3), an MSC will be interconnected to the PTT’s switching hierarchy. The mobile operator may also interconnect its signalling system with the PTT’s. Independent service providers (at higher layers) may interconnect to the PTT to receive lower-layer transport services. These new paths in the interconnection space often represent innovative technical relations in terms of interface standards, management of security or mobility, allocation of service quality levels, etc. Such new paths also involve entirely new economic transactions between organisations, with private and public costs and benefits yet to be determined.

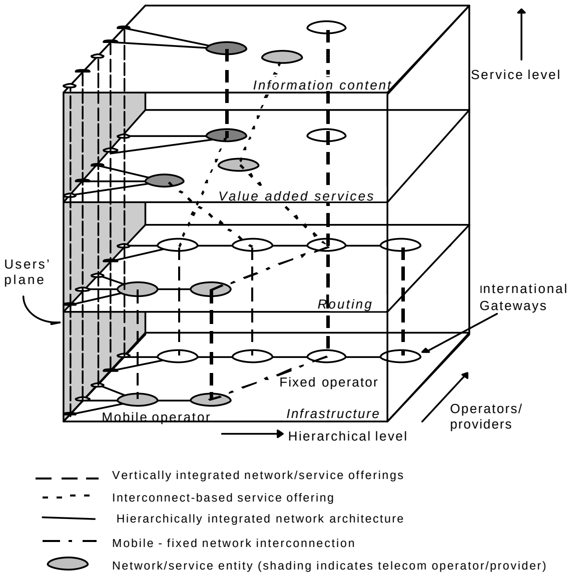

Figure 3 – **Interconnection space for competitive provision of networks and services**

The policy issues facing a regulator are to decide to what extent the costs and benefits of a particular path through the interconnection space can be discovered – and allocated – by a free market, or if regulations are required to enforce desirable interconnection paths. For instance, regulatory intervention might be deemed necessary to open appropriate paths by standardisation of crucial interfaces, such as GSM air interfaces or interfaces to the international Signalling System No 7. Paths which depart from overriding public-policy objectives, for instance by wasteful use of radio spectrum or violation of user privacy, may be subjected to financial charges or be completely barred by the regulator.

7.0 Conclusion: Regulation for Technology Success

A key success factor for the rapid international acceptance and continued evolution (Mouly and Pautet 1995) of the GSM networks in more than one hundred countries has been the fact that the GSM standard does not restrict itself to the radio subsystem and its air interface between terminals and base stations. GSM caters for all crucial aspects of interworking with fixed public telecom networks (PSTN and ISDN). This approach was chosen in Europe, because the majority of mobile calls or data applications will, in the foreseeable future, continue to originate or terminate in a fixed national network, often with proprietary national interfaces. The resulting problems of ensuring adequate interworking and mobility management have been much less for mobile systems in Japan and in North America, despite the present competitive multi-operator environment in the USA. The omnipresent “Bell System”, owned and operated by AT&T throughout the USA until formal divestiture in 1984, has ensured a much wider uniformity of the network interfaces and engineering practices than in Europe's multitude of different PTT-organisations.

The operational need for the GSM-system to interwork with the European patchwork of national networks, and to manage user mobility across technically and operationally incoherent European territories, enforced common frequency bands and the joint development of a mandatory mobile-network standard for the entire European Union. Moreover, this standard includes the use of the international Signalling System No. 7 (SS7), for instance to identify and authenticate users away from their own operator. However, the initial costs of this arduous effort have now been earned back with ample interest. In the author's opinion, it may be the most important reason for the unchallenged ability to deploy GSM-based systems so fast world-wide.

An ubiquitous network standard based on SS7 has another advantage, namely, the ability to create and support sophisticated applications. The higher-layer GSM services in Figure 2, such as intelligent voice messaging, information services and the Short-Message Service (SMS, unlike a paging system, provides confirmed delivery of texts of up to 160 characters) can be managed internationally through SS7. This also allows flexible customer care and billing, tailored by an operator or service provider to meet its particular commercial plans. This approach has proved a major asset in competitive mobile markets, where it may be commercially important to attract demanding leading-edge users prepared to pay the marked-up price of value-added services. Mobile telecom management networks (TMN) based on SS7 may also take advantage of the benefits of the recent technology branching shown in Figure 2, by adding the benefits of the most recent, high-performance computer platforms. Such platforms range from affordable PC-based systems for a minor service provider or capacity reseller, to sophisticated multi-processor systems required in the IN of a major operator.

By exploiting all three technology branch effects shown in Figure 1, a digital mobile system becomes empowered to outperform a standard fixed PSTN in terms of the service features available to users of affordable terminals, anywhere and at any time. This provides scope for direct competition with incumbent operators of fixed networks. In the Nordic countries of Europe, the time when effective mobile competition on price and service features will start to deprive the former monopolists of their fixed telephone subscribers, may no longer be far away. It is illuminating to compare the mobile subscriber percentages for Sweden and the USA. While these two rich countries are very comparable in several important respects, both economically (average income and fixed-telephone density) and geographically (population density, landscape), Sweden has substantially outperformed the very country where cellular radio was invented. Can this perhaps be construed to be a consequence of a more coherent mix of public policy objectives and new technologies in Sweden than in the USA?

The Scandinavian trend towards parity of wireless public networking may also provide a perspective for some less privileged countries where the fixed national telephone network has not yet reached a high penetration. Given the present development in performance and cost of wireless and wired network technologies (both terrestrial and satellite-borne (Westerveld 1996)) and user terminals, policies based on the best mix of technologies for leap-frogging towards universal service provision of telephony should be carefully considered.

Endnotes

[1] This article is based mainly on the author's lectures at Delft University of Technology and in the Master-of-Business Telecommunications (MBT) program of Foundation TopTech Studies, Delft, the Netherlands. He is grateful for the academic comments and assistance by university students and staff, and for discussions since 1987 with the professional MBT course participants from many countries.

[2] Well-known examples of such large industrial families are Intel's 286, 386, 486 and 'Pentium' microprocessors, and the 640 Kbytes and 1, 2, 4 and 8 Mbytes memory chips, used in successive PC generations during the period 1985-1995.

[3] A fourth trajectory, that of defence electronics and military computers, is omitted in Fig.1. It would be in the bottom of the Figure, i.e. below the civil telecom industry performance, due to the smaller production numbers and even more demanding performance standards for military technology. Moreover, the prices agreed in defence procurements (and in some procurements from national telecom "champions") are seldom disciplined by competitive, international markets.

[4] The price reductions allowed by modern VLSI techniques can also be seen in the light of the significant reduction of manual labour resulting from circuit integration. A leading mobile terminal manufacturer reports the following average times to assemble and test a mobile handset: 8 hours for an analogue terminal in 1988 and 30 minutes in 1992, compared to 12 minutes for a modern GSM terminal in 1994.

[5] It is seldom recognised in the telecom field that optical fibres were patented and used in medicine for visual probing inside blood vessels since the early 1950's. By 1966, Kao and Hockham (UK) on theoretical grounds proposed application in long-distance transmission of light signals.

[6] Satellites made the World shrink since the Syncom-III TV distribution links to Western broadcasters from the Olympic Games in Japan in 1964, but the most important satellite applications are now in support of mobile users, direct broadcasting, tailor-made links in unforeseen circumstances (e.g., disaster relief; CNN reports from 'hot spots'), and other thin-route traffic.

[7] Certain spectrum policies - e.g., auctioning frequency bands - introduce cost incentives to raise the efficiency of the frequency spectrum (a public good) by better network design (lay-out of cells, etc.).

[8] This applies within the physical limits of line-of-sight radio links, as used in cellular radio.

[9] See the author's companion article elsewhere in this Volume.