ENABLING THE DIGITAL ECONOMY

Research Paper
with Policy Recommendations

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Abstract

In this contribution we argue the importance of an ubiquitous high speed broadband infrastructure in Europe based on an analysis of subsequent technological revolutions, each characterized by a specific core infrastructure which enables the broad deployment of innovations, which in turn leads to a structural improvement in productivity.

To reap the full benefits of the current ICT-driven technological revolution adaptation of the institutional environment is essential, as overtime rules and regulations have been optimized for the previous techno-economic paradigm. A fundamental adaption has been the liberalization of the sector in the late 1990s. This enabled the deployment of Pan-European optical backbone networks.

We argue the importance of infrastructure-based competition in the development of broadband access networks, but also recognize the limits of the market-driven model. Hence, we emphasize the important role of governments where and when commercial models fail to supply broadband.

Here, research has shown a large diversity in alternative approaches and bottom-up solutions across Europe, based on initiatives by municipalities, non-telco entrepreneurs, cooperatives and communities of users. In closing the broadband gap we recommend these initiatives to be leveraged and facilitated by national, regional and local governments.

Next to ubiquitous coverage and affordable broadband, a high degree of usage is critical. This leads to the importance of the other Pillars of the Digital Agenda for Europe on digital literacy, skills and a safe and secure Internet.

Research also suggests that the economic benefits will only materialize if investments in ICT hardware and software are complemented with investment in human capital, i.e. in skills development, and the reconceptualization of the business models and business processes. Early examples are the change from 'print distribute' to 'distribute print' and the disintermediation of the 'middle man'. More recent examples are Airbnb, Uber and Snappcar.

An investigation into Internet usage, in particular the average peak rates which are indicative for the broadband capacity available to end-users, suggests that leading countries in Europe are at par with leading states in the USA, while there is still a gap with South Korea and Japan. South Korea and Japan benefit from a higher starting point enabled by the broad deployment of fibre. Nonetheless, if the leading countries in Europe keep up the current growth rate of 30% demonstrated over the past 8 years the gap with South Korea will be closed by 2020. Hence, policy focus should be on keeping the momentum in the leading countries and on closing the gap by the other countries in Europe.

While legacy copper networks have been crucial for providing the early broad access to the Internet, increasingly higher data rates require increasing use of fibre. Medium and large business users have already the opportunity to be connected by fibre. For residential users this will in the short term likely be in the form of upgrades from fibre to the cabinet to fibre to the distribution point / last amplifier and fibre to the basement, with full fibre deployment in greenfield situations. On the longer term this will have to be all fibre deployments to all users to accommodate the projected growth towards Gigabit data rates in 2025.

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In 1978 Wolter received his 'Ingenieurs'-degree Cum Laude at the Faculty of Electrical Engineering of the TUDelft, with telecommunications as specialization. In 2006 he successfully defended his PhD dissertation exploring and explaining the impact of the Telecom/Internet bubble on the development path of the telecommunication sector. His current research is focussed on telecommunication sector governance, industry structure developments, firm strategic behaviour and innovation trajectories.

He collaborated on various policy studies for the Ministry of Economic Affairs of the Netherlands, including "Rethinking the European ICT agenda" and "Markets and public values". He collaborated on projects for the European Commission, including: DG Information Society and Media - "Steps towards a truly Internal Market for e-communications - in the run-up to 2020"; DG CONNECT - "Regulatory, in particular access, regimes for network investment models in Europe" and "Impact assessment accompanying the review of the regulatory framework for e-communications"; and for DG Enterprise and Industry - "Patents and Standards: A modern framework for IPR-based standardisation"; and for DG Energy - "The role of DSOs in Smart Grids".

His most recent co-authored and co-edited book is: "The dynamic of broadband markets in Europe – Realizing the 2020 Digital Agenda" released by Cambridge University Press in November 2014. This book includes 12 in-depth EU country case studies by in-country experts on the development of broadband. For ECTA he collaborated on the development of a broadband market model and broadband performance index for the EU, using Structural Equations Modelling. He is PhD thesis supervisor in the field of radio spectrum governance at the TUDelft and the co-founder of the Cognitive Radio Platform NL. Furthermore, he co-authored and co-edited the book: "The innovation journey of Wi-Fi – The road to global success" released by Cambridge University Press in 2011.

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ENABLING THE DIGITAL ECONOMY

1 Introduction

In a market economy the leading role has been given to private actors operating in competitive markets. The key assumption is that the aggregate outcome of individually motivated actors provides the best possible outcome for society at large. As such the outcome is emergent. The key role remaining for governments is assuring the proper functioning of competition. This is one extreme in terms of the role perception of governments, the so-called 'regulatory state'. On the other end of the spectrum we find the so-called 'development state'. Also here competitive markets play the central role, but the government operates on the basis of a vision and enables the markets to realize that vision. First and foremost through sharing the vision, by setting goals, monitoring progress and by facilitating the markets where pure commercial interests fail to realize the objectives being set.

In the European Union we operate on a shared vision that transcends the interests of the individual state to create a region with a single market, that enables Europe to lead in an increasingly global market place. Having started the journey in the 1950s with alignment around the steel and coal industries the current focus is on creating a Digital Single Market.

To be successful in realizing the vision it is considered important to recognize the broader context of economic development, such that actions become effective and mutually re-enforcing. This concerns the recognition that we are in the middle of the 'deployment phase' of the ICT-driven industrial revolution.

In each industrial revolution a new infrastructure enables the diffusion of the major innovations characterizing the particular industrial revolution. Each successive industrial revolution thereby provides the opportunity for a stepwise productivity improvement. The implication is that enabling the digital economy hinges on realizing an ubiquitous and dependable broadband infrastructure.

In this Research Paper we explore the critical role of infrastructures in economic development and subsequently focus on the enabling role of broadband infrastructure in the current ICT-driven industrial revolution. To appreciate the critical role of infrastructures in economic development we are going back in time and discuss the regularities that can be observed across subsequent technological revolutions. We link these insights to the current ICT-driven revolution, which was enabled by the liberalization in the late 1990s and leads to a transition to an optically enabled broadband infrastructure. We explore the roles of governments after liberalization in enabling the diffusion of the current techno-economic paradigm, focusing on the development of the communications infrastructure. As we move to an all-fibre environment we address the issue of an infrastructure monopoly re-emerging. We end with exploring the developments towards network virtualization. Based on the analysis policy recommendations are formulated.

The main line of reasoning will be supported and illustrated by salient mini-case studies.

2 The critical role of infrastructures in economic development

From our day to day personal experience we all know that economic development is characterized by ups and downs. Economists have been able to relate these ups and downs to various cycles in economic development, for instance a cycle in inventory build-up and depletion, in investments in capital goods and in building construction.[1] Those economists who have been analysing economic development over longer periods of time and across countries have also discerned a recurring economic cycle or wave with a periodicity of 50-60 years. The Russian economist Nikolai Kondratieff (1892-1938) was one of the first to publish his observations on this long-wave phenomenon.[2] However, explaining the factors that cause these long-waves has challenged economists for many years thereafter. Until in the late 1930s Schumpeter suggested 'major innovations' as the underlying cause. He argued that major innovations are not spread evenly over time, but appear to be clustered, whereby they are leading to new industries resulting in an upswing in economic development.[3] Over time this interpretation has become widely accepted, in particular through the interpretation of these regularities in history by Freeman, Louçã and Perez.[4] It is their interpretation that brings us to the importance of infrastructures in economic development in general and to the importance of communication infrastructure in enabling the digital economy in our day and age.

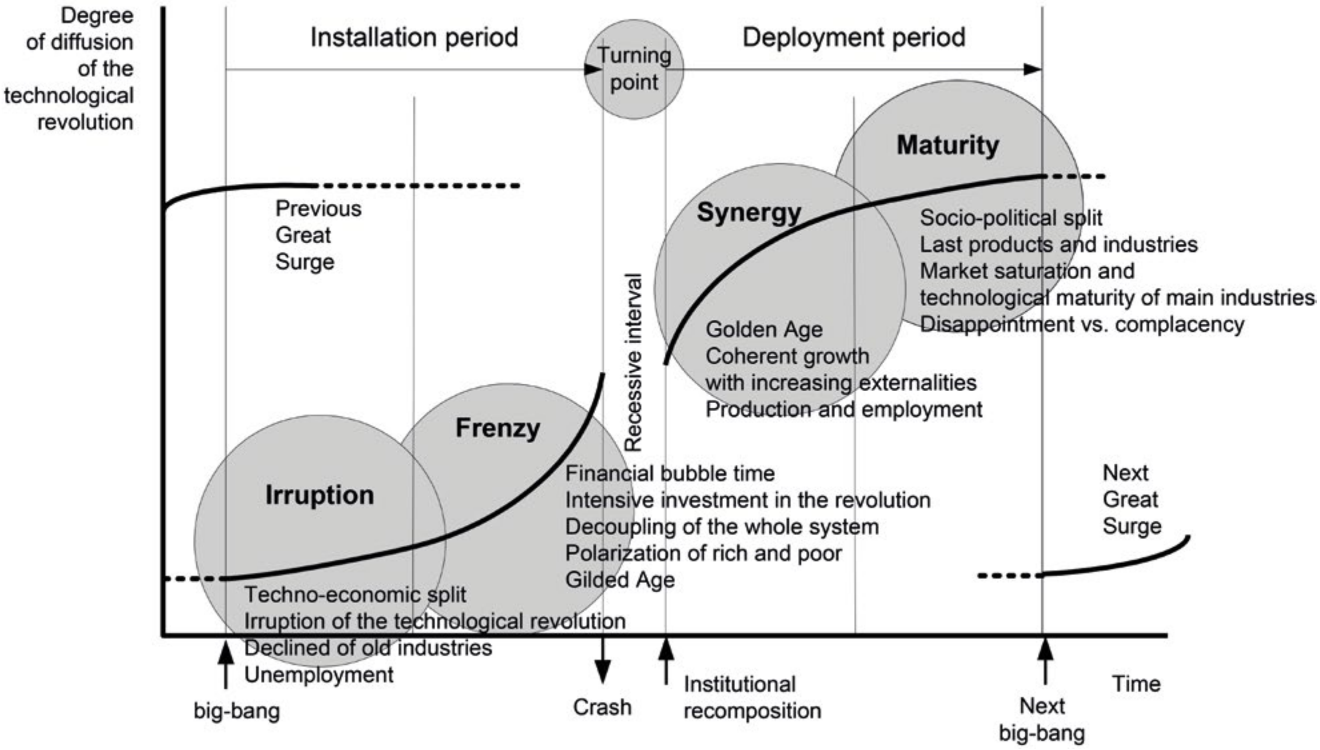
The first occurrence of the long-wave phenomenon can be traced back to the first Industrial Revolution. It started with the water-powered mechanization of industry. The landmarks of the beginning of the first Industrial Revolution were Arkwright's Cromford mill (1771) using water power for cotton spinning and Henry Cort's 'puddling' process (1784) to make iron products, both originating in the United Kingdom.[5] The new infrastructure of the time became the vast network of canals that allowed production sites to be linked to the markets for products. The second Industrial Revolution concerned the steam-powered mechanization of industry and transport. The key infrastructure became the railways. Liverpool to Manchester being the commercial first (1831). It led to a frenzy in railway building in the UK and spread to the European continent and beyond.[6] At this time the telegraph was introduced first in the UK and in the USA and found its use and rights of way along railway tracks. The railway infrastructure replaced the canals as key infrastructure of the previous period. Then followed the third wave, the electrification of industry, transport and the home, enabled by the electricity grid. Edison's Pearl Street Electric Power station in New York (1882) being the landmark. In this period we see the replacement of the telegraph by the telephone, first in the USA then in Europe. The fourth wave concerns the motorization of transport and extension of the motorway network across the USA and Europe. This revolution is typified by Ford's Highland Park assembly line (1913) and the Button process for cracking heavy oil (1913). The current and fifth Industrial Revolution concerns the ICTs, the computerization of the entire economy. Intel's introduction of the microprocessor in 1972 constitutes the landmark event. The micro-electronic 'chips' are to become the core input to this new revolution.

For the diffusion of the major innovations that characterize the industrial revolutions and for society to benefit from these innovations the build-out of the related infrastructures played a critical and essential role. While mostly undertaken by private entrepreneurs, local, regional and national governments played an important enabling role, notably in providing permission for construction and providing the rights of way. For instance in the UK, the construction of each canal and each railway line required a separate bill to be approved in the Parliament.

Each revolution was characterized by a replacement of the core technology of the previous revolution, i.e. water by steam, steam by electricity. In the fourth revolution oil became a replacement but also a complement to electricity. In the fifth revolution, the ICTs are enabled through the availability of electricity. At first the communications infrastructure becomes dependent on the electricity infrastructure, and now, with the introduction of smart grids, the electricity grid becomes dependent of the communications infrastructure. These infrastructures have become 'critical' infrastructures; they have become essential for the proper functioning of the economy and society at large.

Perez in interpreting the subsequent industrial revolutions, has developed a stylized model of the long-wave phenomenon, which she called the 'Great Surge' model, see Figure 1.[7]

Figure 1. Great surge model



She showed that the sequence of 'technological revolution – financial bubble – collapse – golden age – political unrest', is recurring about every half century. This recurrence is considered to be based on:

1. The fact that technological change occurs by clusters of radical innovations forming successive and distinct revolutions that modernize the whole productive structure;
2. The functional separation between financial and production capital, each pursuing profits by different means; and
3. The much greater inertia and resistance to change of the socio-institutional framework in comparison with techno-economic sphere, which is spurred by competitive pressures."

In the early phases there is the battle of the new paradigm with the power of the old paradigm, which is "ingrained in the established production structure and embedded in the socio-cultural environment and in the institutional framework." When this battle is won the new paradigm diffuses across the whole of the economy and society. Hence, the diffusion of the new paradigm can be seen as two distinct periods, the 'installation period' and the 'deployment period', both typically lasting 20-30 years. The 'turning point' from the installation to the deployment is "usually a period of serious recession, involving a re-composition of the whole system, in particular of the regulatory context that enables the resumption of growth and the full fructification of the technological revolution."

In the 'installation' period the new techno-economic paradigm involved the ICT-industries themselves and in the industries with a high intensity of ICT-use, such as the financial industry. In these industries the application of the new techno-economic paradigm is self-evident. We are now in the middle of the deployment period. The period whereby the ICT innovations diffuse across the economy and society at large. This is the period in which the major benefits are to be realized. Critical condition is the availability of the enabling broadband infrastructure for all users, business and consumers alike.

This expansion of ICT enables a stepwise improvement in productivity to be realized. These improvements only accrue if the investments in hardware and software are complemented by investments in human capital and the reconceptualization of the business models and business processes.[8] Investment in human capital includes improving digital literacy and skills to assure the new capabilities are being exploited and are leading to innovation. Examples of early reconceptualization are for information provisioning the change from 'print and distribute' to 'distribute and print' as well as the disintermediation of the 'middle man' in ordering on-line; more recent examples are the emergence of Airbnb, Uber and Snappcar as alternative forms of providing accommodation respectively taxi rides and car rentals.

Here also the 'other' pillars of the Digital Agenda for Europe become important, in particular Pillar III Trust and security and Pillar VI Enhancing digital literacy, skills and inclusion.[9] In these areas the enabling role of government is very important. As it concerns public values and public interests governments are expected to take a leading role. E.g. in collaborating with the industry to fight cyber-crime, malware, phishing, etc.; as well as assuring privacy and data protection.

In enabling the transformation it helps to frame the problem as a change in paradigms, from the old to the new. The process of change reflects the transformation from the previous oil-based techno-economic paradigm and its best practices – including the Fordist approach to manufacturing – to the current ICT-based techno-economic paradigm and its best practices. The best practices of the latter are still subject to development and improvement. Table 1 reflects the main differences: at Level 1 the differences in the core technology and infrastructure; at Level 2 the industrial organization; and at Level 3 the 'common sense' principles or best practices.[10-11]

Table 1. The three levels in the 4th and 5th Techno-Economic Paradigm

	Techno-Economic Paradigm	
	4th Fordist	**5th ICT**
Level 1	**Technology & Infrastructure**	
A constellation of technologies, products and industries with wide generic applicability, and a supporting infrastructure	Internal combustion engine (for autos, tractors, electricity generation, aeroplanes, etc.)	Micro-processor (as information processing engine)
	Oil and gas as fuels	Data as fuel
	Petrochemical industry (refinery, synthetic materials and chemicals)	Communications and Information Technology industry (hardware, software, services)
	Motorways, airports, airlines	Internet, broadband access
Level 2	**Organization**	
An organizational model for best practice in all productive activities	Dedicated mass production	Adaptable production systems
	Compartmented hierarchical pyramids	Flexible networks, flat and broad ranging
	Materials and energy intensive	Information intensive
Level 3	**"Common sense" principles**	
A general set of "common sense" principles for guiding organisational and institutional innovation	Centralization	Decentralization
	Separation of work and organizations by function	Re-integration of functions
	Massification	Diversification
	Negotiation of conflicts	Consensus building
	Regulation and supervisory control	Guidelines, trust and monitored control

For policy making the lessons learned from the analysis of the long wave phenomenon as it relates to subsequent technological revolutions can be summarized as follows:

- Each technological revolution has its own new infrastructure enabling the diffusion of the related innovations. Policies should be aimed at facilitating the widest possible build-out of that infrastructure to be able to reap the benefits of improved productivity across the economy and society at large;
  - In the current ICT-driven techno-economic paradigm it means the build out of a high data rate and highly dependable communications infrastructure with 100% coverage;
- Over time institutional arrangements, including regulations, become optimally tuned to the current techno-economic paradigm. Hence, to enable the diffusion of a new technological revolution, the institutional environment has to be adapted to the needs and best practices of this new techno-economic paradigm. Policies should be aimed at making the necessary institutional, including regulatory, changes to enable the diffusion of the related innovations in order to obtain the benefits of these innovations;
  - In the current ICT-driven techno-economic paradigm it included the liberalization of the electronic communications market in the late 1990s. Today it means adopting technology neutral regulation to facilitate the development of new forms of services provision;
- Each technological revolution brings a new way of working through which productivity improvements are realized. To be able to capture the benefits of this new way of working investments in equipment alone are not sufficient. One needs to invest also in learning the people the new way of working, which includes learning new skills, new routines. Moreover, one needs to adapt existing business models and business processes to incorporate the new capabilities provided by the technological revolution in order to capture the benefits;
  - In the current ICT-driven techno-economic paradigm it means aiming for 100% digital literacy; the transformation of business models and business processes to leverage the electronic provision of services or parts thereof. E.g. through enabling the wide deployment of e-government, e-learning, e-health, etc.;
  - As the ICT-driven techno-economic paradigm not only benefits bona fide but also mala fide business practices, it is essential that governments unite forces to fight cybercrime in all its manifestations to allow unencumbered usage by end-users.

3 Emergence of the new infrastructure

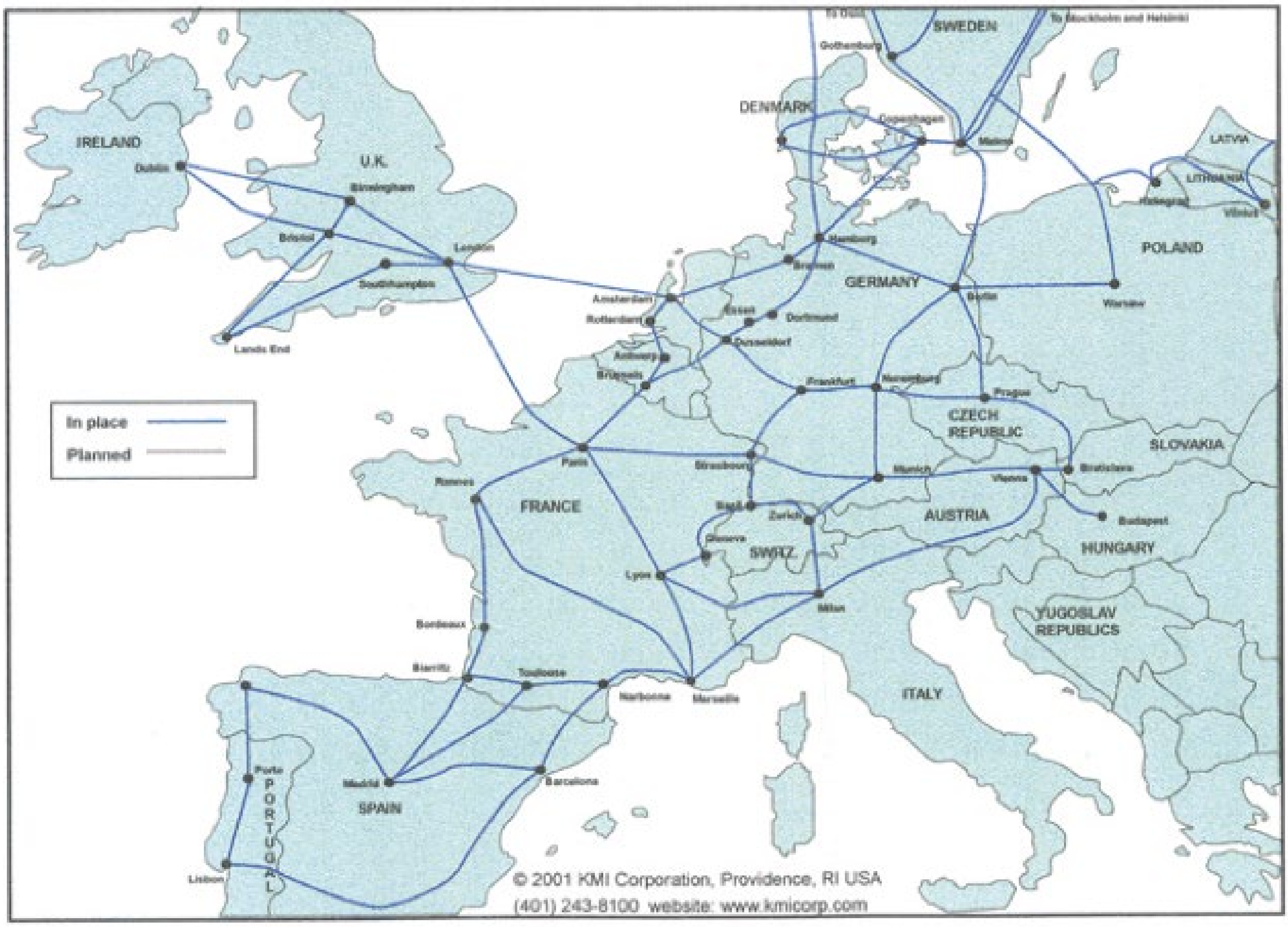
In the 'installation period' the new infrastructure is beginning to be deployed, typically the main arteries, benefitting from the period of frenzy. In the 'deployment period' follows the build-out of the new infrastructure.
In the period of 'frenzy' of the ICT-revolution a number of important technological innovation trajectories came together fueling the euphoric period at the end of the 1990s into the year 2000: (1) the Internet opening-up to the public; (2) the introduction of laptop computing; (3) mobile communications and Wi-Fi.

The developments were enabled by governments, through the liberalization of the communications sector. Already in the late 1960s the data communication technologies of the new ICT paradigm started to put pressure on the institutional structure of the old paradigm – the telephone monopolies, in particular in the USA. Following the 1987 "Green Paper on the development of the common market for telecommunications services and equipment" of the European Commission, the target date for liberalization at the member state level was set at January 1, 1998. A very prominent effect has been the emergence of Pan-European optical backbone networks.

EMERGENCE OF PAN-EUROPEAN OPTICAL BACKBONE NETWORKS

Liberalization allowed incumbent operators and entrants to provide services and install networks across Europe. The prospect of increasing demand from businesses and consumers combined with the availability of high-capacity low-cost optical technology initiated the construction of Pan-European backbone networks. Figure 2 shows the example of Telia's Viking Ring.[12] Similar networks were constructed by e.g. COLT, Deutsche Telecom, Global Crossing, Interroute, KPNQwest, Telecom Italia and Tiscali. All operators were responding to the same new market opportunity at the same time. In the period 1996-2000 some 17,500,000 fiber-kilometer was deployed. The early Pan-European optical networks connected the major business hubs in Europe, including the major financial centres. The actors were both incumbents and entrants.

Figure 2. Telia Pan-European network (Viking Ring)



Following the collapse of the telecom/internet bubble in 2000, only a fraction of the installed capacity was in use – some 2-5%. Nonetheless, it provided readily available transport capacity for the unabated growth in Internet traffic in the following years. These Pan-European optical networks formed the core of the backbone infrastructure – the digital highways – essential for the diffusion of the ICT-driven techno-economic paradigm.

This is a good example whereby technological developments on the one hand force institutional change and on the other hand enable the goals set for the same institutional change to be realized: through competition – more choice, lower prices and higher quality for end-users. At the same time the institutional change enables the deployment of the latest innovations in communications technology to be deployed by the industry.

For policy making the case study reveals the benefits of introducing competitive markets in terms of adopting new and lower cost technologies, leading to reduced prices higher capabilities and increased end-user choice.

3.1 Deployment period: from optical backbones to optical access networks

The business case for backbone networks benefits from highly aggregated traffic streams. This is in stark contrast with serving residential homes and businesses, in particular in rural areas whereby the final kilometer of cable may serve a single home or business. Nonetheless, the families living in rural areas have kids that attend school and need access to the Internet for education and their social interactions. Also precision farming requires large amounts of data to be uploaded and downloaded.

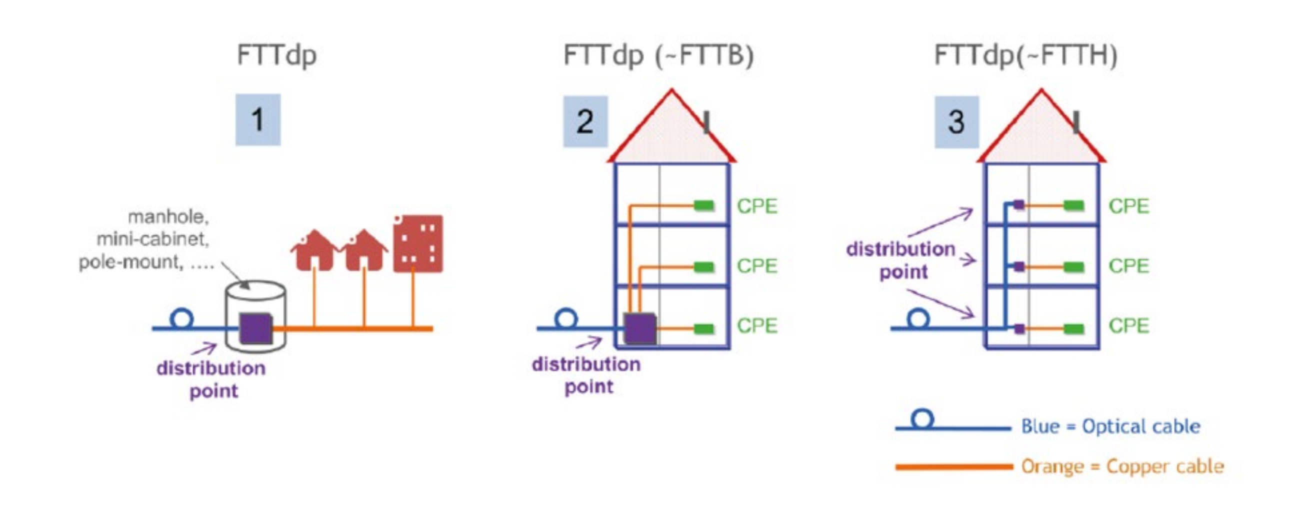
However, liberalization implied privatization and hence operators have become subject to the demands of financial markets for increasing valuations and profits. The business cases that minimize risks and maximize profits are the most attractive. The ability to upgrade existing copper infrastructure in urban areas provides the more attractive alternative. Around the year 2000 we see 'always on' Internet being offered by operators through ADSL on twisted pair copper and through DOCSIS modems on CATV-cable networks. Over time our needs for higher data rates increased. However, providing higher data rates requires the use of higher frequencies, but the use of higher frequencies implies higher attenuation. As a result higher data rates can only be applied on short copper loops, hence, higher data rates can only be provided to subscribers living close to the local exchange or cable network hub. Unless… …the copper loop is shortened. This is where optical transmission comes in.

3.1.1 Upgrading the twisted pair copper loops with fibre

As a first step optical fibre has been introduced between the local exchange and the cabinets in the access networks. This is called Fibre-to-the-Cabinet (FttC). On the remaining part of the twisted pair copper loop VDSL modems are introduced, which provide for the higher data rates, up to 40 Mbit/s.[13]

In a next upgrade, called G.fast, the fibre is extended further into the access network to approx. 100 meters from the individual homes, or into the basement of apartment buildings or multi-dwelling units. In this deployment scenario fibre is extended to the distribution points (FttDP or FTTdp). See also Figure 3.[14] In this configuration G.fast will reduce the serving areas to micro-nodes of 1-48 subscribers. With the G.fast standard having been approved in 2014, many trials being underway and the first commercial deployments being announced, broad deployment of G.fast could start in 2017-2018. G.fast will provide data rates of approx. 250 Mbit/s symmetrical, i.e. in both downlink and uplink.

Figure 3. G.fast deployment options



Legend: CPE: Customer Premise Equipment; FTTB: Fibre-to-the-Basement; FTTdp: Fibre-to-the-distribution point; FTTH: Fibre-to-the-Home

In this upgrade scenario FttDP is becoming equivalent to Fibre-to-the-Building or Fibre-to-the-Basement (FttB) and could be extended to become Fibre-to-the-Home.

3.1.2 Upgrading the coax network with fibre

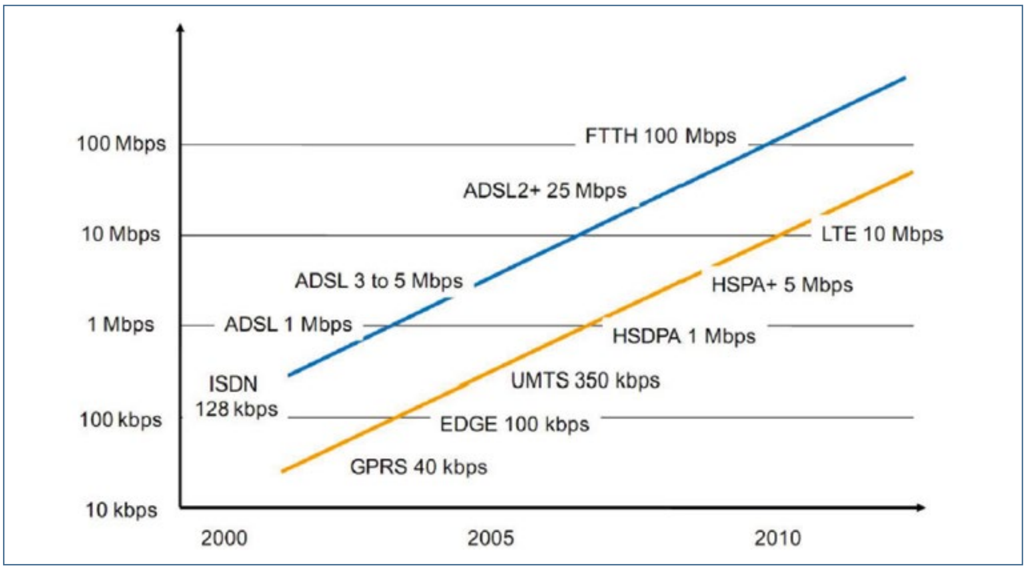
Although coax cables deployed in the CATV-networks have an intrinsic higher usable bandwidth, in these networks the final drop is shared among multiple users. Hence, also in CATV networks fibre is deployed to the cabinet (FttC) to increase the data rate per user, supporting the current generation of DOCSIS 3 modems.[15]

The next generation DOCSIS 3.1, which implies a transition to higher order modulation techniques, is specified with a maximum download rate of 10 Gbit/s and upload of 1 Gbit/s. DOCSIS 3.1 implies the extension of fibre to the Last Amplifier (FttLA) – equivalent to the DP in twisted pair copper networks. Typical rates offered to end-users will be from 100 Mbit/s to 250 Mbit/s, symmetrical or asymmetrical. DOCSIS 3.1 is fully standardized and equipment is becoming available.[16] New terminal equipment at the CATV-hubs is already being deployed by the operators, the deployment of new cable modems is expected to follow the demand for higher data rates.

3.1.3 Upgrading the mobile access networks with fibre

In central European countries the development of the public switched telephone network (PSTN) has peaked at approx. 60% of households. In these countries, mobile has become the default means of communication with for instance penetration rates of 131 mobile phones per capita in Poland and 190 in Latvia.[17] Wireless access is an alternative to wired access, although the data rates in wireless tend to trail those provided on wired networks. See Figure 4 for the comparison. For the next generation of mobile communication -5G- expected to be introduced in the early 2020s a user data rate of 50 Mbit/s is foreseen.[18]

Figure 4. Comparison of fixed and mobile data rates, 2000-2010



Legend: ADSL: Asymmetrical Digital Subscriber Loop; EDGE: Enhanced Data Rates for GSM Evolution; FTTH: Fibre-to-the-Home; GPRS: General Packet Radio Service; HSDPA: High Speed Downlink Packet Access; HSPA: High Speed Packet Access; ISDN: Integrated Services Digital Network; LTE: Long Term Evolution; Mbps: Megabits per second; UMTS: Universal Mobile Telecommunication System

Although the lines in Figure 4 seem to suggest they will never meet, fixed and mobile infrastructures are intrinsically linked. More intense use of mobile communications requires a more dense network of base stations and hence a more dense backhaul network.[19]

While in the past backhaul was typically realized by leased circuits or microwave links, increasingly optical fibre is used to provide the higher capacity and the higher data rates. Higher usage combined with higher data rates leads to densification of base stations. Hence, the optical backhaul network foreseen in the context of the next generation of mobile -5G- is going to look much alike the optical network to be deployed towards the distribution points to enable G.fast or DOCSIS 3.1. For operators that are active in both fixed and mobile service provision these parallel developments provide opportunities for synergies, making the business case for FttH more attractive. Moreover, by investing in full fibre deployments operational costs (OPEX) of the access network will be reduced significantly.

4 The role for governments in the deployment period

Through liberalisation, having given the leading role to private actors operating in competitive markets, what is the remaining role for governments?

There are two relative extremes in the role perceptions that governments may adopt: the 'regulatory state' and the 'developmental state'.[20]

Within the regulatory state the government operates at a distance and plays the role of the 'night watch'. Such a government is relatively small and first of all a facilitator of what 'society wants'. In terms of information production and diffusion it is the 'lender of last resort'. After all other options have been tried, the state plays the role that remains. It monitors and in case it discovers inconsistencies it does not intervene, but feeds information back into the system. The regulatory state is strong with respect to the maintenance of the rules of the game: supervising the process is central and in that respect the state intervenes strongly based on strict rules of competition. In the 'developmental state' the government develops, often in consultation with the private actors, a vision about the desired future. The state defines the objectives and the instruments to be used to realize the vision. Such a state is well informed, is an authority in society, and usually well respected because of its power to guide and direct structural developments.

In both perspectives, having created the market, a key responsibility for governments is monitoring the proper functioning of the market. If market failures are observed, the first step is to analyse its root cause. Depending on the outcome, the market conditions may have to be adjusted. Alternatively, supply may not meet demand and vice versa as a result of high transaction costs. If these are search costs, governments may assist the market by providing information (e.g. by providing price information) or facilitating the interaction between market parties (e.g. by providing a register of radio frequency license-holders). If it concerns a lack of economies of scale, governments may assist through coordination (e.g. by stimulating standardization of products or services). [21-22]

Secondly, when recognizing the importance of the communications infrastructure for the diffusion of the major innovations of the ICT-driven techno-economic paradigm, governments will want to assure the provision of ubiquitous and also dependable infrastructures. Furthermore governments will need to apply 'maintenance' to assure the institutional arrangements remain aligned with technological developments. In the following sections we will address each of these roles. We conclude this section with the special case of regulating Fibre-to-the-Home.

4.1 Assuring competitive markets

With monopolies as the starting point, the role of governments after liberalization concerns interconnection with entrants, preventing the misuse of significant market power and resolving any market failures.

Infrastructure-based competition is thereby considered to be the superior form of competition. It is based on independent network ownership and it allows for more degrees of differentiation in the services offered compared to access-based competition.

However, where CATV-networks are absent[23] infrastructure-based competition is not an option and access-based competition becomes the default, to be realised by prying open of the incumbent network through regulation. This has been realized in a stepwise manner, from resale of services through partial to full unbundling of the twisted pair local loop.[24] Through the so-called 'ladder of investment', the alternative operators are provided with a path towards full infrastructure-based competition.[25] At the lowest 'rung of the ladder' (resale) the investment requirements are relatively low and a customer base can be built. By 'climbing the ladder' more investments provide for less dependency of the incumbent wholesale provider, until at the 'final rung' a wholly-owned network is realized, typically an optical fibre-based access network. A salient example is Free/Iliad in France.

FREE/ILIAD, FRANCE, A VERY SUCCESSFUL ENTRANT

Free/Iliad has been at the forefront of Internet access since its inception as an ISP in 1999. It launched its first 'broadband' offer (512 kbit/s down – 128 kbit/s up) for €29.99/month unlimited use in 2002, with a modem for free. In 2003, Free provided the first Voice-over-IP mass market offering and the first TV-over-ADSL offering. In 2004, Free introduced ADSL-based triple-play offer including a special modem – the 'Freebox'; keeping the price at €29.99. In May, making use of full local loop unbundling, Free offered internet access at 2 Mbit/s, and access to over 100 TV channels for €29.99.

By the end of 2007, Free/Iliad's customer base had grown to about 2.9 million ADSL subscribers, of which 81.5% was provided on the basis of unbundling. As the Regulator ARCEP approved ADSL2+, Free moved up the ladder investing in its own ADSL2+ equipment to offer 15 Mbit/s down and 1 Mbit/s up to its subscribers, again at €29.99, including a new FreeBox version.

In 2006 Free joined the Paris Digital City Initiative. It introduced its first fiber-based offer of 50 Mbit/s at €29.99 in June 2007. In July followed a 100 Mbit/s downstream with 50 Mbit/s upstream, of course... ...again at €29.99.[26] Important for Iliad's success was the access to the Paris sewer system for laying fibre cables. Later to be extended with access to the civil infrastructure of the incumbent Orange, made possible through regulation.

Optical access networks followed in Montpellier in 2008 and Valenciennes in 2009. Herewith Free reached the final rung of the investment ladder, having built its own (optical) infrastructure.

With the introduction of VDSL and G.fast the aggregation point of traffic for alternative operators is moving further down into the access network, from the cabinet to the distribution point. This makes unbundling of the access network less and less attractive. As a consequence, the alternative operators are moving down the 'ladder of investment', once again becoming a pure service provider based on virtual unbundling in the form of bitstream. One may conclude that if alternative operators have not yet reached the final rung of the ladder, they will not reach it in the future either.

4.2 Assuring ubiquitous supply

In the perception of a pure regulatory state, the outcome of the competitive market achieved by private entrepreneurs pursuing private interests is considered the best possible outcome for society. In shifting from a pure regulatory state towards a developmental state, the government recognizes what is at stake and is inclined to guide the market in certain direction to achieve certain outcomes.

The lessons learned from the long-wave phenomenon point to the importance of an ubiquitous and dependable communications infrastructure in enabling the digital economy. For the European Union to set this objective as a goal of policy makes perfect sense. A further step towards the model of the developmental state includes setting specific targets and guiding the industry in realizing these targets.

Liberalization placed the realization of the communications infrastructure in the hands of private actors operating in a competitive market. Hence, where the business case becomes unattractive, in particular in rural areas, alternative means will need to be pursued to provide the desired level of infrastructure extensions and upgrades. This will in various ways call on governments as 'lender of last resort' or 'financer of last resort', including the EU-level regional funds.[27]

IN SWEDEN, ONE IN EVERY TWO MUNICIPALITIES RUNS AN OPTICAL FIBRE NETWORK[28]

Sweden is a large country of 449,964 square kilometers with a population of 9.6 million, resulting in a very low population density of 23 persons/km2. Approx. one third of inhabitants are living in the major con-urbanizations of Stockholm, Göteborg and Malmö.

The current broadband evolution started in 1999/2000 with a government bill that was aimed to support national and local initiatives and investments. The headline was "Trust to IT, Access to IT and IT Competence". Access implied broadband provision, with national, regional and local network support, including SMEs and schools. The financial support included approx. €280 million to a national operator-neutral backbone, €360 million to municipalities to develop access (in the form of tax breaks) and €290 million to regional networks and to create local infrastructure plans.[29]

Local fibre networks are considered to play an important role in the broadband market as they represent an alternative to the former incumbent's infrastructure. Many municipalities believe that the open fibre network is strategically important for their development and growth. A recent survey showed that 77% believe that their network has had a significant impact, while 15% believe they have had a positive impact.[30]

Out of the approx. 290 municipalities around 175 municipalities have deployed fibre networks in the past ten to fifteen years, representing more than 50% per cent of the total fibre coverage.[31] Some of these municipality networks have recently formed regional associations to interconnect the different networks and to facilitate the access to the providers of end-user services, as well as providing access to wholesale market actors.

One of the first effects observed in FttH municipal networks is a saving of 30% to 50% of the total municipal data and telecommunication costs. This is partly due to increased efficiency (reduced equipment, energy consumption, and footprint per unit of transmitted information) and partly due to the fact that the fibre network with high capacity allows for more competition between service providers and thus lower prices. Indirect effects that were observed included the reduction in migration to larger cities, a problem among rural municipalities in Sweden.

In the endgame, municipal supply benefits the private operators, as they can extend their service provision to a much larger part of the population, without the need to invest in access infrastructure.

Assuring infrastructure supply in rural areas is not only a case of local governments supported by national governments. There are many examples of citizens initiatives. Moreover, rural areas are not necessarily low-tech areas. In fact, high-tech farming has broadband demand exceeding that of many urban users. Despite the overall high performance of, for instance, the Netherlands in the broadband league tables, considered to be the result of strong infrastructure-based competition, the country is characterized by many non-telco initiatives to improve service provisioning. This concerns not only rural areas but also the upgrade to fibre in city areas. It has been suggested that the strong tradition of cooperatives may still have its effect on the willingness to take bottom-up collective action, for instance in agriculture, but also in the many housing corporations. The need for such actions in rural areas has been called 'neo-endogenous rural development', a consequence of recent neo-liberal policies emphasizing a smaller role for government and more reliance on self-supporting citizens.[32]

BOTTOM-UP INITIATIVES BY PRIVATE CITIZENS, THE NETHERLANDS[33]

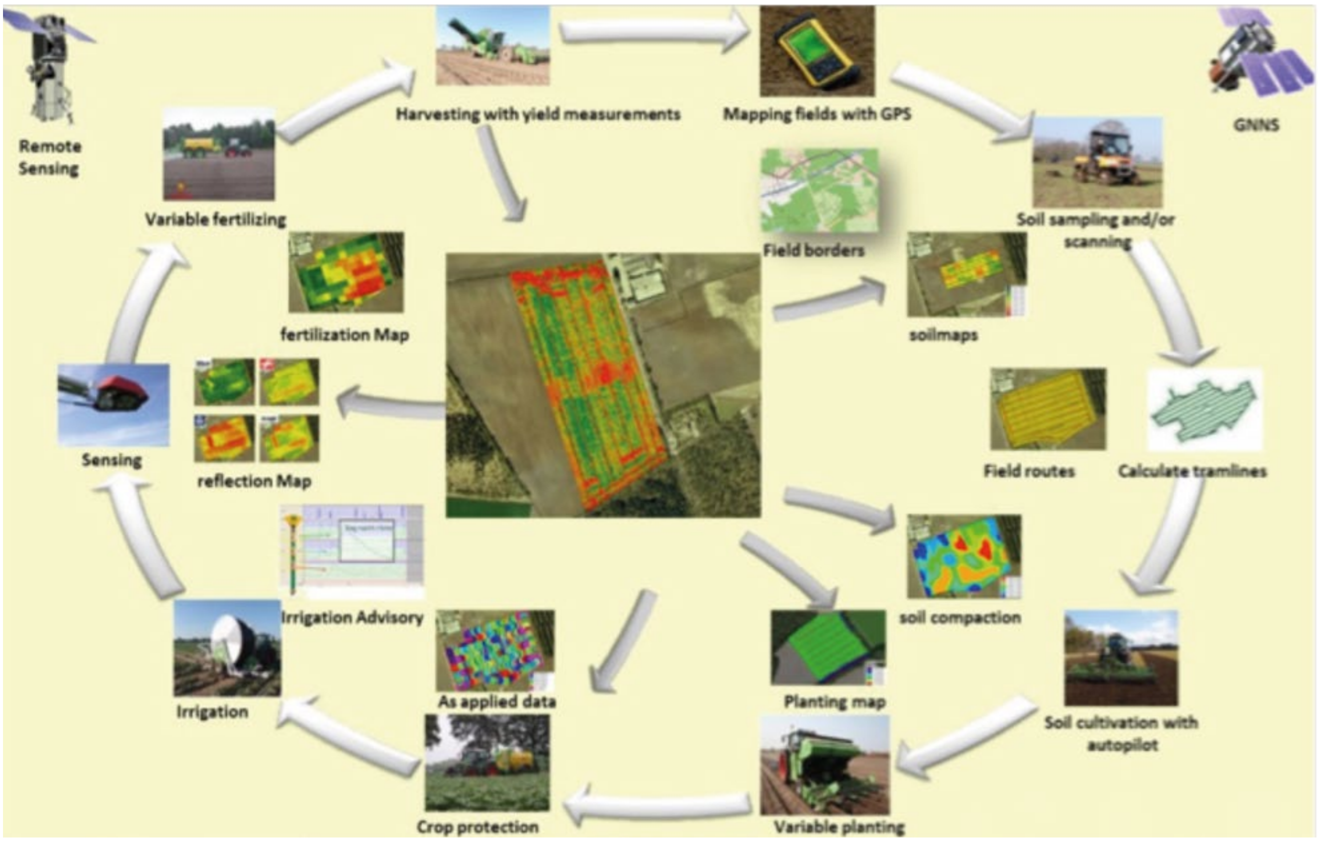
A good example of bottom-up initiatives by residents and entrepreneurs in the rural area is 'KempenGlas' in the Province of Brabant, close to the border with Belgium.[34] 'KempenGlas' is an initiative aimed at the realization of open-access fibre networks and the management thereof in four rural municipalities. The overarching aim is to assure these rural areas remain attractive into the future.

The four local cooperatives have established 'KempenGlas' as a second-layer cooperative, to increase the scale, bundle their expertise and to exploit the networks. They are run by volunteers and supported by a project leader, an experienced ICT manager.

The principle is that all members can participate and obtain a fibre connection on equal terms. The members are the future owners of the passive network. A small entry fee (€25 for residential homes and €100 for firms) is used to establish the corporation and perform the initial activities, such as planning, drawing-up specifications, obtain proposals for network deployment and financing. Upon having arranged a sufficient level of commitment the cooperative will become effective and raise capital of its members, which will be up to €500 per home and €500-2500 per firm. The expected monthly fees are €30 to cover network operations and maintenance, interest and repayment of the loans and €35 for the triple-play bundle.
August 2015, the Province of Brabant approved a soft loan for 'KempenGlas' [35] for up to 50% of the costs of deployment or approx. €3 million. This will be complemented by a €2 million loan from the Rabobank. The loans mature after 17 years. To date, out of the potential 2,900 households, farms and businesses to be served 2,000 have registered as a member of one of the four cooperatives. Together with the approx. €2.5 million equity from these members the project financing is complete and deployment can start.

A key participant and beneficiary of the KempenGlas project is precision farmer Jacob van den Borne. This potato grower applies a series of advanced technologies in the cultivation process, such as RTK-GPS[36] for soil cultivation using autopilot; soil scanning for compaction and conduction; reflection sensing, by satellite and drone, for variable fertilization; crop sensing for variable protection; and soil sensing for variable irrigation. For the processing and storage of the date a high data rate broadband connection is required.[37] See Figure 5 for an illustration.[38]

Figure 5. Precision farming at Van den Borne Aardappelen, Reusel, The Netherlands



In countries where the development of the PSTN has stagnated we can observe cases of 'leap frogging' in technology, directly towards fibre. For example in Bulgaria where local entrepreneurs have taken the initiative in deploying Ethernet over fibre, reducing deployment cost by stringing Fibre-to-the-façade (FttF). See Figure 6. Some 670 local initiatives have been recorded, while estimates run towards 2000.[39]

In Latvia it has been a combination of local entrepreneurship – some 240 entrepreneurs – and the roll-out of fibre by the incumbent Lattelecom, as well as the Latvia State Radio and Television Centre being involved in the roll-out of regional fibre backbone networks.[40]

These initiatives have resulted in leadership positions of Lithuania, Latvia, Romania, Sweden and Bulgaria in the fibre-based broadband league table in Europe, whereby fibre having a technology market share between 40-60% in 2015.[41]

Figure 6. Fibre-to-the-Façade (FTTF), Bulgaria

4.3 Assuring dependable supply

Today, communications is as electricity has become through the previous Industrial Revolution. It has become a commodity we cannot do without. In the supply of communications infrastructure we have decided to rely fully on private actors, for electricity only to a limited extend. As in the perspective of the user communications has become a commodity, similar to water and electricity, governments have a special responsibility in case of market failures. This may include firm failure to supply due to insolvency.

In the aftermath of the euphoric period, the crash showed new vulnerabilities. Telecom firms went bankrupt due to significant levels of debt and a lack of sufficient cash flow. Approx. 125 telecom services firms applied for bankruptcy protection, and the defaults amounted to US$ 183 billion.[42] In the process incumbent telecom operators typically lost their AAA and AA ratings. In the new market reality the continuity of service provision had become at risk. Some incumbent operators required financial support of governments to secure continuity, thereby safeguarding the public values entrusted with the incumbent.

Another potential concern is private equity backed leveraged buyouts (PE-LBOs).[43] In the 1980s, in search of high financial returns institutional and other large investors have become attracted to this new asset class. By taking public firms private the PE-fund managers assume full control over the target firm. This privatisation is financed through large amounts of debt being assumed by the target firm. Subsequently the target firm is prepared for a public offering, or for re-sale at a profit, through improving the short term financial performance by reducing costs, reducing investments, reducing R&D expenditure, applying the sale-and-lease-back of fixed assets, and divesting parts of the firm that do not contribute sufficiently to the cash-flow. In the interim, fund managers improve their returns through management fees, loan returns, and extra-ordinary dividend pay-outs.

These private equity leveraged buyout funds are not concerned with earning returns from investment in expanding the productive capacity for providing goods and services in the real economy; in essence they are concerned with financial engineering aimed at a major redistribution of capital. Hence, the practice of private equity leveraged buyout funds is totally contrary to the public interest objectives in the operation of telecommunications firms. Empirical evidence of the recent cases in, for instance, Ireland (eircom), Denmark (TDC), and Bulgaria (BTC) underscore this conclusion. If the outcome of a restructuring of a telecom services firm through a private equity leveraged buyout is deemed to be economically and/or politically unacceptable, policy measures will need to be designed and enacted ahead of time.

4.4 Applying institutional maintenance

Irrespective the role perception of government, an important task of governments, but not always perceived as a very rewarding task, is the maintenance of the institutional arrangements. Through technological and market development, as well as changing policy perceptions and priorities, the existing rules and regulations tend to become dated, sometimes outdated. Hence, regular maintenance is required. Regulatory solutions are not always technology neutral, despite our best intents. They are solutions chosen at a certain point in time given certain options that reflect the state of the art. Over time these solutions may become inappropriate. A typical example are the solutions once designed for the telephone network as a vertically integrated system, while telephony is being replaced by a voice application on top of an horizontally layered IP-infrastructure. This requires a disentanglement of services from the underlying networks.[44]

4.5 The special case of regulating FttH

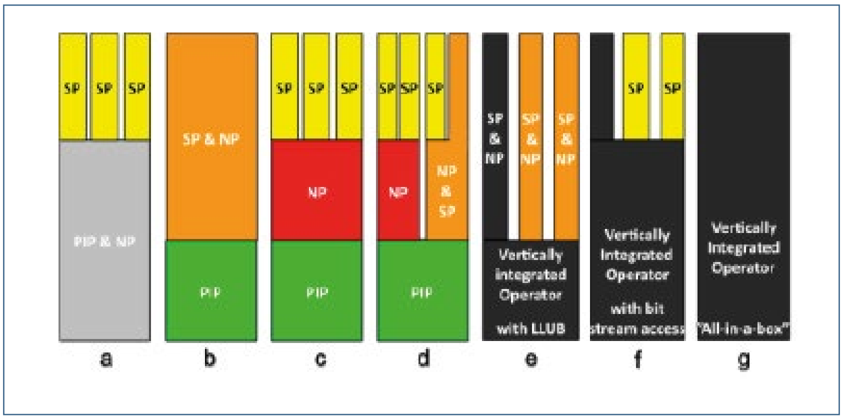
Fibre-to-the-Home presents a special case for regulators. In a 2008 discussion paper Prof. Eli Noam of Columbia University, New York City, posed the question "Do we need Policy 3.0 for Telecom 3.0?"[45] Anticipating an increase in Fibre-to-the-Home deployment, he was concerned that we would return to a monopoly situation, as replication of FttH is only economically feasible in very dense urban areas.[46] If that would be the case, to what extent would regulation need to be adjusted?

To realize competition in the case of a single access network, the historical example of the monopoly telephone network is the application of the wholesale-resale model, which ranges from bitstream access to full unbundling. Alternatively, if unbundling is not feasible, the focus could be on service-level competition, whereby the network operator is not engaged in end-user service provision. Figure 7 shows the various access modalities and related business roles.[47]

It should be noted that each additional layer in the model, representing independent operator entities, adds to the costs of services provision, in particular in terms of operational expenditure (OPEX). Hence, in the case of Sweden we can observe that over time the Models (c) and (d) applied by municipalities tend to migrate to Model (a).[48]

The concern of an evolution towards a single fixed access infrastructure has already informed the regulation surrounding FttH initiatives in underserved areas. FttH networks being built with public funding in so-called 'white areas' are required to be 'open-access' networks. This means that service-level competition is enabled as a next best solution, when infrastructure-based competition is not economically feasible.

Figure 7. Access network layers and business roles



Legend: LLUB: Local Loop Unbundling;
NP: Network Provider;
PIP: Passive Infrastructure Provider;
SP: Service Provider

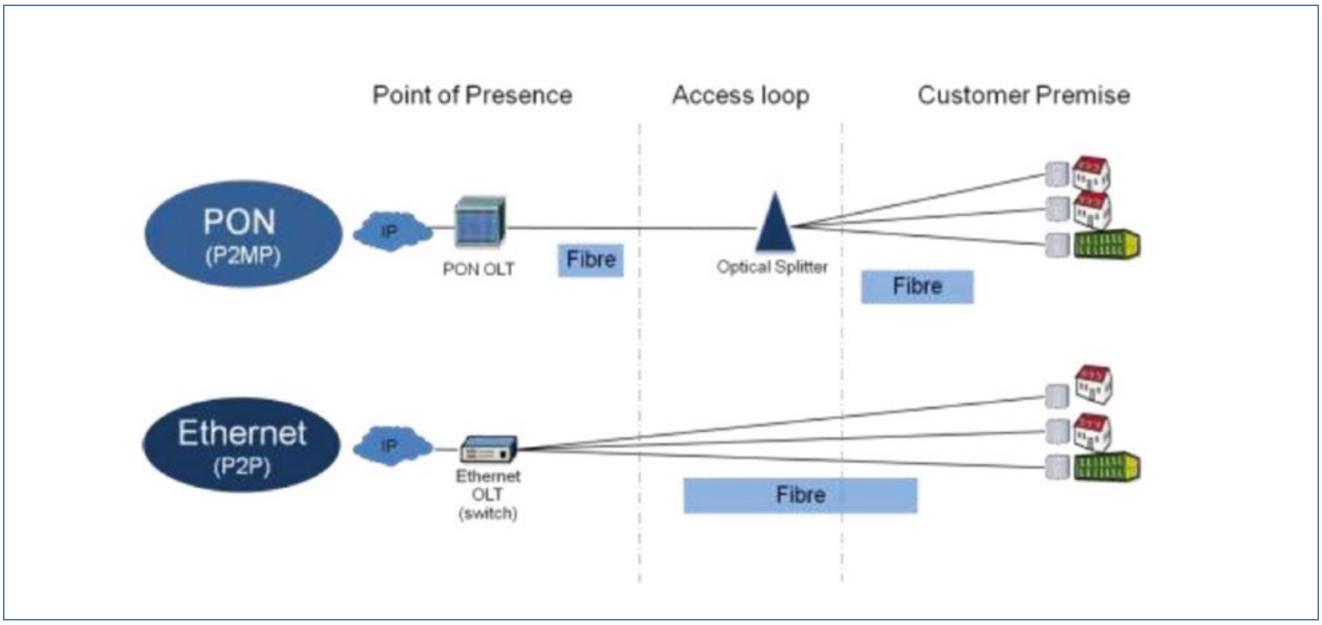
Commercially motivated FttH network deployment 'by non-telcos is typically 'open-access', as this attracts multiple service providers, which enhances the attractiveness to end-users and thereby improves the business case. A typical example is Reggefiber in the Netherlands. When the incumbent KPN obtained a majority share in the company, the regulator required the 'open-access' model to be continued.[49]

Incumbent deployment of FttH typically concerns the use of a passive optical network (PON). To reduce the investments, the fibre from the point-of-presence (PoP) towards the optical splitter is shared among multiple users. From the splitter individual fibre strands run to the customer premises. See Figure 8 top-part.[50] This is called a point-to-multipoint architecture (P2MP). In a point-to-point (P2P) architecture each customer premise is connected by a dedicated fibre to the PoP. See Figure 8 bottom part. In the point-to-point architecture unbundling can be applied, whereby a fibre is on the optical distribution frame (ODF) connected to an alternative provider. As in the PON network the fibre to/from the PoP is shared unbundling at the level of individual subscribers is not possible.

The implication for policy is that unless these PON networks are deployed in competition with other networks, they are less attractive from a regulatory perspective, as competition cannot readily be enabled.

However, there is good news in the making. Next Generation PON, using time and wavelength division multiplexing over PON, will provide for unbundling at the level of a 'wavelength'.[51] This will provide a colourful landscape in which multiple service providers can use the same physical infrastructure. Moreover, it will also allow the combination of residential services – both FttH and FttDP – with business services, and with mobile backhaul. In short, a technical solution is available that solves regulatory concerns in relation to FttH access networks.

Figure 8. FttH network architectures



Legend: P2P: Point-to-Point; P2MP: Point-to-Multipoint; PON: Passive Optical Network; OLT: Optical Line Terminal

5 Enabling the digital economy – the outlook

In Section 2, based on historical evidence, we argued the critical role of infrastructure in economic development, enabling stepwise improvements in productivity each subsequent technological revolution. In Section 0 we showed how communications infrastructures evolve to become increasingly based on optical technology. In Section 4 we reflected on the roles that remain for governments after liberalization, emphasizing the need to assure ubiquitous and dependable communication infrastructures being in place. Moreover, we discussed how the concerns related to an optical-based monopoly infrastructure emerging can be effectively mitigated, by regulation and increasingly through technologies that enable unbundling based on wavelengths.

From the lessons learned during the early IT-part of the current ICT-based techno-economic revolution we learned that the benefits can only be reaped if investments in IT-hardware and IT–software are complemented with (1) investments in human capital and (2) the re-design of business models and business processes. These lessons should be re-applied in the current CT-part of the revolution, as we connect everything and everyone. This points to the importance of all Pillars that constitute the Digital Agenda for Europe, including trust and security, as well as enhancing digital literacy, skills and inclusion.

5.1 Digital Agenda targets

In the previous sections we have discussed the role of private actors in the supply of broadband services in Europe, within a context where the government assumed responsibility for promoting competition as part of the market liberalization process. Beyond this regulatory role, we can observe different roles being assumed by local, regional and central governments in the provision of broadband services. This ranges from information supply by central governments to municipalities declaring market failure and assuming the municipal supply of broadband services.

The Lisbon Agenda and the Digital Agenda for Europe are examples where governments inform the market process. By setting goals they assist the market in developing in a certain direction. Consistency in the plans reduces the uncertainties related to government intervention in markets. The request from the European Commission to Member State governments to develop plans for the realization of the Digital Agenda at the national level points to the importance of local actors in realizing the infrastructure enabling the Digital Economy.

We can observe (formal) national broadband plans that were ahead of the EC plans (e.g. Spain), plans that were more ambitious, either in target and/or in timing (e.g. Denmark), plans that follow the Digital Agenda (e.g. Netherlands), as well as plans that were more modest in the target setting (e.g. United Kingdom). The national broadband plans were often followed by more specific initiatives facilitating broadband market development by sharing information, by bringing broadband actors together, identifying the roles of private and government actors, sharing best practices, etc. (e.g. France, Germany, Netherlands).[52]

Although the case study evidence is insufficient to determine to what degree the plans have contributed to broadband development, the case studies do suggest that the national broadband and related plans have contributed to the awareness of the importance of broadband for economic development. Moreover, the cases show that the various actors involved in broadband development have been brought together for information sharing, planning and implementation purposes. The monitoring and reporting by the European Commission as part of the Digital Scoreboard does exert peer pressure on the Member States. Overall a positive effect can be inferred.

5.2 Resulting broadband usage

Usage of the broadband infrastructure is a result of the interplay between supply and demand. Figure 9 and Figure 10 reflect the average connection data rates for respectively 10 Western European countries and 10 Central European countries as measured by Akamai.[53] These average connection data rates appear as relatively low. According to Akamai, this is a result of: (1) parallel requests, whereby an average webpage generates 94 requests for content; i.e. involving relatively small files as many components make up a webpage; each session being too short to ramp up to maximum speed; and (2) IP address sharing, whereby multiple devices use an internet connection with an unique IP address, with simultaneous requests sharing the available bandwidth.

Figure 9. Average connection data rates for 10 Western European countries, 3Q2007-2Q2015

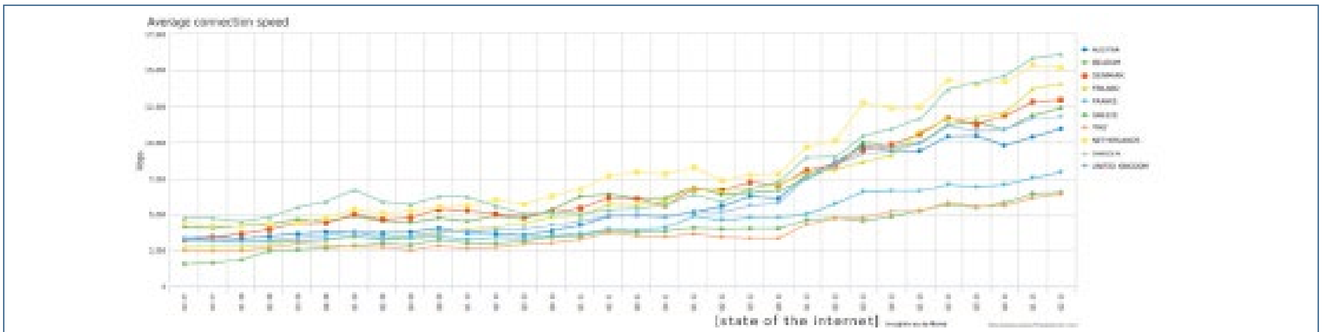


Figure 10. Average connection data rates for 10 Eastern European countries, 3Q2007-2Q2015

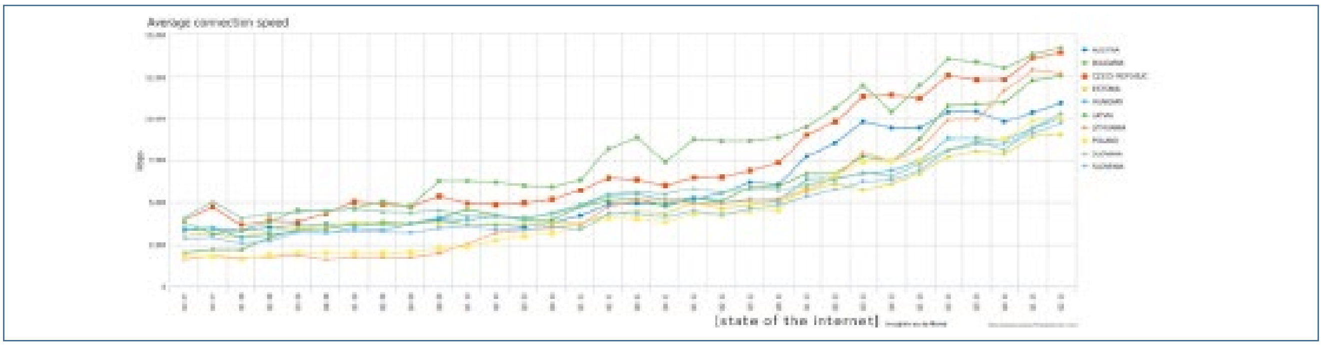


Figure 11 and Figure 12 show for the same countries the average peak connection data rates. These rates are indicative for the maximum achievable data rates on the connections being measured, i.e. the capacity that is supplied by the operators.[54]

Figure 11. Average peak connection data rates for 10 Western European countries, 3Q2007-2Q2015

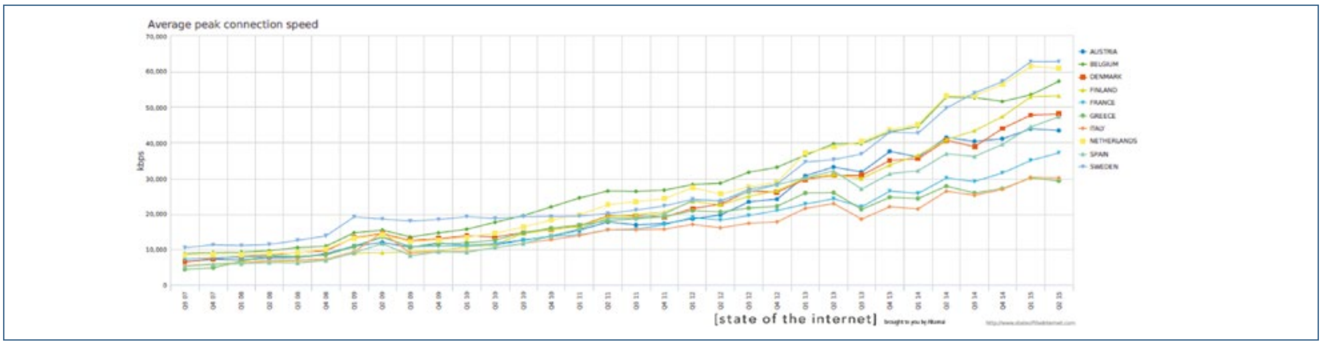
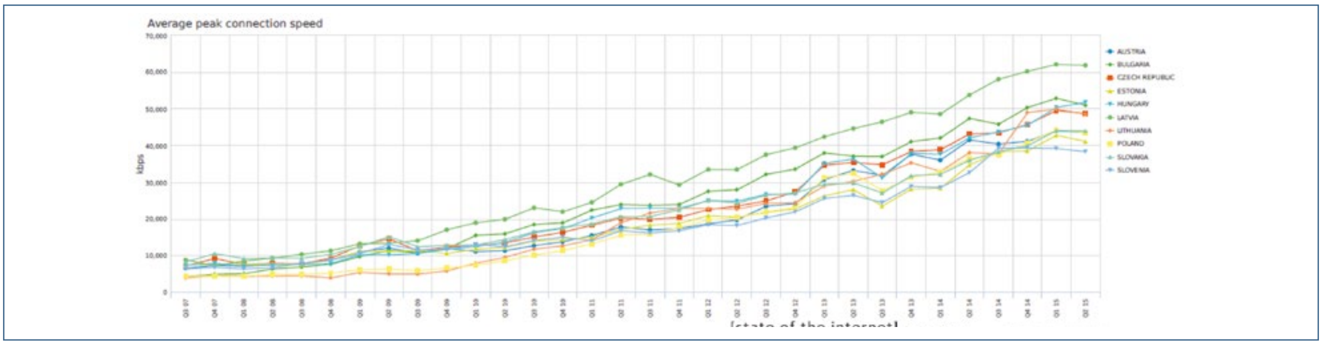


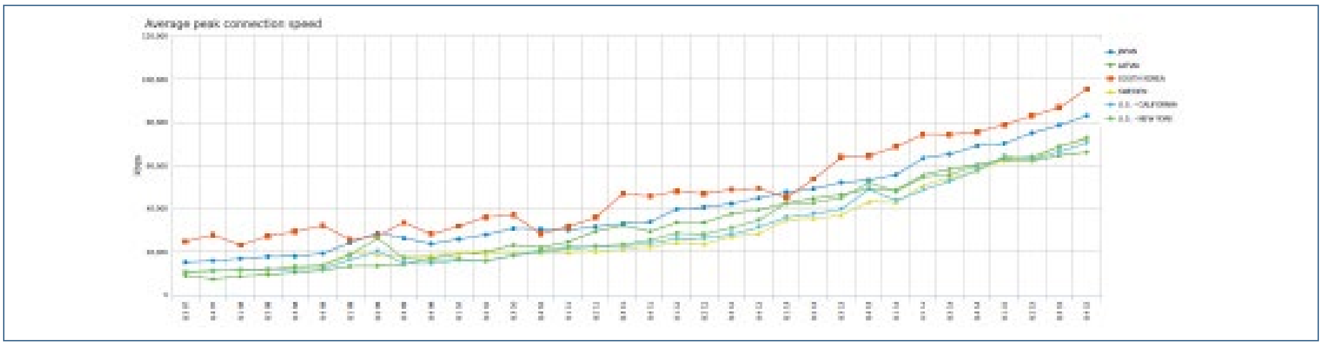
Figure 12. Average peak connection data rates for 10 Western European countries, 3Q2007-2Q2015



A comparison of the average peak data rates for South Korea, Japan, New York State, California, Latvia and Sweden, all leading countries and states in terms of broadband provision, is shown in Figure 13.[55]

The good news is that the leading European countries represented track well with the selected States in the USA. The growth rates are about equal, 28-30%. Moreover, these rates are 10.5-12.5 percentage points higher than that of South Korea being 17.5%. However, due to the higher starting point for South Korea in 2007, as a result of a broad deployment if fibre, the gap is widening, from 17-19 Mbit/s in 2007 to 23-29 Mbit/s in 2015. In the past period only Japan is closing the gap, albeit slowly, as it benefits from a somewhat higher starting point, also enabled by fibre deployment. This suggests that the higher data rates that can be offered on optical fibre from the outset lead to higher usage rates in practice.

Figure 13. Average peak data rates South Korea, Japan, New York, California, Latvia, Sweden, 3Q2007-2Q2015



For the sample states and countries, in order to have kept the gap at the 2007 value would have required 2-3 percentage points additional growth over the past measuring period of 7 years and three quarters. An additional 5-7 percentage points of growth would have allowed the gap to be closed.

If South Korea sustains the growth rate exhibited over the past almost 8 years it will reach an average peak data rate of 308 Mbit/s by 2020. If the leading European countries and US States sustain their growth rates of close to 30% the gap with South Korea will be closed by 2020.

Using extrapolation, in another 5 years – by 2025, South Korea will reach 573 Mbit/s and the leading EU countries and US States will reach 900-965 Mbit/s, i.e., just under 1 Gigabit/s. Sustaining these rates cost effectively will only be possible through a wide deployment and usage of fibre to the premises.

While a catch-up of the US and the EU relative to South Korea is plausible from a difference in supply and demand factors, a reversing of the roles in the period 2020-2025 appears unlikely. More likely would be a convergences of the trends in an increasingly global market place. That our demand for data has not reached its limit yet is reflected in the outlook as described in the following section.

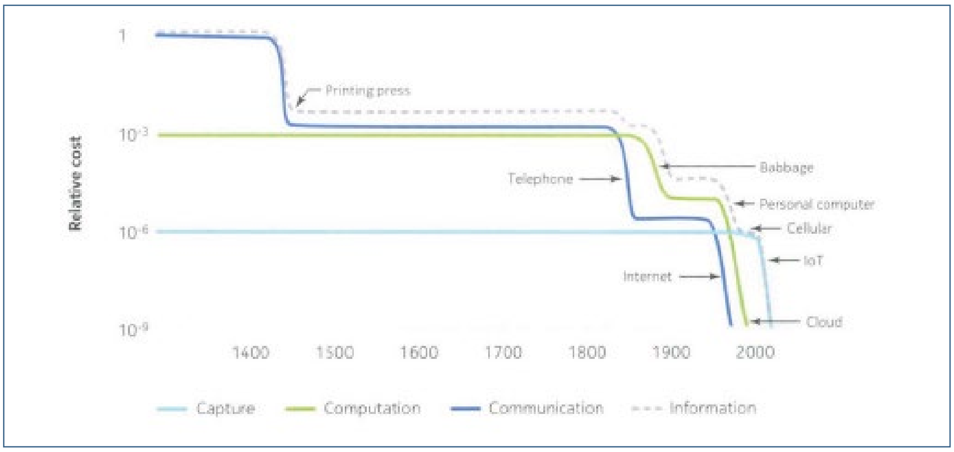
5.3 Outlook for the enabling infrastructure of the Digital Economy

To explore the future of communications we are again going back in time, even beyond the first Industrial Revolution. The purpose is to appreciate the evolution in terms of information capture, computation and communication and how this is shaping the Digital Economy. Figure 14 depicts this evolution as captured by Bell Labs Consulting.[56]

Figure 14. Evolution of the capture, computation and communciation of information

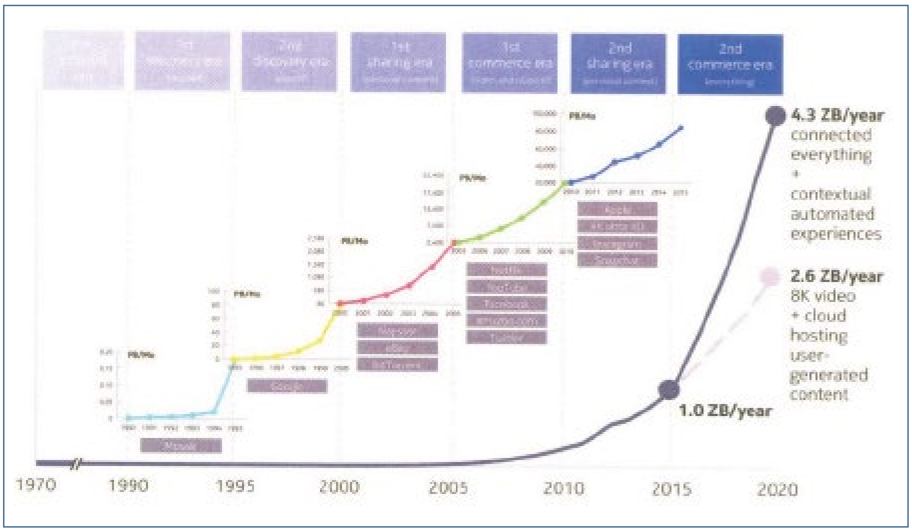
The subsequent transformations combined with the reduction in costs in capture, computation and communication as depicted in Figure 15, fuel the development of the Digital Economy.

Figure 15. Reduction in cost of capture, computation and communication of information over time



It leads to unabated growth in Internet traffic, whereby our dependency on ubiquitous and dependable access and core infrastructures will only increase. Figure 16 provides the analysis by Bell Labs of the global traffic growth in the core network under two scenarios, varying in the degree of augmented intelligence. The time period is broken down in five-year increments with their key innovations.[57]

Figure 16. Growth in core network traffic, 1970-2020



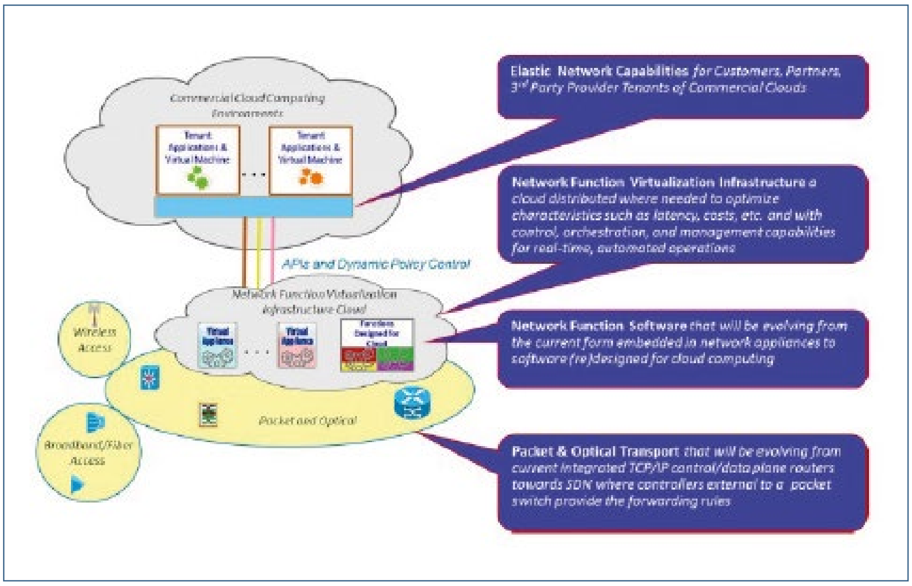
Legend: PB: Petabytes - 1015 bytes; ZB: Zettabytes - 1021 bytes

As Weldon captures the periods[58]: "The internet era started with the ability to discover content on the Internet by entering known URLs into a browser (1990-1995), which was quickly optimized by adding the ability to discover unknown content using search functions (1995-2000). This in turn led to the ability to share personal content (2000-2005), often without the requisite permissions for media content. Next came the first commercial digital era (2005-2010), with the availability of multimedia content and associated rights; the beginning of e-commerce, with the ability to acquire physical goods over the internet; and the sharing of personal images on social media. The last five years (2010-2015) have seen a continuation of this commercial growth, but have been dominated by a sharing of personal content delivered from and to mobile devices… …[The next period] will be led by another phase of commercial usage, this time driven by the digitization of everything, and the associated services that will be enabled. This new era will see unprecedented growth in traffic, as human behavior and businesses are automated to an extend that was never possible before."

The major catalyst foreseen for the next period is the Internet of Things and turning of big data into the smallest amounts of actionable knowledge referred to as augmented intelligence to the benefit of all of us.

To keep the infrastructure that has to support this significant growth manageable we will see the increasing use of so-called network function virtualization (NFV) and software defined networking (SDN).[59] SDN and NFV are also part of the architecture vision for 5G and it forms part of the work program of ETSI.[60] Figure 17 provides the overall architecture vision as communicated by AT&T.[61]

Figure 17.High level cloud networking architecture



In the words of AT&T: "Domain 2.0 is a transformative initiative, both internal and external, to enable AT&T network services and infrastructure to be used, provisioned, and orchestrated as is typical of cloud services in data centers. It is characterized by a rich set of APIs that manage, manipulate, and consume services on-demand and in near real time. Moreover, these network services are to be instantiated, to the extent feasible, on common infrastructure. In a nutshell, Domain 2.0 seeks to transform AT&T's networking businesses from their current state to a future state where they are provided in a manner very similar to cloud computing services, and to transform our infrastructure from the current state to a future state where common infrastructure is purchased and provisioned in a manner similar to [...] support cloud data center services." AT&T has set as goal for the year 2020 to have 70% of its network transformed compared to 5% today.

This is a very compelling and credible vision for the future of the communications network infrastructure.[62] It implies a much larger core infrastructure with optical links and common-of-the-shelf packet-switches combined with ubiquitous optical access for wired and wireless connectivity. This transformation of the communications infrastructure is a further contribution to enable the digital economy. It may become a catalyst as it enables the tuning of communication services to the needs of a broad spectrum of diverse users, business and consumers, manufacturers and services providers.

6 Conclusions and recommendations for policy

The analysis provided above leads to the following conclusions and recommendations for policy formation and implementation:

- The ability to reap the benefits of the ICT-driven technological revolution, including its productivity improvements, depends on three key factors:

  1. The availability of an ubiquitous, high capacity and dependable communications infrastructure, to achieve a wide diffusion of the ICT-driven innovations across the economy and society;

  2. The affordability of the communications services provided on the infrastructure for end-users, to achieve a high adoption rate; and

  3. Safe and secure communications that can be trusted and relied upon.

- Recognizing that the communication services provision has been liberalized, the infrastructure supply depends on two key factors:

  1. A well-functioning competitive market;
     - This requires close monitoring by the government; and
     - In case of market failure governments should intervene.

  2. Complemented with a 'developmental role' by governments to assure infrastructure supply in those areas that are not commercially viable:
     - For this purpose Member State governments should create the necessary budgets or investment funds;
     - At the European level Structural funds should be earmarked for this purpose;
     - They should recognize a diversity in solutions, including the role of non-telcos; and
     - They should provide market coordination where necessary.

- To achieve the productivity improvements, the investments in ICT hardware and software by end-users, governments, business and consumers, are to be complemented with two critical elements:

  1. Investments in the development of human capital:
     - In terms of achieving 100% digital literacy; and
     - Skills to exploit the capabilities of the ICTs, both in terms of usage as well as source of innovation;

  2. Re-conceptualization of the business models and business processes on the basis of the capabilities provided by the ICTs:
     - Through the wide deployment of e-business, e-government, e-learning, e-health, etc.;

- Considering the importance of an appropriate communications infrastructure supply, it is important for governments:

  1. To develop the vision on the future of communications infrastructure and align this vision across Europe and to set related targets that are SMART[63] ;
     - To set the targets for the Digital Agenda II in terms of closing the gap with the world-leading country South Korea;
       - This requires continuation of the current growth rate of 30% for the average peak data rates in the leading EU countries, i.e. a growth of 30% in the headline speeds being supplied; and
       - Closing the gap of the other EU countries with the leading countries in the EU;
       - Retaining the growth target of 30% towards 2025 will only be SMART if supported by a wide deployment of fibre to the premises;
     - Identifying the needs of consumers and business users in the light of serving vertical industries, requiring various combinations in terms of data rates (high/low); latency, power consumption; reliability, number of devices, range; and costs;

  2. To identify the roles of private and public actors to realize this vision;

  3. To communicate and share the vision to reduce uncertainty in the market place;

  4. To monitor the market developments and guide private and public actors in the desired direction through facilitation and coordination;

  5. To intervene as a 'lender of last resort', when commercial markets after having been supported by government facilitation and coordination fail to deliver what society needs.

- Furthermore, as the current institutional arrangements –

the laws and regulations – have been shaped to optimize the previous oil-driven techno-economic paradigm, these should be reviewed and where necessary revised to enable the diffusion of the current ICT-driven techno-economic paradigm, including enabling software defined networking and network function virtualization. This includes but is not limited to:

1. Making public service obligations technology neutral;
2. Enable differentiation in services features and quality, depending on the needs and requirements of diverse 'vertical' market segments;
3. Exploit the opportunities of virtualization of the communication infrastructure, both wired and wireless, to realize lower costs, greater flexibility and faster response times in service creation.

References

5G Infrastructure Association (2015). 5G Vision - The 5G infrastructure public private partnership; the next generation of communication networks and services. Brussels.

Akamai (2015). State of the Internet, 4Q2014. Cambridge, MA.

AT&T (2013). AT&T Domain 2.0 vision white paper. Dallas.

Brynjolfson, E. (1992). "The productivity paradox of information technology: Review and assessment." Retrieved 2004-02-09, from http://ccs.mit.edu/papers/ CCSWP130/ccswp130.html.

Brynjolfson, E. & L. M. Hitt (1998). "Beyond the productivity paradox - computers are the catalyst for bigger changes." Communications of the ACM August

Cave, M. (2004). Making the ladder of investment operational. Brussels: European Commission.

Cave, M. (2005). Encouraging infrastructure competition via the ladder of investment: Warwick University.

Cave, M. (2006). "Encouraging infrastructure competition via the ladder of investment." Telecommunications Policy 30(3-4): 223-237

Cox, C. (2014). An introduction to LTE. Chchester, UK: Wiley.

De Wit, B. (1994). Strategie bouwen op golven - Een onderzoek naar strategieën in cyclical industries, met als case-study de offshore drilling industry. Delft, The Netherlands: Eburon.

EC (2010). COM(2010) 245 A digital agenda for Europe. Brussels: European Commission.

Forzati, M., C. P. Larson & C. Mattsson (2010). Open access networks, the Swedish experience. International Conference on Transparent Optical Networks (ICTON). Munich, Germany.

Freeman, C. (1998). Lange Wellen und Arbeitslosigkeit (Long waves and unemployment). In: H. Thomas & L. A. Nefiodow (Eds). Kondratieffs Zyklen der Wirtschaft - An der Schwelle neue Vollbeschäftigung? Herford, Germany: BusseSeewald.

Freeman, C. & F. Louçã (2001). As time goes by - From the Industrial Revolutions to the Information Revolution. Oxford: Oxford University Press.

Freeman, C. & L. Soete (1997). The economics of industrial innovation. Cambridge MA: The MIT Press.

FttH Council Europe (2014a). FTTH Handbook: FTTH Council Europe.

FttH Council Europe (2014b). G.fast. Brussels: FttH Council Europe.

Göransson, P. & C. Black (2014). Software defined networks - A comprehensive approach. Waltham, MA: Morgan Kaufmann - Elsevier.

Groenewegen, J. P. M. (1989). Dissertation: Planning in een markteconomie. Delft: Eburon. p 365.

Groenewegen, J. P. M. (2005). Designing markets in infrastructures: from blueprint to learning. Delft: TUDelft.

Grote Lewin, H. (1968). The railway mania and its aftermath. Newton Abbot, UK: David & Charles.

Johnson, C. A. (1982). MiTi and the Japanese miracle: The growth of industrial policy: 1925-1975. Stanford: Stanford University Press.

Johnson, C. A. (1999). The Developmental State: Odyssey of a concept In: M. Woo-Cumings (Eds). The developmental state. Ithaca, NY: Cornell University Press.

Kleinknecht, A. H. (1987). Innovation patterns in crisis and prosperity - Schumpeter's long cycle reconsidered. New York: St. Martin's Press.

KMI Research (2001). Fiberoptic networks of Pan-European carriers: Market development & forecast. Rhode Island: KMI Research.

Lakshman, T. V., K. Sparks & M. Thottan (2015). The future of wide area networks. In: M. K. Weldon (Eds). The futre X network - A Bell Labs perspective. Boca Raton, FL: CRC Press - Taylor & Francis Group.

Lemstra, W. (2006). Dissertation: The Internet bubble and the impact on the development path of the telecommunication sector. Department Technology, Policy and Management. Delft, The Netherlands: TUDelft.

Lemstra, W. & J. P. M. Groenewegen (2009). Markets and public values - The potential effects of Private Equity Leveraged Buyouts on the safeguarding of public values in the telecommunications sector. Delft, The Netherlands: TUDelft.

Lemstra, W. & W. H. Melody, Eds. (2015). The dynamics of broadband markets in Europe - Realizing the 2020 Digital Agenda. Cambridge, UK: Cambridge University Press.

Lemstra, W. & N. Van Gorp (2013). Unbundling: Regulation is a necessary, but not sufficient conditions to reach the final rung of the investment ladder. Second Annual Conference on the Regulation of Infrastructure Industries in an Age of Convergence. Florence, Italy: Florence School of Regulation.

Levi-Faur, D. (2011). The Odessey of the regulatory state - Episode One: The rescue of the welfare state. Jerusalem Papers in Regulation & Governance. Jerusalem, Israel: The Hebrew University.

Majone, G. (2010). The transformation of the regulatory State: Osservatorio sull'Analisi di Impatto della Regolazione.

Melody, W. H. (2007a). Private equity funds and public utilities: Where incentive structures collide. Hedge funds and private equity: a critical analysis,. Socialist Group in the European parliament. Lyngby, Denmark: Technical University of Denmark.

Melody, W. H. (2007b). "The private equity takeover of telecom infrastructure in Denmark: Implications for network development and public policy." Nordic and Baltic Journal of information and Communication Technologies 1(1)

Melody, W. H. (2008). "Private equity: Implications for investment and efficient resource allocation." Okonomi & Politik 81(1)

Noam, E. M. (2010). "Regulation 3.0 for telecom 3.0." Telecommunications Policy 34(1-2): 4-10.

OECD (2005). Communications Outlook 2005. Paris: Organisation for Economic Co-operation and Development.

OECD (2007). The implications of alternative investment vehicles for corporate governacnce: A synthesis of research about private equity and "activist hedge funds". Paris: Organisation for Economic Co-operation adn Development.

Perez, C. (2002). Technological revolutions and financial capital: The dynamics of bubbles and golden ages. Cheltenham, UK: Edward Elgar.

Rood, H. (2010). Very high speed broadband deployment in Europe: The Netherlands and Bulgaria compared. Telecom Policy Research Conference, Arlington, VA: TPRC.

Rysavy Research (2015). LTE and 5G innovation: igniting mobile broadband. Bellevue, WA: 4G Americas.

Schumpeter, J. (1939). Business Cycles: A theoretical, historical and statistical analysis of the capitalist process. New York: McGraw-Hill.

Schumpeter, J. A. (1942). Capitalism, socialism and democracy. New York: HarperPerennial.

Shapiro, C. & H. R. Varian (1999). Information Rules - A strategic guide to the network economy. Boston: Harvard Business School Press.

Verizon (2016). SDN-NFV reference architecture Version 1.0. New York City: Verizon.

Weldon, M. K. (2016). The future X network - A Bell Labs perspective. Boca Raton, FL: CRC Press, Taylor & Francis Group.

WIK Consult (2008). The economics of next generation access - Final report. Bad Honnef, Germany: WIK Consult.

ZLTO (2014). Breedband internet/glasvezel voor de landbouw maar vooral voor het gezin: ZLTO.

Notes

1 The inventory or Kitchin cycle is 4-5 years, the capital goods or Juglar cycle is 7-11 years and the building or Kuznets cycle is 15-25 years. Sources: Schumpeter (1939); Schumpeter (1942); De Wit (1994).

2 Nikolai Kondratieff presented his findings in the 1920s. Two Dutch economists Jacob van Gelderen 1891-1940) and Salomon de Wolff (1878-1960) already made observations on the longwave in 1913. However, their publications in Dutch did not receive a wide circulation. Early explanations of the longwave included: international trade (Pareto, 1913); new industries, new territories, prices, production, trade, and finance (Van Gelderen, 1913); investments in long-term infrastructure (De Wolff, 1915, 1924, 1929); investments in infrastructure, discovery of gold, new markets, diffusion of innovation (Kondratieff, 1922, 1929); and gold in circulation, gold supply (Casel 1932; Dupriez, 1935). Source: Freeman (1998).

3 The concept of the long waves was not without its critics, in particular where empirical evidence could not be provided for the claims being made. Kleinknecht refers to the critique by Kuznetz in his review of Schumpeter's 'Business cycles' (1939) and cites two basic questions posed by Kuznetz: (1) Is there any evidence of Kondratieff long waves in important indicators of general economic activity? (2) Is there any evidence of a bunching of Schumpeter's heroic innovations (and if yes: what is the theoretical explanation)? From his research Kleinknecht concludes that Schumpeter's hypothesis about long waves in economic life and an uneven distribution over time of radical innovations can be defended, not only in time but also in certain sectors. Source: Kleinknecht (1987).

4 Sources: Freeman & Soete (1997); Freeman & Louçã (2001); Perez (2002).

5 For a detailed characterization of the Industrial Revolutions see the sources in Note 4.

6 For an interesting account of the railway mania in the UK see Grote Lewin (1968). George Hudson, the chairman of the York and North Midland Railway, established in 1842, became the icon of the railway period in the UK. The account of his business dealings shows a striking parallel with the account of Bernie Ebbers, who build-out LDDS into WorldCom to take over MCI, the icon of the recent period of internet/ telecom frenzy in the USA. Source: Lemstra (2006).

7 Source: Perez (2002 figure: p48; quotes: p5-6, p36).

8 When measured at the aggregate level, the early investments in IT did not show the improvements as expected. This led to the so-called Solow-paradox, in reference to Robert Solow's 1987 quip: "You can see the computer age everywhere but in the productivity statistics." Source: Robert Solow, "We'd better watch out", New York Times Book Review, July 12, 1987, page 36. Detailed firm-level research revealed that the benefits only accrue when the IT investments were complemented with the investments in human capital and by the reconceptualization of the business model based on the new techno-economic paradigm. Sources: Brynjolfson (1992); Brynjolfson & Hitt (1998).

9 The Digital Agenda for Europe has six pillars: Pillar 1: Digital Single Market; Pillar 2: Interoperability & Standards; Pillar III: Trust & Security; Pillar IV: Fast, and ultra-fast internet access; Pillar V: Research & Innovation; Pillar VI: Enhancing digital literacy, skills & Inclusion. Source: EC (2010).

10 Source: derived from: Perez (2002). For a more detailed comparison see Lemstra (2006).

11 Here, the work by Shapiro &Varian in "Information Rules – a strategic guide to the networked economy" is also highly relevant. (1999)

12 Source: Courtesy KMI Research (2001). For a description of the Pan-European optical network build-out see Annex 7 in Lemstra (2006).

13 Typical data rates provided are: ADSL – 8 Mbit/s; ADSL2 – 15 Mbit/s; VDSL2 – 40 Mbit/s downstream; achievable data rates depend on the lengths and quality of the copper loop; these are data rates that can be provided to approx. 80% of subscribers.

14 Source: FttH Council Europe (2014b).

15 Typical data rates provided are: DOCSIS 1 a shared 50 Mbit/s downstream and 10 Mbit/s upstream; DOCSIS 2.0, providing an increase in download data rates; EuroDOCSIS 3.0 can provide a shared downstream rate of 1,600 Mbit/s and upstream rate of 216 Mbit/s.

16 The first deployment of DOCSIS 3.1 is claimed by Comcast, USA, in December 2015. Source: http://corporate.comcast.com/comcast-voices/worlds-first-live-docsis-3-1-gigabit-class-modem-goes-online-in-philadelphia. Retrieved : 2016-04-25.

17 Source: Key statistic at the end of the case study period ~2013, Chapter 1 Introduction in "The dynamics of broadband markets in Europe – Realizing the 2020 Digital Agenda" (Lemstra & Melody, 2015)

18 For a discussion of the 5G objectives and development time line see for instance 5G Infrastructure Association (2015); Rysavy Research (2015).

19 In the context of 4G-LTE base stations are called 'Node B - NB' and 'evolved NB – e NB' (Cox, 2014).

20 Sources: Chapter 2 Methodology in "The dynamics of broadband markets in Europe – Realizing the 2020 Digital Agenda" (Lemstra & Melody, 2015); and Lemstra & Groenewegen (2009). Examples of literature underpinning the framework are Johnson (1982, 1999); Groenewegen (1989); Majone (2010); and Levi-Faur (2011).

21 This section draws on: Groenewegen (2005); Lemstra & Groenewegen (2009).

22 Note that the European Commission has the ability to mandate European standardization bodies, such as ETSI, to commence a standardization effort of a certain kind. In its regulations it may prescribe the use of a particular European standard.

23 While in Belgium, Denmark and the Netherlands the CATV-network reaches almost every household, in Italy and Greece there has not been any CATV-network roll out. In other counties CATV-networks have been deployed mainly in the major cities.

24 Source: Lemstra & Van Gorp (2013).

25 The ‘ladder of investment’ concept was introduced by Cave, see Cave (2004, 2005, 2006).

26 In addition to the success of Free/Iliad as entrant in fixed communications, it has acquired a mobile license in 2012 and has been able to repeat its success in the mobile market.

27 For a discussion of the various national approaches see the twelve country case studies in “The dynamics of broadband markets in Europe – Realizing the 2020 Digital Agenda” (Lemstra & Melody, 2015). For instance for France these include the second generation of PINs – Public Interest Networks. In Poland the municipalities are designated by law as ‘lenders of last resort’. Moreover, the law prescribes the installation of ducts when new roads are being constructed.

28 This case builds upon Chapter 7 Sweden by Forzati and Mattson in “The dynamics of broadband markets in Europe – Realizing the 2020 Digital Agenda” (Lemstra & Melody, 2015) and information from the EC Workshop on “Community led Last-Mile Initiatives”, November 16, 2015, Brussels. The presentations can be found at: https://ec.europa.eu/digital-agenda/en/news/community-led-last-mile-initiatives. A link to the event video record is available at: https://scic.ec.europa.eu/streaming/ community-led-last-mile-initiatives.

29 In 2014, government subsidies equalled about 10 percent of the total investments made in local fibre network. Source: Swedish Local Fibre Alliance (Svenska Stadsnäts Föreningen) http://www.ssnf.org/Global/Bilder/Rapporter%20och%20informationsmaterial/EU/Dokument/Local%20fibre%20networks%20in%20Sweden.pdf. Retrieved: 2016-01-06.

30 Source: Swedish Local Fibre Alliance (Svenska Stadsnäts Föreningen) http://www.ssnf.org/ Global/Bilder/Rapporter%20och%20informationsmaterial/EU/Dokument/Local%20fibre%20networks%20in%20Sweden.pdf. Retrieved: 2016-01-06.

31 Swedish Local Fibre Alliance (Svenska Stadsnäts Föreningen) http://www.ssnf.org/Global/Bilder/ Rapporter%20och%20informationsmaterial/EU/Dokument/Local%20fibre%20networks%20in%20Sweden.pdf. Retrieved: 2016-01-06.

32 Source: Salemink, K., & Strijker, D. (2015). Breedbandcoöperaties op het platteland: Leerscholen voor Next Generation Plattelandsontwikkeling. Bestuurskunde, 24(2), 40-50. 10.5553/Bk/092733872015 024002004.

33 This case builds upon Chapter 4 The Netherlands by Lemstra in “The dynamics of broadband markets in Europe – Realizing the 2020 Digital Agenda” (Lemstra & Melody, 2015) and information from the EC Workshop on “Community led Last-Mile Initiatives”, November 16, 2015, Brussels. The presentations can be found at: https://ec.europa.eu/digital-agenda/en/news/community-led-last-mile-initiatives. A link to the event video record is available at: https://scic.ec.europa.eu/streaming/ community-led-last-mile-initiatives.

34 Source: http://kempenglas.nl. Retrieved: 2015-12-30.

35 The Province has created a revolving development fund of €50 million in support of fibre deployments in rural areas and (small) remote business parks. The fund originates from the sale of the shares in the provincial electricity generation plants and networks.

36 RTK-GPS: Real Time Kinematic GPS, uses two satellite receivers, one on a known fixed point nearby, thereby increasing the accuracy to the centimetre-level. Next to the US NAVSTARR GPS system also the Russian GLONAST satellites will be used.

37 The current practice requires transport of the SD-cards with sensing information to a high data rate access point in the village for upload and download of satellite data.

38 Sources: ZLTO (2014); and http://www.vandenborneaardappelen.com/nl/150/precisie-landbouw-bij-van-den-borne-aardappelen. Retrieved: 2015-12-30.

39 Source: Rood (2010). Note that best practices in façade wiring has been developed and for instance deployed in Lisbon, Portugal. Source: Personal information Prysmian.

40 Sources: Chapter 15 Latvia by Virtmanis & Karnitis in “The dynamics of broadband markets in Europe – Realizing the 2020 Digital Agenda” (Lemstra & Melody, 2015) and information from the EC Workshop on “Community led Last-Mile Initiatives”, November 16, 2015, Brussels. The presentations can be found at: https://ec.europa.eu/digital-agenda/en/news/community-led-last-mile-initiatives. A link to the event video record is available at: https://scic.ec.europa.eu/streaming/ community-led-last-mile-initiatives.

41 Source: EC Digital Scoreboard at https://ec.europa.eu/digital-single-market/en/digital-scoreboard. Retrieved: 2016-05-03.

42 Source: OECD (2005).

43 The Ministry of Economic Affairs in the Netherlands, being concerned with the possible effects of a PE-LBO, requested an investigation into the phenomenon, the potential consequences and the policy recommendations. For the report on the investigation see Lemstra & Groenewegen (2009). See also Melody (2007a, 2007b); OECD (2007); Melody (2008)

44 See for instance the CERRE report “Integrated Regulatory Framework for Digital Networks & Services”. Source: http://cerre.eu/publications/integrated-regulatory-framework-digital-networks-and-services-0

45 Noam referred to the monopoly period as Policy 1.0 and to the related technology and market as Telecom 1.0. Liberalization represents Policy 2.0. The technological development and competitive market as a result of liberalization is denoted as Telecom 2.0.

In 2010 the topic of the discussion paper was subject of a contribution to Telecommunications Policy (Noam, 2010).

46 See for a study on the economics of FttH deployment and the feasibility of replication in Europe the related WIK study: WIK Consult (2008).

47 Source: Adapted from Forzati, Larson & Mattsson (2010).

48 See note 28 and 30.

49 The NRA also set a ceiling to the wholesale prices based on the business case provided by Reggefiber. See for a case description Chapter 4 The Netherlands by Lemstra in "The dynamics of broadband markets in Europe – Realizing the 2020 Digital Agenda" (Lemstra & Melody, 2015).

50 Source: FttH Council Europe (2014a).

51 See for instance the Infographic and White Paper "Preparing for next-generation PON". Sources: http://resources.alcatel-lucent.com/asset/181475 and https://resources.alcatel-lucent.com/asset/185326

52 For instance in Poland the law prescribes the laying of ducts for communications purpose in case of road construction. In France the rural development is coordinated among public and private actors as part of so-called Public Initiative Networks (PINs). Source: Lemstra & Melody (2015).

53 The data presented was collected through Akamai's globally deployed Intelligent Platform and included all countries/regions that had more than 25,000 unique IPv4 addresses request content from Akamai during the particular quarter. On a daily basis Akamai's platforms serve approximately 2 trillion requests for web content. The data represents a blend of residential and business traffic, whereby residential connections greatly outnumber business connections, while known mobile connections are removed from the data set. Source: https://www.stateoftheinternet.com/trends-visualizations-connectivity-global-heat-map-internet-speeds-broadband-adoption.html Retrieved: 2015-11-23. For clarification of the measurements: https://www.stateoftheinternet.com/trends-blogs-2015-02-state-of-the-internet-metrics-what-do-they-mean.html Retrieved: 2015-11-24.

54 The average peak connection data rate reflects the highest connection data rate from each unique IP address. It reflects larger files, such as software updates occurring late at night. (Akamai, 2015)

55 Source: https://www.akamai.com/us/en/our-thinking/state-of-the-internet-report/state-of-the-internet-connectivity-visualization.jsp. Retrieved : 2016-05-23.

56 Source: Figure 1 in Chapter 10 The future of information in "The future X network – A Bell Labs perspective" Weldon (2016).

57 Source: Figure 1 in Weldon (2016).

58 Source: page 17 in Weldon (2016).

59 See for instance the AT&T Domain 2.0 Vision White Paper (AT&T, 2013); Chapter 4 The future of Wide Area Networks by Lakshman, Sparks & Thottan (2015); and for the preceding and similar evolution of data centres Göransson & Black (2014)

60 Sources: 5G Infrastructure Association (2015) and http://www.etsi.org/index.php/news-events/news/1088-2016-04-etsi-5g-summit-report.

61 Source: AT&T (2013).

62 See also the transition to SDN and NFV by Verizon as evidenced in Verizon (2016) and http://innovtion.verizon.com/content/vic/en/4g-lte.html. Retrieved: 2016-05-30.

63 The SMART acronym: Specific, Measurable, Attainable, Realistic and Timely.

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