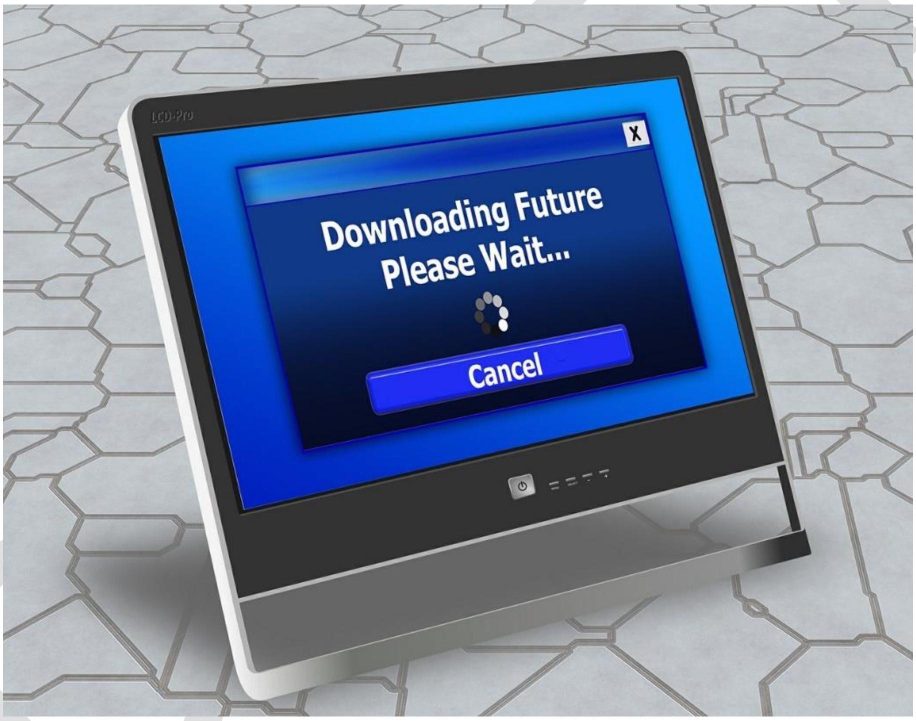
Sustainable Broadband Infrastructure Deployment

2016



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IEM – Institute for Infrastructure Economics & Management

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Contents

1. Executive Summary

The document at hand provides a compact overview for broadband quality parameters and related (future) infrastructure requirements. The analysis can be summarized in eight theses:

- Infrastructure decisions are hardly reversible and create a path dependency.
- Sustainable infrastructure deployment takes the view of future needs set against known physical and economic drawbacks.
- Infrastructure supply creates and drives demand.
- The trend towards exponential growth of bandwidth is set to continue.
- Projections tend to underestimate future demand.
- The future of mobile is fixed.
- Download speed is not the only criterion determining Quality of Service.
- Fiber is the broadband infrastructure with the highest potential to comply with future quantity and quality requirements.

2. Sustainable Infrastructure Planning and Development

2.1. Persistency of Infrastructure Decisions[1]

It is common knowledge that decisions in favor of a certain infrastructure and against others can cause tremendous knock-on effects. The deployment of sustainable infrastructures hence is a major driver for economic, social, and even environmental progress and change. Decisions against such infrastructures, on the other hand, can lead to massive losses and eventually prohibit the development of other competing systems, including potentially superior solutions.

This effect called 'persistency of infrastructure decisions' should not be underestimated. Decisions made are hardly reversible once systems have been established at significant scale. This issue is mainly linked to the technological, organizational, and cultural specificities of infrastructures, preventing them from the use for other but the initial service purpose.

A good example is today's private transport sector, dominated heavily by vehicles based on the combustion engine. Changing the system towards alternative mobility concepts such as electric or hydrogen vehicles is a tremendous challenge. The drawbacks are manifold: There is not only a need for the development of alternative technologies, moreover, systemic adaptions or entire system changes are required. Whilst technological solutions have emerged in the last decades, the real breakthrough has to be made by overcoming the established ecosystem based on the automobile itself. This does not only include streets, petrol stations, parking systems, but also city architecture and planning, manufacturers and suppliers, as well as upstream or downstream service providers. Furthermore, all current new concepts and ideas have one thing in common: They do not have access to a functioning, comprehensive infrastructure, such as the current traffic system, which is based on the present conception of a car. In order to achieve political, social, or ecologic changes desired, prompt but sustainable decisions are therefore crucial.

In most cases, the implementation of infrastructure decisions on the one hand enables the emergence of new industries and welfare potentials for society; on the other hand, it creates long lasting restrictions on future decision-making regarding fundamentally new solutions. This unavoidable path dependency has to be kept in mind when evaluating infrastructural alternatives.

2.2. Sustainable Broadband Infrastructures

Communication infrastructures and networks are an integrative enabler and underlying precondition for economic activity, social interaction, and even environmental protection. Support and investment programs such as the Digital Agenda Europe 2020, National Broadband Programs or the World Bank Broadband Program are underpinning the urgent need for the underlying infrastructure and related fundamental capacity upgrades in order to comply with current and future demands. Central for the

[1] Based on Grove, N. (2014): Infrastrukturökonomie: Neuer Herausforderungen für Gesellschaft und Staat. In D. Klumpp, K. Lenk & G. Koch, eds., Überwiegend Neuland: Zwischenbilanzen der Wissenschaft zur Gestaltung der Informationsgesellschaft. Berlin. Springer.

deployment of broadband infrastructures is the question:

What kind of infrastructure is most sustainable?[2]

The answer to this question requires an analysis on the kind of different infrastructure solutions able to keep up with increasing demand for present and future digital services. If infrastructures cannot be upgraded in order to satisfy future capacity demands, investments made would turn into sunk costs immediately after roll-out and the digital divide would widen further. Focusing on overall costs, infrastructure planning implies a general trade-off between satisfying present and future capacity loads. Another example of road infrastructure sheds light on the cost and capacity planning issues around this trade-off: Early planning on Sydney Harbour Bridge started in 1815, whilst construction of the bridge itself was finished in 1932. Even from a 1932 perspective, a bridge over Sydney Harbour providing eight traffic lanes, two railroad tracks, one cycle path and one walkway might have appeared overambitious. However, capacity lasted without any upgrades of the bridge until 1988, when the construction of the Sydney Harbour Bridge Tunnel was initiated in order to provide additional capacity then required. The example shows that planning high-capacity infrastructure based on future instead of present demand may appear over-ambitious at first glance, but ultimately reduces time and cost consuming infrastructure upgrades as well as efforts to mitigate the overall welfare losses emerging from spill-over effects.

In order to assess the sustainability of certain communications infrastructures compared to others, their physical and economic drawbacks in view of future capacity demands have to be compared. The discussion commonly revolves around the following primary drawbacks (see also Annex)[3]:

- Shared medium
  Wireless and current coaxial (TV cable) communication infrastructures have one key characteristic in common: The shared medium effect[4]. It describes the limits of a transfer channel being open to all connected users[5], creating negative externalities. When all users connected to the same base station, node, or coaxial cable, they all share the maximum bandwidth available. Hence, every single user will reduce or even restrict the usage of all other users.
  The latest developments in mobile broadband traffic show that mobile traffic volumes and growth rates continue to increase exponentially in the near future[6]. Therefore, the next mobile standard 5G has been developed and will be deployed within the coming years in order to counter currently existing

2 The following section is based on Holznagel, B., Picot, A., Deckers, S., Grove, N., & Schramm, M. (2010): Strategies for Rural Broadband: An economic and legal feasibility analysis. Springer Science & Business Media.

3 See Picot, A., Grove, N., Jondral, F. K., & Elsner, J. (2009): Why the Digital Dividend will not close the Digital Divide. Institute for Information, Organization and Management, Munich School of Management, LMU and Communications Engineering Lab, Karlsruhe Institute of Technology (TH).

4 See Picot, A. & Grove, N. (2009): “FTTx in rural Areas: Public Engagement for Infrastructure Provisioning”, Infrastrukturrecht.

5 See Picot, A. & Grove, N. (2009): “FTTx in rural Areas: Public Engagement for Infrastructure Provisioning”, Infrastrukturrecht.

6 See Cisco Visual Networking Index (2016): Global Mobile Data Traffic Forecast Update, 2015–2020 White Paper, Cisco.

bottleneck situations and related capacity issues, including the shared medium effect. However, there are two major preconditions for high-capacity 5G networks: Increasing the number of base stations and in consequence cell density as well as a fiber network directly connected to each base station for backhaul. This highlights the complementarity of mobile compared to fixed solutions, providing the precondition for seamless transitions between fixed and mobile connections.
VDSL Vectoring technology currently applied to twisted copper pair is able to reduce electromagnetic interferences resulting in a bandwidth increase for households connected to a DSLAM[7]. However, as the vectoring optimization levels the interferences of all wires in a bundle, it also implies decreasing bandwidths for wires causing strong interferences, thus resulting in a shared medium effect for all households connected at DSLAM level.

- Restricted availability and reach
  Wireless connections have historically always had less bandwidth and have been less reliable than connections over fixed lines[8]. Depending on the frequency range, availability and reach are restricted due to physical limitations such as signal attenuation or interferences. Specific qualities cannot be guaranteed and signal range is limited, also due to health protection restrictions on maximum signal power. The same effect is true at a lower scale for copper and cable networks, whereas coaxial cable networks are much better shielded against interferences than a twisted copper pair. However, signals have to be amplified and errors corrected every few kilometers. Technical measures including processing power and latest innovations in modulation and error correction algorithms, such as VDSL, Vectoring or even G.fast allow for higher data rates on copper. However, this comes at the price of availability only on short distances only between the DSLAM (at the Main Distribution Frame (MDF) or the street cabinet) and the Customer Premises Equipment (CPE) as well as additional energy consumption (see below). Regarding fiber, signal amplification (repeater) is required every 50-100 km only, whilst for copper-based Ethernet, the maximum distance without amplification is restricted to 100 meters.[9]

- Limited Quality of Service
  For wireless connections, quality levels cannot be conclusively determined. Electromagnetic signal interference restricts Quality of Service (QoS) levels. Likewise, especially twisted copper pair but also cable networks are influenced by electromagnetic interferences such as crosstalking. As fiber networks transmit data via optical signals (light), they are by design immune to electromagnetic interferences and provide hence high QoS levels.

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[7] The bandwidth increase is only able to deliver maximum speed if applied to all copper wires in a bundle and on comparably short wires. The effect decreases significantly if wires are longer than 500m and is irrelevant after 800m length.

[8] See Szafran, U. (1993): “Der Markt für Satellitendienste”, WIK Diskussionsbreitag 107, Bad Honnef. WIK.

[9] See Tanenbaum and & Wetherall (2011): Computer Networks 5th Edition, Tanenbaum and Wetherall, Prentice Hall.

- High energy consumption
  Wireless, coaxial cable, and copper broadband access technologies require large amounts of energy, not only for signal amplification but also for high frequency modulation and related error correction processing. Especially the latest copper innovations such as VDSL, Vectoring, or G.fast consume large amounts of energy for processing and even cooling[10]. As mentioned, fiber connections in contrast require signal amplification just every several (even hundred) kilometers and require less energy for light production and processing.

3. Future Development of Broadband

Uncertainty about future demand makes planning (future) infrastructure capacity rather complex. However, it can be stated that growth in demand is rather unlikely to slow down[11]. Sustainable high-capacity infrastructures as enabler for innovative services are even expected to accelerate demand increase.

3.1. Supply vs. Demand[12]

The question of how much bandwidth will satisfy future needs is closely related to decisions on infrastructure investments and characterized by a chicken-and-egg debate. Seeking an answer, Jakob Nielsen introduced 'Nielsen's Law' (a relationship derived from Gilder's Law on the development of bandwidth and computer power), according to which bandwidth available to home users is expected to increase by 50% per year. Therefore, bandwidth is said to double every 21 months[13]. This relationship describes a market in which supply drives demand. Providing an oversupply with bandwidth today sets the precondition for the development and usage of innovative bandwidth-intense services tomorrow, not vice versa. Latest figures confirm that Nielsen's Law still holds[14]. Hunting for the next 'killer application' that drives demand for additional bandwidth hence becomes inevitable. However, any such application will not be created, spread, and adopted if the required infrastructure does not exist already.

3.2. Development of Bandwidth Requirements

Bearing in mind the continued relevance of Nielsen's Law, bandwidth requirements are expected to grow rather in an exponential than moderate way. Looking at forecasts from 2015 for the year 2025, for instance Deutsche Telekom AG estimated a required

10 Vereecken, Willem, et al. (2011): "Power consumption in telecommunication networks: overview and reduction strategies." Communications Magazine, IEEE 49.6: 62-69.
11 See Cisco Visual Networking Index (2016): Global Mobile Data Traffic Forecast Update, 2015–2020 White Paper, Cisco.
12 Based on Holznagel, B., Picot, A., Deckers, S., Grove, N., & Schramm, M. (2010): Strategies for Rural Broadband: An economic and legal feasibility analysis. Springer Science & Business Media.
13 See Nielsen, J. (1998): "Jakob Nielsen's Alertbox for April 5, 1998: Nielsen's Law of Internet Bandwidth", available online at: http://www.useit.com/alertbox/980405.html [cited on March 19th, 2009].
14 Nielsen (2014): Nielsen's Law of Internet Bandwidth, available online at: https://www.nngroup.com/articles/law-of-bandwidth/

bandwidth of 208 Mbps (download) and 50 Mbps (upload) for a heavy user four-person household [15].

Referring these figures to Nielson's Law, this does not appear realistic from today's perspective. WIK, for example, in 2011 calculated bandwidth requirements of heavy users for 2025 at 350 Mbps (download) and 320 Mbps (upload)[16]. Five years later, WIK had to increase these estimates to 1 Gbps (download) and 600 Mbps (upload) for 2025, however including average users[17]. The increased requirements were justified with six major demand drivers:[18]

- Increasing amount of IP devices per household (PC, tablet, smartphones, TV, radio, devices for gaming, etc.)
- High-resolution video content via Ultra HD TV and 4k/8k
- Video content outside the entertainment sector (e.g. video conferencing, e-learning)
- General bandwidth requirements for e-health, e-home, Internet of Things, or smart applications
- Increased importance of upload speeds in private (social media, personalized cloud services) and business user scenarios (telework, use of VPNs)
- Use of web- and cloud-based applications (especially for data storage)

A similar set of bandwidth drivers has been identified in recent research for the European Commission[19]. Services were categorized into four baskets, a primary basic basket for the use of basic applications, followed by three further ones for increased usage and consumption behavior (see table 1). The primary basket defines digital services that support social inclusion, for instance, e-mail, online newspaper, and online banking. The remaining three baskets are comprised of online services that are less widely used by consumers or that offer online services that are (currently) less important in addressing social exclusion (from e.g. online radio to online gaming up to Ultra HD video services in basket 4)[20].

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[15] Wirtschaftswoche (2015): "Deutsche Telekom: Können wir uns die Glasfasernetze sparen?", available online at: http://www.wiwo.de/unternehmen/it/deutsche-telekom-koennen-wir-uns-die-glasfasernetze-sparen/12330826.html

[16] Doose, A.-M., Monti, A. & Schäfer, R. (2011): "Mittelfristige Marktpotenziale im Kontext der Nachfrage nach hochbitratigen Breitbandanschlüssen in Deutschland", WIK Diskussionsbeitrag 358, Bad Honnef. WIK.

[17] Wernick, C., Henseler-Unger, I. & Strube Martins, S. (2016): Erfolgsfaktoren beim FTTB/H-Ausbau. Bad Honnef. WIK.

[18] Wernick, C., Henseler-Unger, I. & Strube Martins, S. (2016): Erfolgsfaktoren beim FTTB/H-Ausbau. Bad Honnef. WIK.

[19] European Commission (2016): Review of the scope of Universal Service SMART 2014/0011, Luxembourg, Publications Office of the European Union.

[20] European Commission (2016): Review of the scope of Universal Service SMART 2014/0011, Luxembourg, Publications Office of the European Union.

Table 1: Broadband Applications and Services Basket Overview[21]

Primary basket	Secondary basket	Third basket	Fourth basket
Email	Playing/downloading games, images, films or music or other software (SD)	Playing/downloading games, images, films or music or other software (HD)	Playing/downloading games, images, films or music or other software (UHD or multiple viewers)
Search engines	Travel and accommodation services	Listening to web radios and/or watching web TV (HD)	Listening to web radios and/or watching web TV (UHD or multiple viewers)
Information about goods and services[22]	Listening to web radios and/or watching web TV (SD)	Selling goods or services	
Training and education	Uploading self-created content to any website to be shared	Playing networked games with others	
Online newspapers/news	Telephoning or video calls (HD)	Creating websites or blogs	
Buying/ordering goods or services	Jobs/recruitment	File storage	
Professional networking	Civic and political forums		
Finding information about any subject	Making an appointment with a practitioner via a webpage		
Seeking health information			
Internet banking			
Social media/instant messaging			
eGovernment service use			
Telephoning or video calls (standard quality)			

Focusing predictions regarding download and upload bandwidth, the following catalogue of services was estimated in 2016.

[21] European Commission (2016): Review of the scope of Universal Service SMART 2014/0011, Luxembourg, Publications Office of the European Union.

[22] This covers using the internet to seek for information about any household good, e.g. media, video-games, books, e-learning material, clothes, electronic equipment, computer software or services, e.g. banking, financial or health services. This excludes any transactions made.

Table 3: Bandwidth requirements of various applications in 2025 (WIK 2016 model)[23]

Application category	Downstream (Mbit/s)	Upstream (Mbit/s)
Basic Internet	≈20	≈16
Homeoffice/VPN	≈250	≈250
Cloud Computing	≈250	≈250
Media and Entertainment HD/3D	≈150	≈30
Media and Entertainment Ultra-HD, 4k-TV, 8k-TV, 3D, …	≈300	≈60
Communication	≈8	≈8
Videocommunication (HD)	≈25	≈25
Gaming	≈300	≈150
E-Health	≈50	≈50
E-Home/E-Facility	≈50	≈50
Mobile Services / Wifi-Offloading	≈15	≈12

4. Qualifying Broadband

The term “broadband” goes back to the use of a broad frequency range on the electromagnetic spectrum in order to transfer higher amounts of data in the same time slot[24]. In the meanwhile, the common understanding of broadband refers to a connection capable of processing bandwidth-intense applications and services. Qualifying broadband generally goes along with terms such as bandwidth, capacity, speed, or quality. The following section identifies technical parameters for the qualification of broadband connections and draws conclusions on the various broadband (access) infrastructures described above. In order to qualify a broadband connection, two general types of parameters can be distinguished: quantity (or capacity) and quality.

4.1. Quantity

Broadband connections are commonly described and advertised by their maximum download capacity. However, this factor alone provides only little information on the real capacity of a broadband connection.

[23] Monti, A. & Schäfer, R. G. (2012): Marktpotentziale für hochbitratige Breitbandanschlüsse in Deutschland: Abschlussbericht, Presentation. Bad Honnef. WIK;
Godlovitch, I., Lemstra, W., Pennings, C. & de Streel, A. (2016): Public Workshop: Regulatory, in particular access, regimes for network investment models in Europe (SMART 2015/0002). Brussels. WIK, Deloitte & IDATE.

[24] See Holznagel, B., Picot, A., Deckers, S., Grove, N., & Schramm, M. (2010): Strategies for Rural Broadband: An economic and legal feasibility analysis. Springer Science & Business Media.

- Maximum Speed
  Broadband connections are advertised in general with their technically available maximum downstream capacity, representing the maximum data throughput per time unit, measured in bits per second (bps). However, these figures apply under technically ideal conditions. Examples for offers on the market are Internet DSL 16.000, Internet 400.000 (fiber), Internet VDSL 25, or Internet Cable 200 V, whereas 16.000 and 400.000 stands for Kbps (16 and 400 Mbps), 25 and 200 for the respective Mbps maximum download capacity.
- Up-/Download
  The major share of consumer broadband connections is asymmetric. This means that the downstream – or download capacity – defers significantly from the upstream – or upload capacity. Considering the example offers above, this means for DSL 16.000 16 Mbps download and 1 Mbps upload, for the VDSL 25 25 Mbps downstream and 5 Mbps upstream, for the Cable 200 V 200 Mbps downstream and 12 Mbps upstream as well as 400 Mbps downstream and 40 Mbps upstream for the Internet 400.000. In contrast, symmetric connections provide identical download and upload rates and are often offered to business clients. Symmetric connections based on copper (e.g. SDSL) offer up to 20 Mbps down- and upstream, depending on the number of available copper lines, whereas FTTB/H connections enable symmetric connections in the gigabit range.[25]
- Average Speed
  The Average Speed measures the usually available bandwidth distributed over a given timeframe. Recent projects like SamKnows have discovered major differences for end user broadband connections between maximum advertised downstream bandwidth and average delivered bandwidth[26]. These differences can partly be attributed to drawbacks of certain infrastructures and/or technologies. As mentioned above, vectoring applied to DSL signals on copper wires in order to counter electromagnetic interferences and thus increase bandwidth is only able to deliver maximum speed if applied to all copper wires in a bundle and on comparably short wires.

4.2. Quality of Service (QoS)

The transfer of data packages between sender and receiver is called (data) flow. Next to bandwidth, the primary parameters delay/latency, jitter, and packet loss together determine the QoS of a data connection[27]. In addition to these four, complementary parameters such as DNS response time and reliability are outlined in the following.

- Delay/Latency
  Delay or latency describes the general delay for data transfer, in other words, the time a data package needs from sender to receiver. In practice, this is

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[25] Wernick, C., Henseler-Unger, I. & Strube Martins, S. (2016): Erfolgsfaktoren beim FTTB/H-Ausbau. Bad Honnef. WIK: p. 22.
[26] See e.g. SamKnows.com
[27] Tanenbaum & Wetherall (2011): Computer Networks 5th Edition, Tanenbaum and Wetherall, Prentice Hall.

measured by ping times. Ping works by measuring the time between sending a data package to a host (receiver) and its echo reply, confirming reception.

- Jitter
  The term jitter describes latency fluctuations, i.e. the variation in the delay or packet arrival times[28]. It hence measures, how these packet arrival times differ over a specific time period. Jitter can be lowered through buffering processes, however, at the expense of additional delay.
- Packet Loss
  Packet loss, or the packet loss rate, describes the number of (data) packages lost during transmission. This happens, for instance, when a router is overloaded and cannot accept further packages for delivery at a given time.
- DNS Response Time
  The Domain Name System (DNS) is a hierarchical, domain-based naming scheme in distributed data bases in order to map numeric IP addresses with alphanumeric WWW addresses[29]. The time until the response of the next DNS server is measured.
- Reliability (QoS Availability)
  The term reliability describes the level of achieving agreed QoS parameters, such as the ones described above over time.

An overview of the importance of the major four QoS parameters for different applications is presented in .

Table 1: Relevance of QoS parameters for internet services[30]

Application	Bandwidth	Delay/Latency	Jitter	Packet Loss
E Mail	Low	Low	Low	Medium
File Sharing	High	Low	Low	Medium
Web Access	Medium	Medium	Low	Medium
Remote Login	Low	Medium	Medium	Medium
Audio on Demand	Low	Low	High	Low
Video on Demand	High	Low	High	Low
Telephony	Low	High	High	Low
Videoconferencing	High	High	High	Low

Differences between these services and applications are increasingly blurred. Many web applications combine and connect these services to provide, for instance, social network or even search engine services. For example, a social network is providing at a first stage a pure web page service. At a second stage, these web page services are combined with chat and telephony or even real-time video conferencing applications.

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28 Tanenbaum & Wetherall (2011): Computer Networks 5th Edition, Tanenbaum and Wetherall, Prentice Hall.
29 Tanenbaum & Wetherall (2011): Computer Networks 5th Edition, Tanenbaum and Wetherall, Prentice Hall.
30 Tanenbaum & Wetherall (2011): Computer Networks 5th Edition, Tanenbaum and Wetherall, Prentice Hall.

Due to the physical restrictions outlined above, communications infrastructures such as copper, cable, or wireless cannot guarantee QoS parameters at the same level as fiber. Physical limitations can partly be mitigated by highly sophisticated technologies, such as the DSL standard G.fast. However, this comes at the price of higher equipment costs, increased energy use, and longer processing times (increasing latency and/or jitter).

5. Conclusion

Connected cars, autonomous driving, eHealth, industry/mobility/work 4.0, artificial intelligence, Internet of Things, or Gigabit Society are terms that attempt to describe how the digital revolution transcends sectoral boundaries and all facets of everyday life. They all rely on one common precondition in order to materialize: the availability of high-performance broadband infrastructures. Infrastructures are and have always been a precondition for economic and social activity. Digital infrastructures are no different. In former times, global competitiveness was based on the local availability of transport and production factors. Digital infrastructures also have to be deployed locally, but they lift access restrictions on all other local resources – providing Europe with access the rest of the world and vice versa. Today's decisions in favour of sustainable infrastructures determine tomorrow's competitiveness. This race is not about to start: We are right in the middle of it.

Annex: Broadband infrastructure technical overview[31]

Technology	Download	Upload	Characteristics
Fiber to the Home (FTTH)	• Gigabit (potentially terabit) range (Gbps = 1000 Mbps, Tbps = 1000 Gbps) • Somewhat lower for Fiber to the Building (FTTB) due to copper wire inside the building	• Gigabit (potentially terabit) range (Gbps = 1000 Mbps, Tbps = 1000 Gbps) • Somewhat lower for Fiber to the Building (FTTB) due to copper wire inside the building	• Independent of distance • symmetrical (download = upload) • Guaranteed/dedicated (i.e. not shared) • Not limited/restricted
DSL (copper)	max. 25 Mbps	max. 3,5 Mbps	• Dependent on distance (i.e. increased attenuation, the decisive limitation of copper wires) • Not symmetrical (i.e. upload is slower)
Fiber to the Cabinet (FTTC) + VDSL (copper)	max. 50 Mbps	max. 10 Mbps	• Dependent on distance (i.e. increased attenuation, the decisive limitation of copper wires) • Not symmetrical (i.e. upload is slower)
Fiber to the Cabinet (FTTC) + VDSL Vectoring (copper)	max. 100 Mbps	max. 40 Mbps	• Dependent on distance (significant decrease of vectoring effect after 500m, irrelevance after 800m; in addition increased attenuation, the decisive limitation of copper wires)

[31] Based on: http://www.breitband.nrw.de/informieren/technologieueberblick.html; http://breitbandinitiative.de/was-ist-breitband; http://www.elektronik-kompendium.de/sites/kom/index.htm; http://www.ispreview.co.uk/broadband.shtml; http://www.billiger-surfen.de/kabel-internet-vergleich/; Wernick, C., Henseler-Unger, I. & Strube Martins, S. (2016): Erfolgsfaktoren beim FTTB/H-Ausbau. Bad Honnef. WIK: p. 22.

			• Not symmetrical (i.e. upload is slower)
Hybrid Fiber-Coaxial (TV cable)	max. 150 Mbps (potentially gigabit rage with DOCSIS 3.1)	max. 100 Mbps (potentially gigabit rage with DOCSIS 3.1)	• Not guaranteed/dedicated (i.e. shared) • Not symmetrical (i.e. upload is slower)
LTE Advanced (4G)	max. 1 Gbps	max. 500 Mbps	• Not guaranteed/dedicated (i.e. shared) • Not symmetrical (i.e. upload is slower) • Limited spectrum
5G (development)	Potentially gigabit range	Potentially gigabit range	• Not symmetrical (i.e. upload is slower) • Limited spectrum
Satellite	max. 20 Mbit/s	max. 6 Mbit/s	• Not guaranteed/dedicated (i.e. shared) • Not symmetrical (i.e. upload is slower) • High latency/delay

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