The Internet: Only for the Fast?

Jörg Ott, Giovanni Bartolomeo, Mert Mehmet Bese, Rohan Bose, Marcin Bosk, David Guzman, Ljubica Kärkkäinen, Mike Kosek, Nitinder Mohan
Technical University of Munich, DE

Dirk Trossen
Huawei, DE

Michael Welzl
University of Oslo, NO

Lucas Vogel
TU Dresden, DE

IAB BIAS Workshop, January 2024

1. Introduction

The Internet has undoubtedly become a key ingredient of today's life in many societies, for communicating in various and rich flavors, for all kinds of e-commerce (especially online shopping, but also brokered user-to-user sales), for leisure and entertainment, more or less for e-government, and, together with smartphones, for facilitating many aspects of daily lives, and much more.

As the Internet reach has grown over the past four(+) decades, it has done so in multiple dimensions: more people (and things) got connected; Internet connectivity has gotten (much) faster for both the core and the access; the landscape of connectivity providers (ISPs) has become more complex; and hyperscalers emerged with own networks and computing locations close to the end users.

Along with the technical capabilities and performance the Internet offered, applications and services running on top of the Internet have co-evolved to become richer, exploiting (and sometimes demanding!) better network performance. Cloud infrastructure, CDNs, and edge computing support meeting these demands in terms of scale, response times, and reachability.

Arguably, besides enabling scale, a major driver has indeed been offering shinier web sites, more complex services, richer contents. This appears to create a focus toward the *leading edge* of the spectrum, for example, for video experiences shifting from SD to HD to 4K to 8K resolution, to 360º video, and towards immersive experiences. As we concentrate on the more demanding services for the "power users", we may leave quite a few regular users behind, who don't have access to sufficiently fast Internet, be it for cost or simply for lack of availability.

While there may be many *intentional* obstacles to accessing services, with censorship being one prominent example [43], this note seeks to point out one of the *coincidental* barriers that emerge as the Internet and "its" services evolve. We thus face (and possibly reduce) a digital divide between those who have access to the Internet and those who don't; but we also increasingly face a divide between those who have *sufficiently performant* Internet access and those who *just* have Internet access.

2. Internet access

The economic and also societal value of (broadband) Internet access has been studied for a long time. Works such as [44,45] outline the economic benefits from increased broadband deployment in developed regions, here the US and Europe. Nevertheless, work such as [46,47] also point out the rural and urban digital divide that still persists and is expected to widen in the face of often slowing investments into rural build-outs within those markets.

But beyond the divide in existing rollouts, Internet access per se (in any form) has long been demanded as a basic human right [48,49] in that not just the disparity in access is a key issue but enabling ANY form of Internet access, including basic communication, must be considered a basic human right.

Previous efforts in the IRTF, most specifically those in the GAIA RG [48], have documented many practitioners' insights in facilitating Internet access in places where commercial incentives have often not led to any deployment. Those insights range from enabling similar broadband experiences than those existing in other national localities to enabling simple forms of communication, often enabling basic needs for user-to-user sales of food and other necessities in African regions. Initiatives such as those proposed (and actually rolled out) in [50] built on a 'grow-as-you-go' strategy, i.e., starting with the need for local community communication, intertwined with open IP technologies to facilitate cheap that localized communication to foster local trade and communities, leading to growth (and communication) beyond the local needs.

Networks do not only become faster: the gap between the low and high end of achievable data rates appears to widen. This is indicated by the increasing ratio between "average peak" and "average" connection speeds in Akamai reports, from 2010 to 2017. This trend was consistent for global data as well as various countries at the lower or higher connectivity end (Venezuela, China, USA, Switzerland, South Korea), shown in [51]. This paper also reports on Measurement Lab data sets from the Neubot tool over the 2012-2021 time period, again confirming the growing range.

This widening range is a problem for globally unique standards such as end-to-end congestion control. When the proposal to increase TCP's Initial Window (IW) to 10 segments was brought to the IETF, concerns about the impact on users in poorly connected areas such as South America or Africa were raised. These were addressed by the proponents with data from these countries, showing no significant problems: however, these data were limited to the application that uses IW10 [19]. The concern was instead about the collateral damage to other applications, such as Voice over IP. The proponents could not produce such data, yet the IETF went ahead with the publication of [52].

Due to the widening range of worldwide access capacities, such globally unique "magic numbers" cannot be scaled forever. If IW10 is too small for some users, and too large for some others today, then tomorrow, IW100 it will be *much* too small for some, and *terribly* large for others. Solving this dilemma may need an architectural shift – [51] raises the question whether end-to-end congestion control is a sustainable design for the future, or if we should instead move towards proxy-supported control.

2.1 Poor Internet can happen to everyone

In many countries, we find increasing deployment of 5G cellular networks, gradually upgrading broadly deployed LTE (4G) mobile network infrastructure. Both are able to offer high data rates (both uplink and downlink) and short RTTs for smooth service experiences, which can easily achieve performance comparable to fixed broadband network infrastructure. In fact, in some countries – including Finland and Sweden – cellular networks often used as a replacement for fixed Internet access; moreover, cellular networks are used for failover in case of temporary failures of the fixed access network, manually or using home routers that include SIM cards for backup.

While cellular networks *can* offer powerful Internet access, such is not ubiquitous, even if leaving aside temporary load peaks. Especially in rural areas, cellular connectivity may fall back to 3G, EDGE, HSPA, or even GPRS, which reduce data rates to less than 1 Mbps or even less than 100 kbps while increasing latency substantially. When faced with such network characteristics, Internet services as well as mobile apps easily fail to function, web sites may not even load (within a reasonable amount of time). Every reader has probably faced this issue repeatedly: trying to fetch email, load a web page, or just chatting often simply fail when connectivity is EDGE or less. For a simple example the authors measured Internet connectivity via a tethered laptop across Bavaria on 23 and 24 November 2023, finding an RTT band from 50ms to 300ms with peals at 10-100+ seconds.

2.2 Regulation

These issues experienced by users on a regular basis shall be state-regulated, measured, and enforced. However, Internet access and quality of service have been left to the free play of market forces in developed economies [41]. The opposite happens in developing countries with no better results in terms of turning the Internet into a basic human right. In developed economies, for example in Germany, providers must offer universal telecommunication services with defined quality of service (qos) targets for fixed line broadband [18]; yet, no measurable requirements are defined for mobile broadband qos goals (with the exception of the expansion of mobile broadband coverage). Accordingly, no sanctions for not meeting targets are specified. In contrast, mobile Internet access quality parameters have been defined in a developing economy such as Ecuador. These parameters are measured and enforced by the state; however, their complexity and conflict of interests have led to defining and controlling very basic connectivity tests without improving the quality of service or user experience. Raising even further concerns in developing economies, such as the Latin American one, about Internet access's digital equity, i.e., service availability, adoption, and affordability [41].

2.3 Affordability

In Latin America, for example, we can observe one of the strongest gaps in digital equity where poor Internet access is not only due to the coverage but also due to the usage gap, affordability. This affordability gap is driven by service prices, high spectrum prices, and the provider's revenue rate.

Forty-three percent of the Latin American population living in areas served by fixed broadband do not acquire the service [28]. This is due to higher prices for a perceived poor service, i.e. mobile broadband Internet access. Internet access in Latin America is one of the most expensive in the world [30]. In Latin America, spectrum prices were, on average, almost three times more expensive than in developed countries in relation to expected revenues [27]. Moreover, small economies represent small revenues for worldwide ISPs; e.g., Ecuador represents only 10% of the profit made by the major mobile connectivity provider. This situation has had a negative impact on consumer outcomes (coverage and speeds). Lower spectrum costs would have increased the 3G and 4G coverage in Latin America. For example, coverage in Colombia from 71% to 76% of the population by the end of 2019, reaching 2 million additional people with 4G network coverage [29]. Furthermore, in Ecuador, the higher prices slow down roll-out technologies by years, i.e., one year to reach 80% 4G coverage compared to the region. The same is expected for the upcoming networks beyond 5G [40]. Lower costs of spectrum would have also increased download speeds by around 40% by the end of 2019 [30].

3. A few point observations

In this section, we share data from a set of countries where individual contributors have insights into, because these are their countries of origin and/or they live(d) there for a while to benefit from local knowledge.

- Austria

In 2023, 95 percent of all households in Austria were equipped with an Internet connection. In 2002, however, only 33.5 percent of Austrian households had Internet access. Almost all Austrian households used the Internet via some kind of a broadband connection. 95.3 percent of Austrians used the Internet in 2023. The Internet was most frequently used via smartphone at 87.8 percent [23].

Austria has a plan to provide realize a “gigabit society”, where every household should be connected to the fiber optic network by 2030. In 2022, 800,000 households were connected, attaining a total of 57 percent; this means that 1.7 million households do not yet have a fiber connection [24].

- Germany

For Germany, we find multiple sources outlining fixed and mobile broadband subscriptions and their technology breakdown for 2021 [16,17].

While 96% of households have access to fixed broadband, ~82% of households were subscribed to a fixed broadband plan in 2021. Of these subscriptions, ~69% were serviced via DSL, where the remaining ~31% were serviced via other access technologies (e.g., DOCSIS, fiber, fixed mobile access). Further, we observe a strong dominance of the previously state-owned Deutsche Telekom AG which directly serviced a total ~39% of subscriptions in 2021. Yet, the penetration of fiber access is notably lacking, with only ~15% of households being covered by fiber technology. If we take a look at the subscriptions from a bandwidth perspective, we find that ~37% of subscriptions did provide a maximum download bandwidth in the range of >=30 to <100mbps, ~37% in the range of >=100 to <1gmbps, and only 4% with a maximum download bandwidth of >=1gbps.
Notably, the German federal regulatory authority did manifest technical specifications for a fixed broadband universal telecommunications service as of June 2022. According to the law, providers must offer universal telecommunication services with a minimum bandwidth of

10mbps in download and 1.7mbps in upload, and with a maximum RTT of 150ms measured to a national reference point [18].

Considering mobile broadband, we find that 87% of the populated areas in Germany, and ~58% of Germany's area in total, did have 5G coverage in 2021. The mobile broadband coverage was served by ~188k technology-dedicated cellular base stations, of which ~16% were 5G, ~44% 4G, and ~40% 2G in 2021. Notably, 3G base stations were stated with ~0.3%, where 3G was phased out only the end of 2021. Moreover, ~87% of inhabitants were subscribed to a mobile broadband plan in the same year; yet, every inhabitant in Germany did on average had ~1.3 active SIM cards. Of these ~106M SIM cards, the monthly mobile data usage was found to be 4.3GB on average.

- India

Beginning of 2007, internet access penetrated just 4% of the total population in India [31]. Fast forward to 2023, this figure now stands at 59% for broadband internet i.e. close to 840 million people [32]. This rise can be mainly attributed to telecom companies (Reliance Jio, Bharti Airtel, Vodafone Idea) providing cheap cellular and wired connections in the range of 7-50 Euros/month (DSL/Fiber). Statistics show internet plans in India to be the 3rd cheapest globally at 0.17$/GB of data [33].

Wired broadband plans with unlimited internet access are often the norm, while Cellular data caps range from 1GB to 2.5GB/day. Access speeds for fixed-line lie in the range of 30 Mbps to 1 Gbps depending on the subscription and access technology.

5G mobile coverage is supported in most places in India mainly by 2 out 4 of major providers, while others still provide good 4G/4G+ access [34].

However, there exists significant disparity in Internet accessibility in India due to the economic divide between rural and urban population. 66% of Indian population lives in villages and are 12-14% less likely to own medium to access Internet services [35]. Furthermore, these regions only receive around 8 hours of electricity per day, which is essential for powering and accessing the Internet. Recent reports suggest that almost 25000 villages (4% of the total population) completely lack the neccessary Internet and telephone infrastructure [36]. Moreover, there is a disconnect between the cost to access Internet even in rural areas with infrastructure availability as bottom-lines of most Internet access charges are around INR 150 (USD 2.13) per month [37] while the national minimum daily wage is INR 178 or USD2.15 [38]. Due to the nation-wide Digital India movement in the past few years [39], majority of such regions, therefore, cannot access the essential digital-only services, such as e-governance, banking, etc.

- Italy

The current offering for FTTH from the major Italian providers (OpenFiber, TIM, Vodafone, Windtre) spans between 25 to 30 EUR per month for flat rates featuring 2.5 Gbps maximum bandwidth.
Mobile LTE and 5G connectivity are among the cheapest worldwide, with an average cost of 0.12$/GB [11].

In Italy, 97% of the households have access to next-generation (NGA) broadband [12]. FTTP coverage is steadily improving, from 22% of coverage in 2017 to 53% of the territory in 2022, with 82.9% of the population having at least 100Mbps Internet access [13]. In 2023 FTTP accounts for approximately 70.7 % of fixed broadband subscriptions, while 19.7% of fixed subscriptions are still DSL and 9.6% are FWA [14]. Mobile 5G and 4G network coverage in Italy is beyond 98%, and in 2023 it accounts for 108,2 million active subscriptions, with 21% of them for M2M (machine to machine) communications.

- Norway

The spread of the Internet access service corresponds to a large extent with the spread of broadband. A coverage survey for the first half of 2022 shows that 93.6% and 92.5% of all households had a broadband offer with at least 100 Mbit/s, 1000 Mbit/s in download speed, respectively. This is mainly based on fiber or hybrid networks, but fixed wireless broadband also contributes to the coverage.
Almost all households that have an offer of at least 100 Mbit/s download speed also have an offer of alternative connections. There are geographical differences, but taken as a whole, most Norwegian residents have good opportunities to connect to the internet.

Development of the 5G network started in 2020. A coverage survey for the first half of 2022 shows that the basic coverage for 5G is calculated at close to 82% and that, at the same time the year before, it was calculated at around 23% [25].

- Poland

The percentage of households with internet access in Poland in 2022 equalled 93.3% [2]. 92.6% of all households had broadband internet access. Out of the connected households 69.5% had fixed-line broadband access, with 70.6% being connected via mobile broadband access. Vast majority of households with children (99.6%) had internet access at home, compared to only around nine in ten households without children having such access. There were only minor differences in households with internet access within large and small cities compared to rural areas.

In 2022 monthly cost for fixed-line broadband access averaged around 59.17 PLN, with mobile broadband access cost of around 46.43 PLN [4]. The internet access download speed in Poland in 2022 averaged around 110 Mbit/s, with FTTH access averaging around 231 Mbit/s and 5G networks offering average download speeds of up to 142 Mbit/s [5].

- Serbia

In 2023, 85.6% households in Serbia had broadband access to the Internet [1]. Out of those connected households, 89.3% households had fixed access and 76.9% had mobile access. In terms of the speed of fixed broadband access, while the maximum download speed available to the subscribers was 1 Gbps, the average speed amounted to only 70.95 Mbps [15]. The coverage of mobile networks was limited to 4G/4G+, with the average download speed of 52.41 Mpbs [15], and the 5G network was still in its experimental phase.

The digital divide has been observed across different demographics, with the biggest gap that can be attributed to the economic status of subscribers. Only 48.6% low-income households had broadband access, as opposed to 99.1% of the households with an average and higher income. A smaller gap exists between rural (78.9%) and urban (88.9%) areas, where both percentages increased from those in 2022 (with 4% and 1.3% increase, respectively).

- Turkey

In 2023, 95.5% of the households in Turkey had access to the internet and internet usage percentage per population increased 2.1% compared to 2022, from 85% to 87.1%. It was reported that 90.3% of the users were male and 83.3% were female. E-government, e-commerce, streaming and social media were the most commonly used services among the users. 73.9% of the users used e-government, 49.5% used e-commerce services. Whatsapp was the most popular social media platform with %84.9 of the users using it, followed by 69% by Youtube and %61 by Instagram. [3]

Turkey is ranked 105 out of 193 countries, with an average download speed of 24.84 Mbps[6]. Share of fiber optic broadband connection is 22%.

LTE infrastructure made a fast progress, since it was deployed in Turkey in 2016. Currently, 96.8% percent of the population have access to LTE connection. However, Turkey is still one of the few European countries without a 5G infrastructure yet. [7]

Internet censorship is a controversial topic in Turkey, where more than 40000 websites are banned. ISP throttling, access blocking and content removal are widely used methods to limit access to certain websites and contents. One of the most notable and recent examples was the limitation of access to Twitter in 2023 earthquakes, where inadequacy of the rescue efforts were widely criticised. Discussions about right of free speech and access to information often happen in the parliament and appear in the media. [10]

- US

For the US, the FCC provides various reports on telecommunications aspects [20]. We take a closer look at the most recent report on Internet Access Services as of 2021 [21], and the most recent report on the Communications Marketplace from 2022 [22].

In 2021, we find ~126M fixed broadband subscriptions in the US. Of these subscriptions, the vast majority were serviced with a downstream bandwidth of >=100mbps to <940mbps with ~57%, followed by >=25mbps to <100mbps with ~18%. Looking at the breakdown for access technology, we find that ~64% of subscriptions used DOCSIS, followed by ~18% fiber, and ~14 DSL. Notably, Satellite had a penetration of ~1.6% of subscriptions. Conversely, ~52% of inhabitants did have access to fiber technology, where DOCSIS was available for ~78% of inhabitants.

Considering mobile, we find ~384M mobile broadband subscriptions as of 2021, of which the monthly mobile data usage was found to be 12.1GB on average for smartphones. 5G coverage was available in ~55% of the US area, covering ~98% of the inhabitants; 4G coverage was available in ~73% of the US area, covering almost 100% of the inhabitants

- OECD (Organisation for Economic Co-operation and Development)

Looking at the 38 OECD Countries, we find several data points on mobile data usage, mobile broadband subscriptions, and fixed broadband subscriptions [8,9].

The mobile data usage grew 17% from 2021 to 2022, with an average annual growth of 29% from 2017 to 2022 within the OECD countries.
In the same timeframe, the monthly mobile data usage increased from 4.7gb in 2017 to 10.4gb in 2022 on average, and with this roughly doubled in 4 years. Yet, comparing data usage within OECD countries, we observe a strong diversity with an average mobile data usage in Latvia and Finland of ~40gb/month in comparison to Canada, New Zealand, Costa Rica, and Mexico with only ~5gb/month at the other end of the spectrum. Analyzing mobile broadband subscriptions, we observe a growth of 13% from 2019 to 2022 in OECD countries on average, where each inhabitant subscribes to 1.27 mobile plans on average in 2022. The highest penetration of mobile subscriptions plans can be found in Estonia and Japan (~200% of inhabitants), with the lowest penetration with ~80% of inhabitants in Columbia and Türkiye. Regarding mobile access technologies, we find that 37 out of the 38 OECD countries have deployed 5G networks. Yet, only 20 countries provided data for 5G-enabled mobile subscriptions; of these 20 countries, 21% of subscriptions on average were 5G-enabled in 2022.

Considering fixed broadband subscriptions in the OECD, we observe an average of 35 subscriptions per 100 inhabitants in 2022, which is a growth of ~11% from 2019 to 2022. While we again find Columbia at the low end of the spectrum with a penetration of ~17% of inhabitants, France and Switzerland show the highest penetration with ~47% of inhabitants. Of the OECD average of 35 subscriptions per 100 inhabitants in 2022, fiber is now the leading technology with ~38% of subscriptions served with in 2022, followed by DOCSIS with ~32%, and DSL with ~24%. Notably, Satellite has a penetration of ~0.5% of subscriptions.

- Latin America

The report in [28] shows that internet provision across Argentina, Brazil, Colombia, Costa Rica, and Ecuador is not widespread. 7% of the population access the Internet. The report divides the gap between usage, affordability, and the coverage gap. The coverage gap is concentrated in remote areas or locations where making network deployments is economically challenging and unviable. The affordability gap refers to those who live in areas with mobile internet coverage but do not access internet services.

This is reflected in the lack of demand and is the main driver of internet connectivity across Latin America. In urban and rural areas, 31% of the regional population (190 million people) live in locations with mobile internet network coverage but do not access the internet [28]. The coverage gap is relatively small in Latin America, accounting for 7% of the population. It accounts for almost 40 million people. Hence, the affordability gap is the main reason why there is a mobile internet connectivity gap in Latin America, accounting for 190 million of the 230 million unconnected [28].

4. Concluding remarks

The Internet as we know it has long been transformed in many key markets from an open global communication fabric to a delivery infrastructure with high profit margins for (commercial) services. However, as pointed out in our introduction, the Internet has measurably an enormous impact on economic development and the pursuit of societal goals like freedom of expression and others.

While it is understandable that the optimization of those delivery capabilities has a strong focus in the R&D of key market players, and consequently in the SDOs that align the solutions in an interoperable manner, the goal of enabling communication AT ANY LEVEL of performance must not be forgotten. We have observed, not just in this contribution, that the universal rollout of ever improving broadband infrastructure has been and remains a key challenge. Digital divide has not just been documented to exist but it is expected to widen, at least in the near to mid-term and is thus a fact of (digital) life for the foreseeable future!

We thus call upon the industry as well as SDOs like the IETF to push more aggressively for technologies catered to span this digital divide and thus effectively bridge it DESPITE its existence. We believe that there are concrete steps that can be taken, providing here just three examples for those:

1. Increase the span of content provisioning: Content must be usable across ALL capabilities for delivery, thus for low bandwidth as much as the highest possible connectivity option. Not just transcoding of videos (to lower bitrates) must be common practise but also the rendering of website over lower-speed and capacity connections. Best practises must be established for this increased span of content provisioning without which services simply will be excluded from use by those without proper connectivity choices. But further, we must also drive research (and consequently following development) into improving on content generation, rendering, and provisioning across the ranges of connectivity that span the existing digital divide.
2. Develop best practises for Internet rollout: While the commercially driven rollout (and its economic benefits) has been well understood in many markets, particular in developed countries, it is often not enough to bring the Internet to all, even in those developed markets themselves (as documented in other parts of this document, we are far away from truly ubiquitous broadband rollout even in the most developed regions of the world). The GAIA RG community has gathered many insights from practitioners around the world on how to overcome rollout challenges to bring connectivity to their communities. Those insights have been documented by the community [53] but will need a constant update to follow technological developments.
3. Drive best practises into day-to-day SDO work: It is needed, however, that the aforementioned insights are fed back into suitable recommendations for technology development to foster and improve on those alternative rollouts in order to complement the market-driven models that exist. Key here will be the advocacy in the various activities within the IETF. Those could include a dedicated section in drafts (and ultimately RFCs) on considerations for global access (if suitable) as well as the increased involvement of global access advocats in key WGs of the IETF to complement those players currently driving the development of the high-profit ultra broadband Internet many of us know. Attracting those advocats should become a key mission not just of the IAB but also the IETF overall.

What is most important, however, is that we should not forget both aspects of the digital divide, namely the use of Internet technologies under dimished conditions as well as the facilitation of any connectivity AT ALL.

5. Acknowledgements

This paper incorporates some inspirations from the discussions at the Munich Internet Research Retreat Raitenhaslach (MIR[3]), November 2023.

6. References

[1] Usage of information and communication technologies in the Republic of Serbia (Serbian only), Statistical Office of the Republic of Serbia, 2023, https://publikacije.stat.gov.rs/G2023/Pdf/G202316018.pdf
[2] Information society in Poland in 2022, Statistics Poland, Statistical Office in Szczecin, 2022, https://stat.gov.pl/obszary-tematyczne/nauka-i-technika-spoleczenstwo-informacyjne/spoleczenstwo-informacyjne/spoleczenstwo-informacyjne-w-polsce-w-2022-roku,1,16.html
[3] Turkish Statistical Institute, Household Internet Usage Survey in 2023 (Turkish only), 2023, https://data.tuik.gov.tr/Bulten/Index?p=Hanehalki-Bilisim-Teknolojileri-(BT)-Kullanim-Arastirmasi-2023-49407#:~:text=TÜİK Kurumsal&text=Hanehalkı bilişim teknolojileri kullanım araştırması,artarak �%2C5 oldu.&text=İnternet kullanım oranı%2C 16-74,yılında �%2C1 oldu.
[4] Analysis of the functioning of the telecommunications services market in Poland and assessment of consumer preferences (Polish only), Polish Office of Electronic Communications, 2022, https://www.uke.gov.pl/akt/badanie-konsumenckie-klientow-indywidualnych-przeprowadzone-w-2022-roku,470.html
[5] Internet speed in Poland in 2022 based on 42 million tests (Polish only), 2023, https://www.speedtest.pl/wiadomosci/rankingi/predkosc-internetu-w-polsce-w-2022-roku-na-podstawie-42-mln-testow/
[6] Ranked: Countries with the Fasters Internet in the World, 2023 https://www.atlasandboots.com/remote-work/countries-with-the-fastest-internet-in-the-world/
[7] United Nations Economic Commission for Europe, 2022, https://w3.unece.org/SDG/en/Indicator?id=133
[8] OECD broadband statistics update, 2023, https://www.oecd.org/digital/broadband/broadband-statistics-update.htm
[9] OECD Broadband Portal, 2023, https://www.oecd.org/digital/broadband/broadband-statistics/
[10] Internet restrictions in Turkey violate fundamental rights, 2023, https://edri.org/our-work/internet-restrictions-in-turkey-violate-fundamental-rights/
[11] The Cost of Mobile Internet Around The World, 2023, https://www.statista.com/chart/17247/the-average-cost-of-mobile-data-in-selected-countries/
[12] Digital Economy and Society Index Report 2022 - Connectivity, 2023, https://digital-strategy.ec.europa.eu/en/policies/desi-connectivity
[13] AGCOM Broadband Map Italy, 2023, https://maps.agcom.it
[14] AGCOM Report 3/2023, 2023, https://www.agcom.it/documents/10179/31999177/Documento+generico+18-10-2023/fa4705fa-51e7-4d3d-a89a-f8b0e44ecadb?version=1.0
[15] Speedtest Global Index, Median Country Speeds October 2023, 2023, https://www.speedtest.net/global-index
[16] Germany in the Digital Economy and Society Index, 2022, https://digital-strategy.ec.europa.eu/en/policies/desi-germany
[17] Marktdaten Deutschland (German only), 2022, https://www.bundesnetzagentur.de/DE/Fachthemen/Telekommunikation/Marktdaten/start.html
[18] Recht auf Versorgung mit Telekommunikationsdiensten (German only), 2022, https://www.bundesnetzagentur.de/DE/Fachthemen/Telekommunikation/Grundversorgung/start.html
[19] Dukkipati, D., Cheng, Y., Chu, J., and M. Mathis, “Increasing TCP initial window”, presented to the IRTF ICCRG meeting, IETF 78, July 2010, http://www.ietf.org/proceedings/78/slides/iccrg-3.pdf
[20] FCC, Reports, 2023, https://www.fcc.gov/reports-research/reports

[21] FCC, Internet Access Services (As of December 31, 2021), 2023, https://www.fcc.gov/reports-research/reports/internet-access-services-reports/internet-access-services-december-31-2021
[22] FCC, 2022 Communications Marketplace Report, 2022, https://www.fcc.gov/document/2022-communications-marketplace-report
[23] Statista, Anteil der Haushalte in Österreich mit Internetzugang von 2002 bis 2023 (German only), 2023, https://de.statista.com/statistik/daten/studie/153262/umfrage/haushalte-mit-internetzugang-in-oesterreich/
[24] Der Standard, Breitbandausbau: 1,7 Millionen Haushalte in Österreich warten auf schnelles Internet (German only), 2022, https://www.derstandard.de/story/2000137843872/breitbandausbau-1-7-millionen-haushalte-in-oesterreich-warten-auf-schnelles
[25] Internet in Norway – Annual Report 2023, Norwegian Communications Authority NKOM, June 2023, https://nkom.no/aktuelt/slik-star-det-til-med-internett-i-norge/_/attachment/download/054e05d2-111a-4913-a367-2e6c7f53fb30:a64f5076938d4a448a4b42dd1be131de0275f4e4/Internet in Norway - Annual Report 2023.pdf
[26] IDB: LatAm lagging behind on broadband access, November 2023, https://www.ft.com/content/fecc0e6e-84f5-3cc8-a67d-b07f5b57d931
[27] Impact of Spectrum Prices on Consumers, November 2023, https://www.gsma.com/spectrum/wp-content/uploads/2019/09/Impact-of-spectrum-prices-on-consumers.pdf
[28] The report 'Connectivity Gaps in Latin America. A Roadmap for Argentina, Brazil, Colombia, Costa Rica and Ecuador', November 2023, https://www.gsma.com/latinamerica/wp-content/uploads/2023/03/FINAL-Brechas-de-conectividad-en-America-Latina_-LONG-report-SPANISH-DIGITAL-30-03-2023.pdf
[29] Effective Spectrum Pricing in Colombia, September 2021, https://www.gsma.com/latinamerica/resources/effective-spectrum-pricing-in-colombia/
[30] Internet costs comparative Results, November 2023, https://www.broadbandsearch.net/blog/internet-costs-compared-worldwide
[31] Internet penetration rate in India from 2007 to 2022, statista, 2023, https://www.statista.com/statistics/792074/india-internet-penetration-rate/
[32] Highlights of Telecom Subscription Data as on 31st March, 2023, 2023, https://www.trai.gov.in/sites/default/files/PR_No.46of2023_0.pdf
[33] The Cost of Mobile Internet Around The World, statista, 2023, https://www.statista.com/chart/17247/the-average-cost-of-mobile-data-in-selected-countries/
[34] Cellular data networks in India, nperf, 2023, https://www.nperf.com/en/map/IN/-/-/signal/?ll=22.12215821805932&lg=82.785&zoom=4
[35] Key Indicators of Household Social Consumption on Education in India July 2017-June 2018, 2022, http://www.icssrdataservice.in/datarepository/index.php/catalog/153/download/2218
[36] A Survey on Rural Internet Connectivity in India, https://arxiv.org/pdf/2111.10219.pdf
[37] Jio, Airtel, Vodafone Idea prepaid plans compared — here's how the three telcos stack up, 2023, https://www.cnbctv18.com/telecom/jio-airtel-vodafone-idea-prepaid-plans-compared-heres-how-the-three-telcos-stack-up-16174091.htm
[38] A Guide to Minimum Wage in India in 2023, India Briefing, 2023, https://www.india-briefing.com/news/guide-minimum-wage-india-2023-19406.html
[39] Digital India, Wikipedia, 2023, https://en.wikipedia.org/wiki/Digital_India
[40] Effective Spectrum Pricing in Ecuador, Nov 2021, https://www.gsma.com/latinamerica/resources/effective-spectrum-pricing-in-ecuador/
[41] Udit Paul, Vinothini Gunasekaran, Jiamo Liu, Tejas N. Narechania, Arpit Gupta, and Elizabeth Belding. 2023. Decoding the Divide: Analyzing Disparities in Broadband Plans Offered by Major US ISPs. In Proceedings of the ACM SIGCOMM 2023 Conference (ACM SIGCOMM '23). Association for Computing Machinery, New York, NY, USA, 578–591. https://doi.org/10.1145/3603269.3604831

[43] RFC9505, A Survey of Worldwide Censorship Techniques, IETF, 2023, https://datatracker.ietf.org/doc/rfc9505/
[44] The broadband bonus: Estimating broadband Internet's economic value, 2011, https://www.sciencedirect.com/science/article/pii/S0308596111001005
[45] The Economic Significance of Modern Broadband Internet Infrastructures and Services, 2022, https://www.wu.ac.at/fileadmin/wu/d/ri/regulation/WPs_und_GAs/Economic_benefits_highspeed_broadband_December_2022_final_draft.pdf
[46] Economic growth and broadband access: The European urban-rural digital divide, 2023, https://www.sciencedirect.com/science/article/pii/S0308596123000903
[47] Decoding the Divide: Analyzing Disparities in Broadband Plans Offered by Major US ISPs, 2023, https://dl.acm.org/doi/10.1145/3603269.3604831
[48] Global Access to the Internet for All (gaia) RG, IETF, 2023, https://datatracker.ietf.org/rg/gaia/about/
[49] Right to Internet access, wikipedia, 2023, https://en.wikipedia.org/wiki/Right_to_Internet_access
[50] WIRELESS VILLAGE: GROWTH OPPORTUNITY IN EMERGING MARKETS, https://ursi.org/proceedings/procGA05/pdf/C01.7(01705).pdf
[51] Future Internet Congestion Control: The Diminishing Feedback Problem, 2022, https://ieeexplore.ieee.org/document/9817041
[52] RFC6928, Increasing TCP's Initial Window, IETF, 2013, https://datatracker.ietf.org/doc/html/rfc6928
[53] RFC7962, Alternative Network Deployments: Taxonomy, Characterization, Technologies, and Architectures, IETF, 2016, https://datatracker.ietf.org/doc/rfc7962/