Broadband Access for Remote Un-serviced Communities

Abstract

This chapter starts by exploring the various reasons why currently almost 50% of the global population has no access to broadband internet. The latter part of the chapter discusses some enabling technologies to address this issue.

The world is experiencing one of the greatest revolutions ever, driven by the massive flow of information between billions of information technology users around the world, every second of the day, largely enabled by the convergence of the so called SMACT (Social, Mobile, Analytics, Cloud and Internet of Things) technology cluster in smart devices, currently dominated by the smartphone. This information and communication revolution has significantly lowered the entry barrier to trade, allowing millions of new participants into the market with little more than a smartphone as an "office". The glue holding the whole system together is broadband internet access, which by default becomes the basic requirement for entry into this ecosystem. But, what about the "unconnected masses" who are excluded from participation in this internet-enabled economy? How can they be empowered? What are the possible solutions?

1 The Digital Divide

The US Department of Commerce has defined the "digital divide" as the difference between two groups of technology users; on the one extreme, a group of people with access to the very latest computing hardware, software, content, internet, telephony connectivity, training and skills, as opposed to the other end of the social spectrum, where a group exists with little to no access of any of the "digital

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privileges" of the other group.[1] A more expanded view proposed the concept of "digital inequality", where in addition to inequality of equipment, factors such as the 'autonomy of use', required skills, social support network and purpose of the use of technology are also taken into consideration (DiMaggio 2001).

The reason for the existence of the "digital haves and have-nots" has been studied extensively and causative factors have been found to be a combination of social and spatial factors, e.g. where the person lives, income level, age, education, gender even ethnicity (Warf 2001). However, in a global economy enabled by internet access and at macro level, countries with high levels of digital penetration will find it increasingly difficult to trade with countries with low levels of digital integration at ground level.

Though the availability of broadband infrastructure is still the primary exclusion factor for un-connected communities worldwide, the establishment of the connection alone is however not a guarantee of adoption of internet services. There are a number of additional barriers to overcome before a service will be adopted by a target community. A study by the ITU (International Telecommunication Union) concluded that a target user community will adopt a broadband internet service on condition that the following four primary adoption conditions are met.[2]

- Infrastructure—The physical service needs to be made available to the region in a manner that makes fiscal sense to the service provider.
- Cost—The service needs to be affordable to users within the target area. Currently an estimated 57% of the global population cannot afford the internet.[3]
- Capability—If the basic service is available and affordable to the target population, do they have the means to access the service in terms of skill and ancillary equipment required?
- Relevance—Lastly, if all other conditions are met, how applicable is the use of the service to the target community? If there are no relevant needed services available in the region in the local language, chances are that the target population will not see a benefit.

Figure 1 clearly shows that the affordability of internet services is an issue across all regions. Europe has the fewest barriers of adoption, with only affordability as an issue, whereas the African continent is challenged by all four barriers of adoption.

Adoption barriers for the use of satellite broadband are essentially the same as for terrestrial broadband, however satellite broadband does provide a ready opportunity to at least eliminate the "availability" barrier. With a large rural population—over 63% of the Sub-Saharan population live in rural areas as opposed to

[1]McConnaughey, J.W., Lader, W., Chin, R. and Everette, D. 1998. *Falling through the Net II: New data on the digital divide*. Washington DC: National Telecommunications and Information Administration.

[2]Biggs, P. Ed. 2018. *The State of Broadband 2018: Broadband Catalyzing Sustainable Development*. First ed. Geneva: UN Broadband Commission.

[3]UNCTAD. 2017. *Information Economy Report 2017—Digitalization, Trade and Development.* Geneva: United Nations.

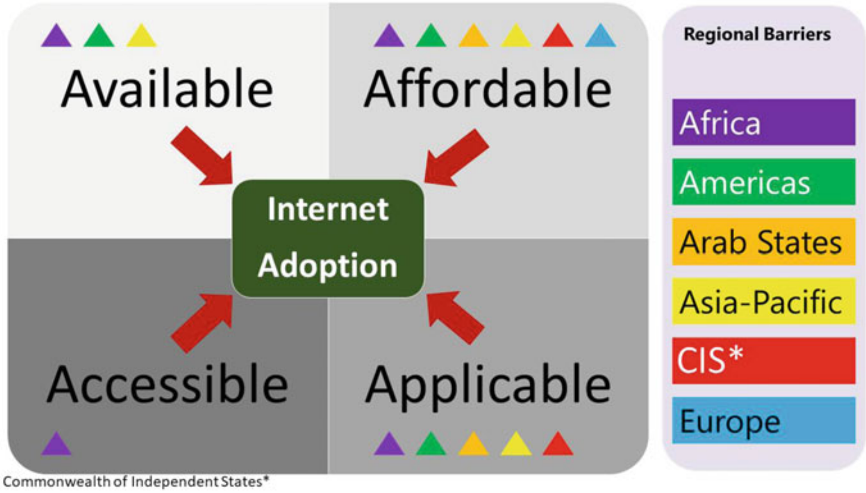

Fig. 1 Barriers to broadband internet adoption (see footnote 6)

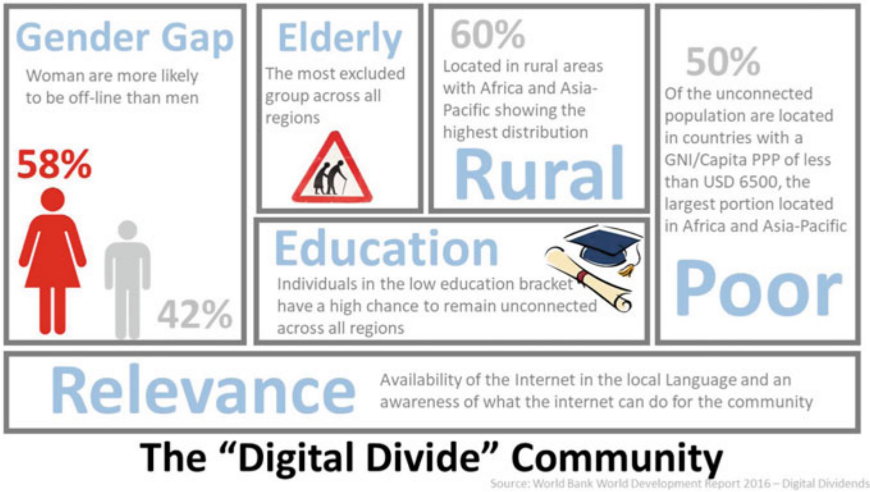

Fig. 2 Profile of the "digital divide" (World Bank. 2016. *Digital Dividends.* (Public 102725). Washington DC: World Bank Group.)

26% in the EU—Africa is well suited for the delivery of satellite broadband to rural communities. Figure 2 describes the typical "digital divide" community, i.e. a poor elderly lady with little to no education, living in rural Africa, has a very high likelihood to be digitally excluded as opposed to a young city dweller in the developed world.

In 2014 Huawei Technologies created the Global Connectivity Index (GCI) to track global digital transformation in 50 countries based on the analysis of 40 indicators. The index groups different nations into three groups—Starters, Adopters and Frontrunners. Designed to provide insights for policymakers tasked with transformation to the digital economy, it has highlighted a disturbing trend, confirming an increasing gap between "Starters" and "Frontrunners". In sociology the "Matthew Effect", a term coined by Robert K. Merton, refers to a situation where advantage propagates further advantage and vice versa—i.e. the rich get richer (Rigney 2010). The 2017 GCI scores show the "Frontrunners" pulling ahead of the "Starters" by a significant margin, exhibiting a "Matthew effect" in connectivity, with the digital divide in fact becoming a "digital chasm". If the lagging nations, typically also the more economically disadvantaged, are not able to play catch-up to the middle group of nations, it will hamper their ability to compete economically.[4] As stated before, the term "digital divide" is a multi-faceted concept involving a bouquet of digital technologies; however the availability of internet and bandwidth (access speed determines the type of content with which a user can engage) is the entry point to the digital economy. Internet access is therefore generally regarded as the "go to" metric to gauge the presence and extent of the digital divide for a specific demographic (Fig. 3).

Africa has the lowest global rate of internet penetration with less than 35% of the total population connected as opposed to North America with more than 90% connected. Bandwidth distribution indicates a bleaker trend, with the gap between the Least Developed Countries and Developed Countries increasing to a factor of 23, as indicated by Fig. 4. Access speed is a key determinant of what type of content a user will be able to engage; the more feature-rich the content, the higher the bandwidth requirement. Low-bandwidth generally creates a secondary level of inequality by preventing users from meaningfully interacting with feature-rich content. A low bandwidth user, typically in a developing country, will be prevented from meaningful access to video-rich content and peer-to-peer interactions, ironically a hallmark of remote education applications such as the typical MOOC (Patru 2016). Globally there has been approximately a sixfold, increase in available bandwidth from 34 Tbps in 2008 to 185 Tbps in 2016.[5] Looking at bandwidth distribution, the picture becomes much skewed. In contrast to the average of 140 kbps per user at the top end of the scale in the developed world, for those at the bottom end in the Least Developed Countries it's only 6 kbps.[6]

[4]GCI. 2018. *Huawei Global Connectivity Index 2018.* https://www.huawei.com/minisite/gci/en/index.html accessed 14 December 2018.

[5]Internet World Stats. 2018. *INTERNET USAGE STATISTICS—The Internet Big Picture, World Internet Users and 2018 Population Stats*. https://www.internetworldstats.com/stats.htm accessed 17 November 2018.

[6]ITU. 2017. *ICT Facts and Figures 2017.* https://www.itu.int/en/ITU-D/Statistics/Documents/facts/ICTFactsFigures2017.pdf accessed 14 January 2018.

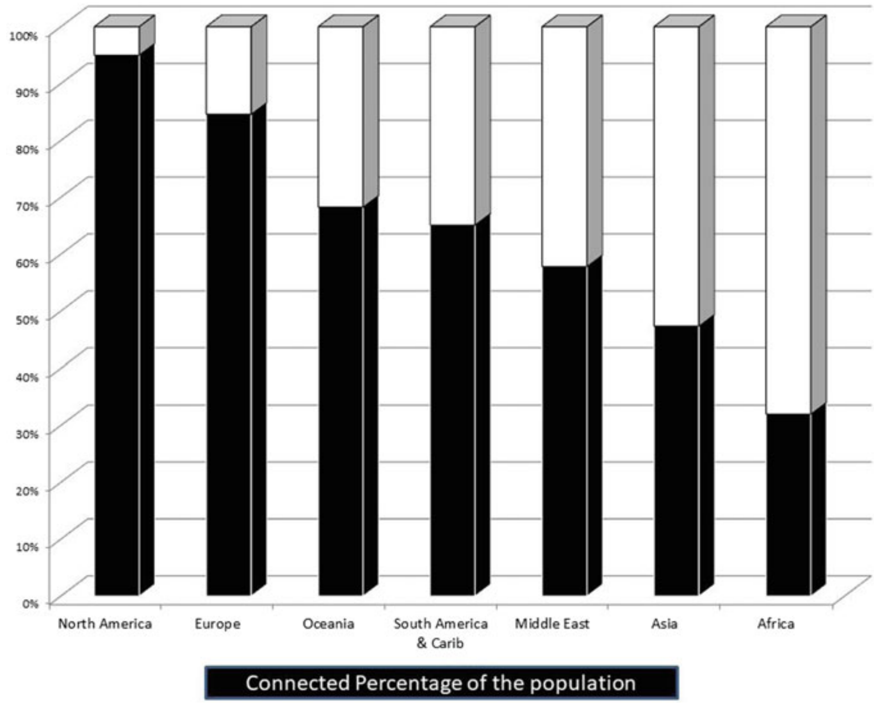

Fig. 3 Global internet connectivity (see footnote 5)

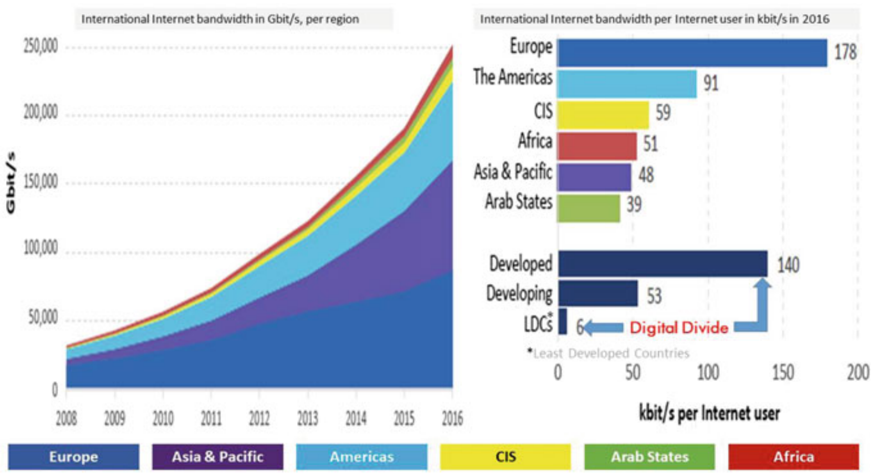

Fig. 4 Global bandwidth distribution (see footnote 7)

On the positive side there has been an almost tenfold increase in available bandwidth from 2008, with the 2016 global aggregate speed almost 250 Tbps. Between 2015 and 2016 alone, global internet bandwidth grew by 32%, with Africa showing the highest regional growth at 72%.[7]

2 Satellite Broadband

On October 4, 1957, the USSR placed the first man-made object into orbit in the form of a man-made satellite called "Sputnik". Whilst the initial use of space technology was largely driven by a politico/ military agenda inspired by the Cold War zeitgeist, the commercial possibilities soon became apparent. The modern satellite industry is classified into four distinct sectors (Table 1), with commercial communication satellites dominating the satellite services industry, representing 35% of all mission types. Eutelsat KA-SAT 9A, a very large HTS (High-Throughput Satellite), placed into Geostationary Equatorial Orbit (GEO) in late 2010, and could be considered the first dedicated broadband satellite.[8] Using spot beam technology, it offered users high-speed internet access with downlink speed of up to 20 Mbps and a potential uplink speed of 6 Mbps. Spot beam technology deploys a conus "beam" to a specific geographical area, which allows for local channels for a defined target area by using signal scrambling that allows the re-use of the frequency spectrum to increase capacity (Reudink 1978). Though the current

Table 1 The satellite industry sector classification[a]

Satellite industry		
Sector	Application	Revenue
Launch	Getting a space craft off the ground into orbit	USD 5.5 billion
Satellite manufacturing	Design and build satellites	USD 13.9 billion
Ground services	Consumer Equipment—Satellite TV, radio, and broadband equipment etc. Network Equipment—Gateways, VSAT, NOC & SNG	USD 113.4 billion
Satellite services	Telecommunications, PNT, Earth Observation, Science, National Security	USD 127.7 billion

[a]Mueller, D. 2017. *What Are the Uses of Direct Current? 25 April 2017. (accessed February 16, 2018).* https://sciencing.com/uses-direct-current-7394786.html accessed 16 February 2018.

[7]Albulet, M. 2017. *FCC Application Technical Document - "SPACEX V-BAND NON-GEOSTATIONARY SATELLITE SYSTEM - ATTACHMENT A TECHNICAL INFORMATION TO SUPPLEMENT SCHEDULES."*. https://www.ucsusa.org/nuclear-weapons/space-weapons/satellite-database?#.XEBRb81S_IU accessed 21 July 2017.

[8]Howell, D. 2015. https://www.techradar.com/news/internet/broadband/satellite-broadband-what-you-need-to-know-1151205 *(accessed April 14, 2017).* https://www.techradar.com/news/internet/broadband/satellite-broadband-what-you-need-to-know-1151205 accessed 14 April 2017.

contribution of satellite broadband is the lowest of the sector, it is growing with a subscriber base that approached two million in 2016.[9] Further growth is driven by increased adoption of converged technology such as high resolution (4K& UHD) "Smart TV" and the increasing use of broadband based streaming services such as Netflix.

The broadband satellite industry is undergoing significant technological innovation, most notably via new development of High Throughput Satellites in lower MEO (Medium Earth Orbit) and LEO (Low Earth Orbit) orbits. Reducing latency and increasing bandwidth whilst at the same time driving down costs, is making satellite broadband the "go-to" technology to connect the "un-connected". Consumer confidence has also improved to a significant extent, with satellite broadband operators competing well against terrestrial providers in two performance categories, namely "best peak offerings" such as xDSL and fibre in terms of the speed to price ratio with the added ability to introduce broadband in areas not serviced by any terrestrial service.[10] Latency issues are still problematic for certain applications, but non-GSO systems are offering a potential solution in problem application areas.

Currently the broadband segment is well poised for growth, having already recorded a significant (50%) revenue growth over the initial 5 year period and "delivering on advertised performance" according to the FCC's latest State of Broadband Report.[11] The market already has at least five major systems currently available: Eutelsat Tooway, HughesNet, Inmarsat Global Xpress, SES-O3b, and ViaSat Exede. Additionally, a number of major projects have been announced that will add significant additional bandwidth in the short and medium term. ViaSat in conjunction with Boeing has announced the ViaSat3 program, an example of an extreme high throughput broadband satellite system. This three-satellite constellation will provide global coverage through the deployment of three geostationary 'ViaSat3' high capacity satellites, each capable exceeding one Tbps of network capacity.[12] At the time of the announcement in 2016, the company stated that each of the three satellites will add more bandwidth than the cumulative capacity of all the operational telecommunications satellites at the time. The first satellite is scheduled for launch in 2019. SES has also announced a planned expansion to their current global O3B offering to form a system called "O3B-POWER" claiming that it will "better" the ViaSat-3 output by 300% once fully operational translating into a significant amount of satellite bandwidth available for connectivity use.[13]

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[9]State of the Satellite Industry. 2017. *State of the Satellite Industry Report June 2017*. Washington D.C.: Satellite Industry Association.

[10]See footnote 6.

[11]FCC. 2018. *2018 Broadband Deployment Report*. (Broadband Progress Report). Washignton, DC: FCC.

[12]Henry, C. 2016. *Dankberg: ViaSat 3 Satellite Will Have More Capacity than the Rest of the World Combined*. https://www.satellitetoday.com//telecom/2016/02/10/dankberg-viasat-3-satellites-will-have-more-capacity-than-the-rest-of-the-world-combined accessed 2016.

[13]Henry, C. 2017. Generation of O3b satellites that will have more than triple the capacity of ViaSat's future ViaSat-3 constellation. *SpaceNews* 11 September. https://spacenews.com/ses-building-a-10-terabit-o3b-mpower-constellation/ accessed 3 December.

In addition to the expansion of existing systems, there have been a number of “mega constellations” announced by Boeing, OneWeb and SpaceX. Frequency applications by the three companies at the FCC indicate a total of almost 16,000 broadband satellites if all were to be deployed. To put this figure into perspective according to the current Union of Concerned Scientists satellite database, as of November 2018 there were 1957 operational satellites in orbit, of which most were communication satellites, a figure dwarfed by the application of 3000 satellites for Boeing alone and more than 11,000 for SpaceX.[14] These very large constellations all feature a blend of technologies featuring “mixed” orbits, multiple frequency bands and small footprint “steerable” user-terminal antennae.[15]

3 The “Last-Mile”

Last-mile is a figurative term used in the telecommunications sector referring to the link between the telecoms infrastructure in place and the end user. It has nothing to do with physical distance, which could be very short, as in the link from a telephone pole to a house, or thousands of miles in the case of a satellite link. For a large portion of the global population, bridging the “Last-Mile” remains the principal problem preventing the provision of broadband internet services. The more remote the area, the higher the likelihood of no connection, as putting down physical cable infrastructure such as fibre optics is impractical or not even possible normally due to cost, accessibility and/or maintenance issues. There are a number of ways to connect the “Last-Mile”. These are normally deployed in a “fit-for-form” fashion depending on the nature of the last mile customer location, guided by the 3A’s: availability, accessibility and importantly affordability. The internet service provider (ISP) as a commercial enterprise will typically not deploy to an area if there is no financial incentive to do so.

In addition to all the direct technological infrastructure requirements, the user has to have access to basic infrastructure to enable functioning of all components. A user needs an account with an ISP, an organization providing basic internet access and related services such as e-mail domain hosting to an end-user. It will normally provide the user with the physical data transmission means to connect the user location with the ISP “backbone”, typically referred to as the “Last-Mile”. User access to the internet basically requires connecting the end-user and the data source through their respective ISP. This ultimately boils down to the successful linking of the “Last-Mile” between the service provider and end-user, provided it is available, accessible and affordable to the end-user. It also needs to make financial sense to the

[14] Union of Concerned Scientists. 2018. *UCS Satellite Database.* https://www.ucsusa.org/nuclear-weapons/space-weapons/satellite-database?#.XEBRb81S_IU accessed 14 January 2019.
[15] See footnote 7.

Table 2 "Last-Mile" connections

Typical last mile connection technology		
DSL—digital subscriber line		
Physical	Supports high speed	Inexpensive
Fiber optics—dedicated fiber to premises		
Physical	Very high delivery speeds	Very expensive
LAN—Local Area Network		
Physical	Supports very fast local delivery	Costly
Radio—Cellular communications, 3G, LTE etc.		
No physical link	Supports high speed	Very expensive
Satellite technology		
No physical link	High speed—latency can be an issue with GEO satellites and service speed can be influenced by severe weather conditions anywhere in the transmission path	Perceived to be costly
Wireless Network—Wi-Fi and WiMAX		
No physical link	Fast access	Not cost effective for low numbers

supplier (profit) and in addition, the supporting infrastructure needs to be available, e.g. electricity and service roads. The most popular technologies used to bridge "the last mile" are indicated in Table 2.

4 Basic Requirements for Internet Access in Rural Communities

There are five base "components" a user needs available in one place to access the internet—the "Internet" itself, electricity, hardware, software and communication services. The Federal Networking Council (FNC) officially created a definition for the "Internet" in 1995 describing it as follows:[16] "Internet" refers to the global information system that:

(i) Is logically linked together by a globally unique address space based on the Internet Protocol (IP) or its subsequent extensions/follow-ons;
(ii) Is able to support communications using the Transmission Control Protocol/ Internet Protocol (TCP/IP) suite or its subsequent extensions/follow-ons, and/or other IP compatible protocols; and

[16]NITRD. 1995. *Networking and Information Technology Research and Development.* https://www.nitrd.gov/fnc/Internet_res.pdf accessed 25 May 2016.

(iii) Provides, uses or makes accessible, either publicly or privately, high level services layered on the communications and related infrastructure described herein."

The 2017 UNCTAD Report on the Information Economy indicates that global internet powered e-commerce had grown from no contribution less than two decades before to a value exceeding 25 trillion USD by 2015.[17] The proliferation of the digital economy has unfortunately also expanded the global electricity consumption footprint significantly to drive the requirements of the internet components.

Electricity

To store and process data, all digital devices need a certain amount of electricity in the form of DC (Direct Current) to provide the constant flow of electrons required by the components of the circuit boards that process the data.[18] A Berkeley Lab report predicts that electricity use ascribed to internet data centres will reach 70 billion kWh by 2020, the equivalent of approximately eight large nuclear reactors.[19] If not for predicted increases in efficiency over current systems, these data centres would likely be using two hundred billion kWh by 2020 (Koomey 2010). The emergence of the Internet of Things (IoT) as a mainstream technology has the potential to increase internet-related electricity consumption even more. By 2025 some 152,000 new devices are estimated to engage the internet every minute.[20] As opposed to the primary electricity consumption ascribed to the internet to power ever-increasing large data centres, the electricity requirement of the end-user hardware is quite minimal, as depicted in Table 3.

For urban users the availability of access to electricity normally is not a problem in most areas of the world where, on average, 96.4% of the urban population has access, as opposed to 73% of the rural population.[21] On a regional scale, the difference between urban and rural can be much more pronounced, especially in Sub-Saharan Africa, a region with ironically the fastest growing population in the world—by 2035 this region will also have the youngest population in the world[22] (see Fig. 5).

[17]See footnote 3.

[18]Mueller, D. 2017. *What Are the Uses of Direct Current? 25 April 2017. (accessed February 16, 2018).* https://sciencing.com/uses-direct-current-7394786.html accessed 16 February 2018.

[19]Helman, C. 2016. *Berkeley Lab: It Takes 70 Billion Kilowatt Hours A Year To Run The Internet.* https://www.forbes.com/sites/christopherhelman/2016/06/28/how-much-electricity-does-it-take-to-run-the-internet/#3eedc6d71fff accessed 12 May 2018.

[20]Kanellos, M. 2016. *How To Keep The Internet Of Things From Breaking The Internet.* https://www.forbes.com/sites/michaelkanellos/2016/06/16/how-to-keep-the-internet-of-things-from-breaking-the-internet/#7a2b2edd6a7c accessed 12 May 2018.

[21]SE4ALL. 2018. *Sustainable Energy for All.* https://datacatalog.worldbank.org/dataset/sustainable-energy-all accessed 22 November 2018.

[22]Bello-Schünemann, J. 2017. *Africa's population boom: burden or opportunity?* https://issafrica.org/iss-today/africas-population-boom-burden-or-opportunity accessed 25 February 2018.

Table 3 User-end broadband power requirement[a]

	Broadband "User End" power requirement				
"Last-Mile"	ADSL	Fiber Optic	LTE/xG	Satellite	Wi-Fi
Consumption	4–20 W	12–60 W	3.5–12 W	50–100 W	2–60 W
Access device	"Feature Phone"	Notebook	PC	Smartphone	Tablet
Consumption	2–6 W	20–100 W	90–350 W	2–6 W	2–6 W

[a]Energy Use Calculator. 2019. *Energy Use Calculator*. http://energyusecalculator.com/ accessed 12 February 2019

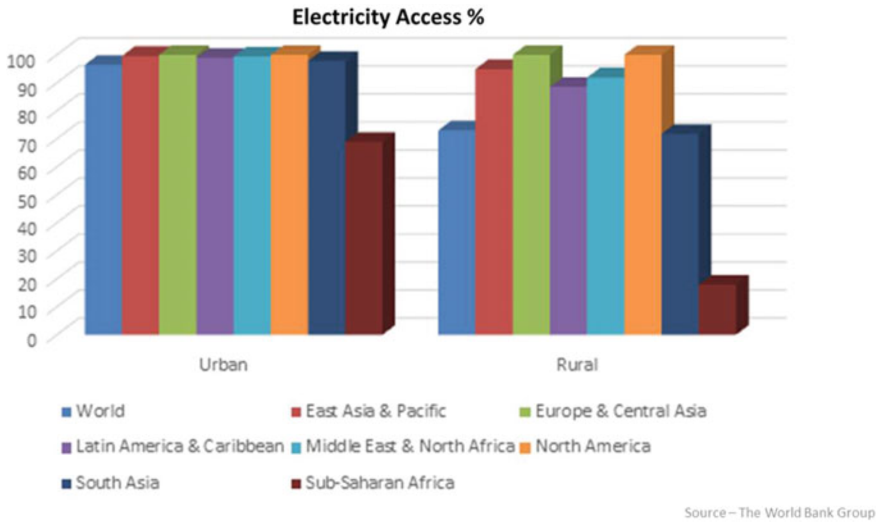

Fig. 5 Global Access to Electricity Availability—Urban vs Rural (see footnote 21)

Renewable energy sources have the ability to provide a decentralized electric power supply on a small scale that can be deployed rapidly making it ideal for low-power applications in isolated areas. Renewable energy and battery technology has been developing rapidly over the last decade, benefiting from new materials and manufacturing techniques to drive down costs and boost efficiency.

Hardware

Internet connectivity will only be possible if a user has the basic necessary hardware to engage the internet. The hardware needs to support two main functions;

- Connect—link the user to the ISP, normally though some type of modem (modulator-demodulator) used to "translate" the digital source into the correct analogue format used by the transmission medium.
- Interface—a hardware device with the necessary software allowing the user access to engage the internet e.g.—computer, smartphone, tablet etc.

The hardware requirement can be fully integrated as in the case of a smartphone. It can also be a combination of separate components such as a satellite receiver with a separate modem connected to a Wi-Fi access point where a user might access it with a tablet computer.

Software
Internet connectivity requires two basic functional software components:

- An operating system capable of supporting TCP/IP to complete the link to the ISP and authenticate the user, e.g. Android, iOS, Linux, etc.
- A web browser to allow the user to "surf the net" and interact with the internet, e.g. Mozilla Firefox, MS Explorer etc.

For a user to overcome the limitations imposed by the lack of infrastructure in a remote area all the above technology and services need to be combined into a functional system.

5 Bridging the Last Mile in the Era of Mega Constellations

As stated previously the broadband mega-constellations planned within the next few years have the potential to revolutionize the lives of the unconnected masses. Does it also provide an opportunity to reconsider the way in which satellite broadband can be integrated into the daily lives of the people? What if it were possible to create a device with the ability to deliver broadband internet to any remote community—integrated into a familiar object, without the need for power or communication infrastructure to be available at the target site. What if such a product could be integrated into the daily lives of unconnected individuals and communities in such a way that full acceptance of the technology is achieved to the maximum benefit to all stakeholders? To take the example of GPS (arguably the most widely used "space technology" by individuals and businesses alike), when it first found its way from its military roots to the commercial market, it was merely a niche market for navigation devices providing basic numerical data in the form of GPS III in 1998.[23] The technology gained additional traction when the intentional dilution of precision was discontinued, which prompted manufacturers like Garmin and Tom-Tom to bring easy-to-use personal navigation devices to market. These devices focused on providing a map-based user-interface navigation service, as opposed to the raw navigation data only—placing GPS technology in the hand of the masses. As the technology evolved, the ubiquitous square antenna defining the initial devices started to disappear. Today GPS technology is rather a sub-set of a converged device or service e.g. smartphone or Airbnb.

[23]Mark Sullivan, 'A brief history of GPS', https://www.pcworld.com/article/2000276/a-brief-history-of-gps.html accessed 15 May 2019.

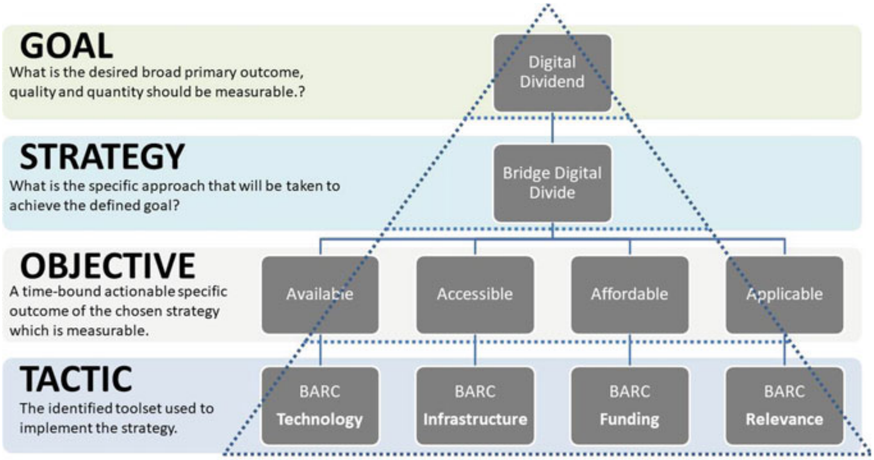

Fig. 6 GSOT model: Strategic framework positioning of the intended facility

The projected increase in broadband satellite capacity over the next decade, will present similar opportunities, especially to communities where there are currently no services. Satellite broadband could be seamlessly integrated into such a community through innovative design. A proposed apparatus developed in this work, to connect a remote community to the internet, proposes just that; a device incorporating all the necessary requirements to deliver a practical broadband internet experience to remote users. Our goal is to not only develop a concept that provides adequate power for communication needs but also creates an environment to optimise use, e.g. by providing charge points for user devices and light at night to extend productive use of the device packaged in a functional form.

Currently there are over 4 billion people without access to broadband internet who therefore cannot benefit from the "Digital Dividend" due to the preventative factors such as the "4A's" as discussed earlier. A principal preventative barrier for most of the unserved communities globally is the lack of infrastructure, i.e. the "Last-Mile". A product that can bridge the "Last-Mile" whilst providing the ability to address the other barriers of broadband adoption effectively presents an improvement opportunity for the broadband-disenfranchised masses. The first step in designing such as product referred to in this study as BARC (Broadband Apparatus for Underserviced Remote Communities), is to define a macro view in order to position the product using a generic GSOT (Goal, Strategy, Objective, Tactic) model, as illustrated in Fig. 6. The model is best illustrated as a hierarchical pyramid, at the top-end framed by a single "What" and at the base, one or more "How's"—the tactics—bound together by a strategy and objectives. The proposed product can therefore be framed as indicated by where the base layer is represented by different features of the intended solution which triggers the requirements process.

5.1 Enabling Technologies

Apart from broadband satellite technology, two additional technologies are of specific interest notably, renewable energy power generation and LED illumination.

Renewable Energy

There are primarily two types of proven renewable energy technologies that can be deployed with relative ease to provide power to small under-serviced communities;

- **Photovoltaic** (PV) technology generates electricity when light shines on a semiconductor material. Since its introduction by Bell Labs in 1954, PV have found their way into multiple applications, from powering satellites and space missions to pumping water in the desert.[24] The technology has gone through a number of iterations as new materials have become available. Traditional first-generation crystalline silicon-based PV have been superseded by second generation "thin film" flexible panels, expanding the application footprint. The third generation, characterized by non-silicon-based materials allows radical application expansion including the ability to "print" or "spray" PV materials on different surfaces an shapes.[25] PV technology is by far the most popular technology for rapid roll-out of power at un-serviced sites providing an unmatched level of decentralized capability, e.g. from a "pocket" solar powered "energy bank" for a smartphone to large panels driving a reverse osmosis desalination system for a coastal community.
- **Wind** produces electricity by converting the kinetic energy of the wind into rotational force through the use of a propeller driven turbine to spin a generator. Small wind generators are not as complicated as the large commercial systems typically deployed at a windfarm—but they are less efficient. These small generators can be deployed effectively in remote areas which experience windy conditions frequently. The efficiency of the technology has improved through new materials and improved blade design and generation through direct-drive systems (Kishore et al. 2014). Wind power can be used in areas unsuitable for PV or to compliment PV see Table 4.
- **Fuel Cells** In addition to the staple of solar and wind power technologies, there have been notable developments in fuel cell technology, including hydrogen fuel cells, methanol and biofuel, etc. Fuel cells generate electricity through an electrochemical reaction between oxygen and a hydrogen to produce water as effluent.[26] This process is extremely energy efficient (80–95%). In addition, the heat profile of the fuel cell can also be used for heating or cooling. One of the biggest advantages of a fuel cell is that, since it essentially is a battery running on

[24] NREL. 2017. *Solar Innovation Infographic*. https://www.nrel.gov/solar/infographic.html accessed 14 February 2019.

[25] Energy.gov. 2013. *Solar Photovoltaic Cell Basics*. https://www.energy.gov/eere/solar/articles/solar-photovoltaic-cell-basics accessed 12 December 2016.

[26] Kurtz, J. 2016. *Hydrogen and Fuel Cells for IT Equipment* (NREL/PR-5400-66610). Golden, CO: NREL—National Renewable Energy Laboratory.

Table 4 Renewable energy for remote communities[a]

Solar cells—photovoltaic (PV)				
Advantages	Very low eco impact	Low opex	Ease of use	Portability
Disadvantages	Limited power supply	High capex	Day only—needs storage system	Efficiency determined by environment
Small wind turbine				
Advantages	Cost effective—depending on location	Can produce power as long as the wind blows	Relatively portable	Small installation footprint
Disadvantages	High opex	Mechanical failure	Spare part availability in rural areas	Efficiency determined by environment

[a]Fong, D. 2014. Global Network Institute—Sustainable energy solutions for rural areas and application for groundwater extraction. http://www.geni.org/globalenergy/research/sustainable energy-solutions-for-ruralareas-and-application-for-groundwater-extraction/Sustainable-Energyfor-Rural-Areasand-Groundwater-Extraction-D.Fong.pdf. accessed 14 July 2017

"fuel", it solves the energy storage problem normally associated with wind and solar power. Cost and lack of true portability for systems with a practical generation capacity currently limits the usability of fuel cell technology for remote communities. Though current portable versions are not practical for remote communities as yet (typically requiring hydrogen in cartridges), development in technology of fuel cells and peripherals (e.g. solar hydrogen generators) does hold potential for applications in rural communities in the future. There are a number of commercial initiatives internationally driving the research into fuel cells, most notably by the platinum mining industry wanting to create new markets for its product, which can ultimately lead to the development of a practical power-generating unit for rural communities.[27]

LED

"Light Poverty" refers to people without the benefit of "decent" light at night. This is typically a function of not having access to electricity, resulting in a number of constraints after dark, including movement, security and productivity amongst others. Almost 17% of the global population spends up to 1000 times more money per unit of light than the "on-grid" populace, forced to burn a mixture of fuels to provide light, resulting in the equivalent greenhouse-gas emissions of 30 million automobiles.[28] LED illumination provides a high Lumen output, using very little power. This, coupled with their high longevity compared with other lighting

[27]Minerals Council South Africa. 2017. *Powered by Platinum—Factsheet 2017*. http://chamberofmines.org.za/industry-news/publications/fact-sheets/send/3-fact-sheets/381-chamber-of-mines-fuel-cell accessed 13 January 2018.

[28]Mills, E. 2015. *Can technology free developing countries from light poverty?* https://www.theguardian.com/global-development-professionals-network/2015/jul/30/can-technology-free-developing-countries-from-light-poverty accessed 19 July 2017.

technologies, makes LED illumination ideal as a supplementary service for a device, such as BARC, rolled out in remote areas.

6 Goals and Structure of This Study

The purpose of this study is sixfold;

1. Investigate how the "Last-Mile" challenge can be addressed to supply broadband to underserviced (i.e. lacking infrastructure) communities through the use of a BARC enabled by existing and emerging technology, including satellite broadband, renewable energy etc.
2. Define the requirements for such a device based on the "4A" framework—Available, Accessible, Affordable and Applicable.
3. Explore and evaluate several possible conceptual designs to select a concept design for further development.
4. Propose a detailed design based on a requirements framework for such a device and explore practical challenges, constraints and solutions.
5. Explore the benefits flowing from of such a design for the various stake-holders in terms of identified challenges affecting internet adoption, i.e. how will the design bridge the digital divide, create a digital dividend and support the attainment of the SDGs?
6. Explore potential models to fund such a design.

This study is divided into seven chapters. The first chapter introduces the concept of a device to deliver a practical broadband internet experience to users at underserviced locations, presenting the "digital divide" and "Last-Mile" as challenging concepts. Chapters 2–4 address the various aspects of the design process, from establishing requirements to presenting a detailed design. The fifth chapter is dedicated to an assessment of the potential impact of broadband introduction to unserved communities ("digital dividend"). Chapter six investigates potential funding models. Chapter seven concludes the study with suggestions for additional research into the topic.