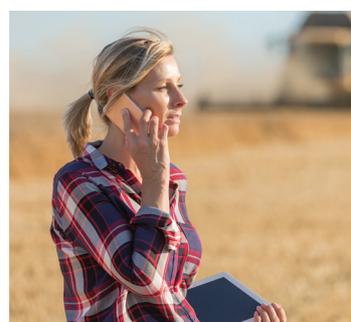
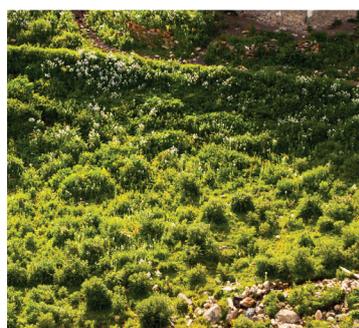
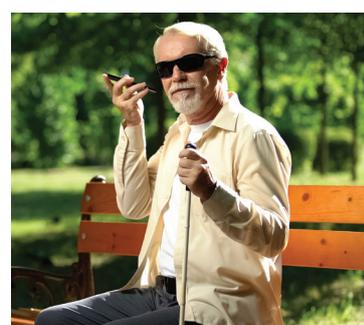


The Last-mile Internet Connectivity Solutions Guide

Sustainable connectivity options
for unconnected sites

2020



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**Sustainable connectivity
options for unconnected sites**

2020

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Foreword



It is now 35 years since the Maitland Report¹ made a compelling case for universal connectivity as the essential foundation of economic and social prosperity.

Yet today, 3.7 billion people remain totally unconnected to the power of the online world, and many hundreds of millions more lack the truly meaningful connectivity that would change their lives.

COVID-19 has laid bare the realities of our modern world: in this post-digital age, not being connected means being shut out of employment, education, access to vital healthcare services and information – in short, shut out of the full economic and social participation that every citizen should enjoy.

Finding ways to extend meaningful connectivity and bridge the digital divide is ITU-D's core

mandate. While there are many barriers to access, getting network infrastructure in place to support broadband services remains a huge challenge for nations – both developing and developed – where vast geographical distances, rugged or inhospitable terrain, or widely dispersed island communities are a factor.

In addition, the low return on investment in network deployment in sparsely populated areas means that, in many developing countries, connectivity is largely limited to urban areas, leaving rural and remote areas totally cut off.

Achieving meaningful connectivity for all and ensuring no one is left behind means finding new ways to provide reliable and affordable last-mile networks and services to unserved and under-served citizens and communities.

The Last-mile Internet Solutions Guide addresses these challenges. It consists of guidelines that can help policy-makers and professionals select and customize appropriate last-mile connectivity solutions to match their own unique environments and digital targets.

This guide is part of the ITU Telecommunication Development Bureau's (BDT) broader Last-mile Connectivity Toolkit, which aims to drive new collaborative strategies to extend connectivity to those at the bottom of the social pyramid, and to enable key stakeholders to take a more holistic approach that treats broadband as a basic public utility and core tool for socio-economic development.

¹ ITU, *The Missing Link*, report of the Independent Commission for Worldwide Telecommunications Development (chaired by Sir Donald Maitland) (Geneva, 1984).

To complement this Solutions Guide, BDT is developing a range of resources to help Member States address last-mile connectivity challenges, including a database of case studies and interactive last-mile connectivity diagnostic and decision-making tools. We also offer capacity-building services and assistance on design, planning and implementation, including identifying unconnected areas and providing expert guidance on the selection of sustainable technical, financial and regulatory solutions.

BDT also has a number of programmes that will use this guide to help design and implement sustainable connectivity solutions, such as Giga - a joint initiative between ITU and UNICEF to connect every school to the Internet, and every young person to information, opportunity and choice; our Smart Villages 2.0 partnership with the Government of Niger and others; and Connect2Recover - an initiative which aims to reinforce the provision of affordable and reliable connectivity in beneficiary countries.

I trust that ITU membership, along with stakeholders across the entire ICT ecosystem, will welcome this Solutions Guide as an indispensable tool that will facilitate efforts to extend broadband access to all citizens and communities, wherever they may live.



Doreen Bogdan-Martin
Director

Telecommunication Development Bureau, ITU

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Abbreviations

ARPU	Average revenue per user
BDT	ITU Telecommunication Development Bureau
CDMA	Code-division multiple access
CIESIN	Center for International Earth Science Information Network, Columbia University
(A/V)DSL	(asymmetric/very high speed) digital subscriber line
FTTH	Fibre-to-the-home
GB	Gigabyte
Gbit/s	Gigabits per second
GDP	Gross domestic product
GEO	Geosynchronous Earth orbit
GNI	Gross national income
GSM	Global System for Mobile Communications
GSMA	GSM Association
HAPS	High-altitude platform station
IP	Internet Protocol
ICT	Information and communication technology
IoT	Internet of Things
IMF	International Monetary Fund
IMT	International Mobile Telecommunications
ISP	Internet service provider
ITU	International Telecommunication Union
Kbit/s	kilobits per second
LEO	Low-Earth orbit
LDCs	Least developed countries
LMC	Last-mile connectivity
LTE	Long-term evolution
(k)m	(kilo) metres
Mbit/s	megabits per second
MEO	Medium Earth orbit
M(V)NO	Mobile (virtual) network operator

(continued)

ms	millisecond
PoP	Point of presence
QoS	Quality of service
SDG	Sustainable Development Goal
TDMA	Time-division multiple access
UNHCR	United Nations High Commissioner for Refugees
USAID	United States Agency for International Development
(V)HTS	(Very) high-throughput satellite
VoIP	Voice over Internet Protocol

Executive Summary

Despite the meteoric growth of the Internet and broadband connectivity, about 49 per cent of the world's population, or 3.7 billion people, were still offline and excluded from the direct benefits of the global digital economy at the end 2019.¹ Offline populations are particularly concentrated in least developed countries, where only 19 per cent of individuals were online in 2019. Regionally, in Africa and Asia-Pacific, less than half of the population is online (29 and 45 per cent, respectively) (see Figure 4).

There are several overarching reasons why billions of people remain offline, ranging from a lack of network infrastructure availability and affordable Internet services to gaps in skills and ability, the availability and cost of personal devices, and a perceived lack of relevancy. For example, over 750 million people (approximately 10 per cent of the global population) are not covered by mobile broadband (3G or higher).² This lack of coverage is particularly concentrated in rural and remote areas. In addition to the coverage gap, usage gaps exist in places with broadband coverage. For example, while up to 31 per cent of individuals in Africa do not have mobile broadband coverage, around 45 per cent do not use mobile Internet even though they live in places with mobile coverage. Estimates also suggest that there are at least 88 countries worldwide where average prices for entry-level mobile broadband service are considered unaffordable (above 2 per cent of average monthly GNI per capita).³

The Last-Mile Connectivity Internet Solutions Guide was developed to support the design and development of programmes and interventions that address two of these main issues:

- the lack of Internet infrastructure availability in certain areas;
- high Internet service prices that make Internet connectivity unaffordable for local populations.

The Solutions Guide presents a methodology for introducing sustainable, affordable connectivity solutions in unconnected and underserved geographies. Although the other challenges (e.g. digital literacy, personal devices and locally relevant content) are as important, they are not the focus here, as they are addressed in depth in other resources listed in the Annex 2.

This Solutions Guide was developed to help accelerate actions by Member States to address last-mile Internet connectivity issues in situations that include a lack of network infrastructure and with a view to encouraging more affordable service delivery. It has been written from the perspective of localities and users in geographies without Internet access: the last-mile connectivity communities. The tools, service interventions and policy solutions therefore reflect how best to extend Internet access to those localities, taking into account their unique characteristics.

¹ ITU, *Measuring digital development. Facts and figures 2020* (Geneva, 2020).

² C. Handforth, *Closing the Coverage Gap. How Innovation Can Drive Rural Connectivity* (London, United Kingdom, GSMA, 2019).

³ ITU, *Measuring digital development. ICT Price Trends 2019* (Geneva, 2020). Furthermore, in many countries that meet the 2 per cent criterion, average prices for lower-income segments of the population are above 2 per cent of average monthly GNI per capita.

The Solutions Guide is designed for use during initial consultations on how to address these gaps and includes reference materials, resources and links to other content to support the process, dialogue and decision-making that accompanies intervention design. As such, it should serve as the first stage in attempts to design sustainable solutions to connectivity gaps.

The Solutions Guide discusses the four main steps in the process (see Figure 1), each of which is covered in a separate chapter and can be broken down into the following activities:

Chapter 1: Identify digitally unconnected (and underserved) geographies (Step 1)

1a - Understand background challenges to mapping access and adoption

1b - Select a top-down and/or bottom-up mapping approach

1c - Map key elements: network infrastructure assets, potential demand and financial viability, and constraints on technology options

Chapter 2: Review options from existing solutions (Step 2)

2a - Review the case study database of last-mile connectivity solutions

2b - Utilize the categorization/typology of interventions

2c - Understand the main characteristics of, and trade-offs between, different interventions

Chapter 3: Select sustainable solutions by matching viability subject to constraints (Step 3)

3a - Select an affordable last-mile connectivity solution

3b - Identify the components of an appropriate last-mile connectivity solution

3c - Draw up the decision matrix for feasible solutions

3d - Consider additional tools to assess solutions

Chapter 4: Implement interventions to extend sustainable connectivity service (Step 4)

4a - Options for intervention - Introduction

4b - Options for intervention - Market efficiency actions

4c - Options for intervention - One-time financing (smart subsidy)

4d - Options for intervention - Recurring financing/subsidy

4e - Examples of options (from case study submissions)

In addition to the steps defined above, an introductory section presents background material on Internet connectivity and telecommunications, sharing common definitions and figures to convey key terms. Last-mile networks, also known as access networks, are defined as where the Internet reaches end users and end-user devices. This sets them apart from middle-mile networks (also known as backhaul), which connect a national backbone network (or core network) to a point in outer regions or geographic areas, thereby extending service for broader distribution to the last mile. National backbone networks are high-speed, high-capacity networks connecting a country's larger population centres and are usually the first point of connection for international Internet traffic. The Solutions Guide uses the term "last mile" as synonymous with "first mile", on the grounds that many localities are themselves actively building infrastructure links to connect to the broader global communication network.

In Chapter 1, Identify digitally unconnected (and underserved) geographies, the Solutions Guide discusses the importance of mapping existing network infrastructure assets in a given geography, and other socio-economic, geographic and environmental constraints. The challenge to mapping is the absence of a single universal dataset incorporating all network connectivity technologies and how to overlay that information with key information (such as population density) and other critical constraints (such as geographic terrain or electrical grid availability). Chapter 1 discusses two different approaches to mapping (top-down versus bottom-up, see Figure 15) and their use in combination, along with different types of mapping of network availability (demand, infrastructure, investment and service mapping). It provides a number of global resources on different types of infrastructure map by connectivity technology, together with examples of country-level data on connectivity collected by national governments.

Chapter 2, Review options from the classification of existing solutions, begins with a description of the Last-mile Connectivity Case Studies Database developed for this Solutions Guide. The case studies comprise primary data for 51 cases submitted directly to the authors for this project, plus 72 other cases from secondary sources. The database includes information on 17 different dimensions of the intervention (see Table 10).⁴

The cases were analysed to derive a typology of interventions based on two different categories: the type of network service (mobile network deployments versus general ISPs) and profit (commercial versus not-for-profit entities). Based on these two categories, the entities are classified into four main last-mile connectivity solution types: commercial ISPs; commercial MNOs; not-for-profit local ISPs; and not-for-profit MNOs (see Table 11).

The remainder of Chapter 2 articulates the various issues facing different interventions and their characteristics, including usage features, business models, revenue models, common wireless and wired network access technologies, backhaul technologies, policy and regulatory regimes, emerging access technologies and the growing deployment of hybrid solutions in terms of both technologies and business models.

Chapter 3, Select sustainable solutions by matching viability subject to constraints, focuses on the process for identifying a suitable last-mile connectivity intervention. The model it presents for the critical components of the selection process includes identifying the relevant criteria on the basis of affordability, usage, financial viability, structure and sustainability (see Figure 33).

⁴ View the data [here](#).

Chapter 3 considers each component in detail and presents a [decision matrix](#) that shows how an iterative approach can help determine what type of solution may fit best in a given situation. Each solution may, however, comprise a range of technologies and/or business models. Additional decision support tools and investment models are presented at the end of Chapter 3.

Chapter 4, Implement interventions to extend sustainable connectivity service, presents options for supporting interventions on the basis of policy and regulatory adjustments to improve the economic feasibility of direct intervention, and different types of subsidy interventions (one-time subsidies versus ongoing, recurring interventions). Examples of various case study interventions are presented, highlighting the policy actions that supported their deployment.

The Solutions Guide concludes by presenting a range of additional content in the annexes. It is but one part of the overall Last-Mile Internet Connectivity Toolkit.

Introduction



This Solutions Guide is designed to address, in consultation, engagement and discussion with governments, service providers, communities, civil society, technical organizations and young innovators, the lack of telecommunication service delivery (voice and data communications) in developing countries around the world. It details a process for identifying solutions to extend telecommunication services to unserved and underserved geographies in developing countries, which are home to the bulk of the 49 per cent of the world's people who are not yet connected to the Internet. The solutions presented here can also, however, be applied to underserved and unconnected geographies in higher-income countries.

The Solutions Guide articulates a process that helps identify specific solutions for localities that are unserved or underserved in terms of telecommunication options and that do not currently benefit from connectivity. The link to the global network of voice and data communications is referred to as the "last mile", which in this Guide is synonymous with "first mile".

1 About the Solutions Guide

The Solutions Guide clearly focuses on two aspects. First, it describes the solutions that can currently be deployed for sustainable, affordable communication service to unconnected communities in developing countries (low- and middle-income countries, landlocked developing countries and small island developing States). As the focus is on sustainable, affordable solutions for currently underserved localities and on interventions that can be deployed today, it refers to legacy access technologies found in advanced economies and emerging technologies that are not yet in widespread commercial deployment, but does not discuss them at length.¹

Secondly, the Solutions Guide focuses on the conditions and constraints facing individual localities, and the solutions it presents are aimed at providing communities with sustainable, affordable service. While these individual interventions can be aggregated and viewed through a regional or national lens (for example, by national government agencies focused on universal access), they are for the most part presented individually. Additional elements of the ITU Last-Mile Connectivity Toolkit build on the Solutions Guide by developing interactive regional and national planning tools.

The Solutions Guide addresses the constraints on Internet access and use posed by gaps in infrastructure coverage and service affordability issues. While there are other significant constraints to Internet use (such as digital literacy, relevant content, accessibility to personal devices and prevailing cultural attitudes towards gender), these are addressed in other reference documents, allowing the Solutions Guide to focus on infrastructure deployment and affordability.

The Solutions Guide draws on lessons learned by governments, service providers, technology vendors, international organizations, multilateral development banks, bilateral donors, academics and others over the past thirty years. It is not an exhaustive technical guide to addressing Internet connectivity challenges, but it does present critical issues and potential solutions, enabling each individual to assess the goal of service provision.

The Internet interconnects networks of networks in a highly decentralized system, and the opportunities and constraints of each situation will be significantly influenced by the overarching national policy and regulatory framework, prevailing market structures, geographic considerations and demographics. The Solutions Guide therefore aims to present users with the tools they need to identify, assess and consider various possible solutions. It is intended to be a living, active guide that is continuously updated, revised and added to.

The Solutions Guide can be approached in two main ways. Users can approach it as a comprehensive guide, working in cooperation with relevant partners to go through the full process and the steps identified here in order to identify, review, select and implement an intervention to extend connectivity service to previously unserved communities. Alternatively, they can adopt a modular approach. Each of the sections, from the introduction through to the annexes, are stand-alone resources and tools that can be utilized independently.

¹ For example, the use of copper infrastructure for DSL connectivity may be appropriate for areas with legacy wired telephony networks, but would not be recommended in new deployments because of its low throughput and high cost.

2 Navigating the Solutions Guide

The Solutions Guide is divided into the four main steps that constitute the planning and policy development phases of interventions to encourage deployments (see Figure 1).

Figure 1. Steps in the Last-mile Internet Connectivity Solutions Guide



Each step is broken down into sub-steps with indications of sources for the content presented and resources for a more in-depth review of the topic.

3 Definitions²

Backhaul communication: Transport of aggregate communication signals from base stations to the core network.

Bandwidth: The range of frequencies available to be occupied by signals. In analogue systems, it is measured in terms of Hertz (Hz) and in digital systems in bit per second. The higher the bandwidth, the greater the amount of information that can be transmitted in a given time.

Base station (or central station): The common name for all the radio equipment located at one and the same place used for serving one or several cells.

Broadband wireless access: Wireless access in which the connection(s) capabilities are higher than the primary rate.

Connectivity: The capability to provide connection to the Internet or other communication networks to end users.

Customer premises equipment: The equipment/network administered by the user.

End user: A human being, organization or telecommunication system that accesses the network in order to communicate via the services it provides.

Fixed wireless access: Wireless access (end-user radio connection(s) to core networks) application in which the location of the end-user termination (the end-user radio equipment antenna) and the network access point to be connected to the end user are fixed.

High-altitude platform station: A station located on an object at an altitude of 20 to 50 km and at a specified nominal, fixed point relative to the Earth.

Internet service provider: An entity, usually a private company but in some cases a non-profit or government owned, that provides Internet access through data connectivity using a variety

² See ITU-R [Recommendation F.1399-1](#): Vocabulary of terms for wireless access.

of technologies such as telephone cables (dial-up), DSL, cable (coaxial), wireless or fibre. Normally, ISPs are separate from telecommunication entities or MNOs, which provide voice services in addition to data.

Last-mile network: This is where the Internet reaches the end users and includes the local access network, including the local loop, the central office, exchanges and wireless masts.

Middle-mile network (backhaul): A distribution network that connects the national backbone to a point in a locality/geographic area (PoP) for broader distribution out to the last-mile network.

National backbone (or core) network: Connects international Internet traffic (usually through undersea or terrestrial fibre-optic cables) to the national high-speed, high-capacity backbone network connecting the country's bigger cities and major population centres.

Mobile wireless access: Wireless access application in which the location of the end-user termination is mobile.

Mobile network operator: An entity that provides mobile cellular services over either its own network infrastructure or another operator's infrastructure (in which case it would be a mobile virtual network operator). This includes voice and text (SMS) services in addition to, potentially, data.

Nomadic wireless access: Wireless access application in which the location of the end-user termination may vary but must be stationary while in use.

Universal access: Refers to reasonable telecommunication access for all. Includes universal service for those who can afford individual telephone service and widespread provision of public telephones within a reasonable distance of others.

Wireless access: End-user radio connection(s) to core networks. Core networks include public switched telephone networks, integrated services digital networks, public land mobile networks, public switched data networks, the Internet, wide area/local area networks and community antenna television.

Wired (fixed line): A physical line connecting the subscriber to a network, the term "wired" or "fixed-line" being used to distinguish the network from its wireless counterparts.

4 Describing telecommunication network components

As noted in the definitions, there are multiple ways to describe the different components of a telecommunication network (see also Figure 2 and Table 1).³These include the following:

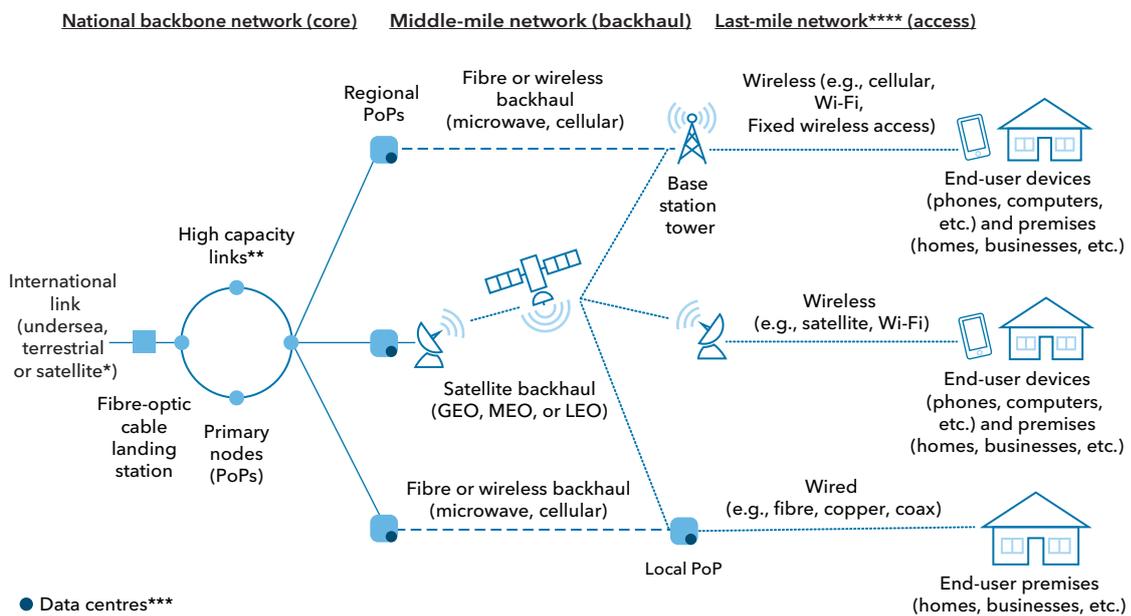
National backbone (or core) network: This connects international Internet traffic (usually through undersea or terrestrial fibre-optic cables) via submarine cable landing stations (or terrestrial gateways for land borders) to the national high-speed, high-capacity backbone network connecting the country's bigger cities and major population centres. A country's core network provides the first layer of overall network redundancy in case there are breaks between core network PoPs and data centres.

³ See, for example, the typologies and figures presented by the [European Union](#) and the [World Bank](#).

Middle-mile network, or backhaul: This is the distribution network that connects the national backbone to a point in an outer locality/geographic area for broader distribution out to the last-mile network.

Last-mile or access network: This is where the Internet reaches end users, and includes the local access network, including the local loop, central office, exchanges and wireless masts. The access network reaches end-user devices, typically basic and smartphones, laptops, tablets, computers and other Internet-enabled devices. In this Solutions Guide, “last mile” is synonymous with “first mile”, as localities are in many cases themselves actively building the infrastructure links needed to connect to the broader global communication network.

Figure 2. Telecommunication network components supporting last-mile interventions in developing countries



Source: Authors, adapted from various sources

Notes: Not exhaustive, for illustrative purposes and some segments are interchangeable further, particularly in the last-mile;

*In few country cases, satellite continues to be the main, or only, source of international connectivity;

** These are predominantly fibre-optic links (terrestrial and undersea) but in few country cases, national backbone networks utilize wireless microwave and satellite;

*** Data centres can be placed in various parts of the network, depending on the need to aggregate data (such as in core networks, or place data as close to end users as possible (such as in middle mile and last-mile networks);

**** The technologies listed for the last mile are not exhaustive.

Table 1. Telecommunication network components supporting last-mile interventions in developing countries

Component name	Also known as	Brief description	Typical distances	Common infrastructure technologies
International cross-border traffic	International bandwidth	Connects countries to other countries and the world	Thousands of km	Fibre-optic cables (undersea and terrestrial), satellite
International transit traffic	Transit	Applies to traffic crossing countries to land-locked countries, adding to international bandwidth costs	Hundreds to thousands of km	Fibre-optic cables (undersea and terrestrial), satellite
National backbone network	Core	Connects major network servers and data centres (PoPs) within a country	Hundreds to thousands of km	Fibre-optic cables (terrestrial and some undersea), satellite
Middle-mile network	Backhaul	Connects core network to regional PoPs	Tens to hundreds of km	Fibre, microwave, satellite
Last-mile network	Access	Reaches end users with connectivity from regional PoPs	Tens of km	Wireless (cellular: 2G, 3G, 4G, 5G, fixed wireless access, Wi-Fi, satellite, etc.); wired (fibre, copper, coax, etc.)

5 Background, motivation and objectives

The digital transformation of economies is predicated on universal connectivity, which is itself underpinned by broadband connectivity. In 2016, when it adopted the SDGs, the global community included a specific target (target 9c) on universal affordable Internet access in least developed countries by 2020.⁴ In 2019 alone, three major high-level multi-stakeholder groups emphasized the centrality of extending universal Internet access as a first step on the path to digital transformation. For example, in its June 2019 summary report, the United Nations Secretary-General’s High-Level Panel on Digital Cooperation⁵ wrote: “We recommend that by 2030, every adult should have affordable access to digital networks, as well as digitally-enabled financial and health services, as a means to make a substantial contribution to achieving the SDGs.”

Similarly, a report released by the New European Union-African Union Digital Economy Task Force in June 2019⁶ identified its first goal as follows: “1. Accelerate universal access to affordable broadband”; and a 2018 report by the Pathways for Prosperity Commission on extending universal access focused on meaningful connectivity.⁷

The global focus on universal connectivity is driven in part by the fact that, despite the meteoric growth of Internet use and broadband connectivity, about 49 per cent of the world’s population,

⁴ The Alliance for Affordable Internet nevertheless estimates that SDG 9c will only be achieved in 2044, 22 years after the intended target date of 2020 (see Alliance for Affordable Internet, *Affordability Report 2015/16* (Washington, DC, 2016)).

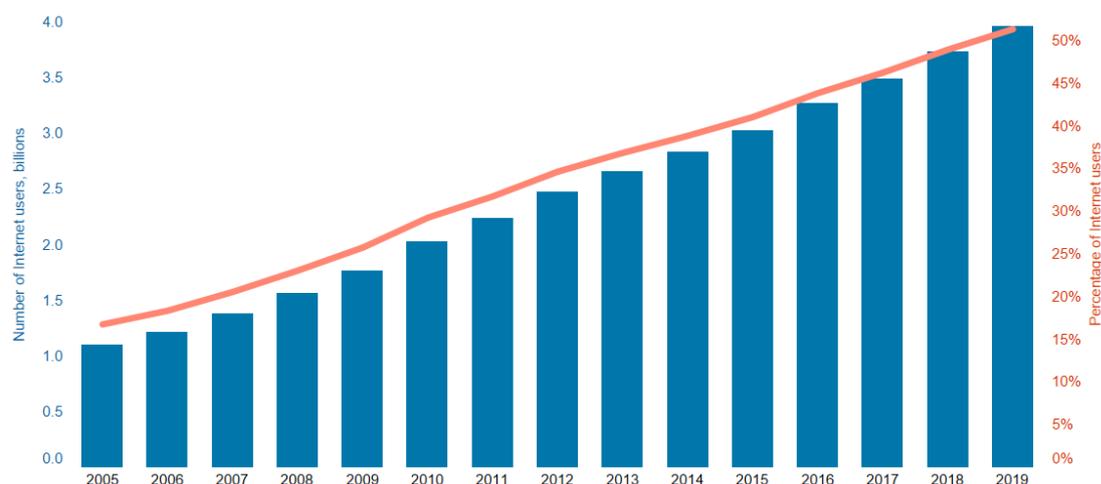
⁵ United Nations, *The age of digital interdependence, Report of the UN Secretary-General’s High-Level Panel on Digital Cooperation* (New York, 2019), p.7.

⁶ New European Union-African Union Digital Economy Task Force, *Accelerating the Achievement of the Sustainable Development Goals* (2018).

⁷ Pathways for Prosperity Commission, *Digital Lives. Meaningful Connections for the Next 3 Billion* (2018).

or 3.7 billion people, were still offline and excluded from the benefits of the global digital economy at the end 2019⁸ (see Figure 3). Offline populations are particularly concentrated in least developed countries, where only 19 per cent of individuals were online in 2019. Regionally, less than half of the populations of Africa and Asia-Pacific are online (29 and 45 per cent, respectively) (see Figure 4).

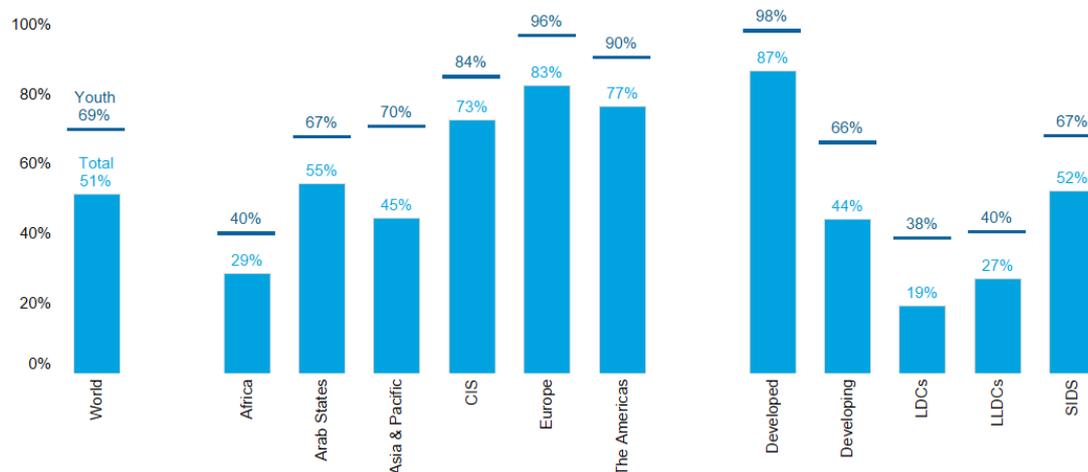
Figure 3. Individuals using the Internet, 2005-2019*



Source: ITU, see note 2

*Estimate

Figure 4. Percentage of individuals using the Internet, by region and development status, 2019*



* ITU estimate. Source: ITU
 Note: youth means 15-24 year old individuals using the Internet as a percentage of the total population aged 15 to 24 years.

Source: ITU, see note 2

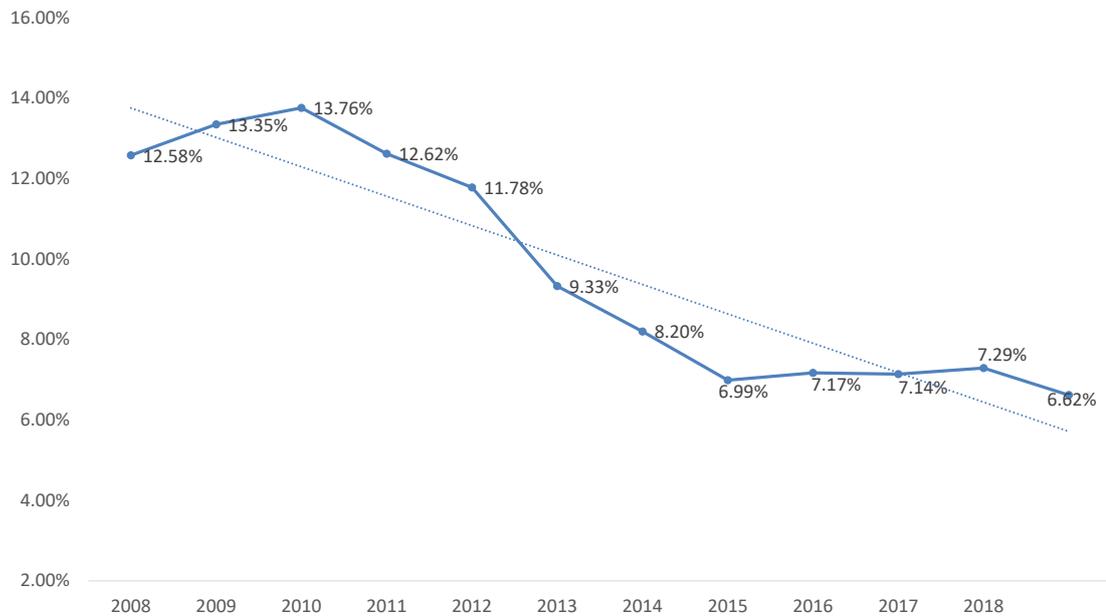
*Estimate

Despite the success of private sector-led network deployments, Internet user growth is slowing, delaying the benefits of Internet adoption for hundreds of millions of people. For individuals

⁸ ITU, op. cit., note 2.

using the Internet, the growth rate slowed for the aggregate world population. As Figure 5 demonstrates, the three-year trailing average of global Internet user growth continues to decline. While slowing growth may be expected as technology adoption matures, global Internet adoption is only just above 50 per cent, and universal adoption may be decades away.

Figure 5. Slowing rate of growth in the number of Internet users worldwide



Source: Calculations based on “end-2020 estimates for key ICT indicators” from ITU data in *ICT Facts and Figures 2020*

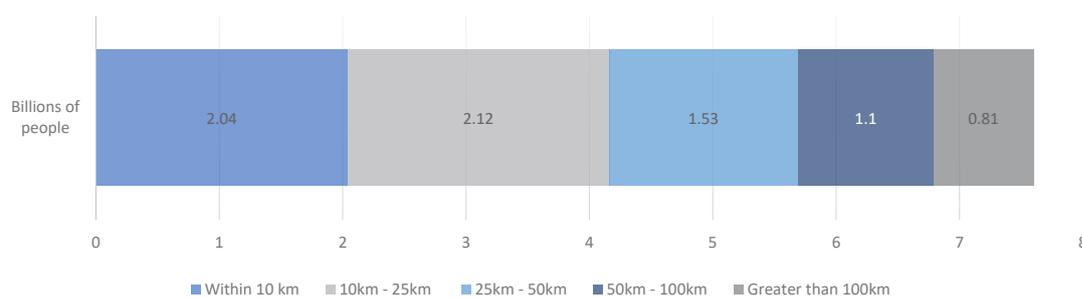
There are four overarching reasons why billions of people remain offline: lack of network infrastructure availability; lack of affordable Internet service; gaps in skills and ability; and lack of perceived relevancy.

Coverage gaps remain in the deployment of all network technologies. For example, while mobile cellular networks provide widespread levels of connectivity, recent data from GSMA (the association of network operators) indicate that up to 750 million people worldwide live in areas where there is a “coverage gap”, i.e. no signal from any mobile broadband network (at least 3G).⁹ A further 3.28 billion people are in the “usage gap”, i.e. they live in an area covered by a mobile broadband network but are not using the mobile Internet, for reasons related to affordability (of service and devices), relevance and user skills.

Fibre-optic cable networks provide high-speed data connectivity but have limited reach to populations outside urban and suburban areas. Around the world, only 2 billion people are within ten km of current fibre-optic cable networks, suggesting that the vast majority of the world’s population still does not have even potential access to fibre networks because of geographic distance (Figure 6). In addition, the figure for actual access to fibre networks may even be overstated, because even if individuals reside within ten km of fibre networks, there may be no current PoP, optical line terminal or fibre drops able to link the network to the individual’s residence or office.

⁹ GSMA, *Connected Society. The State of Mobile Internet Connectivity 2019* (2019).

Figure 6. Population within reach of fibre, March 2019*

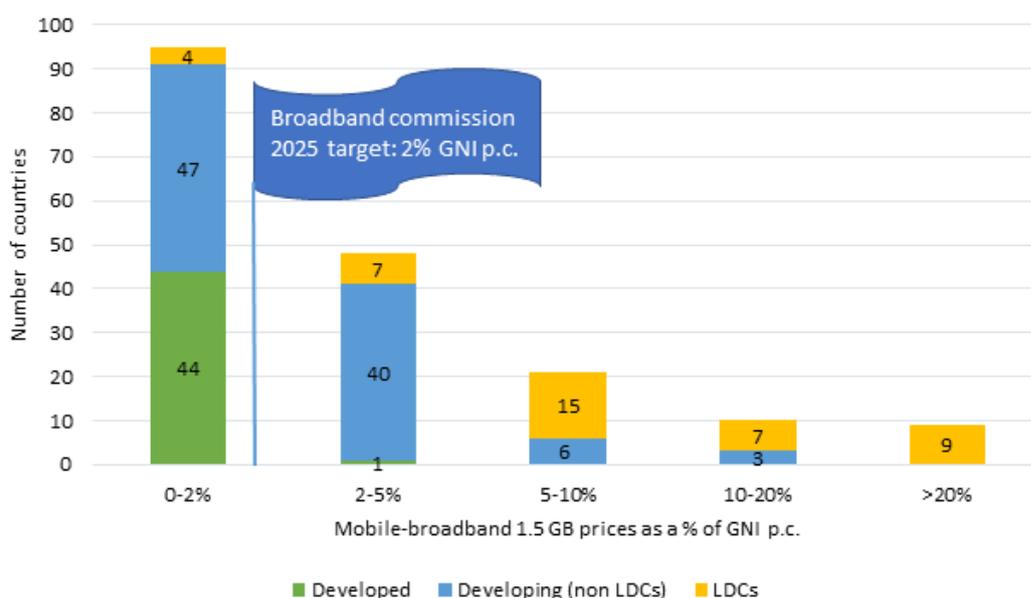


Source: ITU

* Not cumulative; the figure depicts the population within the category not inclusive of lower thresholds.

Moreover, even when telecommunication networks are present, access to the Internet may be limited by prohibitively high prices. Service may be economically viable for the service provider in such situations, as certain segments of the population may be purchasing it, but lower-income individuals and families may be priced out of connectivity. This is why the ITU/ UNESCO Broadband Commission for Sustainable Development has adopted a target whereby entry-level broadband services in developing countries should cost less than 2 per cent of monthly GNI per capita.¹⁰ The latest data from ITU suggest that the average prices for entry-level mobile broadband service in at least 88 countries worldwide – almost all of them are developing and least developed countries (see Figure 7 and 8) – are considered unaffordable (above 2 per cent of average GNI).

Figure 7. Number of countries having achieved the Broadband Commission targets for computer-based mobile-broadband services (1.5 GB per month), 2020*

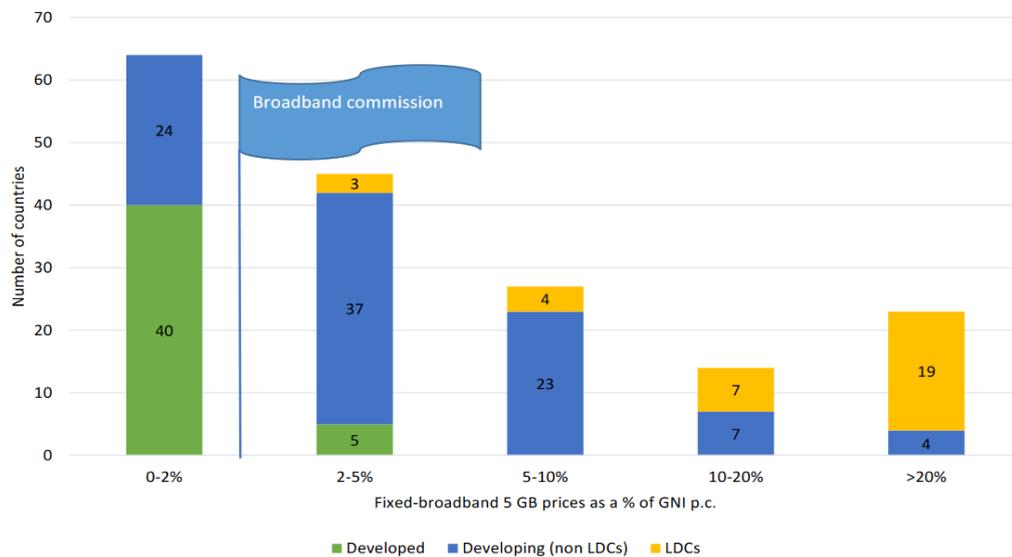


Source: ITU, *Measuring Digital Development: ICT Price Trends 2019* (Chart 21, p. 46)

* Data speeds of 3G and above

¹⁰ See <https://www.broadbandcommission.org/Pages/targets/Target-2.aspx>.

Figure 8. Number of countries having achieved the Broadband Commission targets for computer-based fixed-broadband services (5 GB per month), 2020



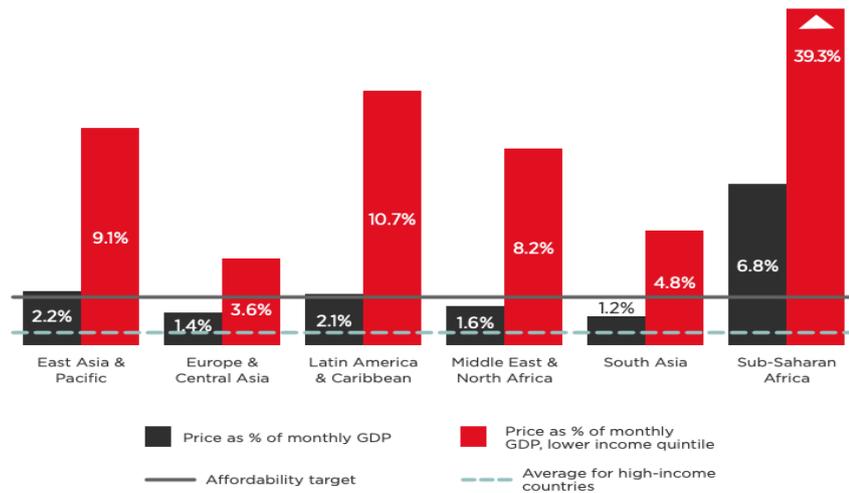
Source: ITU, *Measuring Digital Development: ICT Price Trends 2019* (Chart 37, p. 65)

*** Data speeds of 256 Kbit/s and above**

The 2-per-cent threshold has been adopted across different organizations as a useful metric to estimate affordable service. It must be borne in mind, however, that this is average income for a given population and that even in situations where a country's pricing meets the threshold, access prices for lower-income groups may be significantly more than 2 per cent of GNI and a more granular and targeted focus on lower income groups may be necessary¹¹ (see Figure 9). That is why this Solutions Guide focuses on interventions that provide affordable service.

¹¹ The Alliance for Affordable Internet "1 for 2" campaign defines affordable Internet as 1 GB of mobile broadband data priced at 2 per cent or less of average monthly income (<https://a4ai.org/affordable-internet-is-1-for-2>). The *Affordability Report 2015/16* (see note 9, chapter 3) discusses the distorting effects of income inequality on affordability measures.

Figure 9. Affordability of 1 GB of data in low- and middle-income countries, by region (2018)



Source: GSMA Intelligence calculations based on pricing data from Tariffica. For each region, the mean average is taken based on the countries for which we have available data. Data on income distribution is sourced from the World Bank.

Source: GSMA (see note 14)

This Solutions Guide was developed to help accelerate actions by Member States to address last-mile Internet connectivity issues, which include lack of network infrastructure, and to encourage more service delivery in cases of unaffordable access. It has been written from the perspective of localities and users in geographies where Internet access is out of reach: the last-mile connectivity communities. The tools, service interventions and even the policy solutions it recommends relate to how best to extend Internet access to those localities, taking into account their unique characteristics. The other main challenges – skills (i.e. digital literacy) and perceived relevancy (i.e. locally relevant content) – are addressed in depth in other resources, including those listed in Annex 2.

6 Solutions Guide steps

The Solutions Guide sets out four distinct steps, each comprising a series of sub-steps. Figure 10 below details the steps and sub-steps.

Figure 10. Steps in the Last-mile Internet Connectivity Solutions Guide



Step 1: Identify digitally unconnected (and underserved) geographies

1a - Understand background challenges in mapping access and adoption

1b - Select a top-down and/or bottom-up mapping approach

1c - Map key elements: network infrastructure assets, potential demand and financial viability, and constraints on technology options

Step 2: Review options from existing solutions

2a - Review the case study database of last-mile connectivity solutions

2b - Utilize the categorization/typology of interventions

2c - Understand the main characteristics of, and trade-offs between, different interventions

Step 3: Select sustainable solutions by matching viability subject to constraints

3a - Select an affordable last-mile connectivity solution

3b - Identify the components of an appropriate last-mile connectivity solution

3c - Draw up the decision matrix for feasible solutions

3d - Consider additional tools to assess solutions

Step 4: Implement interventions to extend sustainable connectivity service

4a - Options for intervention - Introduction

4b - Options for intervention - Market efficiency actions

4c - Options for intervention - One-time financing (smart subsidy)

4d - Options for intervention - Recurring financing / subsidy

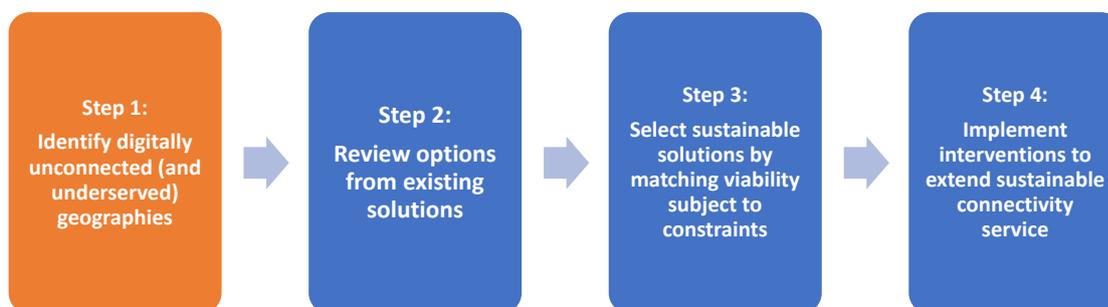
4e - Examples of options (from case study submissions)

Chapter 1. Identify digitally unconnected (and underserved) geographies (Step 1)



The first step on the path towards providing sustainable, affordable connectivity is identifying the geographic limits of network infrastructure in relation to the population's location. The challenge here is that there is no systematic, publicly available, universal dataset of global connectivity infrastructure. Figure 11 situates Step 1 in the overall process and sets out its activities.

Figure 11. Step 1 in the Last-mile Internet Connectivity Solutions Guide



Step 1 activities to identify digitally unconnected (and underserved) geographies:

- 1a - Understand background challenges in mapping access and adoption
- 1b - Select a top-down and/or bottom-up mapping approach
- 1c - Map key elements: network infrastructure assets, potential demand and financial viability, and constraints on technology options

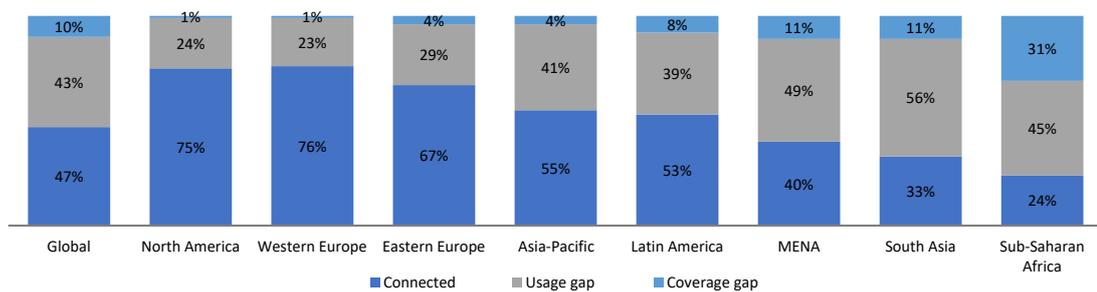
1.1 Understand background challenges in mapping access and adoption (Step 1a)

The rationale for beginning with mapping is to identify areas of limited or no affordable connectivity in order to begin the process of identifying both the potential reasons for the limited service and potential sustainable solutions.

Mapping connectivity is fraught with complications because numerous technologies provide digital communications; an amalgam of the coverage areas served by those technologies therefore needs to be developed and compared to the geographic location of individuals. For example, ITU estimates that just over 2 billion people reside within at least 10 km of high speed fibre-optic cables (see Figure 6). However, in terms of cellular connectivity, GSMA estimates that 90 per cent of the world’s population lives within the coverage areas of mobile data network operators (see Figure 12).

According to GSMA,¹² over 750 million people (approximately 10 per cent of the global population) are not covered by mobile broadband (3G or higher), particularly in rural and remote areas. This is compounded by a usage gap in places with broadband coverage. For example, while up to 31 per cent of individuals in Africa do not have mobile broadband coverage, around 45 per cent of those with such coverage do not use mobile Internet.

Figure 12. Terrestrial mobile coverage and usage gaps around the world



Source: Handforth, see note 3

Satellite providers, on the other hand, are providing service to some geographies that remain unserved by terrestrial networks (comprised of fibre, cellular and other technologies), including suburban, rural and isolated areas.¹³

However, a composite view of all, or even most, service coverage areas has not been developed at global level, and seldom exists at national level, because mapping the various types of communication network infrastructure is a complicated endeavour, for a number of reasons: different layers of technology with different coverage reach; much of the infrastructure data are commercially proprietary; the data are constantly changing over time because of investment and decommissioning; geographic scope; and the need to overlay relevant geographical features such as topography and socio-economic data.

There is at present no systematic, publicly available, universal dataset of global connectivity infrastructure. This is not the case for other major basic infrastructure, such as road networks or electrical grids mapping, or for other significant resources, such as global forest cover. For

¹² Handforth, op. cit., note 3.

¹³ See, for example, Satbeams, at <https://www.satbeams.com/footprints>.

example, the World Bank, Facebook and others have collaborated to develop a new predictive model for more accurate electrical grid mapping. Similarly, the World Resources Institute manages Global Forest Watch, a near real-time forest cover monitoring platform.

Robust network infrastructure data exist in isolation: either in disparate layers or behind proprietary datasets. Service providers tend to have robust maps of their network infrastructure. However, most often, those data remain proprietary and in isolation, uncombined with all other relevant infrastructure layers. Some providers, particularly online content service providers and over-the-top Internet companies, have visibility into their customer's geographic locations as they have hundreds of millions, if not billions, of users, and the applications running their services are also able to determine what types of connectivity individuals use to connect to the Internet. In many cases, these entities will provide access to the data for network planning purposes, but only on a case-by-case basis.

1.2 Select a top-down and/or bottom-up mapping approach (Step 1b)

There are two main approaches to the geographical mapping of network infrastructure and access, depending on the geographic scope of the exercise. The first is top-down and involves mapping a large geographic area by accessing secondary data sources and identifying gaps in infrastructure service. This differs from the more granular and localized bottom-up approach, which starts with an ex-ante selection of a specific locality and builds an understanding of current conditions through a direct census of residences and physical survey of network assets. Both approaches overlay infrastructure assets and coverage against population density. Figure 13 below differentiates between the two, but a given mapping exercise may take elements from both approaches, accessing secondary mapping of network assets, population density and other relevant infrastructure, and combining it with an on-the-ground survey and census.

Figure 13. Differences between the top-down and bottom-up approaches to mapping unconnected and underserved populations

Top-down approach:

Large geographic areas (national or sub-national) are mapped by accessing secondary mapping data in order to identify infrastructure coverage gaps.

Additional characteristics:

- Data gathered from secondary sources such as national government agencies or third-party aggregators (e.g. satellite data, operator infrastructure, etc.)
- Tends to cover large geographic areas
- May develop multi-pronged approach to connectivity interventions beyond a single site/location

Bottom-up approach:

Starts with the specific, targeted locality, mapping local data and testing for different aspects of network infrastructure availability.

Additional characteristics:

- Local mapping (testing network infrastructure available in the vicinity)
- Adding socio-demographic attributes at the local level gathered via census
- Includes relevant geographic and environmental conditions

The data collected may pertain to available network infrastructure (access and backhaul networks and pricing, mobile network towers, radio spectrum utilization, Wi-Fi hotspots, cable and fibre PoPs), financial viability (locality size by geographic area and population, population density, per capita income levels, demographic data such as adult share of population, literacy levels and gender distribution) and other environmental and geographic constraints (grid electrification presence, road networks, topography and weather patterns). In addition to the two main approaches, there are at least four different types of connectivity

map covering different elements and aspects of connectivity service: demand mapping, infrastructure mapping, investment mapping and service mapping (see Table 2¹⁴).

Table 2. Core mapping content of different types of connectivity maps

Demand mapping	Infrastructure mapping	Investment mapping	Service mapping
<ul style="list-style-type: none"> • Demand for bandwidth • QoS • Willingness to pay • Required services 	<ul style="list-style-type: none"> • Telecommunication infrastructure • Other relevant infrastructure (utilities) • Construction works (roads, buildings) 	<ul style="list-style-type: none"> • Segmenting infrastructure by investment sources • Private/funded • Planned/realized 	<ul style="list-style-type: none"> • Bandwidth and access technology (level of service availability) • Provider • Data volume usage, take-up • Price

A standard process of map development can incorporate three stages (see Table 3): data collection, data processing and data publication. Data collection spans the identification of relevant sources and the appropriate data series to be collected. Data processing involves combining data series and robust quality checks. Data publication encompasses the sharing of data with appropriate audiences at relevant levels.

Table 3. Common process for all types of broadband mapping

Data collection	Data processing	Data publication
Choice of <ul style="list-style-type: none"> - data sources - information to be collected - spatial level of data collection - Data supply process/frequency 	<ul style="list-style-type: none"> - Quality checks (additional manual checks/user feedback) - Data conversion - Additional data spatial integration 	Choice of <ul style="list-style-type: none"> - data access level - spatial level of publication - publication format

Source: J. Navas-Sabater, *Broadband Mapping - International Good Practices and World Bank Experience* (slide presentation, 2 July 2019), World Bank Group

Once a review of the two approaches (top-down and bottom-up) has been conducted, a decision can be made on which approach to pursue, or which elements from both approaches to combine. As the Solutions Guide has been drafted from the perspective of individual communities that are not yet served by accessible and affordable telecommunication services, it will focus on the elements needed in the bottom-up approach. There are, however, many firms and resources (as noted in the description of the top-down approach) that can be contacted for comprehensive support for a top-down approach. The bottom-up approach tends to be more user- and locality-driven. Table 4 summarizes the pros and cons of both approaches. Additional mapping examples and case studies are presented in Annex 1.

¹⁴ The European Union presents differences and examples between different mapping types here: <https://ec.europa.eu/digital-single-market/en/broadband-and-infrastructure-mapping-project>.

Table 4. The top-down versus the bottom-up approach: pros and cons

	Top-down approach	Bottom-up approach
Pros	<ul style="list-style-type: none"> • Comprehensive view across a large geographic region • Can identify multiple communities in need of connectivity service support • Can fulfil multiple objectives in robust data gathering and monitoring (service obligations, electrification issues, etc.) 	<ul style="list-style-type: none"> • Able to focus in depth on developing a very granular picture of connectivity for a specific locality that would not necessarily be possible for a large region or many communities • Can be conducted and completed more effectively with fewer resources
Cons	<ul style="list-style-type: none"> • Resource intensive: time, labour, capital, skills and processing power • May require regulatory intervention to obtain certain datasets • Requires commitment to ensure data validity and accuracy (updating) • May bias intervention approach if the datasets are incomplete (e.g. focusing only on cellular options vs all wireless technologies) 	<ul style="list-style-type: none"> • Reduces the geographic focus to a single or a few communities • Affects only the locality in view, not a country or region • Can also be time- and labour-intensive in the drive to collect as much relevant data as possible

Five mapping resources may be of particular value for large-scale mapping efforts.

1) The ITU Broadband Map (<https://itu.int/go/Maps>) is an online interactive broadband transmission map developed by ITU and available to the public. It shows undersea and terrestrial backbone infrastructure; it provides location intelligence through data visualization and a GIS tool for ICT development.

Currently the map depicts data from over 480 operators, 19 775 nodes, and over 3.5 million km of network infrastructure. The mapping tool also includes overlays of United Nations-recognized boundaries, natural Earth topography, population density, distances to nodes, satellite earth stations and Internet exchange points.

2) The African Terrestrial Fibre Optic Cable Mapping Project (AfTerFibre, <https://afterfibre.nsrc.org>) provides a map of African terrestrial (and now undersea) fibre-optic infrastructure initiatives. It was developed with initial support from Google and is now hosted and supported by the Network Startup Resource Center. AfTerFibre is an open-data initiative with data sources available for public download. Maps for AfTerFibre are typically sourced as raster images, sometimes from the corporate websites of operators, sometimes from studies or reports on regional infrastructure development, and sometimes through personal contacts. Maps that are not already available on the web are uploaded to a Flickr website. The raster images are then digitally traced and converted into GIS format and uploaded to CartoDB, a cloud-based GIS platform.

3) The Connected Pacific (<https://connectedpacific.org>), which is also supported by the Network Startup Resource Centre and the APNIC Foundation, derives its cable routes from a range of primary sources, including FCC licences, financial filings, nautical charts, cable ship location data, environmental approvals and operator presentations.

Table 5. Top-down infrastructure mapping: examples

Map name	Geographic coverage	Terrestrial or undersea networks	Publicly available or commercial service	All data downloadable by the public	URL
ITU Broadband Maps	Global	Terrestrial fibre, microwave and undersea fibre	Public	Limited access	https://itu.int/go/Maps
Telegeography Submarine Cable Map	Global	Undersea fibre	Public	Yes	https://www.submarinecablemap.com/ and https://github.com/telegeography/www.submarinecablemap.com
African Terrestrial Fibre Optic Cable Mapping Project (AfTerFibre)	Africa	Terrestrial fibre and undersea fibre	Public	Yes	https://afterfibre.nsrc.org/
The Connected Pacific	East Asia and the Pacific	Undersea fibre	Public	Yes	https://connectedpacific.org
Satbeams	Global	Satellite	Public	Some	https://www.satbeams.com/
GSMA Mobile Coverage Maps	Africa (8 countries)	Terrestrial cellular	Public	No	http://www.mobilecoveragemaps.com/
Masae Analytics	Global	Terrestrial networks and undersea	Commercial	No	https://www.masae-analytics.com/
InfraNav	Global	Terrestrial networks and undersea	Commercial	No	https://www.infranav.com/
Fraym	Africa	Terrestrial networks and undersea	Commercial	No	https://fraym.io/
TowerSource (infrastructure)	Global	Terrestrial networks	Commercial	No	https://www.towersource.com/
mapELEMENTS (coverage)	Global	Terrestrial mobile coverage	Commercial	No	https://www.mapelements.com/
Opensignal	Global	Terrestrial cellular coverage	Commercial	No	https://www.opensignal.com/

4) The newly updated GSMA Mobile Coverage Maps (<http://www.mobilecoveragemaps.com/>) were created by GSMA on the Mobile Coverage Maps platform to address the lack of reliable and accurate coverage data in emerging markets. The interactive maps allow users to:

- gain an accurate and complete picture of mobile coverage in a given country for each generation of mobile technology (2G, 3G and 4G);
- assess the coverage status for every population settlement in the country, no matter how small or remote;
- simulate the deployment of new mobile sites and estimate the population covered.

To ensure that they are relevant, accurate and actionable, the coverage maps are based on first-hand high-granularity data. To that end, GSMA collects network information (such as the location of antennas and the height of towers) directly from mobile operators and estimates the combined coverage of all the mobile operators in the market using a standard propagation model. The coverage data are then overlaid with high-resolution population data developed by the Facebook Connectivity Lab and the CIESIN. The data estimate human population distribution at a hyperlocal level, based on census data and high-resolution satellite imagery. Finally, the maps integrate other socio-economic indicators and key buildings such as schools, hospitals and medical centres. The online platform currently hosts eight maps: Ghana, Côte d'Ivoire, Liberia, Nigeria, Rwanda, Tanzania, Uganda and Zambia; other countries are to be added in the coming months. The coverage maps have a number of use cases, but the main one is planning for rural infrastructure. For this, GSMA has developed algorithms that use the underlying data in the maps to generate optimal deployments that maximize population coverage while minimizing costs. With this analysis, GSMA is helping mobile operators identify rural areas where they can extend coverage in a commercially viable way. It also helps public authorities prioritize their connectivity efforts by identifying areas that require some form of subsidy or concession to lower the cost of deployment (e.g. import duty relief).

5) Satbeams (<https://www.satbeams.com/footprints>) is a compendium of geostationary/communication satellites, including their coverage zones, technical details and frequency charts. It currently has one of the biggest libraries of satellite footprints, with detailed information on over 1 800 beams, over 400 geostationary satellites, 7 500 transponders and 32 000 channels.

At country level, various government departments are developing and tracking network infrastructure and service deployment. See Table 6 for examples of how the national governments of Poland, the United Kingdom and Ireland, along with the European Union, all maintain mapping databases to inform service deployment.

Table 6. Top-down country mapping: examples

Country	Department	Map type	Open data	URL
Poland	Office of Electronic Communications	Infrastructure	Yes	https://wyszukiwarka.uke.gov.pl/
United Kingdom	Office of Communications (Ofcom)	Mobile service coverage	No	https://checker.ofcom.org.uk/
Ireland	Commission for Communications Regulation (ComReg)	Mobile service coverage	No	https://coveragemap.comreg.ie
European Union	European Commission Directorate General for Communications Networks, Content & Technology (DG CNECT)	Broadband service coverage	Yes	https://www.broadband-mapping.eu/

Box 1. Top-down mapping example: Internet para Todos (Peru)

Internet para Todos (<https://internetparatodos.tid.es/>) (IpT) is an effort to expand Internet connectivity, initially in Peru, led by Telefónica in partnership with the Inter-American Development Bank, Facebook and the Development Bank of Latin America. It is an independent company that deploys, operates and owns its own mobile infrastructure (including open radio access network infrastructure) in support of its MNO partners, acting as a connectivity-as-a-service operator (see Table 16 for business model definitions).

A key element of IpT was a robust top-down mapping element of the project that focused on the initial problem of identifying all the relevant information needed for technical and financial decision-making. IpT tackled the mapping challenge by incorporating high-definition country-wide satellite imagery, combined with other datasets and its own internal network information, and applied neural network models, such as machine-learning algorithms trained by census data, in order to correctly identify houses, settlements and other relevant features.

See also:

<http://www.ipt.pe>

<https://www.telefonica.com.pe/es/ipt>

<https://www.linkedin.com/pulse/how-telef%C3%B3nica-uses-ai-ml-connect-unconnected-patrick-lopez/>

<https://www.slideshare.net/wap13/big-data-for-social-good-106562070>

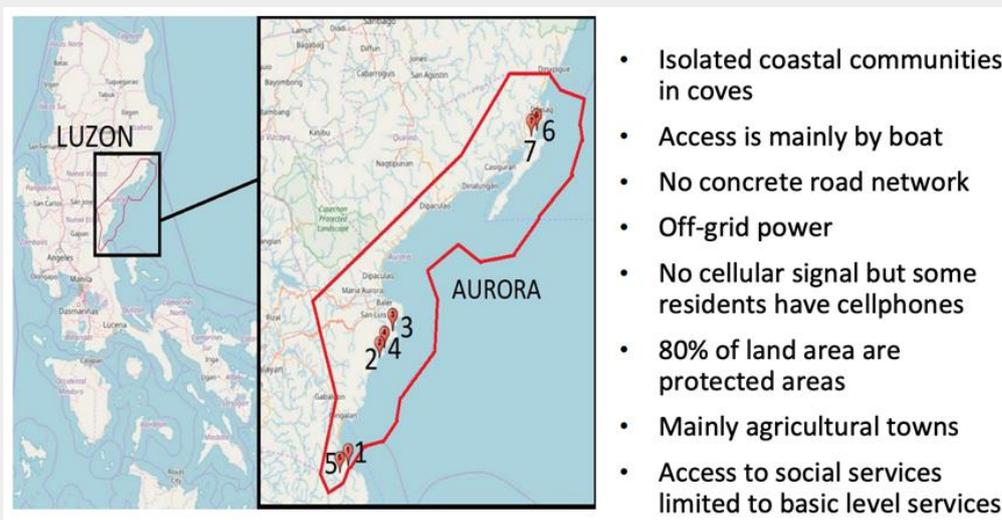
Box 2. Bottom-up mapping example: PCARI VBTS Project (Philippines)

The PCARI Village Base Station (VBTS) Project (<https://pcarivbts.github.io/>) is a community cellular network project focused on providing basic voice (2G) and SMS service to previously unconnected remote villages along the eastern coast of the Philippines. An example of a non-profit local mobile network (see section 2.2 Utilize the categorization/typology of interventions), the VBTS project partnered with a national MNO for interconnection and permission to utilize the MNO's spectrum assignment.

The project also aimed to assess the economic impact of nascent voice and data connectivity (see the randomized control trial that resulted from the effort: http://jblumenstock.com/files/papers/jblumenstock_2020_ccn.pdf). The first step in the process was to identify communities that had no connectivity service. The project team took a series of steps to identify connectivity constraints, including:

- preliminary on-the-ground verification (asking villagers about their device use, signal availability, locations to access signal);
- spectrum analysis using a variety of tools (portable spectrum analysers, wideband antennas for checking frequencies and cellphones equipped with special monitoring ability) (see Figure 14);
- mapping the results of the received signal strength indicator, which measures signal quality in decibels.

Box 2 figure: VBTS deployment sites



Source: J. Dionisio, C. Festin and C. Barela, Village Base Stations (VBTS): Connecting Communities Through Mobile Networks, presentation at the US-ACTI Workshop on Internet Access Centers and Last Mile Delivery in ASEAN, 15 August 2018, University of the Philippines

For more information, see:

<https://pcarivbts.github.io/>

https://kurti.sh/pubs/ccn_takeup_paper.pdf

1.3 Map key elements: network infrastructure assets, potential demand and financial viability, and constraints on technology options (Step 1c)

Regardless whether a top-down, bottom-up or blended approach is selected, existing network infrastructure will have to be mapped to identify what potential service options are available or will need to be established.

This includes identifying sources of backhaul capacity, such as fibre-optic cable routes and PoPs, in order to understand the amount of capacity that will be available for the access network – and its cost. One of the biggest operational expenses for rural and remote networks is the cost of backhaul (middle mile) Internet capacity. The availability of existing backhaul service to a locality thus lowers the cost of service provision (both capital and operating expenses). The existence of other connectivity services (such as cellular, even if only 2G) may indicate existing backhaul capacity links to the locality. However, this capacity may need to be augmented if more throughput is needed, or demanded, for more data-intensive services.

Additionally, new backhaul links may be required if insufficient capacity is available (or capacity is non-existent). The level of demand and willingness to pay of the locality would then determine the type of backhaul capacity that would be supported by the new service. In some cases, lower-cost backhaul may be available, such as point-to-point microwave links or cellular backhaul options. In other cases, particularly for very remote sites, satellite backhaul may be required, at a higher cost per throughput.

Backhaul mapping includes identifying existing backhaul options currently available to the locality, identifying the nearest PoPs for other core-network and middle-mile infrastructure, and determining the cost of establishing new backhaul links.

Similarly, mapping mobile network coverage and tower location data in a target locality is a good way to identify existing coverage and potential sources of backhaul. While some MNOs provide coverage maps, in most countries, coverage data are not available directly from MNOs or national regulators. In such cases, other sources, such as crowd-sourced tower location data, can be used to first see if any towers located within the area are providing service coverage. Two such resources are OpenSignal (<https://www.opensignal.com>), which maps network coverage, and OpenCellId (<https://opencellid.org>), which identifies tower location meta-data.

The presence of nearby towers suggests that it may be possible to:

- work with the existing MNO to either extend or increase coverage and capacity;
- develop a third-party model that extends the MNO's service through a revenue-sharing agreement; or
- identify the towers' source of backhaul and contracting capacity for a new service to be extended to the locality concerned.

Table 7. Sources of network infrastructure data

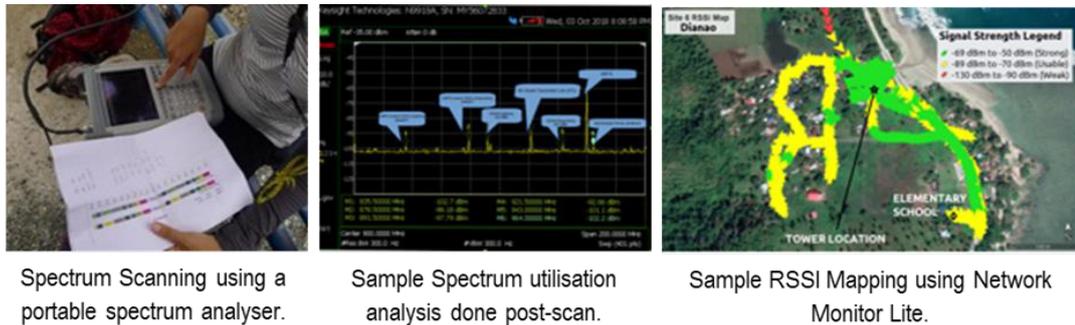
Infrastructure type	Rationale for mapping	Potential sources
Fibre-optic cable routes and PoPs	Signals backhaul availability for high-capacity, lower-cost bandwidth	Fibre backhaul providers, national regulator, ITU Broadband Transmission Maps
Cellular network (coverage and towers)	Signals potential backhaul (fibre- or microwave-to-the-tower) and existing access network availability	MNO coverage maps, national regulator, crowd-sourced data (e.g.: OpenSignal, OpenCellID)
Satellite coverage maps	Identifies whether satellite services cover the area, and what type of service is available	SatBeams: https://www.satbeams.com/ ; LyngSat Maps: http://www.lyngsat-maps.com/ (see Annex 2 for additional satellite map references)
Wi-Fi hotspots	Signals potential backhaul (fibre- or microwave-to-the-premise) and existing access network availability	Mozilla Location Services and Facebook App
Spectrum rights	Can determine if spectrum bands allocated to given services are already assigned to providers. If yes, then confirmation is obtained that obligations are being met; if no, then potential arises for legally leveraging unassigned (or unused) spectrum.	National regulator, crowd-sourced open telecommunication data tracking (for Africa: https://opentelecomdata.org/spectrum-chart/)

Depending on the options being considered, a review of spectrum use would help to determine availability of service and bands. Mapping spectrum bands in the immediate vicinity of the locality would serve to identify:

- if any used spectrum bands are being used in standard cellular channels;
- if there are used spectrum bands in other relevant channels (particularly for microwave);
- the extent of interference in Wi-Fi and unlicensed bands.

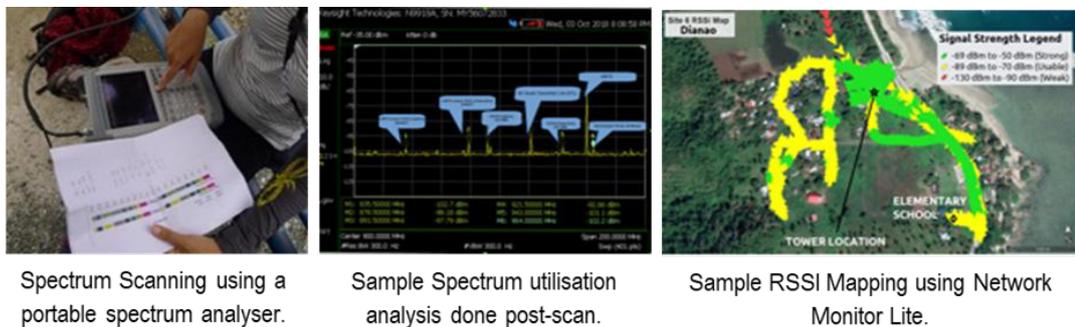
Standard approaches to mapping spectrum band utilization include deploying spectrum analysers on walking (Figure 14) or drive tests (Figure 15).

Figure 14. Example of a walking test to identify GSM spectrum utilization for deploying a community cellular network



Source: PCARI Village Base Station Project, at <https://pcarivbts.github.io/>

Figure 15. Example of a drive test to identify spectrum availability



Source: International Centre for Theoretical Physics (ICTP), Trieste, Italy, at <http://wireless.ictp.it/Papers/RFTrack-ICTD.pdf>; for an explanation of drive tests, see <https://www.telecomhall.net/t/what-is-rf-drive-test-testing/6392>

Additional options for mapping spectrum utilization include drones. For example, one partner of Microsoft’s Airband initiative, Astrea, is using drones outfitted with spectrum analysers to measure the signal-to-noise ratio at various heights above ground level and determine how “clean” the spectrum is at a given location. Radio service in the same area and on the same frequency would cause interference and the performance of the wireless signal would degrade. In the near future, LEO satellites may be able to help monitor radio spectrum utilization and inform potential service options.¹⁵

More publicly available information on network infrastructure would help all interested parties identify service gaps more quickly. However, such information is limited, suggesting that open-data initiatives that share more information could have an impact. A first step towards identifying spectrum availability in a given region is to try and obtain spectrum allocation and assignment information from the relevant bodies in a given country. “Allocation” refers to the process of determining the use of a given block of frequencies, while “assignment” refers

¹⁵ For example, one such LEO solution, HawkEye 360, purports to utilize space-based sensors that provide the capability to survey a broad range of frequencies across large regions of the Earth. Their service provides companies and regulators with radio frequency analytics to improve operational efficiency and resiliency of communications and helps operators to quickly identify and locate sources of problems when faced with interference to critical communications networks.

to the determination of who is allowed to utilize that block.¹⁶ However, in many countries, identifying spectrum allocation and assignment can be difficult. More governments could support open publishing of spectrum allocation and assignment, as well as other aspects of network infrastructure, in order to accelerate the process of extending service into unconnected geographies and increase coverage efficiency overall. Publishing open information on different aspects of network infrastructure would promote both top-down and bottom-up efforts to map and extend network service. Such information includes:

- spectrum allocation and assignment by national regulators;
- pricing data on international gateway (landing station) traffic; core network middle-mile transit pricing; and access network service;
- mobile network tower location data.

Examples of national efforts in this regard include, in terms of spectrum assignment, Nigeria, which stands out when comes to how it shares assignment data.¹⁷ The Malaysian regulator is making wholesale pricing more transparent.¹⁸ The Canadian regulator publishes a machine-readable and downloadable Comma Separated Value file with the location of every tower in Canada.¹⁹ For more information on open telecommunication data, see <https://wiki.opentelecomdata.org/good-practice/transparency>. Figure 16 gives an example of a National Frequency Allocation Table and Figure 17 displays a crowd-sourced, open-data initiative-tracking spectrum assignment in Africa that could be expanded. One resource on tracking developments in this regard is opentelcomdata.org.

¹⁶ For more information, see the Radio Regulations, particularly Article 4, whereby allocation of a frequency band signifies the registration in the Table of Frequency Allocations of a given frequency band for its use by one or more terrestrial or space radiocommunication services, while assignment is the authorization given by an administration for a radio station to use a radio frequency or radio frequency channel under specified conditions.

¹⁷ See Nigerian Communications Commission, [900 MHz band plan](#).

¹⁸ See S. Raja and R. Record, [Malaysia's need for speed: How regulatory action is unleashing ultrafast Internet](#) (blog post, 7 August 2019, World Bank Blogs).

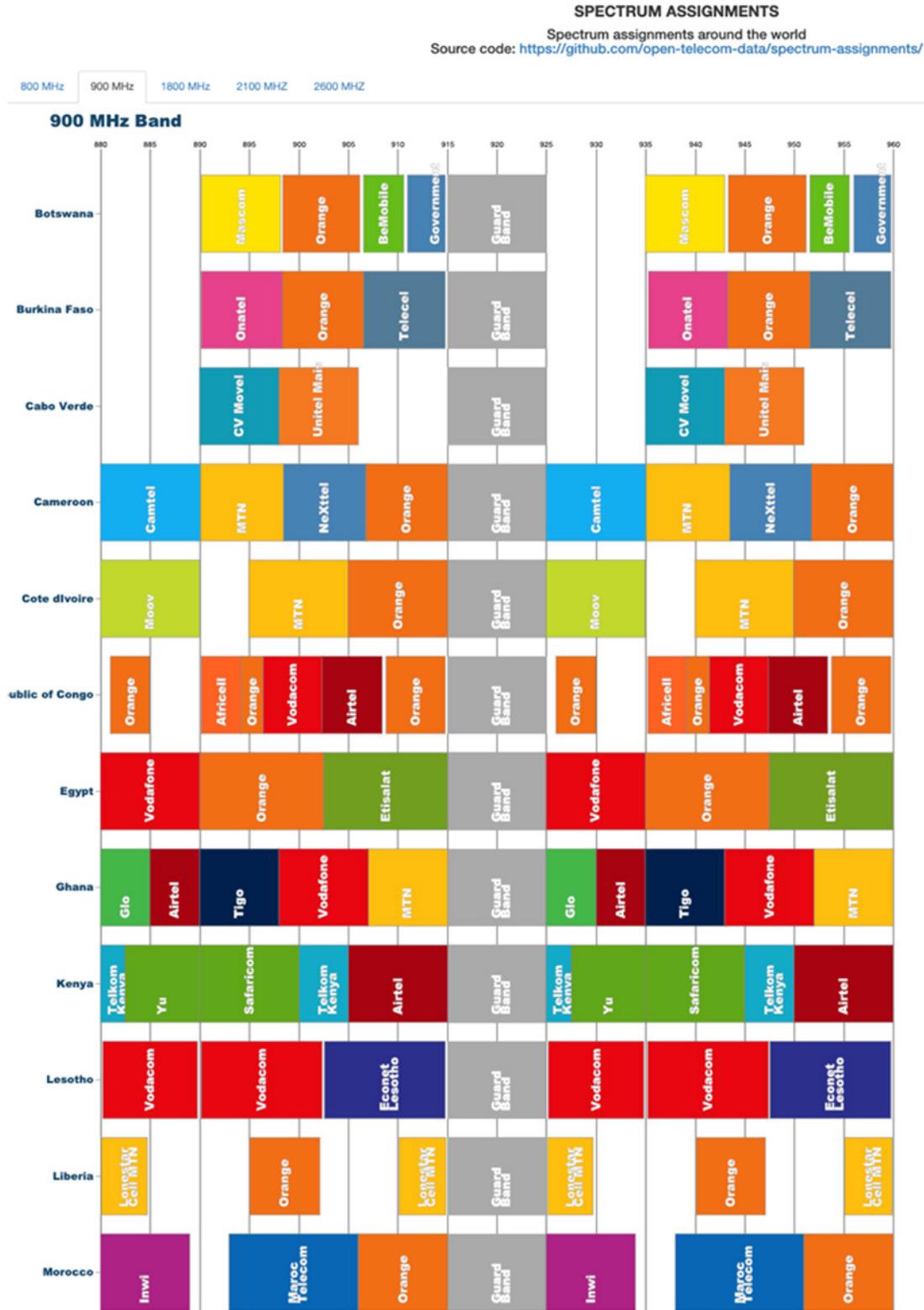
¹⁹ See Government of Canada, [Spectrum Management System Data](#) (webpage).

Figure 16. Example of a National Frequency Allocation Table: Moldova

Region 1	National allocation		
Frequency band - Services - footnotes	Frequency band - services	Footnotes	Usage
143.65 - 144 MHz AERONAUTICAL MOBILE (OR) 5.210, 5.211, 5.212, 5.214	143.65 - 144 MHz AERONAUTICAL MOBILE (OR)	RN018, RN035	G
144 - 146 MHz AMATEUR SATELLITE - SATELLITE 5.216	144 - 146 MHz AMATEUR SATELLITE - SATELLITE	RN018, RN035	NG
146 - 148 MHz FIXED MOBILE except aeronautical mobile (R)	146 - 148 MHz FIXED MOBILE except aeronautical mobile (R)	RN018, RN018A, RN018B, RN035	G
148 - 149.9 MHz FIXED MOBILE except aeronautical mobile (R) MOBILE-SATELLITE (Earth-to-space) 5.209 5.218, 5.219, 5.221	148 - 149.9 MHz FIXED MOBILE except aeronautical mobile (R) MOBILE-SATELLITE (Earth-to-space)	5.209, 5.218, 5.219, 5.221 RN018, RN018A, RN035	G
149.9 - 150.05 MHz RADIONAVIGATION- SATELLITE 5.224B MOBILE - SATELLITE (Earth-to-space) 5.209, 5.224A 5.220, 5.222, 5.223	149.9 - 150.05 MHz RADIONAVIGATION- SATELLITE MOBILE - SATELLITE (Earth-to-space)	5.209, 5.220, 5.222, 5.223, 5.224A, 5.224B RN018, RN018A, RN035	P
150.05 - 153 MHz FIXED MOBILE except aeronautical mobile RADIO ASTRONOMY 5.149	150.05 - 153 MHz FIXED MOBILE except aeronautical mobile RADIO ASTRONOMY	5.149 RN018, RN018A, RN019, RN035	P
153 - 154 MHz FIXED MOBILE except aeronautical mobile (R) Meteorological Aids	153 - 154 MHz FIXED MOBILE except aeronautical mobile (R) Meteorological Aids	RN018 RN018A RN019, RN035	P
154 - 156.4875 MHz	154 - 156.4875 MHz	5.226	P

Source: ITU, *Guidelines for the preparation of a National Table of Frequency Allocations (NTFA)* (Geneva, 2015)

Figure 17. Example of an open-data effort to track spectrum assignments in Africa (900 MHz band)



Source: opentelecomdata.org, at <https://opentelecomdata.org/spectrum-chart/>

In addition to network infrastructure elements, socio-demographic data will be needed to estimate potential demand for different services. Identifying potential demand for, and the financial viability of, different Internet connectivity services involves:

- identifying the size of the locality’s population, to construct a potential user/subscriber base;
- defining the geographic area to be covered, which will determine the viability of different access technologies;
- estimating per capita income, which will signal potential ARPU;
- estimating potential “anchor tenants” or enterprise subscriptions from commercial entities and government offices (including schools and health clinics), which will determine other sources of service support (income); and,
- estimating subsidies from government or donor sources.

These are summarized in Table 8. Note that demographic factors (literacy rate; gender balance and dynamics; population distribution and young adult share of the population) can also impact the subscriber base. The ITU *ICT Infrastructure Business Planning Solutions Guide 2019*²⁰ details various methodologies for estimating demand (simple calculations, econometric models, Delphi panels) and potential revenue (see in particular Chapters 2 (Estimating demand for broadband services) and 3 (Estimating revenues from broadband service provision)).

Table 8. Socio-demographic data needed to estimate potential demand for different services

Socio-economic data type	Rationale	Potential sources
Population size	To construct potential base of individual subscribers of connectivity services	Direct survey/census; government datasets; satellite Earth observation data on population density (for example: JRC's Global Human Settlement Layer population , WorldPop - University of Southampton , Landscan - Oak Ridge , CIESIN's Gridded Population of the World (GPW) , CIESIN / Facebook High Resolution Settlement Layer (HRSL) Map)
Geographic area for service	The total service area has to be estimated to select viable access technologies	GIS mapping
Per capita income estimates	Signals potential ARPU estimates required for net revenue and financial viability of different services	Direct survey/census; government datasets
Potential customers (anchor tenants: government, enterprise, commercial)	Factors into estimates required for net revenue and financial viability of different services	Direct survey/census
Other revenue sources (e.g. government subsidy or donor funding)	Factors into estimates required for net revenue and financial viability of different services	Direct survey/census

²⁰ ITU, *ICT Infrastructure Business Planning Solutions Guide 2019* (Geneva, 2019).

Geographic characteristics and environmental factors may act as constraints on technology options. For example, population density, as an input into overall total potential revenue, is key for determining the viability of various technology options. It would also be useful to incorporate other geographic elements and infrastructure assets in order to obtain a more complete picture of opportunities and constraints. These include the extent of electrification in the area, topography (mapping radio frequency propagation) and other environmental factors.

The extent of available electrical grid infrastructure will determine if additional costs will be incurred in the form of capital (for adding power-generation systems) and operating expenses. Recently, the World Bank, the World Resources Institute and Facebook released a new predictive model for accurate electrical grid mapping (see Table 9).

Mapping topography is important for determining radio frequency propagation. Estimates of network service coverage can be dramatically different when topography and radio frequency propagation are taken into consideration. A commonly used open-source tool for mapping radio frequency propagation against topographical data is SPLAT (Signal Propagation, Loss and Terrain, see Table 9). Other commercial software exists, including: CloudRF (<https://cloudf.com>), GEOG (which refers to a database of United Kingdom terrain heights, at <https://www.qsl.net/g8yoa/geog/geog.html>), QRadioPredict (<http://qradiopredict.sourceforge.net/>), Radio Mobile (<http://www.ve2dbe.com/english1.html>), TAP Mapper (<https://www.softwright.com>) and Tower Coverage (<https://www.towercoverage.com/>).

Other risk factors may be identified and mapped, particularly if they represent above-average risks for the locality concerned. For example, for communities in locations that are prone to seasonal hurricanes or monsoons, it may be useful to identify the path usually taken by such extreme weather across the region.

Table 9 summarizes the additional elements to include in any mapping analysis.

Table 9. Other geographic elements and infrastructure assets to incorporate in order to obtain a more complete picture of opportunities and constraints

Other relevant data	Rationale	Potential sources
Electrification	The extent of available electrical grid infrastructure will determine if additional costs will be incurred for capital (for adding power-generation systems) and operating expenses.	World Bank, World Resources Institute and Facebook have released a new predictive model for accurate electrical grid mapping: https://engineering.fb.com/connectivity/electrical-grid-mapping
Roads	This will help to gauge the accessibility of the locality and of the sites where infrastructure may need to be constructed.	Open Street Maps (https://www.openstreetmap.org/) or national government transportation agencies
Topography	Important for determining radio-frequency propagation. Estimates of network service coverage can be dramatically different when topography and radio-frequency propagation are taken into consideration.	A commonly used open-source tool for mapping radio frequency propagation against topographical data is SPLAT (Signal Propagation, Loss and Terrain: http://www.qsl.net/kd2bd/splat.html) Other commercial software exists.
Other risk factors	The community concerned may face above-average risks. For example, for communities in locations that are prone to seasonal hurricanes or monsoons, it may be useful to identify the path usually taken by such extreme weather across the region.	Case-by-case

Chapter 2. Review options from the classification of existing solutions (Step 2)

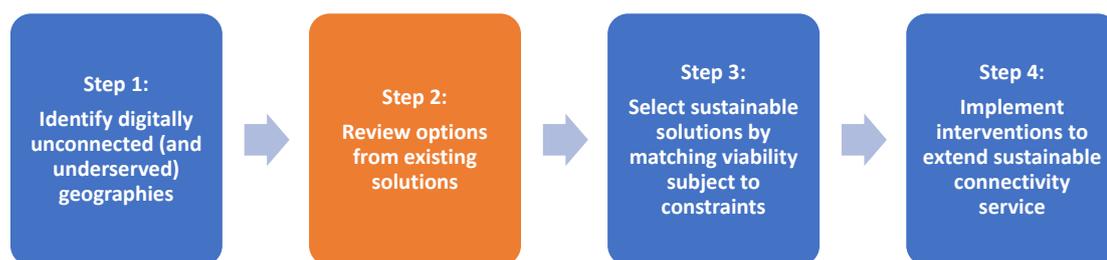


An extensive and heterogeneous range of connectivity solutions is currently deployed worldwide. As one measure of the sheer extent of the number of networks that form the Internet as a whole, the latest data as of 4 May 2020 show that there are at least 96 175 distinct autonomous system numbers²¹, which is indicative of the number of individual domains that are controlled by a set of IP addresses. Autonomous system numbers tend to be ISPs and large enterprises that manage their own IP addresses. While this number overstates the number of ISPs globally, even in smaller countries the number of autonomous system numbers is in the high hundreds or thousands, many of which are connectivity service providers. Further, a number of recent reports highlight the challenges and approaches being taken to extend connectivity further into remote and rural regions.²² However, these reports stop short of presenting a process to identify appropriate solutions adopted in the light of specific characteristics. This section shares examples of existing solutions in different categories and highlights the characteristics of solution components. Figure 18 situates Step 2 in the overall process and sets out the activities it comprises.

²¹ Regional Internet Registries Statistics, at https://www-public.imtbs-tsp.eu/~maigron/RIR_Stats/RIR_Delegations/World/ASN-ByNb.html.

²² See Annex 2 for additional resources.

Figure 18. Step 2 in the Last-mile Internet Connectivity Solutions Guide



Step 2 activities to review options from existing solutions:

2a - Review the case study database of last-mile connectivity solutions

2b - Utilize the categorization/typology of interventions

2c - Understand the main characteristics of, and trade-offs between, different interventions

2.1 Review the case study database of last-mile connectivity solutions (Step 2a)

In order to inform the process of identifying appropriate affordable solutions, this analysis started by developing the Last-Mile Connectivity Case Studies Database, a wide-ranging database of different case studies of last-mile connectivity solutions. The solutions were sourced from primary (direct engagement with solution managers and implementers) and secondary sources (reports, etc.). The cases were classified in 17 dimensions across five main categories (reference material, entity, technologies, locality characteristics, additional information).

As of August 2020, the database contained 123 cases, of which 51 are from primary sources and 72 from secondary sources, particularly 1 World Connected (<http://1worldconnected.org/>) and APC/IDRC *GIS Watch 2018*²³. The database is a live document and will be continually updated as more case studies are submitted.

Table 10. Categories of characteristics of the interventions in the LMC Case Studies Database

Reference material	Entity	Technologies	Locality characteristics	Additional information
Organization or project name; country	Access network operational entity; revenue model; level of subsidy	Backhaul technologies; access network technologies; primary device for access	Population density/urbanization level; population size; geographic area; topography; per capita income/ARPU of users; literacy levels; other socio-demographic and environmental factors	Still in operation; regulatory and policy considerations

²³ Association for Progressive Communications (APC) and International Development Research Centre (IDRC), *Global Information Society Watch 2018. Community Networks* (United States, APC, 2018). Photo provided by Bluetown

2.2 Utilize the categorization/typology of interventions (Step 2b)

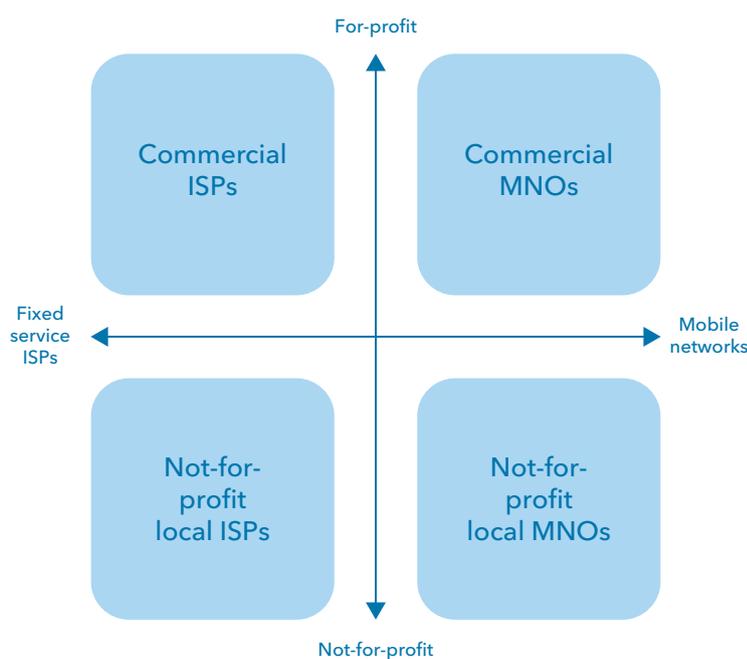
The review of 123 different interventions presented in the Last-Mile Connectivity Case Studies Database showed that interventions differed along two axes (see Figure 19). The first is the *type of network service*, as defined by the primary access network technology utilized. Interventions focused either on:

- a) mobile network deployments providing various mobile wireless services, including voice service, and where the end-user device is mobile and non-stationary; or,
- b) general ISPs that utilized a range of different technologies, both fixed and wireless, to provide data-focused services.

The second axis relates to *profit*. While most entities incorporated formal business operations in partnership with commercial services, some interventions were either:

- a) not-for-profit, delivering connectivity service without an emphasis on commercial returns; or
- b) commercial, basing investment decisions on economic return calculations.

Figure 19. Categorizing last-mile interventions based on type of network and profit considerations



Analysis and review of the range of last-mile connectivity interventions collected in the database suggests that the solutions can be effectively organized by type of profit motive (commercial versus not-for-profit) and access network technology (mobile cellular network operators versus generalized Internet (data) service providers).

Each type of last-mile connectivity intervention is characterized by the services it offers, its revenue model and the access technology or technologies it uses. Depending on the type of intervention and the network's operational design, the intervention will also be subject to various types and levels of regulation, which together give it a mix of advantages and challenges.

Interventions are categorized according to what service they provide and whether they operate for profit or not. ISPs, which can be either commercial or not-for-profit, offer predominantly

Internet connectivity. Commercial ISPs can be regional or national service providers, operating under licences or authorization (less stringent), in both fixed-line (fibre, cable, etc.) or wireless networks, including satellite networks. On the other hand, not-for-profit local ISPs are small data-only networks that are usually operated by volunteers.

Other interventions offer more than just Internet services and usually include mobile voice services. Commercial MNOs normally offer traditional voice and data services and operate through a national licensing regime (e.g. telecommunication licences) using licensed spectrum. Not-for-profit local MNOs, in comparison, are small cellular networks that are often voluntarily operated by local end users.

In terms of revenue model, both commercial ISPs and MNOs generate income from a mix of usage-based fees for voice, data and other paid services, such as VoIP. Not-for-profit MNOs offer a mix of paid services and free access, with the exact model depending on the intervention's context. Not-for-profit local ISPs, for their part, offer predominantly free access, or give users access to low-cost, sometimes complementary services.

What revenue model an intervention uses is often heavily influenced by the degree to which it is subsidized, if any. While both kinds of commercial networks tend to receive little or no subsidies except universal service funds to support deployment in marginalized areas, not-for-profit ISPs and MNOs often benefit from access to partial (one-time and recurring) or full recurring subsidies, sometimes including pooled resources.

What access technology an intervention makes use of depends on the service it provides (whether Internet-only or full service) and the technology's technical appropriateness for the target locality, keeping in mind cost and other considerations. MNOs use licensed spectrum technologies such as 2G, 3G and 4G. Commercial MNOs that have the benefit of funding and scale also use newer or more niche mobile technologies (including 5G), such as millimetre wave, or supplement their mobile network with Wi-Fi access points for cellular offloading.

ISPs utilize one or a mix of fixed-wired (fibre, coax, copper) and/or wireless (fixed wireless access, Wi-Fi hotspots, or satellite connectivity) technologies. Some not-for-profit ISPs have also used experimental emerging technologies to expand their reach and connect more localities to their network.

In addition to deciding on what access technology to use, interventions must also choose among the various backhaul technologies available, namely fibre, microwave or satellite backhaul. What specific mix of technologies a network ultimately utilizes determines in part what regulations the intervention will be subject to, bearing in mind that different jurisdictions have different laws and policies in place.

All MNOs normally have to deal with regulations on the use of licensed spectrum, radio certifications, a telecommunication franchise (where applicable), right-of-way and pole attachment agreements, and business licences (normally local licences for not-for-profit MNOs, and national and regional licences for commercial MNOs). ISPs, for their part, are subject to most of the same regulatory requirements, with the exception of the franchise and the spectrum licence, as they usually use unlicensed frequencies, if any. Interventions based on satellite technology may also need to obtain satellite landing rights from the respective regulator.

Another challenge for the use of mobile in the last mile is the availability of appropriate spectrum resources and, where those resources are available, of the proper licences for specific radio

frequencies. While regulatory regimes vary across jurisdictions, mobile radio frequencies are generally assigned at auction, which tends to mean that they get assigned to large full-service operators. While it can therefore be difficult for small, last-mile access-only networks to obtain the proper licences for cellular frequencies, particularly if they only serve a small area or a small user base, not-for-profit MNOs are nevertheless emerging and proving their viability.

The differences between the various intervention types entail specific advantages and challenges. Commercial MNOs are likely to have the most extensive geographic coverage, sometimes owing to coverage obligations arising from national policy or regulations that may also include QoS standards. However, their business model requires significant capital resources and tends to prioritize geographic areas that have a higher return on investment.

Alongside traditional full-service operators, the presence of commercial ISPs helps increase competition for data service, particularly by differentiating offers from cellular service. Unfortunately, their geographic coverage may be limited by backhaul access and coverage limitations, especially compared to traditional operators.

In a similar vein, not-for-profit local MNOs demonstrate the viability of cellular service where traditional MNOs do not provide coverage, often in areas that would otherwise have no service at all. These are normally very small deployments with limited scale, however, and still require local capacity to negotiate interconnection with traditional MNOs and maintain the network. Not-for-profit local ISPs also show that data services can be viably provided to communities without access, or where other services are cost-prohibitive. Still, the sustainability of service without ongoing subsidies is a challenge for these interventions, as is scale of networks and service.

Table 11. Categorizing last-mile Internet connectivity interventions

		Access network technology	
		Mobile networks	Fixed-service ISP
Revenue model	Commercial	Commercial MNOs : Traditional MNO service provision, and similar interventions where the user and device are mobile	Commercial ISPs : ISPs, wireless ISPs, focusing on rural and urban communities with both fixed-line and wireless technologies
	Not-for-profit	Not-for-profit local mobile networks : Communities owning and/or operating their own cellular network infrastructure, sometimes in partnership with traditional MNOs	Not-for-profit local ISP networks : Networks established by non-profits, governments or communities, focused on providing access to underserved areas

2.2.1 The revenue model: Commercial vs not-for-profit

Various organizational types exist for last-mile access networks in areas where traditional providers are either not present or unable to provide adequate service (in terms of quality, price, coverage, or some combination of the three). To a certain extent, these organizations are designed to achieve the same goal of covering the network's capital and operational expenses to ensure sustainability. They can therefore be understood and differentiated based on their investment and revenue models, which in turn help determine how appropriate they are for a specific context.

Commercial entities are organizations that operate expressly to make a profit. This aspect of their revenue model is their distinguishing feature and has a significant impact on investment. Commercial networks must necessarily operate in areas that can generate revenues above their break-even point and are therefore likely to invest and provide service only in areas where there is a sufficient business case for the network – communities where users have the financial capacity to pay for a subscription or some other form of membership. However, the need to generate financial returns on investment (to cover capital costs) may lead to an expeditious roll-out of service coverage.

Not-for-profit networks exist primarily to serve the needs of their host communities. They tend to operate in areas where the most pressing connectivity issue is lack of access – communities where access from traditional operators is sparse or non-existent. While many not-for-profit networks provide access on a subscription or pay-as-you-go (such as prepaid payments for a fixed amount of data, or time-based access vouchers) basis, some rely on voluntary contributions from their users or provide access completely free of charge. Not-for-profits are particularly suited to small and marginalized communities, which may have specific needs or circumstances that are not easily catered to by other organizational models (especially traditional commercial operators).

Table 12 summarizes the various aspects of the four different last-mile connectivity intervention types, along different dimensions.

Table 12. Characteristics of the various last-mile Internet connectivity intervention options

Type of intervention	Description/services	Revenue model (access network)	Level of subsidy	Commonly used access technologies	Commonly used backhaul technologies	Regulatory concerns	Examples from the Case Studies Database (submissions)	Advantages	Challenges
Commercial MNO	Traditional voice and data services; operates through a national licensing regime (e.g. telecommunication licences) using licensed spectrum	Mix of usage-based services for voice and data, and other paid services	Little to none, except universal service funds to support deployment in marginalized areas	Licensed spectrum technologies: 2G, 3G, 4G, 5G; Wi-Fi		Licensed spectrum; radio certifications; franchise; right-of-way and pole attachment agreements; national, regional and local business licences	Ruralistar Ghana; WTL Morocco; WTL Tanzania	Extensive geographic coverage (sometimes owing to coverage obligations); QoS standards to fulfil	Significant capital resources required; reluctant to serve geographic areas that afford low return on investment
Commercial ISP	Can be regional or national, operating under licences or authorization (less stringent), in both fixed-line (fibre, cable, etc.) or wireless networks, and including satellite networks	Mix of usage-based services for voice (fixed line) and data, and other paid services (even though VoIP is regulated in some countries)	Little to none, except universal service funds to support deployment in marginalized areas	Fixed wired (fibre, cable, coax, copper); fixed wireless access (including Wi-Fi); satellite	Fibre; microwave; satellite	Radio certifications; franchise; right-of-way and pole attachment agreements; national, regional and local business licences; satellite landing rights	AirJaldi India; Mawingu Kenya; Bluetown Ghana and India; Brightwave South Africa; Viasat Mexico	Increases competition for data services, particularly by differentiating offers from cellular service	Geographic coverage may be limited by backhaul access and coverage limitations
Not-for-profit local mobile network	Small cellular network, usually community operated	Mix of paid services and free access	Partial (one-time and recurring) to full recurring; sometimes includes pooled resources	Licensed spectrum technologies: 2G, 3G, 4G		Licensed spectrum; radio certifications; franchise; right-of-way and pole attachment agreements; local business licences	CELCOM Brazil; Tecnologias Indigenas Comunitarias	Demonstrates the viability of cellular service where traditional MNOs do not provide coverage	Very small deployments so limited scale; requires local capacity to negotiate interconnection with traditional MNOs and maintain the network
Not-for-profit local ISP networks	Small data-only networks, usually community operated	Predominantly free access or low-cost services	Partial recurring to full recurring; sometimes includes pooled resources	Fixed wired (fibre, cable, coax, copper); fixed wireless access (including Wi-Fi); satellite		Radio certifications; franchise; right-of-way and pole attachment agreements; local business licences	Zenzeleni Networks, Alitermundi, Pamoja Net and BOSCO Uganda	Demonstrates viability of providing data services to communities without access (or where other services are cost-prohibitive)	Sustainability of service without continued subsidy; scale of networks and service

2.3 Understand the main characteristics of, and trade-offs between, different interventions (Step 2c)

The Last-Mile Connectivity Case Studies Database presents a range of different interventions, each with a unique combination of organizational characteristics. The interventions can nonetheless be categorized using the main features discussed below.

The first meaningful characteristic differentiating interventions is usage, i.e. the intended usage of the connectivity services and the corresponding technical requirements. The intended usage influences the intervention's operational and technical choices, most obviously when it comes to the level of QoS to provide.

The next point of differentiation is the choice of business model, i.e. how the operating entity organizes its operations, constructs its organizational structure, and establishes and maintains its commercial relationships.

Another point of classification is the choice of revenue model, i.e. whether the operating entity covers the cost of service provision by collecting revenue and/or by alternate means, including subsidies and in-kind support.

The operating entity's choice of access network technology is another distinguishing feature. The different ways technologies are used in the access network set the entity apart from others and can determine who gets access to connectivity and how. This includes, in some cases, the use of emerging access technologies that can help address technical issues specific to a usage or a locality's context.

While not as apparent to the end user, the choice of backhaul technology or mix of technologies to provide bandwidth capacity can have a big impact on the QoS provided to users. Backhaul technologies are therefore another meaningful point of differentiation.

All of these choices affect what sort of policy and regulatory regimes are applicable to the operating entity, which also helps differentiate interventions from one another, in that differences in the policy and regulatory environment act as enablers, or constraints, for different types of business model, revenue model, technology use and operational entity.

2.3.1 Usage characteristics

Differences in usage characteristics and constraints may be based on a range of constraints. Some of these differences are noted in Figure 20. There are various ways to look at differences in usage, as usage characteristics and constraints differ widely based on a range of service requirements and technological constraints. It can be useful to define an intervention's usage in terms of its scope and scale relative to other interventions.

For example, the intervention's *extent of connectivity* may be limited to the local network (e.g. when a local router provides limited shared local network access to, for example, offline educational resources). At the other extreme, another intervention may offer robust connectivity to the global public Internet, which, as the network of networks, provides access to the widest possible extent of connectivity in terms of both geography and breadth and depth of content.

Continuity of service is another important way to look at an intervention's usage characteristics and can influence what sort of activities users can engage in with the connectivity provided.

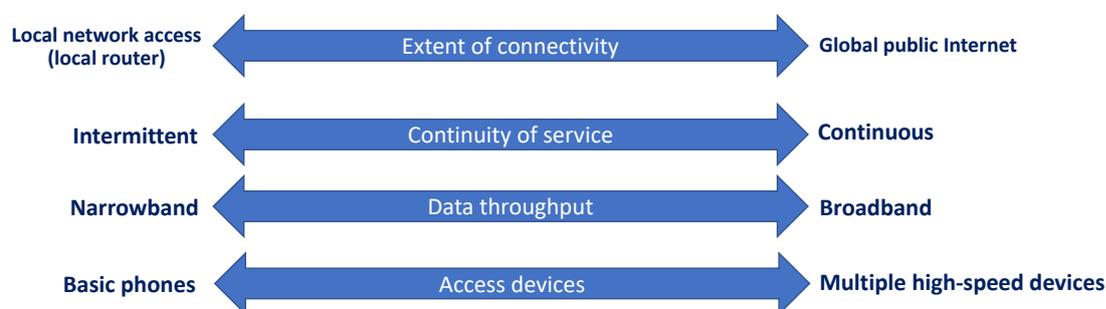
At one end, intermittent connectivity may mean access is available only for a few hours a day, allowing users to make occasional use of the network to, say, send an e-mail or download files for offline use. At the other end, an uninterrupted connection can change usage patterns and allow users to make applications such as real-time messaging and remote working part of the fabric of their daily lives.

What *ICT type* a network provides access to also determines what users can do with the connectivity provided. With a 2G voice and SMS connection, for example, users can send and receive basic text messages and make calls to other users. In comparison, the availability of high-speed data and voice allows users to access multimedia content, both from other users and from the Internet in general, opening up many more possibilities in terms of applications and use cases.

Data throughput is another useful way of differentiating between the usage characteristics of various networks. A narrowband connection allows users to view low-bandwidth content, such as text e-mails or basic social networking. With a broadband connection, however, users can access a wider variety of content, such as high-definition videos from online platforms and content streaming sites, engage in real-time video calls and access multimedia-heavy sites with ease.

Looking at what *access devices* are required to connect to an entity's network is another useful way of examining usage. If a network is designed mostly to work for basic phones, for example, it is likely meant to enable only basic voice and call services. A network that is intended to provide access to multiple high-speed devices, on the other hand, is generally capable of catering to a wider variety of applications being accessed all at the same time.

Figure 20. Differences in usage characteristics



The World Economic Forum, on the other hand, categorizes usage levels differently²⁴ (see Figure 21). It examines the Internet usage patterns that a network enables, categorized via the degree of centrality Internet access has in users' daily lives. This typology also describes the minimum technical requirements necessary for each level of Internet use, in terms of both QoS and of specific technologies capable of delivering the required level of service.

The lowest level of Internet usage, Level 1, is described as "Internet use in its most basic form", or "limited access to the Internet, typically due to poor connectivity, resource constraints, limited skills, or lack of relevant content". In practice, this likely refers to sending the occasional e-mail or infrequent use of Internet resources in a school or work setting.

²⁴ World Economic Forum, *Financing a Forward-Looking Internet for All*, White Paper (Geneva, 2018).

In comparison, Level 2 usage is characterized by “frequent Internet use, mostly unconstrained by cost of access, that is incorporated into some aspects of daily life”. Users that check into social media throughout the day and use online messaging platforms for regular personal communication fall under this category.

Levels 3 to 5 are marked by the increasing importance of Internet connectivity defined as the proportion of user activities that rely on access and how important those activities are to the users. This ranges from connectivity being “essential for both personal and professional reasons” (Level 3) to a reliance on constant connectivity and the IOT that make Internet outages “hugely disruptive and sometimes dangerous” (Level 4). The highest level of Internet usage in this typology, Level 5, is reserved for emerging usage patterns whose centrality to individuals and society exceeds even Level 4: “an as-yet-unknown role for the Internet’s future applications”.

In QoS terms, the World Economic Forum also describes the standard of Internet service required to enable each level of usage, in terms of download and upload speeds, latency, and the total monthly bandwidth consumption per user corresponding to each usage level. Level 1 usage, for example, requires download speeds of only 512 Kbit/s, upload speeds of 64 Kbit/s, a latency of 1 000 ms and total monthly consumption of 10 to 100 megabytes.

By contrast, Level 3 usage calls for download speeds of 25 Mbit/s, upload speeds of 10 Mbit/s, latency of 20 ms and a monthly consumption of 50 gigabytes. Going further, Level 5 consumption is projected to be possible only once both download and upload speeds reach at least 1 GB per second, latency is at 10 ms (and at 1 ms or less for select applications), and a monthly consumption of 1 terabyte is considered normal.

Not all technologies can deliver the necessary level of service for each usage level. Higher levels of usage require progressively newer, more capable technologies. The World Economic Forum identifies what last-mile technologies are necessary at the last 100 metres to enable each level of usage.

Levels 1 to 3, for example, can be served by copper wired infrastructure, depending on the specific deployment and network design. Whereas 2G can enable Level 1 usage wirelessly, Level 2 requires at least a 3G connection and Level 3 requires 4G. This underscores that different technologies have different limitations, and more intensive usage will require more modern solutions capable of delivering the necessary QoS. The World Economic Forum report notes that only fibre (for wired) and the emerging 5G standard (for wireless) are likely to be sufficient for Level 5 usage.

The usage and QoS threshold requirements for each application and service differ by sector, and how much bandwidth is “enough” can vary depending on user needs and demands, and on what applications the connectivity will be used for. Careful consideration must therefore be given to what users are likely to be doing with access and what applications they are likely to use, in order to ensure that there is enough bandwidth for all.

Figure 21. Different levels of Internet usage (World Economic Forum)

	1	2	3	4	5
	Internet users in its basic form	Internet to enrich day-to-day life	Internet as a vital part of most activities	Internet as the enabler of society	Internet as the backbone of the future
	Limited access to the Internet, typically due to poor connectivity, resource constraints, limited skills or lack of relevant content	Frequent Internet use, mostly constrained by cost of access that is incorporated into some aspect of daily life	Near-constant connectivity, that is considered essential for both personal and professional reasons	Constant interconnectivity via the Internet of things; Internet outages are hugely disruptive and sometimes dangerous	An as-yet unknown role for the Internet's future applications
	Level 1	Level 2	Level 3	Level 4	Level 5
D/L speed	512 Kbit/s	2-3 Mbit/s	25 Mbit/s	100 Mbit/s	1 Gbit/s
U/L speed	64 Kbit/s	512 Kbit/s	10 Mbit/s	100 Mbit/s	1 Gbit/s
Latency	1,000 ms	400 ms	100 ms	20 ms	10 ms (1 ms for select applications)
Monthly use	10-100 MB	500 MB	50 GB	200 GB	1 TB

Source: adapted from World Economic Forum, note 29

In real-world terms, this means that some sectors are likely to need more bandwidth than others, and what may be sufficient for one sector will be untenable for another. In the United States, for example, the State Educational Technology Directors Association estimated the broadband speeds required in the education sector to use certain applications or conduct certain activities²⁵ (see Table 13).

Where users are likely to get by with just a 0.03 Mbit/s connection when browsing social media, even streaming just standard definition video requires speeds 100 times faster – at least 3 Mbit/s. This requirement jumps to 25 Mbit/s when streaming videos in Ultra HD quality, showing just how much connectivity requirements can change even for the same activity as content has become more bandwidth-intensive.

The education sector also provides a good illustration of how better connectivity can enable a wider range of usages, increasing productivity for users on the network. Although a speed of 0.25 Mbit/s is enough for a student to take an online class or complete a multiple-choice assignment, for example, increasing speed to just 1 Mbit/s can allow the same student to watch or participate in a video conference, engage with a simulation, or conduct research on the Internet.

Interventions must determine what level of usage they want to enable in order to estimate what speeds they want end users to receive. This involves an understanding of who their users are,

²⁵ State Educational Technology Directors Association, *The Broadband Imperative II: Equitable Access for Learning*. (2016)

what they do, and what they need or are interested in. An understanding of the locality the intervention will be operating in is important for delivering impact for users on the network.

Table 13. Sample broadband requirements for various activities in the education sector (download speeds)*

Activity	Broadband speeds
Taking an online class	0.25 Mbit/s
Searching the web	1 Mbit/s
Checking e-mail	0.5 to 1 Mbit/s
Downloading digital instructional materials, including open educational resources	1 Mbit/s
Engaging with social media	0.03 Mbit/s
Completing multiple choice assessments	0.06 Mbit/s
Music streaming	2 Mbit/s
Video streaming - standard definition quality	3 Mbit/s
Video streaming - HD quality	5 Mbit/s
Video streaming - Ultra HD quality	25 Mbit/s
Streaming HD video or a university lecture	4 Mbit/s
Watching a video conference	1 Mbit/s
Participating in HD videoconferencing	4 Mbit/s
Participating in a video conference	1 Mbit/s per user
Engaging with a simulation and gaming	1 Mbit/s
Engaging in two-way online gaming	4 Mbit/s

Source: adapted from State Educational Technology Directors Association, note 30

*** The table is not intended to be used to calculate projected bandwidth for an entire school or district, as other factors, such as administrative applications, cloud-based services and aggregation strategies, need to be considered.**

The healthcare sector provides a good example of how emerging or maturing applications can be very bandwidth-intensive, requiring robust connectivity to enable usage.

While patients can often get by with a 1.5-to-3-Mbit/s connection for video consultations, a single-physician practice will require at least 4 Mbit/s to serve as a telemedicine provider²⁶ (see Table 14). Such a connection “supports practice management functions, e-mail, and web browsing; allows simultaneous use of electronic health record (EHR) and high quality video consultations; enables non real-time image downloads; [and] enables remote monitoring”.

²⁶ Health IT, *What is the recommended bandwidth for different types of health care providers?* (HealthIT.gov., 2019).

This shows that bandwidth demand increases commensurate with the scope of activities. The demand for bandwidth scales with the number of users as well: a small doctor’s practice with two to four physicians engaging in the same activities as the single-physician practice described above requires at least a 10-Mbit/s connection.²⁷

Table 14. Sample bandwidth requirements by telemedicine provider type

Telemedicine participant	Services	Bandwidth
Patient	Video consultation; accessing electronic records	1.5 to 3 Mbit/s
Single-physician practice	Supports practice management functions, e-mail and web browsing; allows simultaneous use of electronic health records and high-quality video consultations; enables non-real-time image downloads; enables remote monitoring	4 Mbit/s
Small doctor’s practice (2-4 physicians)	Supports practice management functions, e-mail and web browsing; allows simultaneous use of electronic health records and high-quality video consultations; enables non-real-time image downloads; enables remote monitoring; enables HD video consultations	10 Mbit/s
Nursing home	Supports facility management functions, e-mail and web browsing; allows simultaneous use of electronic health records and high-quality video consultations; enables non-real-time image downloads; enables remote monitoring; enables HD video consultations	10 Mbit/s
Rural health clinic (approximately 5 physicians)	Supports clinic management functions, e-mail and web browsing; allows simultaneous use of electronic health records and high-quality video consultations; enables non-real-time image downloads; enables remote monitoring; enables HD video consultations	10 Mbit/s
Clinic/large physician practice (5-25 physicians)	Supports clinic management functions, e-mail and web browsing; allows simultaneous use of electronic health records and high-quality video consultations; enables real-time image transfer; enables remote monitoring; enables HD video consultations	25 Mbit/s
Hospital	Supports hospital management functions, e-mail and web browsing; allows simultaneous use of electronic health records and high-quality video consultations; enables real-time image transfer; enables continuous remote monitoring; enables HD video consultations	100 Mbit/s
Academic/large medical centre	Supports hospital management functions, e-mail and web browsing; allows simultaneous use of electronic health records and high-quality video consultations; enables real-time image transfer; enables continuous remote monitoring; enables HD video consultations	1,000 Mbit/s

Source: Health IT, note 31

More advanced or complex telemedicine applications will also require more bandwidth than basic video consultations. One of the appeals of telemedicine is the ability to consult with specialists remotely merely by sending them the appropriate diagnostic data. With more data,

²⁷ Health IT, *What is the recommended bandwidth for different types of health care providers?* (HealthIT.gov., 2019).

however, come larger file sizes, meaning that some medical tests will require more bandwidth and faster speeds in order for specialists to examine the data in a timely manner.

2.3.2 Business models

The business model is another useful way of classifying operating entities, examining the differences between them and matching the locality with a model able to meet its needs. The Last-mile Connectivity Case Studies Database revealed six types of business model providing some level of service in the local access last-mile network. These are summarized in Table 15.

The *integrated international operator* owns national transmission, backhaul and last-mile access network infrastructure, and may provide retail services. The main concern of operators with this business model is to sell capacity to local operators and MVNOs, and to service retail customers, all from bandwidth purchased internationally or at cable landing stations.

The *integrated local operator*, on the other hand, owns the regional backhaul infrastructure and last-mile access network, and provides retail services. Such operators may sell wholesale capacity to other regional operators and provide retail service to end users. They usually purchase bandwidth from the local domestic national backbone provider.

The *infrastructure-as-a-service operator* owns passive network infrastructure but does not operate active network equipment or provide network service to any user. Instead, this business model revolves around renting real estate (towers, ducts and dark fibre) to active network operators, who can then use the infrastructure as part of their own network.

By contrast, the *connectivity-as-a-service operator* owns active network infrastructure in the last-mile access network but does not provide its own branded retail service. Instead, it sells wholesale capacity on regional networks to retail providers, who then sell the capacity to users using their own branding. Entities using this business model may purchase national backbone or international gateway capacity for their network.

The *LMC integrated operator* owns last-mile access network infrastructure and provides its own branded retail services while purchasing backhaul capacity. In comparison, the *LMC service operator* does not own any network infrastructure but provides its own branded services. Instead of operating its own network, this operator purchases capacity directly on local access networks.

Table 15. Business models offering services in last-mile networks

Business model	Description	Partnership/business agreement	Examples
Integrated international operator	Owns national transmission, backhaul and last-mile access network infrastructure, and may provide retail services	Sells capacity to local operators, MVNOs and retail customers; purchases bandwidth internationally or at cable landing stations	Liquid Telecom
Integrated local operator	Owns the regional backhaul infrastructure and last-mile access network, and provides retail services	May sell wholesale capacity to other regional operators, and provide retail service; purchases bandwidth from domestic national backbone provider	
Infrastructure-as-a-service operator	Owns passive network infrastructure but does not operate active network equipment or provide network service	Rents real estate (towers, ducts, dark fibre) to network operators	IHS; American Tower
Connectivity-as-a-service operator	Owns active network infrastructure in the last-mile access network but does not provide its own branded retail service	Sells wholesale capacity on regional network to retail providers; may purchase national backbone or international gateway capacity	Internet para Todos (Peru); Africa Mobile Networks
LMC integrated operator	Owns last-mile local access network infrastructure and provides its own branded retail services	Sells retail branded services while purchasing backhaul capacity	Bluetown (India); AirJaldi (India)
LMC service operator	Does not own any network infrastructure but provides its own branded services	Sells retail branded services while purchasing capacity on local access network	

2.3.3 Revenue models

Generally speaking, in last-mile connectivity the organizational business models address initial capital expense demands, while the revenue model articulates operating expense coverage. Last-mile connectivity access networks feature four main revenue models, each with its variations, and focus on operating expense management. One of the most important considerations for a last-mile access network’s sustainability is its long-term revenue source. While capital expenditures for network infrastructure can be cost-prohibitive, the availability of low-cost network technologies can make it easier for small networks to raise funds for the deployment of a network. In the long term, coping with operational expenses – recurring costs such as bandwidth, electricity, personnel and maintenance – is a persistent challenge to a network’s survival (see Table 16).

A usage-based, prepaid (also known as pay-as-you-go) revenue model involves the sale of time- or data-limited access to connectivity; users pay upfront to access the network until their time expires or their data plan is consumed. Access is sold through a voucher-based or similar system, or at the point of use in cases where connectivity is delivered through a shared access centre.

Another type of usage-based revenue model is the postpaid or subscription model. Like prepaid systems, postpaid/subscription models are based on consumer (or corporate) connectivity services. Subscription-based access involves regular recurring payments over a period, giving the network a regular source of revenue from a stable base of users. Subscriptions normally cover a monthly period, during which users have access to a fixed or unlimited amount of data.

From the network management perspective, subscriptions simplify the task of calculating the total amount of bandwidth the network needs to buy or otherwise provide to users. They can be onerous for low-income users, however, who may not be able to meet their regular financial obligation to the network. Relying on a subscription-based revenue model therefore requires a stable base of users capable of paying for their connections or bringing the cost of the subscription down to an affordable level by leveraging subsidies or cost-sharing arrangements.

Prepaid access can be more cost-effective for users that use data only sporadically or otherwise have limited data requirements. It allows more people to access the network and revenue to be generated from users who would not otherwise have been able to pay for a regular subscription. In one case, an operating entity generated revenue solely from tourists who would pay for short-term access to connectivity; that revenue allowed the network to subsidize permanent members of the locality and give them access for free.²⁸ In another example, from India, a government-run network provided access on a subscription basis to village residents and on a prepaid basis to occasional visitors during religious festivals.²⁹

One possible drawback of a primarily prepaid revenue model is the extent to which demand for bandwidth varies compared to a user base composed mainly of subscriptions. This can be especially apparent when the revenue base is transient, as when access is sold to tourists who come and go as they please. In this context, and to a smaller extent even when the primary users are residents of a locality, properly managing variable operating expenses (particularly the cost of bandwidth) will require effective demand forecasting. Prepaid service revenue can be more lumpy, irregular and volatile than subscription-based revenue if there is high customer churn.

Outside of usage-based revenue models, some access networks also have new or alternative revenue streams. One approach is to charge for access or use of value-added services. In this case, operating expenses are covered by services beyond data usage, such as paid advertising or other value-added services (mobile money, agricultural information services, education, etc.) that cross-subsidize data provision. The value-added service model is not widespread, but it is seen in last-mile projects where specific end-user benefits are apparent. In one example, a network that provided access through a shared access centre did not charge for use of the Internet but did charge for printing and other in-person services. Additionally, action-based payment models allow users to pay for connectivity by non-financial means. Users or customers can perform certain actions (i.e. recycle plastics or take training courses) in exchange for blocks of connectivity time or capacity. This creates options where public or aid spending can be effectively used to drive outcomes using connectivity as a reward. This model is relatively new and currently unproven but has great potential.

Similarly, sponsored content, such as entertainment and sports events that are tailored to local preferences, gives connectivity providers a supplemental revenue stream by using a very low per-use pricing model. One example is PockitTV, a mobile entertainment and sports platform

²⁸ APC & IDRC, *op. cit.*, note 28, Small and Medium Telecom Operators Association of Georgia and Tusheti Development Fund, pp. 124-127.

²⁹ *Ibid.*, Case on Gram Marg Rural Broadband Project, pp. 150-156.

based in Africa that charges as little as USD 0.06/day for access to local and international content. Zero-rating is a form of sponsored content whereby data charges are subsidized primarily by the service provider for access to specific applications or services.

Some interventions operate entirely on a not-for-profit basis or on the principle of providing free access to users. The limited revenue/not-for-profit/free access model often relies on in-kind contributions (such as community management of the network) or an ongoing recurring subsidy to cover operating expenses.

Examples of networks exist where users provide voluntary contributions for shared bandwidth and network infrastructure maintenance.³⁰ Recurring subsidies, from either public or private donor-partners, allow operating entities to provide connectivity for free or (when combined with other revenue models) at very low cost to users. Subsidies can come in the form of monetary or in-kind contributions, such as free bandwidth from an ISP with a nearby PoP.³¹ In such cases, subsidies cover part or all of the network’s operating expenses. Capital expenditures such as network expansions and equipment replacements, on the other hand, can be covered by separate one-time subsidies or other revenue sources.³²

That being said, this model runs the risk of revenues falling short of network costs, particularly when the network relies on voluntary contributions. It is therefore more appropriate for smaller networks where risks are more manageable or, alternatively, as a complement to subscriptions or prepaid charges, which can represent a more stable source of revenue.

Table 16. Revenue models in last-mile retail services

Revenue model	Description
Usage-based (prepaid)	This is the standard pricing system for consumer connectivity services in emerging markets, where the consumer pays for traditional data services through a prepaid (also known as pay-as-you-go) model. Prepaid service revenue can be more lumpy, irregular and volatile than its subscription-based counterpart if there is high customer churn.
Usage-based (postpaid/subscription)	Like the prepaid model, postpaid/subscription models are based on consumer (or corporate) connectivity services.
Value-added services	Operating expenses are covered by services other than data usage, such as paid advertising or other value-added services (mobile money, agricultural information services, education, etc.) that cross-subsidize data provision; not widespread, though seen in last-mile projects with clear specific end-user benefits.
Limited revenue, non-profit, free access	In this model, operating expenses tend to be covered by in-kind contributions (such as community management of the network) or an ongoing subsidy

³⁰ Ibid.

³¹ Ibid., Cases on Tunapanda Institute (pp. 166-170) and on Gram Marg Rural Broadband Project (pp. 150-156).

³² Ibid.

2.3.3.1 *The rationale for subsidies (none, one-time or recurring)*

Some last-mile access networks receive varying levels of subsidies from public or private donors and partners. In addition to the level of subsidy relative to the network's total expenses, these subsidies also differ in regularity, with some subsidies taking the form of one-time grants and others reoccurring over a significant period, if not the entire lifetime, of the network. This section examines the varying levels of subsidies, what they are used for, how they are most optimally used, and their implications for the operations of the network.

Traditional commercial networks are not, generally speaking, subsidized. Possible exceptions include deployments in unprofitable areas, in which case the operators may receive a subsidy in the form of a payment from a universal access or service fund. Not-for-profits, on the other hand, are more likely to receive subsidies from the public and private sectors. Government-run networks are often recipients of public sector contributions.

The most significant difference between subsidies is their periodicity. One-time subsidies are usually meant to help with the deployment of a network, the acquisition of equipment, or other costs that can be considered capital expenses. Recurring subsidies, on the other hand, can be intended to cover at least part of the operational costs of a network as well.

Full one-time subsidies allow an organization to install the network and commence operations; the network will still have to generate revenues to cover the costs of operations. Partial one-time subsidies operate in the same manner but to a lesser extent, helping networks acquire equipment, deploy personnel and cover costs associated with the construction of infrastructure.

One-time subsidies, while helpful, do not necessarily impact the network's revenue-generation model in a significant way. Subsidies are "full" when they are sufficient to cover all capital and operating expenses over a period of time. While not having to recoup capital expenditure from revenue can be helpful, the network will still have to cover operating expenses once the subsidy runs out – which it inevitably will. Similarly, recipients of partial one-time subsidies will have to generate revenues, with the difference that they will face that challenge more immediately than networks that receive full one-time subsidies.

Examples in the literature show that networks receiving one-time subsidies operate similarly to those that do not; that is, they continue to rely on subscriptions or other revenue-generating activities to ensure sustainability.³³ The biggest benefit of one-time subsidies is that they help networks overcome financial barriers to entry (lowering investment risks), allowing them to deploy in areas where investment capital may be unlikely or unwilling to take the risk. In comparison, recurring subsidies have a more tangible long-term impact on the operations of a network.

Full recurring subsidies, as the name implies, cover the full cost of a network's activities for the lifetime of the network, or for a significant period of time. Partial recurring subsidies, on the other hand, normally cover part of a network's operating expenses. They have a greater impact than one-time subsidies in that they allow networks to operate in communities where they would otherwise be unsustainable.

³³ Ibid.

Full recurring subsidies allow the network to provide access completely free of charge.³⁴ They are most common in communities where users would otherwise be unable to pay for access or the characteristics of which make it unlikely that costs could be recovered from conventional revenue-generating activities. Examples include a network in Borneo that serves indigenous jungle communities and an urban network in Kenya designed to provide access to poor users.³⁵

Networks that enjoy full recurring subsidies can have a transformative impact on their communities, but can also run into sustainability issues if that is their sole source of funding: funding cuts can mean the death of the network. To hedge against this possibility, some fully subsidized networks generate revenue from value-added services on the network, although access to connectivity itself remains free.

Finally, partial recurring subsidies are designed to cover part of a network's recurring operational costs. A common example of a partially recurring subsidy is the cost of bandwidth, which is either covered by a private partner ISP free of charge or paid for through financial contributions from donors.³⁶ While networks that receive partial recurring subsidies generally do not offer services free of charge (unlike those that receive full recurring subsidies), they can usually offer connectivity at a lower rate than would have been possible if the subsidy were not in place. They must nevertheless create revenue streams in order to cover other costs and ensure network sustainability.

The question of when subsidies are most efficient is an important consideration for both public and private institutions that may be considering some form of subsidy to improve last-mile access. ITU's ICT Regulation Toolkit provides a helpful guide for determining when subsidies can create impact³⁷ (see Figure 22).

When a market efficiency and expansion gap exists, subsidies may not be the best tool to improve access. Instead, private service provision can bridge the gap if policy is enacted to remove non-economic barriers by adopting enabling regulations and instilling a positive fiscal, business and investment climate that focuses on encouraging market participation. This allows the private sector to cater to existing demand, without recourse to subsidies and relying purely on market incentive.

On the other hand, some areas may not be attractive for private sector investment, perhaps owing to the technical difficulties of extending the existing network to the target locality. In such cases, the ICT Regulation Toolkit proposes the use of what it calls "smart subsidies", which are one-time subsidies that can encourage new or existing operating entities to deliver service in the area. As previously discussed, the main use of the subsidy is to help an intervention cover what might otherwise be prohibitively high network deployment capital expenditure, after which the operator can be expected to conduct business as usual. Such subsidies are most appropriate in localities with a viable business case for a commercial entity, were it not for technical barriers that can be bridged or mitigated with a one-time subsidy.

Finally, some areas are unlikely to be commercially viable at all, at least in the near and medium term. These are likely to be far-flung, sparsely populated areas where a commercial operator will be unable to recoup its operating expenses. The ICT Regulation Toolkit describes this as a

³⁴ Ibid.

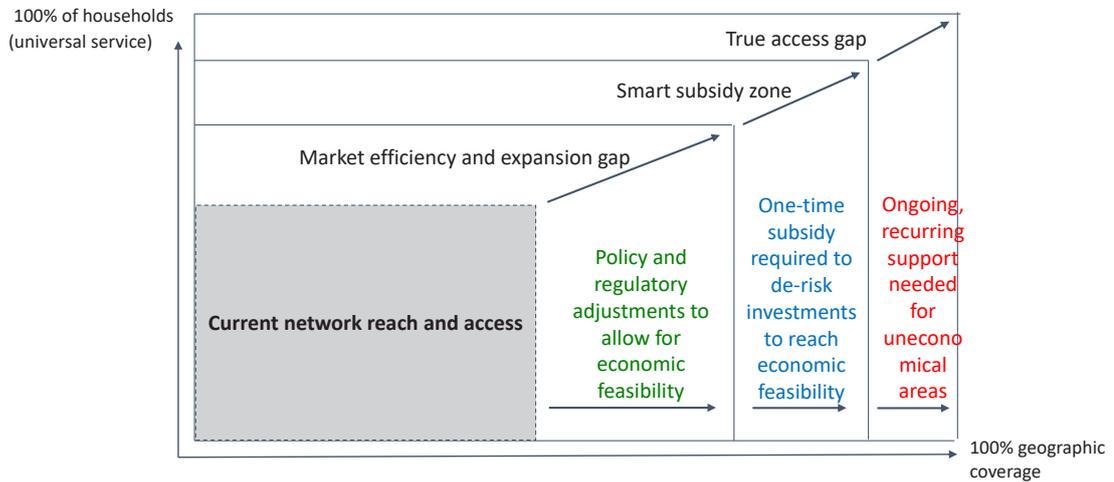
³⁵ Ibid., Cases on FORMADAT (pp. 157-161) and on Tunapanda Institute (pp. 166-170).

³⁶ Ibid.

³⁷ ITU, [ICT Regulation Toolkit](#), Chapter 4.1.3.3 (Market Gaps and Universal Access Policy).

“true access gap”, where the case for extending connectivity is made on the basis of the public good as opposed to commercial gain. Such cases call for ongoing, recurring economic support, which can take the form of full or partial recurring subsidies that can help an operating entity cover the costs of deploying its network to the locality.

Figure 22. Intervention distinctions for the various access gaps



Source: ITU ICT Regulation Toolkit, see note 42

2.4 Common access network technologies (wireless)

This section compares various wireless and wired connectivity technologies used in last-mile access network deployment in the light of a range of factors, including capital expenditure deployment costs, operating costs, technology range and bandwidth throughput. The comparison focuses on per-site deployment, in line with the Solutions Guide’s general emphasis on potential solutions for individual unconnected and underserved localities. There are nevertheless other differences, including between business licences and spectrum fees versus the cost of the underlying technology deployment, that factor into total cost of ownership of an overall network. Also, differences in range and throughput per site factor into the total cost of ownership of different sized networks.

Some networks offer last-mile access primarily using cellular technology. Cellular last-mile access involves connecting end users’ devices directly to base stations, with no need for an intermediary point of connection. This is the main access network technology used by operators that also offer basic telecommunication services; in this case, voice, SMS and data are all served via radio frequencies allocated and assigned or auctioned to mobile services.

Cellular technology can cover a wide area through a single tower, although it is also subject to interference and quality can fall off over distance. This means that end users with smartphones and other mobile Internet-enabled devices can get connectivity anywhere within the range of the tower – even while on the move. The main drawback of cellular as an access technology is cost. The deployment of cellular networks can also be complicated by difficult topography, which can make it unreasonably expensive, if not wholly impractical, to use cellular in remote locations or on difficult terrain.

Another challenge for the use of mobile in the last mile is the availability of appropriate spectrum resources and, where those resources are available, of the proper licences for specific radio frequencies. While regulatory regimes vary across jurisdictions, mobile radio frequencies are generally assigned at auction, which tends to mean that they are assigned to large full-service operators. While it can be difficult for small, last-mile access-only networks to obtain the proper licences for cellular frequencies, particularly if they only serve a small area or a small user base, not-for-profit MNOs are nevertheless emerging and proving their viability. If appropriate national licences have already been obtained, however, there are no incremental fees for expansion of coverage.

Fixed wireless access uses licensed radio frequencies allocated to fixed services or unlicensed bands (e.g. Wi-Fi) to provide connectivity. Although it can also use mobile service bands, the use of such bands for fixed-wireless access would not receive additional interference protection beyond what is intended for mobile users. The main difference with cellular is that fixed wireless access is primarily meant to be received by a fixed wireless access point, instead of directly by consumer devices. The range of a fixed wireless access tower is comparable to that of a cellular tower, but a modem is required to transmit the connectivity over the Ethernet or Wi-Fi.

One example of fixed wireless access is WiMAX, a part of the 3G family of technologies that uses microwave technology to deliver connectivity from a PoP to an access point. Microwave technology utilizes ultra-high or higher frequencies to connect radios within the line of sight. The line-of-sight requirement is its main drawback, as mountainous and other difficult terrain can prevent radios from connecting to each other. The need for a nearby PoP can also limit the applicability of microwave; if no fibre-connected microwave station is available within the line of sight, a microwave relay will need to be built, adding to the cost of deployment. As a wireless technology, the use of microwave radios is also subject to radio spectrum regulations, which can differ depending on the jurisdiction in which the network is located.

In geographies where cellular, fixed wireless access and microwave options are untenable, satellite connectivity can be used to provide bandwidth to an access network. This technology relies on satellite-based bandwidth providers to connect the most remote communities. Depending on the exact type of technology used, satellite connectivity can be deployed quickly, without having to build the costly and technically challenging infrastructure needed for other technologies.

A variety of satellite providers exist that offer differing levels of service, with GEO satellites catering to high-bandwidth applications and MEO satellites serving smaller users, including last-mile access networks.

Although satellites have the advantage over other technologies for ease and speed of deployment, their QoS lags behind alternatives such as fibre, particularly in terms of bandwidth and latency. Depending on the specific satellite technology and band used, quality can also deteriorate in certain weather conditions. The future development of large constellations of LEO satellites promises to improve the quality and affordability of satellite connectivity.

The aforementioned technologies, except for cellular, all require a modem or similar customer premises equipment to distribute connectivity to end users' devices. One wireless option for connecting users is Wi-Fi. Although it is a wireless access technology, Wi-Fi uses unlicensed frequencies and therefore does not need the same sort of regulatory approval as cellular. Wi-Fi

is also very common, which means that a plethora of affordable consumer-grade routers are available. These two factors make Wi-Fi a relatively affordable technology to deploy.

However, the unlicensed nature of the industrial, scientific and medical frequency bands used by Wi-Fi technology forces systems to accept interference not only from other services but among themselves (Wi-Fi congestion), while at the same time ensuring minimal radiation levels.

The quality of a Wi-Fi connection can thus vary greatly, as it is prone to interference. The range is also very limited: the range of a single average Wi-Fi router is several orders of magnitude lower than that of a cellular station.

On the scale of a network, however, there are ways to overcome some of these limitations and to leverage Wi-Fi affordability and ease of deployment on a larger scale. An increasingly popular approach among operating entities is to use Wi-Fi routers in a mesh network architecture, with individual routers connecting to each other on an ad hoc basis and obtaining their connectivity from whatever router is closest or has the strongest connection to them.

Using a mesh network, Wi-Fi technology can serve a wider area and is also more robust, as no single point of failure exists when a mesh network is fully decentralized. Some mesh networks nevertheless have a significant limitation, in that some routers are unable to transmit and receive data simultaneously, and the efficiency of an overall network can decrease as the number of routers increases. In addition, mesh networks generate low spectrum reuse, as only a few non-overlapping channels can be used at a time.

Despite these limitations, Wi-Fi mesh networks have successfully connected communities, even in challenging terrain, making Wi-Fi technology an even more appealing option for networks where there is no existing infrastructure and other technologies would be too expensive or difficult to deploy.

Table 17 provides a summary comparison of common wireless access network technologies and Table 18 details IMT families and their technologies.

Table 17. Comparison of common wireless access network technologies*

Access network technology	Potential throughput / QoS	Range	Capital expenditure to deploy new network	Operating expenses	Infrastructure required	Suitability for rural deployments	Spectrum licensing requirement	Access device type
Wi-Fi: 802.11	2 Mbit/s (a) to 10 Gbit/s (ax)	100s of m	Low	Low	Wi-Fi routers	Yes, but backhaul required (satellite, microwave or fibre)	No specific licence but compliance with technical specifications via "blanket licence" under non-interference/non-protection regime	Wi-Fi enabled smartphones, tablets, computers
Mobile cellular (2G, 3G, 4G, 5G)	0.1 – 1000 Mbit/s	5 to 15 km	Medium to high	Medium to high	Towers and radio equipment	Yes, but backhaul required (satellite, microwave or fibre)	Yes	Cellular mobile phones, laptops, personal computers (via dongles)
Fixed wireless access (4G/ 5G)	20 – 1 000 Mbit/s	Up to 10 km	Low to medium	Low	Towers and radio equipment	Maybe, depending on financial viability and demand	Depends on country regulations	Consumer premises modems to Ethernet or Wi-Fi
Satellite (HTS GEO and MEO)	5 – 150 Mbit/s	1 000s of km	High (for new satellite deployment); low (for end-user terminals)	Low	Earth station, satellite, very-small-aperture terminal	Yes	Yes	Very-small-aperture terminal, consumer premises modems to Ethernet or Wi-Fi

Source: adapted from various sources, including the European Union, Cisco, Huawei, ITU, the Inter-American Development Bank, the World Bank and the EMEA Satellite Operators Association (technical references listed in Annex 2)

* Thanks to the development of 4G and 5G, throughput can reach up to 1 Gbit/s.

Table 18. IMT families

	IMT-2000	IMT-Advanced
ITU-R Recommendation	ITU-R M.1457-14 (01/2019): Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications-2000 (IMT-2000)	ITU-R M.2012-4 (11/2019): Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications Advanced (IMT-Advanced)
Main technical criteria	1. High degree of commonality of design worldwide	1. A high degree of commonality of functionality worldwide while retaining the flexibility to support a wide range of services and applications in a cost-efficient manner
	2. Compatibility of services within IMT-2000 and with the fixed networks	2. Compatibility of services within IMT and with fixed networks
	3. High quality	3. Capability to interwork with other radio access systems
	4. Small terminal for worldwide use	4. High-quality mobile services
	5. Capability for multimedia applications, and a wide range of services and terminals	5. User equipment suitable for worldwide use
	6. Worldwide roaming capability	6. User-friendly applications, services and equipment
		7. Worldwide roaming capability
		8. Enhanced peak data rates to support advanced services and applications (100 Mbit/s for high and 1 Gbit/s for low mobility were established as targets for research (rates sourced from ITU-R M.1645)

Table 18. IMT families (continued)

	IMT-2000		IMT-Advanced	
	Standard	Commercial name	Standard	Commercial name
Recognized radio interfaces	1. IMT-2000 CDMA Direct Spread	W-CDMA UMTS UTRA FDD, (UMTS/HSPA/LTE family; 3GPP)	1. LTE-Advanced	E-UTRA Release 10 (LTE family; 3GPP)
	2. IMT-2000 CDMA Multi-Carrier	CDMA 2000 UMB (3GPP2)	2. WirelessMAN-Advanced	WiMAX IEEE 802.16m (WiMAX family; IEEE)
	3. IMT-2000 CDMA TDD	TD-CDMA UMTS UTRA TDD, E-UTRA TD (UMTS/HSPA/LTE family; 3GPP)		
	4. IMT-2000 TDMA Single-Carrier	UWC 136 (ATIS/TIA) EDGE (GSM family)		
	5. IMT-2000 FDMA/TDMA	DECT (ETSI)		
	6. IMT-2000 OFDMA TDD WMAN	WiMAX IEEE 802.16-2012 (WiMAX family; IEEE)		

Source: ITU

Table 19. Comparison of common wired access network technologies

Access network technology	Potential throughput / QoS	Range	Capital expenditure to deploy new network	Operating expenses	Infrastructure required	Suitability for rural deployments	Additional regulatory issues	Access device type
Fibre	100 - 1 000 Mbit/s	100s of km	Overhead cabling: low to medium	Medium	Tower, poles, cabinets, active network equipment	In some cases, with sufficient purchasing power and population densities	Pole attachment	Fibre modem to Ethernet-enabled devices or to Wi-Fi
			Below ground: medium to high (new excavation)	Low to medium	Subterranean duct work, cabinets, active network equipment	No	Right of way	
Coax (cable)	Up to 200 Mbit/s	Up to 100 km	Low to medium	Low to medium	Tower, poles, cabinets, active network equipment	In some cases, with sufficient purchasing power and population densities	Pole attachment	Cable modem to Ethernet-enabled devices or to Wi-Fi
Copper	0 to 24 Mbit/s (for ADSL, ADSL 2+, ADSL 2+); 100 Mbit/s (for VDSL, VDSL2, Vectoring); 1 Gbit/s (G.Fast)	0.1 to 5 km	Low to medium	Low to medium	Tower, poles, cabinets, active network equipment	In some cases, with sufficient purchasing power and population densities	Pole attachment	Modem to Ethernet-enabled devices or to Wi-Fi

Source: adapted from various sources, including the European Union, Cisco, Huawei, ITU, the Inter-American Development Bank, the World Bank and the European School of Antennas (technical references listed in Annex 2)

2.5 Common wired access technologies

Wired access technologies include fibre, copper and coaxial (cable). They have the drawback of costing more to deploy per user. This makes wired access problematic in localities where user density is insufficient to reach economies of scale. Table 20 summarizes common wired technologies for last-mile deployments.

In places where legacy copper or coaxial networks are already in place, however, using existing infrastructure to deliver connectivity is relatively straightforward. The biggest problem with wired access is the technical, financial and regulatory issues to overcome when deploying new infrastructure.

Among wired technologies, fibre delivers the highest maximum bandwidth. Furthermore, as a wired technology, fibre does not need spectrum resources and is therefore exempt from some types of regulatory approval. However, wired deployments require approval for rights of way, electrical pole attachment, grounded tubes and other aspects of deployment. Fibre can be very expensive to deploy, especially in remote or sparsely populated areas, or through challenging terrain.

Because fibre has to go through a location physically, it and other wired technologies (copper/DSL and coaxial) can also run into right-of-way and other construction-related permit issues. These issues become even more prominent when fibre is used exclusively for connecting users through an FTTH or fibre-to-the-premises network architecture. Like cellular, therefore, fibre is best suited to areas where user density is relatively high and economies of scale can bring down the cost of deployment per user.

The main advantage of both coaxial and copper is the existence of legacy networks in areas that might not yet have fibre. Where fibre regularly reaches speeds of 1 000 Mbit/s, coaxial cables – most commonly used for cable TV services – normally have a ceiling of 200 Mbit/s.³⁸ One advantage of coaxial, however, is its range, which can reach 100 km before the signal deteriorates and repeaters and other equipment become necessary. In contrast, copper telephone wires have a range of only 0.1 to 5 km (depending on certain technical conditions), while a continuous line of fibre can be deployed across hundreds of kilometres before signal degradation becomes an issue.

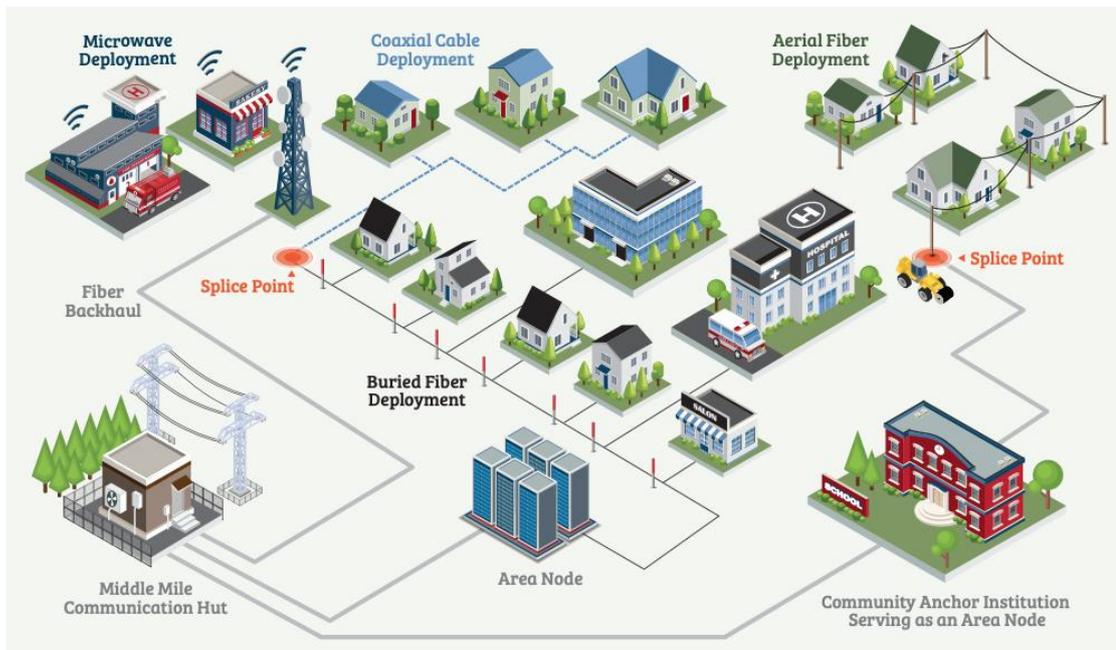
Compared to fibre and coaxial, copper has the most limited range before active network equipment becomes necessary, and usually offers lower maximum speeds, with VDSL, VDSL2, and vectoring technologies reaching only 100 Mbit/s (although the relatively uncommon G.Fast copper networks can reach speeds of 1 Gbit/s). Copper is popular because of how common it is: legacy wired telephone networks use copper cables, meaning that in many places, the infrastructure is already available.

This is important, as the cost of deploying fibre underground can be quite significant, although deploying it through overhead cabling is also an option. For most wired technologies, however, the costs of deployment and operating range from low to medium. All wired options also require a variety of active network equipment, in addition to passive infrastructure such as towers, poles, cabinets and subterranean ducts. Once fibre, copper or cable reaches the premises, it then connects to a modem that outputs connectivity through the Ethernet or via Wi-Fi.

³⁸ European Union, [Comparison of wired and wireless broadband](#).

For all wired technologies, a barrier to rural deployment is the lack of sufficient purchasing power and low population density in some communities. Without these, it can be difficult for operating entities to cover the costs of deploying and running the network. Pole attachment issues can also make it difficult (and expensive) to deploy a network, and securing right of way for subterranean ducts is critical to underground deployments. Figure 23 depicts wired deployments alongside wireless.

Figure 23. Common network deployments



Source: United States National Telecommunications and Information Administration, [Costs at-a-Glance: Fiber and Wireless Networks](#) (May 2017)

* Excludes a number of access technologies such as satellite and DSL

2.6 Common access technologies explained

2.6.1 Wi-Fi

Wi-Fi is the commonly used name for the range of different radio access technologies that are based on the IEEE 802.11 group of standards, used mostly to transmit data over licence-exempt spectrum frequency bands. Wi-Fi is commonly used for personal local area networking, connecting the Internet to a Wi-Fi access point which in turn is connected to end-user devices. Wi-Fi-based mesh networks can also be deployed to connect villages and communities in underserved areas.

Wi-Fi is a very common and cost-effective last-mile access technology. Not only does the technology operate in spectrum bands that allow unlicensed operation (reducing the cost of deployments and operation), many devices are Wi-Fi enabled (phones, laptops, etc.) and are thus directly able to connect to Wi-Fi access points. A common feature of last-mile networks is the connection of an access point in the locality to backhaul using fibre.

Wi-Fi operates in unlicensed frequencies and therefore does not require a licence to operate if the administration has made the spectrum licence-exempt. Licence-exempt spectrum allows users to operate any technology for any recreational or business purpose in the band (e.g. LTE-U, MulteFire, NR-U, ZIGBEE, Bluetooth, remote-control toys, wireless keyboard/mouse). Licence-exempt does not always mean unregulated, however. Some administrations may impose additional regulations (indoor/outdoor, point-to-point, limited transmission power). Since Wi-Fi use is widespread, a plethora of affordable consumer-grade routers are available.

The technology is supported in a variety of unlicensed, or licence-exempt, spectrum bands³⁹: 2.4 GHz and 5 GHz.⁴⁰ The frequencies involved give Wi-Fi a potential range of hundreds of metres for local area access points, to tens of kilometres for point-to-point and point-to-multipoint radios - based on, and subject to, regulatory exceptions and the density of Wi-Fi and other devices in the same unlicensed band. The quality of a Wi-Fi connection can thus vary greatly, as it is prone to interference. The range is also very limited: the range of a single average Wi-Fi router is several orders of magnitude lower than that of a cellular station.

As an evolving standard, Wi-Fi has seen various iterations over the years, each bringing with it improvements to the maximum data rate. The initial 802.11 (a), (b) and (g) standards, for example, which were deployed from 1997 to 2003, saw speeds ranging from 2 to 54 Mbit/s. The next standard released, 802.11n, had a maximum data rate of 600 Mbit/s - more than ten times as fast. The newest 802.11ax standard, released in 2020 and dubbed Wi-Fi 6, is notable not only for improvements to speed (from 6 900 Mbit/s for 802.11ac to 9 600 Mbit/s for 802.11x), but also for its use of the 6 GHz frequency band alongside the 2.4 GHz and 5 GHz bands (see Table 21).

Table 20. Comparison of various generations of Wi-Fi technology

IEEE 802.11 Protocol version	Year deployed	Spectrum frequency band(s), GHz	Maximum data rate (Mbit/s)
802.11ax ("Wi-Fi 6")	2020	2.4 GHz, 5 GHz, 6 GHz	9 600 Mbit/s
802.11ac	2014	5 GHz	6 900 Mbit/s
802.11n	2009	2.4 GHz and 5 GHz	600 Mbit/s
802.11 (a), (b), (g)	1997 - 2003	2.4 GHz and 5 GHz	2 Mbit/s to 54 Mbit/s

One distinct advantage of Wi-Fi is that it combines low per-device cost, no cost for spectrum utilization, modular technologies and hardware, and a mature ecosystem with many vendors. As a result, the topographical network designs of deployments are very large, as they can leverage access points meshed together through point-to-point and point-to-multipoint links.

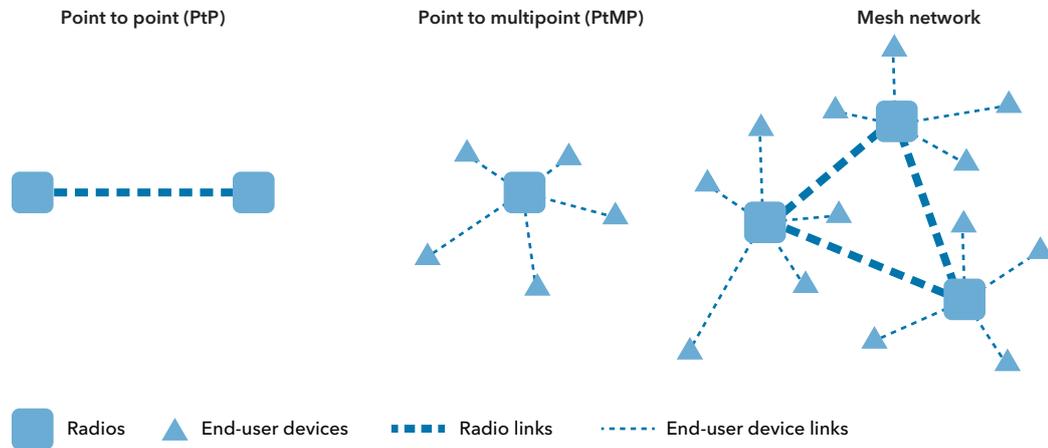
Some of the network typologies for Wi-Fi include Tree, where all traffic is aggregated upwards hierarchically; Ring, where each node is connected to two other nodes; Meshed, where each node is connected to several nodes for redundancy; and Star, where each node connects to a central node (see Figure 24).

³⁹ Moreover, unlicensed bands are not exclusive, but rather shared with other primary/secondary services, and promote opportunistic use of spectrum.

⁴⁰ In some regions, such as the United States, 6 GHz is being allocated for Wi-Fi 6.

The versatility of Wi-Fi combined with its low cost and ease of deployment make it an appealing option for localities where expertise might be in short supply and users are expected to conduct some of the basic upkeep of the network themselves. Wi-Fi also works well with other technologies as the last layer bridging, say, fibre or microwave technology to end-user devices.

Figure 24. Examples of Wi-Fi network topologies*



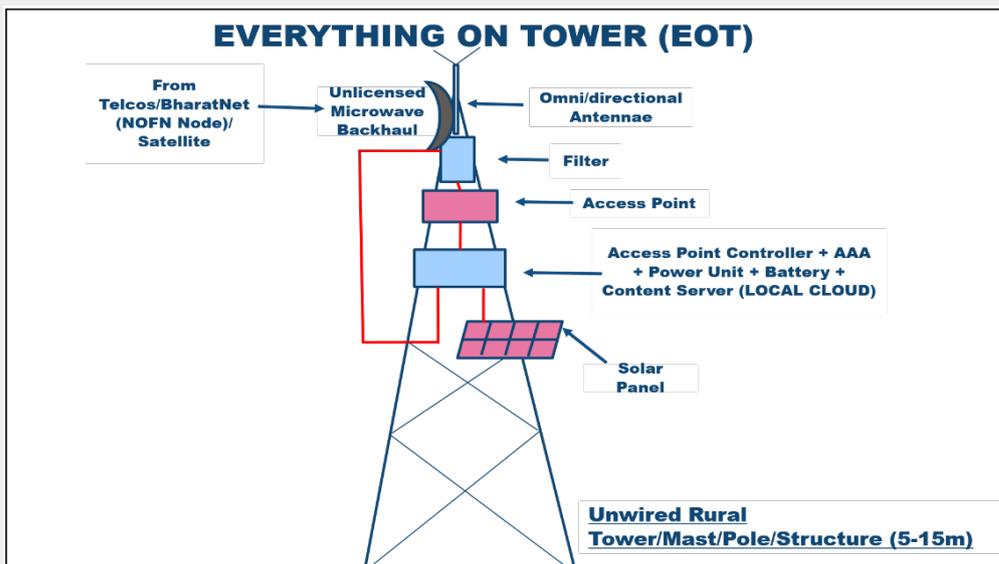
* Additional network topologies can be found at <https://ec.europa.eu/digital-single-market/en/network-and-topology>.

Box 3. Case study: Wi-Fi access network (India)

In India, Bluetown has reported operating as a managed hotspot service provider for rural areas in partnership with BSNL in Jharkhand, a state in eastern India. With backhaul from BSNL, Bluetown reports providing Wi-Fi hotspots in rural areas in over 782 remote locations across Jharkhand as part of an upgrade of service in locations that previously only had 2G access.

The business model is based in part on the Telecom Regulatory Authority of India recommendation for an unregulated model, wherein an aggregator (Public Data Office Aggregator) can provide last-mile Wi-Fi infrastructure and small entrepreneurs set up Public Data Offices in local areas for customer access. The Public Data Office Aggregator will facilitate multiple Public Data Offices to provide public Wi-Fi services, without requiring a telecommunication licence, as they will work mainly as the reseller for ISPs.

Broadband is provided in such rural areas by a Managed Hotspot Service Provider (MHSP), which, working in partnership with telecommunications/ISP, installs equipment that will be managed by a Village-level Entrepreneur (VLE). The VLE, working as a franchisee of the MHSP, acts as single point of contact for all broadband-related products and services. It is given basic training by the MHSP for regular maintenance and operation of hotspot infrastructure and provides Wi-Fi for assisted broadband services to the villagers. It is also responsible for digital literacy and assisted broadband services (such as e-governance) among the rural masses. The VLE will use the Wi-Fi infrastructure to generate revenues through other activities (such as mobile charging, railroad ticketing, obtaining market prices of crops and assisting in business transactions, rural e-banking, facilitating medical care from urban health centres, to name but a few).



Currently, Bluetown offers the following plans:

Prepaid plans	Download offered (in GBs)	Plan validity period	Amount (INR)	Amount (approx. USD)
PLAN 1	30	28 days	69	1
PLAN 2	7	7 days	39	0.5
PLAN 3	2	2 days	19	0.25

Cost per GB: The average cost of broadband connectivity is working out at USD 1 per 30 GB i.e. USD 0.03 per GB

Source: direct contribution by Satya N. Gupta (Bluetown India)
 See also <http://saamcorp advisors.com/assets/converting-unemployment-into-intrapreneurship-through-rural-wi-fi-hotspots.pdf>

2.6.2 Mobile

Mobile technologies have been rapidly adopted by billions of people worldwide, driving the “mobile miracle” across Africa and Asia. Today, there are over 5 billion unique mobile cellular users, making cellular mobile one of the most, if not the most, widely adopted digital technologies worldwide. The vast majority of the world’s population will continue to connect to the Internet via mobile technologies.

Cellular refers to the generations of technology adopted thanks to mobile phones. Mobile cellular technology features a mature ecosystem with many device vendors, modular technologies and hardware, and larger coverage areas (higher output power) than Wi-Fi. It uses various licensed bands that are allocated to mobile services and assigned to cellular operators, normally through auctions, “beauty contests” and/or administrative fiat. A single tower can cover a wide area spanning tens of kilometres, but is also subject to interference and other technical constraints.

One distinct advantage of mobile cellular technology is the affordability and wide availability of access devices in the form of mobile phones. The technology has evolved over successive generations, with each iteration bringing improvements to QoS. The first generation of cellular technology (1G) was purely analogue and facilitated only voice communication. With the introduction of 2G technologies (GSM, CDMA, TDMA), end users gained access to data-based messaging (in the form of SMS) with peak upload and download rates of 14.4 Kbit/s (see Table 21 for a comparison of the characteristics of the various generations of cellular technology).

By the third full generation (3G-3.5G, encompassing UMTS, W-CDMA, EV-DO, HSPA, HSPA+, DC-HSDPA), mobile cellular technology was fully geared to accommodate data-based usage, including applications such as video streaming and Internet surfing. This generation of technologies had peak download rates that could reach 42 Mbit/s, with peak upload rates of 22 Mbit/s. Data was clearly the way forward, and improvements in cellular technologies made the revolution in smartphones and other constantly connected devices possible.

The relationship between the evolution of cellular technologies and of data-based usage patterns went the other way, too. With the introduction of 4G (IMT-Advanced: LTE Advanced, Wi-Max Advanced), cellular fully adopted data and IP as the overarching paradigm. 4G can be described as a “mobile data broadband evolution” offering much faster speeds than the preceding generation and with provision for the transition of traditional services (such as voice) to an IP-based platform (as with Voice over LTE, or VoLTE).

Table 21. Comparison of various generations of cellular technology*

Generation	Description	Technologies	Peak download data rates	Peak upload data rates
5G	Very high data rates, very low delay (latency)	IMT-2020: technology evaluations in progress	20 Gbit/s	10 Gbit/s
4G (LTE Advanced, Wi-Max Advanced)	Mobile data broadband evolution, high speed, IP-based	IMT-Advanced: LTE Advanced, Wi-Max Advanced	1 Gbit/s	500 Mbit/s
3G	Voice and data (video and Internet surfing)	IMT-2000: UMTS, W-CDMA, EV-DO, HSPA, HSPA+, DC-HSDPA, WiMAX	384 Kbit/s to 42 Mbit/s	63 Kbit/s to 22 Mbit/s
2G	Voice and data (SMS); digital	GSM, CDMA, TDMA	14.4 Kbit/s	14.4 Kbit/s
1G	Analogue radio signals, voice only (no SMS)	NMTS, AMPS, TACS	n/a	n/a

Sources: various

*** Rates are based on technical standard maximums**

An analysis of the coverage area provides important insights into just how much the specifics of a deployment matter to the final level of network performance. The coverage areas of different cellular technology deployments are impacted by a wide range of factors, including the spectrum band utilized (see Table 22), the height of the radio tower, electrical power/ amplification of radio signals (on both transmitting and receiving devices) and environmental conditions (such as atmospheric pressure and humidity).

For example, according to GSMA, when it comes to rural deployments, coverage areas differ depending on tower height, all other factors being constant:⁴¹ a tower over 30 m high can cover a wide area (8-15 km), while towers that are between 12 and 30 m high may only cover 4 to 8 km. Targeted solutions with tower heights between 9 and 19 m, meanwhile, can transmit signals over 2 to 4 km. With the ultrawide-area innovative solutions currently in development, such as HAPS, that can be used for both backhaul and last-mile access, coverage areas from 500 to 2 000 km may even be possible.⁴²

⁴¹ Handforth, op. cit., note 3.

⁴² Google Loon is an example of a HAPS used as a last-mile coverage solution direct to devices.

The peak performance figures indicated for each cellular technology in Table 21 must therefore be considered with the understanding that real-world performance may differ from the technology’s technical upper limits. Analysing the benefits and drawbacks of any given cellular technology for a deployment requires a good understanding of the network’s proposed technical and environmental characteristics.

Cellular technology can cover a wide area through a single tower, although it is also subject to interference and quality can fall off over distance. This means end users with smartphones and other mobile Internet-enabled devices can get connectivity anywhere within the range of the tower – even while on the move. The main drawback of cellular as an access technology is the implementation cost, such as the cost of tower infrastructure, with base stations ranging from USD 20 000 to 100 000. The deployment of cellular networks can also be complicated by difficult topography, which can make it unreasonably expensive, if not wholly impractical, to use cellular in remote locations or difficult terrain. A comparison of network deployments using various technologies requires total cost comparisons that take into account a range of factors, such as total coverage area, number of radio base stations required and backhaul. Infrastructure-sharing arrangements among MNO could help lower the cost of extending and densifying their networks.

Table 22. Maximum coverage area by radio frequency (MHz) using LTE*

Frequency (MHz)	Cell radius (km)	Coverage area (km ²)	Relative cell count (compared to 450 MHz characteristics)
450	48.9	7 521	1
850	29.4	2 712	2.8
950	26.9	2 269	3.3
1800	14.0	618	12.2
1900	13.3	553	13.6
2500	10.0	312	24.1

Source: J. Bright, [LTE450](#) (slide presentation at the LTE450 Global Seminar 2014) (Ovum, 2014)

* This is a theoretical comparison of base station coverage at different bandwidths, based on flat terrain, a tower-mounted amplifier with a radio 60 m above ground, and no interference. The maximum coverage area can be achieved when the main criterion is wave propagation and not traffic load.

Box 4. Last-mile cellular network deployments (Africa Mobile Networks)

Africa Mobile Networks (AMN) is one example of cellular deployment in rural and remote geographies to extend service to sparsely populated communities. AMN is predominantly a connectivity-as-a-service operator (see 2.3.2 Business models) and works in partnership with MNOs such as Orange and MTN across Africa. It deploys the active and passive infrastructure needed to operate mobile networks on behalf of its MNO partners in revenue-sharing and operating expense models (whereby the operator pays AMN a fixed fee rather than a share of the revenue). It currently operates approximately 2 000 sites in Cameroon, the Republic of the Congo, the Democratic Republic of the Congo, Guinea Bissau, Guinea, Liberia, Nigeria and Zambia, with deployments also planned for Sudan and South Sudan in 2020.

AMN provides commercial service to remote communities with settled low populations (500 to 5 000 people) and low ARPUs (USD 1.20).

Typical site deployment infrastructure includes either a 9.5-m tower that is a monopole plus antenna or a 20-m lattice tower, both of which support 2G, 3G and 4G radio equipment. All sites are solar- and battery-powered, with uptimes of 99.8 per cent or more year-round, and use mainly very-small-aperture terminals for backhaul (there are a few that use microwave backhaul).



Remote AMN small site deployments that typically service populations of around 1 000 people. Coverage areas range from 1.5 to 3 km for the 12-m tower, and 3.5 to 7 km for the 20-m tower, depending on terrain.

Source: Africa Mobile Networks, AMN Overview as published on LinkedIn, January 2017

Additional sources:

<http://www.africamobilenetworks.com/>

<https://media-exp1.licdn.com/dms/document/C4E1FAQF7O-xfEKuMvw/feedshare-document-pdf-analyzed/0?e=1592272800&v=beta&t=Za7bDiqlc1BtlC9GtXY8n5EdVfLHTkQNJVO4ghA2-Jc>

2.6.3 Optical fibre

Optical fibre technology transports the vast majority of global IP data traffic, carrying 99 per cent of international cross-border Internet traffic over terrestrial and undersea fibre cables.⁴³ In backhaul, fibre's price per capacity is one of the more cost-effective connectivity technologies.

Fibre is also increasingly deployed in access networks as it becomes cheaper and less complex to install. It is typically deployed right to the premises or to a nearby cabinet in a local neighbourhood (where existing copper or wireless is used to transmit the final distance).

Fibre has several advantages: high performance, high data capacity and low transmission error rates. However, it remains a relatively high-cost access technology. Although overhead deployments can somewhat lower the cost of the last mile, subterranean installation remains an expensive undertaking, particularly in areas with no existing passive infrastructure.

When combined with the cost of the active network equipment needed for fibre deployments, the technology can be prohibitively expensive for some localities, narrowing the business case for fibre. As the cost of civil works for deployments benefits heavily from economies of scale, fibre is best suited to densely populated areas where multiple users can be reached by a single phase of deployment.

Deployment costs for fibre backhaul vary widely and are affected mainly by the civil works and regulatory compliance costs. A review of one publicly subsidized United States government programme for middle-mile deployment revealed a wide range of average costs per mile of fibre deployment, from about USD 65 million for the most cost-effective 10 000 miles of fibre to nearly USD 820 million for the least cost-effective 10 000 miles, or USD 6 500 per most cost-effective mile to USD 82 000 per least cost-effective mile.⁴⁴ In estimates of the cost structure of fibre deployments, an average of about 45 per cent of network operations relate directly to deployment costs (recovery of capital expenditure), reflecting their capital-intensive nature.

Deployment costs and coordination challenges are major impediments to the installation of fibre-optic cables, particularly in rural areas. They can be overcome by focusing on aerial fibre via telephone or electrical pole attachment, although it can, in some cases, be cumbersome to obtain the requisite regulatory approval or commercial agreements. In some jurisdictions, policies can be adopted to facilitate fibre deployments (e.g. "dig once" policy⁴⁵, easing rights of way⁴⁶, or the One-Touch Make-Ready pole attachment statutes and ordinances⁴⁷).

That being said, fibre can cover a wide area, as the technology itself has a range of hundreds of kilometres. Another advantage of fibre is its very high capacity, with a single strand of optical fibre able to carry enough bandwidth to support the needs of multiple users. As fibre-optic cables themselves (called dark fibre) are a passive technology, they benefit from advances in active network technologies, such that the same cable can be used to deliver progressively faster service to more users.

⁴³ NEC, *Secrets of Submarine Cables - Transmitting 99 percent of all international data!*

⁴⁴ S. Wallsten and L. Gamboa, *Public Investment in Broadband Infrastructure: Lessons from the U.S. and Abroad* (Technology Policy Institute, June 2017).

⁴⁵ Federal Communications Commission, *Model Code for Municipalities. Federal Communications Commission Broadband Deployment Advisory Committee Model Code for Municipalities Working Group* (Draft 7/19/18).

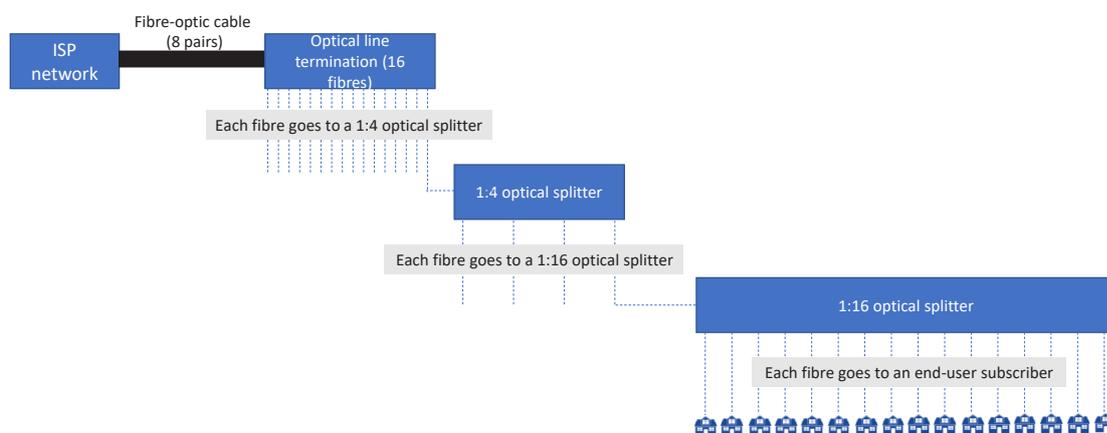
⁴⁶ OECD, *Public Rights of Way for Fibre Deployment to the Home*, OECD Digital Economy Papers, No. 143 (OECD Publishing, Paris, 2008).

⁴⁷ See https://en.wikipedia.org/wiki/One_Touch_Make_Ready.

For example, with wave division multiplexing, the capacity of optical fibre can be continuously upgraded by using multiple light frequencies. Passive optical network technology, particularly the gigabit version (GPON), is increasingly being deployed as a way for fibre-optic technology to reach end-user premises (home or office) in a more affordable manner, as the active network equipment extends only to a central exchange. Instead of deploying active equipment to handle each connection to an end user, a network can use a series of optical splitters to deliver bandwidth from a central exchange to multiple premises. Using this method, a single fibre-optic cable with eight paired strands (for a total of 16 fibre-optic strands) can service as many as 1 024 subscribers, making it easier to attain the economies of scale needed for business viability and lowering access costs for end users (see Figure 25).

A combination of improvements in fibre technology and of policies that mitigate the high cost of civil works for fibre deployment can make fibre affordable even for developing localities. In a number of emerging markets, ISPs are offering FTTH service at ARPU levels that are significantly lower than in developed economies, demonstrating the affordability of high-throughput services. Examples of high-bandwidth, affordable service offerings from ISPs in emerging markets include that of the Viet Nam Posts and Telecommunications Group, the government-owned national telecommunications and post company, which offers fibre-in-the loop services with a monthly ARPU of only USD 8.70.⁴⁸ Meanwhile, WorldLink in Nepal, the country's largest Internet and network Service provider, has a monthly fibre-in-the loop ARPU of USD 10.⁴⁹

Figure 25. How a 16-strand GB passive optical network can service 1 024 subscribers



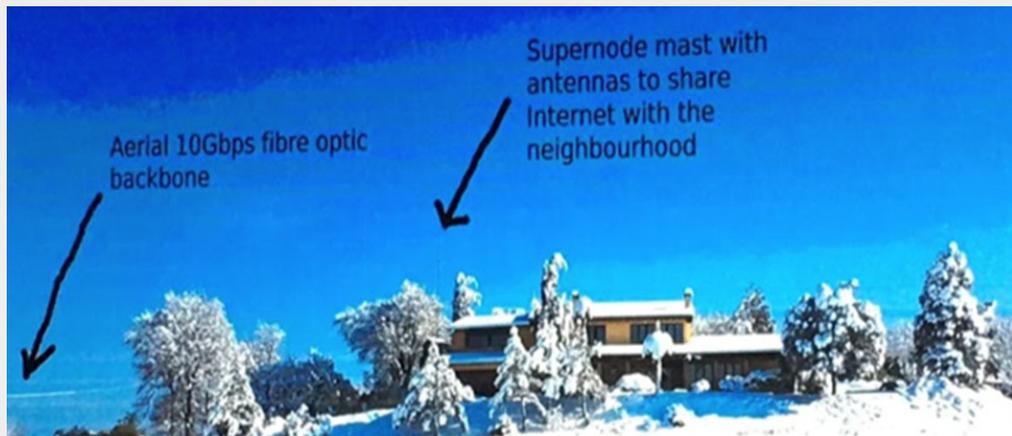
Source: adapted from J. Brewer et al., note 53

⁴⁸ J. Brewer et al., *From Analog to Digital - Philippine Policy and Emerging Internet Technologies* (The Asia Foundation, October 2018).

⁴⁹ Direct interviews with ISPs by [Connectivity Capital](#), an impact investment fund and debt capital provider.

Box 5. Optical fibre deployments in rural communities (Spain)

Guifi.net is an open access telecommunication network based on a commons model that was started in 2004 in Osona county in Catalonia, Spain, to address the lack of broadband in rural areas amid a dearth of interest among traditional operators to provide service. Today, Guifi.net has over 30 000 active nodes operating across 68 000 km of links (wireless and fibre). In 2009, the network started deploying optical fibre in rural areas under the Fibre From the Farms Broadband Initiative. The network could achieve a reduced cost of fibre deployment per kilometre because of the active involvement of the community.



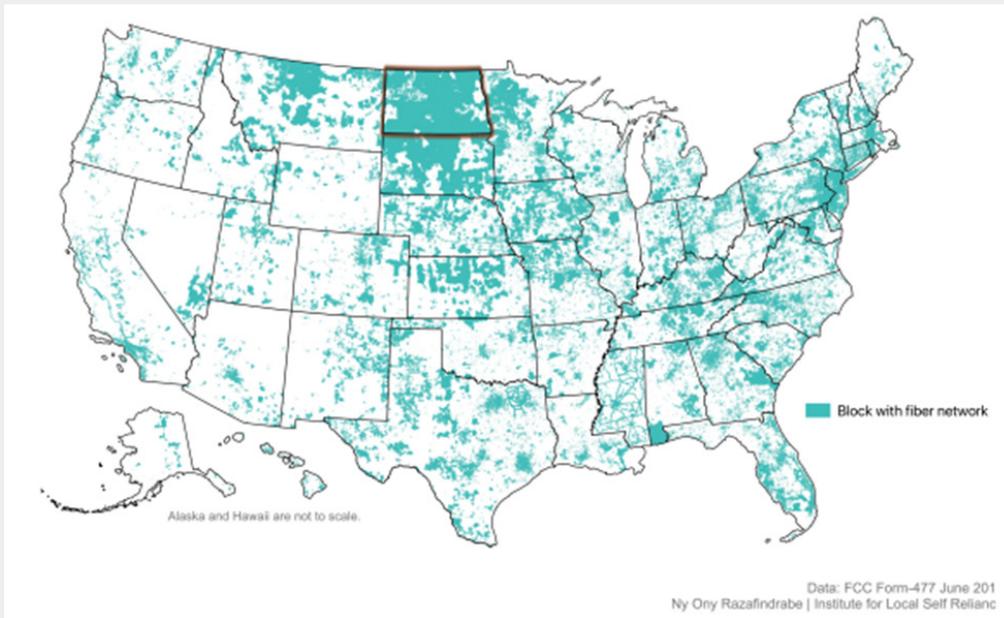
Example of Guifi.net aerial fibre-optic deployments

Source: presentation by Ramon Roca, 14 November 2019

Additional resources: <https://guifi.net/> and <https://en.wikipedia.org/wiki/Guifi.net>

Box 6. Optical fibre deployments in rural communities (United States)

In the United States, municipal and rural cooperative networks in the state of North Dakota have been leaders in terms of deploying fibre networks to communities in rural and remote regions. Their efforts have been driven in part by cooperation among small rural telephone exchanges and by leveraging federal funds to invest in broadband infrastructure. Today, more than 75 per cent of the state's rural population has access to fibre (compared to only 20 per cent of rural residents nationwide) and over 80 per cent of the state is covered by fibre networks.



Access to fibre networks by census blocks (June 2019) (North Dakota highlighted in outline)

Source: K. Kienbaum et al., *How Local Providers Built the Nation's Best Internet Access in Rural North Dakota* (Institute for Local Self-reliance, May 2020)

2.6.4 Satellite

Satellite technology is a mature technology that is increasingly used for Internet data communications. There are currently over 775 communication satellites orbiting the planet, and the technology is particularly useful for reaching suburban, rural, remote and ultra-remote parts of geographies that are beyond the reach of other communication infrastructure.⁵⁰

Satellite connectivity is utilized for a range of different deployment scenarios in support of last-mile connectivity, e.g. mobile backhaul, Wi-Fi and direct broadband satellite-to-the-premises. Satellites are usually grouped in three different categories: GEO, MEO and LEO (see Table 23 for a comparison of GEO, MEO and LEO characteristics).

GEO satellites sit highest in the atmosphere, at an altitude of 35 786 km, in a position fixed relative to a point on the ground. Their height means that data transmitted to and from the satellite have a relatively high latency, with an average round-trip latency of 477 ms. However, the position of GEO satellites also means that few satellites are needed to span the entire globe, with three satellites being sufficient to have a footprint almost everywhere. With large high-capacity satellite beams, GEO HTS and VHTS can achieve data rates of up to 1 terabit per second.⁵¹ At a cost of anywhere from USD 100 to 400 million per satellite, GEO satellites are the most expensive kind to deploy. Their cost is partially offset by their long effective lifetimes, with each satellite capable of providing service for 15 to 20 years.

MEO satellites are found between LEO and GEO satellites, as low as 2 000 km above ground. This significantly improves latency, with round-trip latency to the nearest MEO satellites totalling about 27 ms. One drawback is that their lower height means that more satellites are needed to have a global footprint, with anywhere from 5 to 30 satellites required depending on their altitude. MEO satellites cost between USD 80 and 100 million per satellite and have an effective lifespan of 10 to 15 years.

LEO satellites are an emerging category of satellite that promises to deliver very low latency service to users, comparable to that of terrestrial technologies. Sitting at altitudes as low as 160 km above ground, LEO satellites can have a round-trip latency as low as 2 ms and provide up to 70 Gbit/s throughput per satellite.⁵² While LEO satellites cost less than GEO and MEO satellites – anywhere from USD 45 million to as low as USD 500 000 each – the total cost of a constellation of LEO satellites can be substantial, as hundreds or thousands of satellites may be required to provide global coverage because of their smaller beams. Account may also have to be taken of additional parameters, such as terminal and gateway costs, and the satellites may also have a relatively short lifespan, with each satellite expected to be in service for only 5 to 10 years. LEO satellites are a promising technology for applications that require very low latency and for providing service to areas with no existing infrastructure.

⁵⁰ ITU/UNESCO Broadband Commission for Sustainable Development, *The State of Broadband 2019. Broadband as a Foundation for Sustainable Development* (Geneva, 2019).

⁵¹ Viasat, *Going Global*.

⁵² E. Ralph, *SpaceX says upgraded Starlink satellites have better bandwidth, beams, and more* (blog post, Teslarati, 12 November 2019).

Table 23. GEO, MEO and LEO satellite characteristics

Satellite category	Altitude	Orbital period	Latency (round-trip)	Number of satellites to span globe	Cost per satellite	Effective lifetime of satellite
GEO	35 786 km	24 hours	approx. 477 ms	3*	approx. USD 100 to 400 million	15 to 20 years
MEO	2 000 to 35 786 km**	127 minutes to 24 hours	approx. 27 to 477 ms	5 to 30 (depending on altitude)	approx. USD 80 to 100 million	10 to 15 years
LEO	160 to 2 000 km	88 minutes to 127 minutes	approx. 2 to 27 ms	Hundreds or thousands (depending on altitude)	approx. USD 500 000 to 45 million	5 to 10 years

Source: various authors (see Annex 2)

* This excludes high-latitude areas, i.e. above the polar circles.

** Theoretically; in practice, 5 000 to 20 000 km.

Satellite use requires access to licensed spectrum resources, as satellite technologies operate in frequency bands allocated specifically to them. The biggest advantage of satellites is their very wide coverage area, with service available wherever there is a line of sight to the satellite from a station located anywhere within the satellite’s footprint. Satellite connectivity provides global coverage, including for suburban, rural and isolated areas. Despite this, hybrid solutions and direct access to satellite broadband are not widespread on all continents, as they remain relatively unknown solutions. Some continents are already quite advanced, while others are still developing.

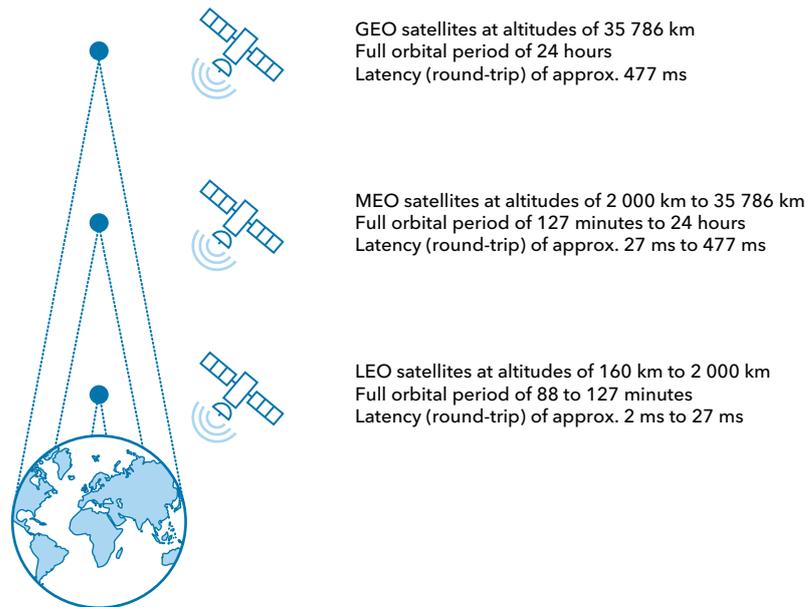
For last-mile access, very-small-aperture terminals for the end user’s premises are themselves relatively low cost, particularly in situations where supportive regulations do not impose regulatory barriers such as high licence fees for satellite service or import duties on equipment.⁵³ However, satellite bandwidth pricing can be higher compared to the alternatives, and bandwidth availability may be much more limited, especially compared to fibre. Satellites themselves are very expensive, and new satellite network deployments require significant capital investment, including in the satellite, its launch and the ground station hub.

Because of the significant capital investment required, projects that involve building and launching a satellite are commonly undertaken by private satellite operators. Some countries may find it cost-effective to make use of that existing capacity, while others may find it more economical to use indigenous satellite capacity to bridge the digital divide. Costs continue to decline for the production and launch of all categories of satellite.

⁵³ Blanket licenses and proportionate import fees for satellite ISPs are the policy most conducive to affordable service.

With improvements in satellite technology, data rates are increasing with next generation GEO satellites (HTS), new MEO satellites and emerging LEO deployments. LEO satellites have the particular advantage of lower latency, although deployments have shown that GEO latency is acceptable for VoIP and video calls and MEO latency is within range for MNO 4G deployments. Figure 26 illustrates the differences between GEO, MEO and LEO constellations.

Figure 26. Comparison of GEO, MEO and LEO satellite characteristics, including coverage areas*



* Not depicted: small satellites, nano satellites, cube satellites in the 50 to 500-kg range that are typically used for gathering scientific data and radio relay.

Latency does affect user experience, albeit in different ways. While satellites are known for higher latencies, some real-world deployments show that GEO latencies are acceptable for some broadband applications (including streaming, voice and video call), GEO and MEO latencies can support 4G/LTE networks, and LEO latencies are expected to be even lower.

Figure 27 demonstrates the impact of latency on performance and experience for different applications in certain select consumer and industrial applications. For some, the impact on user experience can be significant.

Figure 27. Impact of latency on select applications and services

How Latency Affects the User Experience

For some applications, latency has little impact on performance or experience. For others, the impact on user experience can be significant, or even render an application unusable. Some selected examples of consumer and industrial applications are below:

Application	Sensitivity to Latency	Mitigation Techniques	Likely Transmission Medium
Television	Low	Some	Fibre, Cellular, Public Wi-Fi, Satellite
SCADA, and other telematics applications	Low	Some	Fibre, Cellular, Public Wi-Fi, Satellite
Streaming services	Low	Many	Fibre, Cellular, Public Wi-Fi, Satellite
Over-the-Air (OTA) updates	Low	Some	Fibre, Cellular, Public Wi-Fi, Satellite
Internet browsing	Medium	Many, very effective	Fibre, Cellular, Public Wi-Fi, Satellite
Encrypted Internet Browsing	Medium	Few	Fibre, Cellular, Public Wi-Fi, Satellite
Voice & Videoconferencing	Medium	Few	Fibre, Cellular, Public Wi-Fi, Satellite
Cloud-computing & ERP	Medium - High	Some	Fibre, Cellular, Public Wi-Fi, Satellite
High-frequency trading	Extreme	Few	Fibre, Cellular, Public Wi-Fi, Satellite
V2V and V2X	Depends on application	Few	Fibre, Cellular, Public Wi-Fi, Satellite
Mobility connectivity (In-flight/maritime/Cars /train)	Depends on application	Many	Fibre, Cellular, Public Wi-Fi, Satellite
IoT	Depends on application	Very Few	Fibre, Cellular, Public Wi-Fi, Satellite

Source: EMEA Satellite Operators Association

2.7 Backhaul technologies

A last-mile access network's backhaul is the method by which the network acquires upstream bandwidth for distribution to its customers. Various technologies and their corresponding business arrangements can be used for backhaul; each has its own characteristics that determine its suitability for a given context. This section provides a brief overview of various backhaul technologies and a comparison of their advantages and disadvantages for use in different contexts.

A range of different technologies that are commonly used in access networks are also used for longer distances in middle-mile/backhaul links. While the majority of data traffic for terrestrial links in backhaul networks transits through microwave links, other technologies such as fibre, satellite, cellular links and even copper wire continue to be used today. Copper continues to be phased out, however, and other wireless and emerging technologies (such as WiMAX and HAPS) are also currently used in limited situations.

The technology with the largest share of terrestrial backhaul traffic, microwave technology utilizes ultra-high or higher frequencies in high-capacity, high-power wireless radio network links between towers that connect last-mile access networks to the national backbone network. These links, which usually take the form of point-to-point relays that require topology and/or towers to provide direct line of sight between radios, can cost less per distance than optical fibre deployment, especially in geographies and terrain where topography or other physical challenges (such as bodies of water) hamstring fibre deployment. High-power microwave links can cover Between tens and several hundred kilometres in a single hop, and multiple hops are utilized in backhaul transmissions.

Directional wireless links typically operate in peer-to-peer mode, are mainly used as a cost-effective wire-like alternative in the backhaul segment to connect last-mile technologies to the backbone, and are usually used to provision mobile base stations and Wi-Fi access points or to fulfil the communication needs of businesses and schools, which in turn provide their own access solution (i.e. Ethernet, Wi-Fi, LTE).

The main drawback of microwave backhaul is the need for line of sight, which can be challenging in mountainous and other difficult terrain. The need for a nearby PoP can also be a limiting factor; if no fibre-connected microwave station is available within the line of sight, a microwave relay will need to be built, adding to the cost of deployment. A wireless technology, microwave radio is also subject to radio spectrum regulations, which can differ depending on the jurisdiction in which the network is located.

Fibre backhaul, which uses fibre-optic cables to deliver bandwidth to a network, can consistently provide bandwidth at high speed. Delivering connectivity at the speed of light, the maximum allowable bandwidth that can be transmitted through fibre is continuously being upgraded, as the active network equipment used in transmission is developed without necessarily requiring replacement of the fibre-optic cables.

Fibre can be difficult and expensive to deploy, however, and is particularly difficult to use in challenging terrain. It is therefore ideal in dense, urban areas with existing infrastructure pathways where, combined with economies of scale, it is possible to implement low-cost fibre backhaul. Fibre backhaul also relies on a PoP being available relatively close to the last-mile access network, which can be challenging in distant or isolated communities. Combined with the relatively low bandwidth demands of rural communities, the use of fibre backhaul for rural last-mile networks can be uneconomical. Provided these factors are overcome, however, fibre can be suitable for rural deployments and is a good way to ensure that infrastructure is in place to cater to the growing demands of a locality.

Another wireless technology that can be used for backhaul is cellular. Cellular backhaul relies on mobile data frequencies to deliver bandwidth to the network. The network connects to a cellular base station, which in turn gets its bandwidth from fibre or microwave. Depending on the context and specific mobile technology, cellular can be ubiquitous and can provide adequate speeds for redistribution using a last-mile network, although total bandwidth can be limited, especially compared to fibre.

Like microwave, cellular can provide convenient access to bandwidth in places where fibre is uneconomical or otherwise hard to deploy. Unlike microwave, however, cellular does not require line of sight in order to get a connection. That being said, microwave can have a longer effective range than cellular, which leads to the main issue with using cellular as backhaul: the need for proximity to a cellular base station. Where microwave can be used across longer distances to connect even isolated communities, the availability of cellular backhaul is limited to the range of the nearest cell tower, which for cost reasons is unlikely to be present in sparsely populated areas.

Putting up a cell tower can be prohibitively expensive, which is perhaps one of the main reasons why cell towers are usually operated only by big full-service (voice, SMS and data) providers. The cost of cellular network infrastructure, estimated at around USD 200 000 to 250 000 per site, means that operators will put up a tower only when there is a business case to be made for

deployment.⁵⁴ Unfortunately, this usually applies only in urban and peri-urban locations, and leaves out rural and other far-flung or isolated communities. Thus, while cellular backhaul may be easier to use than fibre, its application is similar in that it is best suited to urban or densely populated areas.

A related system is fixed wireless access, which utilizes technologies such as 4G and 5G to deliver connectivity up to a range of 10 km. With a potential throughput of 20 to 1 000 Mbit/s, fixed wireless access provides high-capacity links for backhaul with infrastructure requirements similar to cellular. Because of its short range compared to microwave, however, fixed wireless access requires multiple repeaters to cover a wide area. It also relies on an existing network to obtain bandwidth, limiting its use to localities where a PoP is available nearby.

In areas where no terrestrial PoP is available, satellite may be the only backhaul technology available. Satellite backhaul relies on satellite-based bandwidth providers to connect the most remote communities. Depending on the exact type of technology used, satellite backhaul can be deployed quickly, without the need to build the costly and technically challenging infrastructure required for other backhaul technologies.

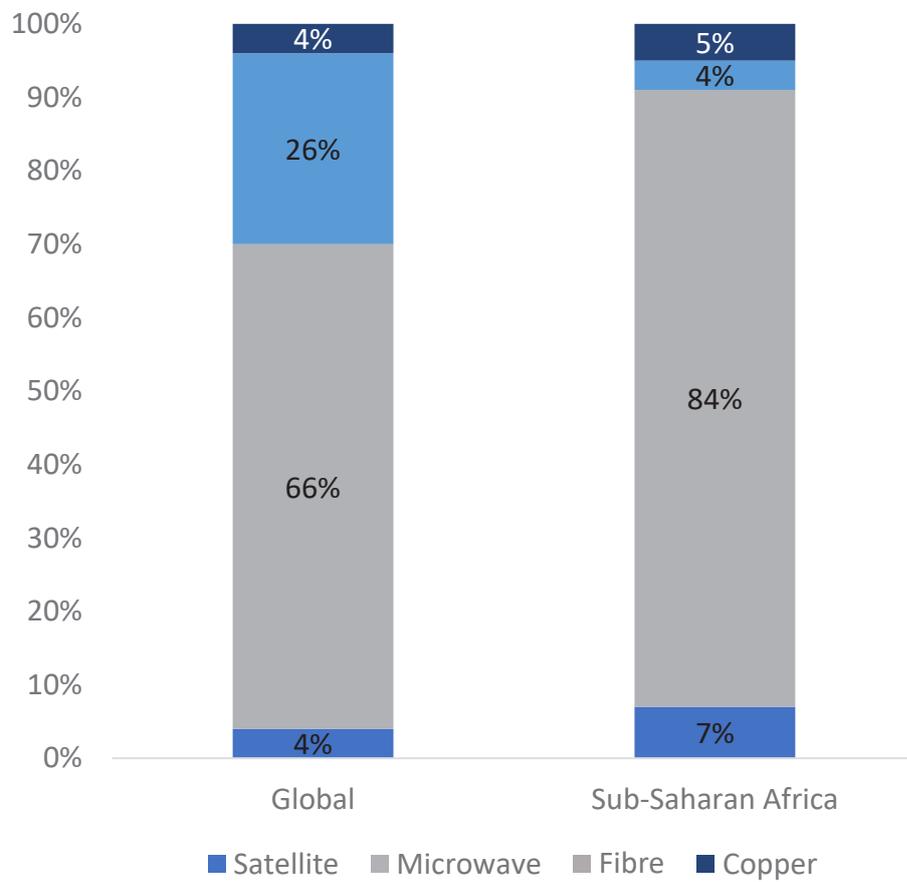
Although satellites have an advantage over other backhaul technologies for ease and speed of deployment, their QoS lags behind alternatives such as fibre, particularly when it comes to bandwidth and latency. Depending on the specific satellite technology and band used, quality can also deteriorate in certain weather conditions. Satellites are nevertheless an effective backhaul technology in areas where there are no other options for procuring bandwidth. The biggest challenge for using satellites remains cost. That being said, the cost of satellite bandwidth has been falling, particularly with the launch of HTS GEO satellites and the emerging LEO constellations. While the cost of satellite bandwidth is comparatively higher than other backhaul methods, savings are made thanks to the fact that no terrestrial infrastructure is needed to connect the last mile.

Figure 28, which depicts the shares of total backhaul traffic for mobile voice and data globally and in sub-Saharan Africa in 2017, shows that most places in the world today rely predominantly on microwave for cellular networks, but also fibre and satellite. It also shows, however, that LEO and MEO satellite systems (as well as HAPS) are being deployed that may offer compelling alternatives to point-to-point microwave backhaul, owing to their ability to cover all geographies cost-effectively and to the ease of deployment. And satellite technologies have recently been used to expand and upgrade terrestrial mobile networks from 2G to 3G and 4G, often in combination with terrestrial fixed links. There have been promising such deployments in such diverse places as Chile, the Democratic Republic of the Congo, Myanmar and Papua New Guinea.⁵⁵

⁵⁴ GSMA, *Rural Coverage: Strategies for Sustainability (Country Case Studies)* (2015), p. 15.

⁵⁵ See, for example, Intelsat, *Intelsat and AMN Bring Mobile Connectivity to 1,000th Site in Sub-Saharan Africa* (Intelsat Corporate Communications, 20 April 2020) and HISPASAT, *HISPASAT proveerá enlaces satelitales en banda Ka para extender la Red Compartida de Altán en zonas remotas de México* (press release, 4 June 2020).

Figure 28. Backhaul for mobile voice and data by method, global and sub-Saharan Africa (2017)



Source: Handforth, note 3

Table 24 provides a summary comparison of different backhaul technologies and their characteristics.

Table 24. Comparison of common backhaul technologies

Backhaul technology	Potential throughput/ QoS	Range	Capital expenditure to deploy new network	Operating cost	Infrastructure required	Suitability for rural deployments	Advantages	Disadvantages
Microwave	5 - 200+ Mbit/s	100s of km	Lower	Lower	Radio equipment, towers/poles	Yes	High capacity, low-cost equipment; low-cost deployment	Requires line of sight; licensing constraints
Satellite backhaul (GEO, MEO)	1 - 1 600 Mbit/s	1 000s of km	Medium to high	Medium to high	Satellites, hub earth stations, remote earth stations	Yes	Wide coverage; ease of deployment; overcomes topographical challenges	Latency; cost
Fiber	100 - 1000 Mbit/s	100s of km	High	Medium	Fibre-optic cable installed in-ground or overhead via poles	Maybe	Highest speeds; reliability; flexibility (upgrades)	Cost; deployment time; limited geographic reach

Source: adapted from various sources, including the European Union, Cisco, Huawei, ITU, the Inter-American Development Bank, the World Bank and the EMEA Satellite Operators Association (technical references listed in Annex 2)

2.8 Emerging access technologies

Various emerging technologies currently being developed for commercial use promise to improve coverage and quality of connectivity. These emerging technologies have, in some cases, already been used to provide last-mile access to remote areas as a test of their viability. Some, like LEO satellites and fibre via overhead medium-voltage distribution lines, are newer versions or adaptations of existing technology, while others, such as free-space optical communication and HAPS, are relatively new developments.

When examining emerging technologies for last-mile access, it is important to look at their suitability for rural deployment. This rules out the use of technologies such as radio frequency identification, Bluetooth Low Energy and Light Fidelity, which work better over short distances in densely populated areas. Without large-scale commercial deployments, however, their financial viability remains open to question.

TV White Space (TVWS) is a portion of spectrum in a band allocated to the broadcasting service and used for television broadcasting. It is identified by an administration as available for wireless communication at a given time, in a given geographical area, on a non-interfering and non-protected basis with regard to other services, with a higher priority on a national basis.⁵⁶

TVWS is an example of a last-mile technology that leverages dynamic spectrum access and makes "opportunistic use" of spectrum, in a given zone and at specific time, particularly in frequencies not being used by a primary service (such as television broadcasting). In such cases, spectrum can be used opportunistically by other services. TVWS can reach long distances and transmit through dense or challenging topography, beyond the line of sight. However, the frequencies considered for TVWS are currently allocated to television broadcasting, and not all jurisdictions have adopted rules on their use for delivering data. This has made it not only legally challenging to use TVWS but also difficult to address critical issues of interference, given the range of a TVWS station. The business case for TVWS is also uncertain, as long-term spectrum tenure cannot be guaranteed.

Another emerging wireless technology, HAPS, currently uses high-altitude balloons or autonomous drones to host access equipment that beams connectivity down to the ground. HAPS are stations located on an object at an altitude of 20 to 50 km and at a specified nominal, fixed point relative to the Earth. Systems using HAPS consist of a HAPS and ground stations located at the end-user termination. HAPS broadband connectivity could provide Internet access to users either directly (e.g. home access) or as a backhaul to an access. It could be an alternative solution in areas where challenging terrain or other factors make it difficult to deploy traditional infrastructure.

Because of their height, HAPS can have a range of thousands of kilometres and are suitable for delivering connectivity even to remote rural areas. Google's implementation of HAPS, known as Project Loon, used cellular equipment to deliver access to test locations, making

⁵⁶ ITU, *Introduction to cognitive radio systems in the land mobile service*, Report ITU-R M.2225 (2011), M Series Mobile, radiodetermination, amateur and related satellite services.

it easy for mobile devices and other equipment using the technology to get connectivity.⁵⁷ This, combined with HAPS' ease of deployment, makes them attractive options for deploying emergency connectivity where necessary.

LEO satellites, which were discussed earlier, are designed to work in an array in order to provide global coverage (including the polar caps, above 67° latitude). Constellations of LEO satellites are intended to cover portions of the globe, enabling round-the-clock connectivity with earth stations that maintain line of sight to individual satellites.

Examples of LEO connectivity projects include SpaceX's Starlink, which aims to start offering initial access in the near future. An important consideration for LEO satellites is their cost: launching hundreds of satellites is expensive, making it an activity undertaken essentially by commercial entities. While pricing and other details remain unclear, the coverage area of LEO constellations makes them a promising option for providing connectivity to areas where no other infrastructure is available.

The use of millimetre wave (mmWave) is another emerging wireless solution that aims to deliver connectivity using very high frequencies (30 GHz and above). The nature of the frequencies involved means that the range is limited to hundreds of metres at most. However, it also means that the potential throughput of the technology is very high, with speeds reaching up to 20 Gbit/s. Application of mmWave involves the deployment of 5G networks.

Moreover, in order to make full use of the potential of mmWave, fibre backhaul is all but required in order to deliver the necessary bandwidth. These two considerations combined make mmWave unsuitable for rural deployments, confining it largely to densely populated urban areas.

In comparison, long-range (LoRa) technology is a low-power, low-throughput solution using sub-gigahertz frequencies in the licence-free industrial, scientific and medical bands. LoRa has a range of tens of kilometres and is designed mainly for use by IoT devices. Although its range suggests it is suitable for rural deployment, its value may be limited by the very low speeds it is able to deliver - only up to 50 Kbit/s. While this might be sufficient for IoT devices to communicate, it would make the viewing of any multimedia online very difficult. LoRa technology also uses dedicated radios, which are not usually present in end-user devices, limiting its application to IoT. LoRa is useful for limited communications and not as a broadband technology.

⁵⁷ Global radio regulations governing HAPS are fluid. See, for instance, the following Radio Regulations:

- No. 1.66A: High altitude platform station: A station located on an object at an altitude of 20 to 50 km and at a specified, nominal, fixed point relative to the Earth.
- No. 1.66: Fixed station: A station in the fixed service.
- No. 4.23: Transmissions to or from high altitude platform stations shall be limited to bands specifically identified in Article 5.
- No. 5.388A: In Regions 1 and 3, the bands 1 885-1 980 MHz, 2 010-2 025 MHz and 2 110-2 170 MHz and, in Region 2, the bands 1 885-1 980 MHz and 2 110-2 160 MHz may be used by high altitude platform stations as base stations to provide International Mobile Telecommunications (IMT), in accordance with Resolution 221 (Rev.WRC-07). Their use by IMT applications using high altitude platform stations as base stations does not preclude the use of these bands by any station in the services to which they are allocated and does not establish priority in the Radio Regulations. HAPS as an IMT base station must comply with the technical parameters defined in Resolution 221 (Rev. WRC-07).

Free-space optical communication uses optical wavelengths to transmit huge amounts of data over a range of several kilometres. It therefore has a potential throughput between tens and hundreds of Gbit/s, much faster than other wireless solutions. As free-space optical communication involves specialized equipment that uses light to transmit high-speed data, it is mainly used for backhaul and requires other layers of equipment before end users are able to access connectivity. It is promising mainly as an alternative backhaul solution, including in rural areas where there is line of sight between equipment.

An emerging trend in wired technology is fibre via overhead medium-voltage (OHMV) distribution lines, which utilizes supervisory control and data acquisition infrastructure to enable the power grid to deliver connectivity to the premises. As with fibre in general, fibre via OHMV lines has a very high QoS, delivering average speeds of between 100 Mbit/s to 1Gbit/s. They also have a range in the hundreds of kilometres, and the fact that they are eight times longer than high-voltage lines gives them the potential to reach many more end users. For fibre via OHMV to work, however, significant amounts must be invested in both passive infrastructure and active network equipment, and whether power entities are willing to use resources to that end remains to be seen.

Table 25 presents a number of emerging connectivity technologies and compares their characteristics. A number of these technologies are still in the trial phase; they may not be commercially available and their market ecosystems may not yet have attained the level of maturity of the common wireless and wired technologies presented earlier.

Table 25. Comparison of emerging technologies in connectivity

Technology	Wired or wireless	Potential throughput / QoS	Range	Infrastructure required	Suitability for rural deployments	Spectrum licensing requirement	Backhaul suitability	Access device type
HAPS		Up to 30 Mbit/s	1 000s of km	High altitude balloons, autonomous drones	Yes	Yes	Could work for both backhaul and access	Cellular devices in last-mile cases (such as Google Loon)
LEO satellite		*Up to 100 Mbit/s	1 000s of km	LEO satellites (for new network deployments)	Yes	Yes	Could work for both backhaul and access	To be determined
Millimetre wave	Wireless	Up to 20 Gbit/s	1 to 10 km	Towers and radio equipment, fibre backhaul	No	Yes for certain bands, some unlicensed / licence-exempt	Local backhaul	To be determined
Free-space optical communication		10s to 100s of Gbit/s	1 to 10 km	Specialized equipment using light to transmit high-speed data	Yes, but requires line-of-sight data transmission	No	Local backhaul	Used for backhaul
TV White Space		5 - 150 Mbit/s	10 to 25 km	Towers and radio equipment	Yes, especially for non-line of sight	Authorization of use required under the opportunistic use principle	Could work for both backhaul and access	Consumer premises modem to Ethernet or Wi-Fi
Long range		Up to 50 Kbit/s	10s of km	Towers and radio equipment	Yes (though very low throughput)	No (utilizes licence-free industrial, scientific and medical bands)		Long-range radios to IoT devices / applications

* Footnote: The value of 100 Mbps states in this report is provided by ESOA from reported beta-testing.

Table 25. Comparison of emerging technologies in connectivity (continued)

Technology	Wired or wireless	Potential throughput / QoS	Range	Infrastructure required	Suitability for rural deployments	Spectrum licensing requirement	Backhaul suitability	Access device type
Power line communications: fibre via overhead medium-voltage distribution lines	Wired	100 - 1 000 Mbit/s	100s of km	Tower, poles, cabinets, active network equipment	Yes (eight times longer than high voltage lines)	No	Yes	Fibre modem to Ethernet-enabled devices or to Wi-Fi

* Footnote: The value of 100 Mbps states in this report is provided by ESOA from reported beta-testing.

Source: adapted from various sources, including the European Union, Cisco, Huawei, ITU, the Inter-American Development Bank, the World Bank and the EMEA Satellite Operators Association (technical references listed in Annex 2)

* Other emerging communication technologies are in use or entering the market. However, many of these (radio-frequency identification, Bluetooth Low Energy, near field communication, Light Fidelity, Zigbee, etc.) are not suitable for rural deployments.

2.9 Hybrid solutions in technology and business models

Hybrid solutions are key to bridging the coverage gap, since last-mile connectivity deployments will most certainly utilize different technologies in the access network and upstream in the middle mile and core. Even networks that deploy emerging technologies in the access network will usually converge on Wi-Fi or cellular to reach end-user devices, and will connect to fibre at some point upstream. These are hybrid technology networks that incorporate a number of different connectivity technologies (sometimes called heterogeneous networks, or HetNets, if a range of different operating systems and protocols are utilized).

Hybrid business models also occur in last-mile networks where operators blend a range of upstream relationships with differing revenue models.

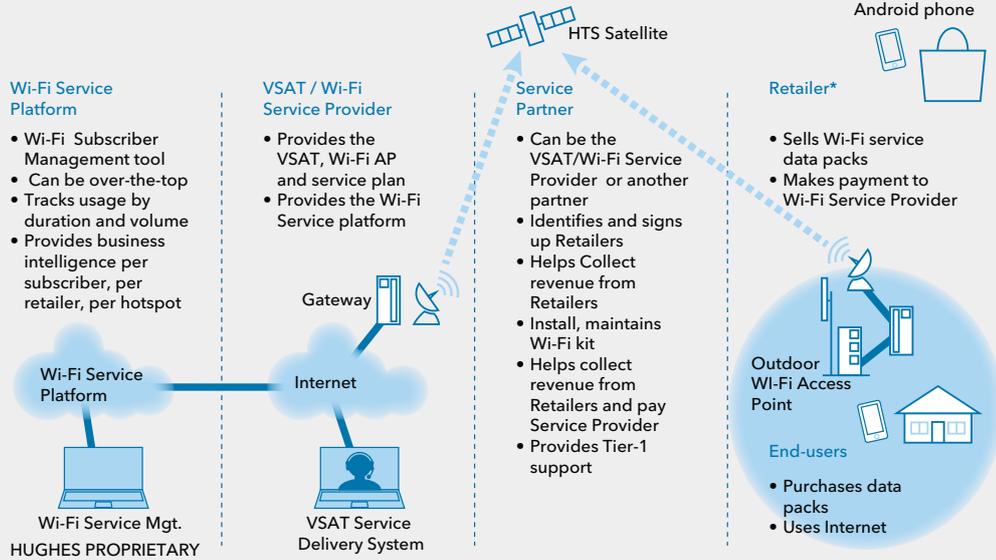
Box 7. Hybrid network example (Hughes Express Wi-Fi)

Across Brazil, Colombia, Mexico and Peru, Hughes has reported deployments of a community Wi-Fi solution known as Hughes Express Wi-Fi, in partnership with Facebook. Each Hughes Express Wi-Fi Hotspot is backhauled over satellite links, enabling merchants to offer Internet access on a pay-per-use basis to about 500 people in a rural community where terrestrial service is too expensive or simply unavailable.

This service allows end-users in rural communities to connect to the Internet using multimedia broadband connectivity for browsing, messaging, e-mail, voice and video chat. For those people who cannot afford a monthly subscription and require pay-as-you-go, Hughes Express Wi-Fi offers data-pack prices using their bring-your-own-device Wi-Fi mobile gear (phones/tablets/notebooks) equipped with any type of operating system (Android/iOS/Windows/Linux).

The service model includes bite-sized usage plans, e.g. 100 megabytes for USD 0.50 or one hour of use. Hughes Community Wi-Fi solutions include a very-small-aperture terminal and Wi-Fi equipment that extend the signal across a 50- to 80-metre radius with low-cost mobile phones; with a high-profile phone, the reach is improved 100 per cent. Once a site is deployed and set up with the hotspot, the local community of users can benefit from high-speed Internet access. The target market is communities of around 500 to 1 000 people with limited connectivity service.

Satellite Connected Wi-Fi Service Ecosystem



* Or government sponsored location where subsidized service is offered.

Hughes satellite-connected Wi-Fi service ecosystem

Data packs			
Package	Data (Megabytes)	Price (Pesos)	Price (approx.)* (USD)
1 hour	100	10	0.5
1 day	250	30	1.5
3 days	500	60	3
1 week	750	90	4.5
Month	1000	120	6
Month	2000	220	11
Month	4000	400	20

* Approximated values, original prices were provided in Pesos and converted in USD

Hughes express Wi-Fi data packages

Case study provided by Hughes¹. Additional information: <https://www.hughes.com/expresswifi/mexico>

¹ Figure and table are adapted from the submitted case study

2.10 Policy and regulatory regimes

The overall policy and regulatory environment for Internet connectivity in any given country will either contribute significantly to enabling and encouraging new service deployment for unconnected communities or act as a gating impediment. There are three steps to understanding the potential constraints imposed by existing policies and identifying permissible options.

- 1) *Identify the country's overall ICT regulator environment by reviewing ITU's generations of ICT regulation (see [ITU Global ICT Regulatory Outlook 2020](#))*

The latest data from ITU's Regulatory and Market Environment group⁵⁸ can help to determine how a specific country ranks in terms of overall ICT regulatory maturity.

- 2) *Identify the country's policy on universal access and coverage*

Many countries implement specific policies designed to encourage and directly support initiatives to expand connectivity access to underserved areas. These include national broadband plans and universal service policies, and may include universal service obligations and funds. For example, the ITU/UNESCO Broadband Commission for Sustainable Development tracks the number of countries⁵⁹ that have established national broadband plans and that have included broadband in universal access initiatives, with underlying data and tracking provided by ITU's ICT Eye database⁶⁰. These initiatives are usually led by the relevant executive branch agency designated as the lead for telecommunications (agencies, departments, etc.), but some are headed by relevant ministries (education, social development, etc.).

- 3) *Specifically research existing policy options for:*

- *new entities to deliver new service to the unserved area;*
- *policies that facilitate existing service providers to expand service to the area;*
- *policies that compel either new entities or existing service providers to establish service.*

These policies include the existing licensing and approvals process for the establishment of new Internet service providers; policies that allow existing service providers to expand to the underserved area, potentially through subsidies; and policies that require coverage expansion, such as coverage obligations linked to spectrum auctions or assignments of coverage spectrum, usually in exchange of lower fees. For example, operator licences are typically oriented towards large national operators, so it can be expensive and administratively complex for new small operators to obtain licences. However, in some countries, such as Brazil, South Africa, Uganda and Argentina, exemptions allow small, not-for-profit or local operators to set up and offer services. Similarly, access to wireless spectrum differs across countries. For licence-exempt/unlicensed technologies and spectrum bands (Wi-Fi), some countries require registration and an annual fee for each point-to-point line (permitted power output levels can also vary, limiting the technology's effectiveness). For IMT spectrum, mobile cellular spectrum has been licensed nationwide but Mexico, Brazil, the United States and the United Kingdom are pioneering licence frameworks that enable use of unused IMT spectrum in rural areas. Dynamic spectrum regulations in other countries, such as Mozambique, South Africa, Nigeria and Uganda, are beginning to allow for the use of TV White Space technology. Similarly, policies that ensure

⁵⁸ See <https://www.itu.int/en/ITU-D/Regulatory-Market/Pages/default.aspx>.

⁵⁹ ITU/UNESCO Broadband Commission for Sustainable Development, op. cit., note 56.

⁶⁰ See <https://www.itu.int/net4/itu-d/icteye/FocusAreas.aspx?paramWorkArea=TREG>.

open access to backhaul and open and affordable peering (such as at Internet exchange points) help to support new deployments and expansions.

The appropriateness of an intervention depends in large part on the cause or causes of the access gap in any given context. As previously discussed, interventions can be classed according to what they address, and how. The *what* of interventions, broadly speaking, speaks to what they do in order to improve access, and can be understood in terms of three, non-mutually exclusive impacts (that is, an intervention can have more than one impact.) These impacts are: facilitate the new entry of new entities to deliver new service to underserved or unserved areas; facilitate and/or compel existing service providers to expand service to underserved or unserved areas; and enable usage of connectivity, such as related to devices, or capacity building.

These impacts all address a cause of lack of access by enabling connectivity either on the supply or the demand side. In areas where supply (that is, the availability of connectivity) is the binding constraint to getting people online, interventions that encourage existing providers to extend their footprint or facilitate the entry of new providers can be most helpful. On the other hand, enabling usage by lowering the cost of access devices is appropriate in areas where networks already exist.

Many interventions combine two or all of these impacts in order to deliver effective connectivity to users. Furthermore, combining interventions can help address the multiple causes of an access gap, particularly when the causes pertain to structural barriers preventing the deployment and operation of networks.

The *how* of interventions refers to the typology of interventions discussed earlier. The typology groups interventions according to the mode through which impact is delivered: market efficiency and expansion interventions; one-time financing or subsidy interventions; and recurring subsidy interventions.

The context in which an intervention group or type is most appropriate has already been discussed. It is important to note, however, that multiple contexts and access gaps can exist simultaneously, and the use of two or more intervention types alongside each other can work to address the different causes of access gaps. Generally speaking, the use of one intervention does not preclude the use of others; in many cases the limit lies in the amount of resources that can be allocated across interventions, or the policy priorities of a government or other intervening body.

Table 26 depicts different potential interventions grouped by access gap issue and whether they facilitate the entry of new providers, facilitate and/or compel existing providers to expand service coverage areas, or enable usage of connectivity by addressing demand-side issues such as device availability and capacity building.

In the market efficiency and expansion interventions group, many of the interventions are designed to remove structural barriers preventing new or existing operators from delivering services in underserved or unserved areas. Examples include allowing the secondary use of spectrum,⁶¹ removing limits on foreign ownership and investment for ISPs, and allowing innovative uses of communication technology for commercial and non-commercial service deployment. These interventions enable the market to fulfill existing demand by expanding to

⁶¹ Secondary use is distinct from secondary allocation and is more commonly associated with the possibility of sharing a current spectrum licence.

new areas, using new or more appropriate technologies for certain areas, or allocating funding for networks in localities without existing service.

Some interventions in this category have the potential to deliver multiple impacts, helping operating entities to deliver connectivity to localities and end users to access the networks. One example is allowing the commercial and non-commercial use of unlicensed bands. This allows network operators to deploy networks on the unlicensed bands and users to connect to the networks on those frequencies using devices they may already have or can obtain at low cost. A system like this can deliver connectivity to a location where no network exists, or provide an alternative and/or competing service to that offered by traditional operators.

On the other hand, implementing a “dig once” policy to ensure the co-deployment of the ductwork needed for fibre networks when new roads are constructed is primarily a supply-side intervention. It allows operators to reduce the cost of network deployment, lowering the threshold for creating a business case for a target locality. Such interventions are useful for encouraging new and existing providers to deploy networks in new areas.

An intervention that reduces taxes on mobile handsets and connectivity devices is a form of subsidy that can help operators reduce the cost of procuring equipment for their networks while making more affordable devices available to end users. In this case, the access gap exists at least partly because of the challenge of financing connectivity. Such interventions, which involve one-time financing or subsidy, can help address the cost barrier to bridging the access gap, while other interventions may be deployed alongside them to address more structural barriers.

Finally, for true access gap cases where no business case is viable even with existing market efficiency and subsidy interventions, governments or other bodies can use recurring subsidies to provide access in target localities. In contexts where challenging conditions, remoteness or other factors make it unlikely that the market will provide commercial access, policy-makers can consider more flexible and beneficial tax arrangements for not-for-profit local complementary networks in order to help deliver connectivity. This is best seen as an effort to encourage a new, not-for-profit entity to create an alternative network in a non-commercially viable area and to fill the space that would otherwise be taken by a commercial provider.

Table 26. Comparing interventions by access gap category against applicability

Access gap issue	Interventions	Facilitates entry of new entities to deliver new service to underserved /unserved areas	Facilitates (and/or compels) existing service providers to expand service to underserved /unserved areas	Enables usage of connectivity (e.g. device-related) or capacity building
Market efficiency and expansion interventions	Improve market information data resources on, e.g. network coverage, infrastructure assets, population density and income, grid electrification, in order to identify uncovered populations and the relevant solutions	√	√	√
	Establish specific licences for rural areas with simplified requirements	√		√

Table 26. Comparing interventions by access gap category against applicability (continued)

Access gap issue	Interventions	Facilitates entry of new entities to deliver new service to underserved /unserved areas	Facilitates (and/or compels) existing service providers to expand service to underserved /unserved areas	Enables usage of connectivity (e.g. device-related) or capacity building
	Establish community operator licences that do not have the same expensive fees and strict obligations as commercial operators	√		√
	Discount spectrum licences for rural areas and/or provide a direct assignment for social purposes	√		
	Allow secondary use of spectrum	√	√	
	Allow commercial and non-commercial use of unlicensed bands	√	√	√
	Implement and enforce coverage obligations (with QoS requirements) for national spectrum licence assignments, e.g. in exchange for lower licence fees or subsidies		√	
	Promote innovative use of communication technology for commercial and non-commercial service deployment	√	√	√
	Support national roaming and infrastructure sharing (passive and active networks)	√	√	
	Regulate price of middle-mile wholesale broadband capacity, ensuring fair terms for small access ISPs	√		
	Remove limits on foreign ownership of ISPs and investment restrictions	√	√	
	Consider alternatives to allocation of spectrum via high-priced auctions	√	√	
	Encourage market competition	√	√	
	Reduce lengthy licensing processes and high regulatory fees for terminals and spectrum	√	√	
	Implement “dig once” policies that ensure co-deployment of ductwork for fibre deployments when new roads are constructed	√	√	

Table 26. Comparing interventions by access gap category against applicability (continued)

Access gap issue	Interventions	Facilitates entry of new entities to deliver new service to underserved /unserved areas	Facilitates (and/or compels) existing service providers to expand service to underserved /unserved areas	Enables usage of connectivity (e.g. device-related) or capacity building
	Ease right-of-way and pole attachment requirements for middle-mile deployment to rural and remote areas	√	√	
	Establish/revise universal service fund policies that are technology neutral	√	√	
	Enable market presence with no in-country satellite hub or gateway obligation when technically unnecessary	√		
	Introduce blanket licensing for end-user terminal equipment	√	√	
One-time financing or subsidy interventions	Collect and distribute universal service funds for one-time subsidies to de-risk deployments	√	√	
	Encourage public-private partnerships to reduce risk	√	√	
	Encourage blended finance investment structures pooling commercial capital for project finance with forms of public and/or sub-commercial return-seeking private capital (known as patient capital)	√	√	
	Allow flexible in-kind contributions (hardware, software and technical capacity) to non-commercial entities by the private and public sectors	√	√	√
	Introduce tax incentives for last-mile service providers	√	√	√
	Reduce taxes on mobile handsets and connectivity devices	√	√	√
	Reduce import duties on network equipment	√	√	
Recurring subsidy interventions	Collect and distribute universal service funds as recurring subsidies to de-risk deployments	√	√	
	Consider more flexible and beneficial tax arrangements for non-profit local complementary networks	√		√

Box 8. Cybersafety and -security for new users in last-mile connectivity deployments

The number of cybersecurity incidents will continue to increase as more people become connected and conduct more of their daily activities online. Since 2010, the top 10 data breaches have resulted in over 20 billion records¹ being breached. Many users in low- and middle-income countries connect to the Internet through their phones;² however, GSMA Intelligence³ has found that safety and security concerns are among the key barriers to mobile Internet adoption in low- and middle-income countries. According to Nokia's Threat Intelligence Report,⁴ the average monthly infection rate in mobile networks was 0.31 per cent in 2019 (one out of every 300 mobile devices had a high threat-level malware infection). In 2019, cybersecurity incidents were rated a higher risk to global businesses⁵ than supply chain disruption, political upheaval or natural catastrophes.

Connectivity brings opportunities, but also risks. Cybersecurity needs to be considered at a strategic level to ensure a coherent approach to threats that could outweigh the socio-economic gains of improved connectivity. A range of measures can be taken to reduce cybersecurity risks; all require continuous, active engagement on the part of governments, the private sector, civil society and individuals – and resources.

ISPs play a particularly crucial role in ensuring that their networks are sufficiently cybersecure. In January 2020, the World Economic Forum and its partners released high-level principles⁶ for ISPs to bear in mind when deploying network services, and these may also be relevant for last-mile connectivity deployments. The four principles are:

1. Protect consumers by default from widespread cyberattacks and act collectively with peers to identify and respond to known threats;
2. Take action to raise awareness and understanding of threats and support consumers in protecting themselves and their networks;
3. Work more closely with manufacturers and vendors of hardware, software and infrastructure to increase minimum levels of security;
4. Take action to shore up the security of routing and signaling to reinforce effective defence against attacks.

¹ Information is beautiful, [World's Biggest Data Breaches & Hacks](#) (last updated 11 May 2020).

² J. Clement, [Share of mobile internet traffic in selected countries 2020](#) (online article, Statista, 20 June 2020).

³ GSMA, op. cit., note 14.

⁴ Nokia, *Threat Intelligence Report 2019*. Available at <https://networks.nokia.com/solutions/threat-intelligence/infographic>.

⁵ Allianz, *Allianz Risk Barometer 2020. Identifying the Major Business Risks for 2020* (2020).

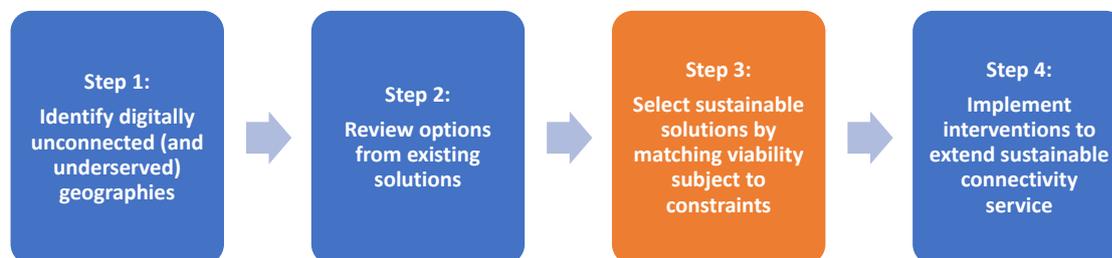
⁶ World Economic Forum, *Cybercrime Prevention – Principles for Internet Service Providers* (Geneva, 2020).

Chapter 3. Select sustainable solutions by matching viability subject to constraints (Step 3)



Step 3 of the Solutions Guide focuses on the process of selecting sustainable, affordable solutions that can operate within the constraints posed by each unique scenario. Figure 29 situates Step 3 in the overall process and sets out the activities it comprises.

Figure 29. Step 3 in the Last-mile Internet Connectivity Solutions Guide



Step 3 activities to select sustainable solutions by matching viability subject to constraints:

- 3a** - Select an affordable last-mile connectivity solution
- 3b** - Identify the components of an appropriate last-mile connectivity solution
- 3c** - Draw up the decision matrix for feasible solutions
- 3d** - Consider additional tools to assess solutions

3.1 Select an affordable last-mile connectivity solution (Step 3a)

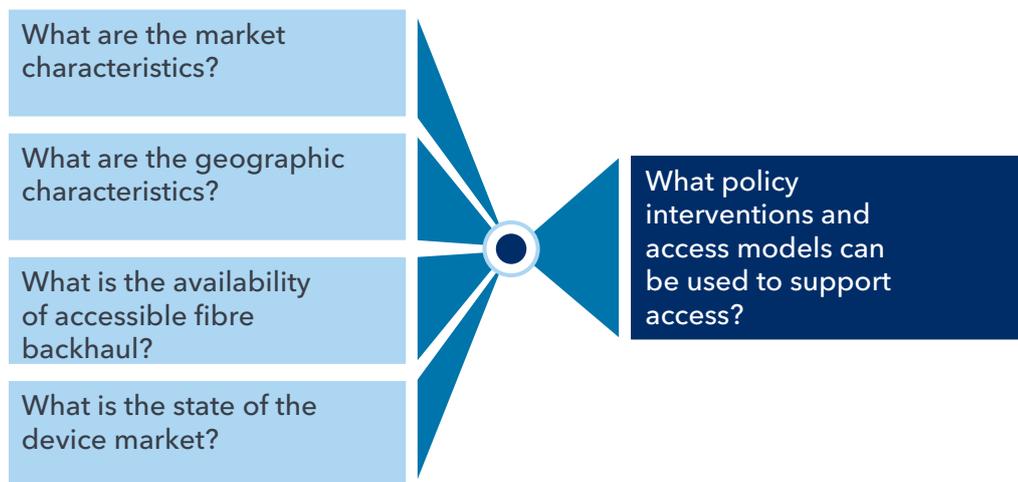
Selecting a last-mile access solutions means first understanding the nature of the access gap in the target locality or localities. The solution will fail unless it is viable despite the constraints. What is “best” involves combining the most appropriate technical, financial and organizational measures in the context.

Identifying solutions for unconnected communities is a highly context-specific endeavour. A number of recent reports on last-mile connectivity provide guidance on potential solutions. For example, one report suggests using a ratio based on the “expected Quality of Experience and the costs of each respective technology in relation to its Technology Readiness Level” to determine how appropriate a technology or technical solution is relative to other options.⁶²

Others, such as the World Bank, note that a range of considerations need to be taken into account, including the business environment (is the market competitive?), a potential business case for the private sector, missing links in the existing infrastructure, sufficient regulatory power to control market dominance, and the government’s ability to enter the market in a public-private partnership, if necessary.⁶³

USAID has proposed a problem-solution matrix (see Figure 30) for identifying what access model is needed to improve last-mile access for a specific context, noting that “each market is likely to require a portfolio of access innovations that will meet the needs of diverse communities”.⁶⁴

Figure 30. Access models grouped by challenge (USAID)



Source: USAID et al., note 77

⁶² See Fraunhofer Institute for Applied Information Technology, *Connecting the Unconnected - Tackling the Challenge of Cost-effective Broadband Internet in Rural Areas* (Germany, 2019).

⁶³ See World Bank, *Innovative Business Models for Expanding Fiber-optic Networks and Closing the Access Gap* (Washington, World Bank Group, 2018).

⁶⁴ USAID, Caribou Digital and the Digital Impact Alliance, *Closing the Access Gap - Innovation to Accelerate Universal Internet Adoption* (2017), p. 31; see also Table 2 in the report, “Key Considerations Unique to Each Community Scenario”.

To identify suitable last-mile connectivity interventions, after a specific unconnected geography /locality has been selected, it is necessary to first determine the five main aspects of a given situation that serve as binding constraints and can provide direction for any possible solution. These are depicted in Figure 31, which demonstrates that identifying the most feasible and affordable last-mile Internet connectivity solution is a matter of fit between different aspects and can be considered an iterative process that requires identification and refinement of the options and selections made within the dimensions of the following factors:

- 1) **Affordability:** Ensuring that connectivity service user pricing falls within a given affordability threshold, such as the 2 per cent of monthly GNI per capita for 1GB of mobile broadband data discussed above. Affordability is critical to providing access to the intended users in a locality. Technical and financial decisions can have an impact on the final cost of connectivity; it is important, therefore, to select for characteristics that can help achieve the target level of affordability.
- 2) **Usage:** Identifying the applications and services that need to be available to the locality, and the level of QoS that those applications and services require. Understanding what the connectivity will be used for is important not only to ensure the delivery of meaningful access, but also to determine what kind of network is best suited for a locality. For example, a high-speed, high-bandwidth network might not be the most practical network to deploy in sparsely populated rural communities that are likely to use only basic messaging applications.

At the same time, however, the network should be able to accommodate demand growth and changing usage patterns, such that it does not become a bottleneck to the development of digital skills and uptake of useful online services. Selecting the appropriate last-mile access solution involves a balance between catering to present (or expected) usage and enabling future growth.

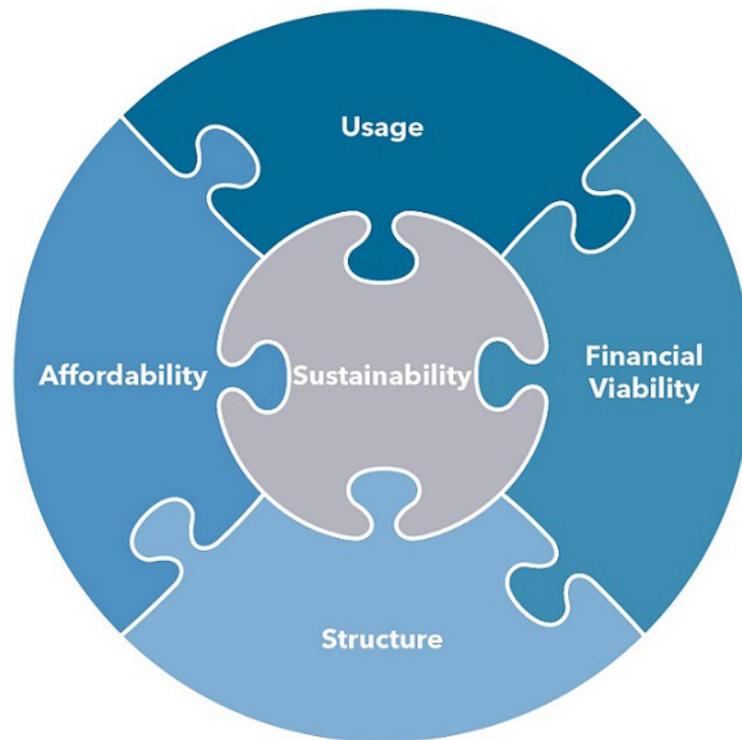
- 3) **Financial viability:** This includes measuring the economic viability for private investment of the connectivity service, based on estimates of ARPU, availability of backhaul / middle-mile connectivity, options for different local access technologies and the potential level of the service's QoS. This dimension helps determine the nature of the access gap in the target locality and has a large potential impact on what sort of operating entity is appropriate for the intervention. Areas that can potentially support a financially viable network may only need a market efficiency or one-time subsidy intervention, while those that are unlikely to support any sort of commercial service will require recurring subsidies.

Financial viability also influences other aspects of the last-mile access solution, as some technologies are better suited to commercial operations, while not-for-profit entities are likely to prefer low-cost access technologies. As with the other dimensions, properly assessing the conditions of the target locality requires a holistic view of the characteristics of the target area, understanding how different dimensions affect each other and determining which solutions are most appropriate.

- 4) **Structure:** This involves articulating the service delivery business model and identifying any regulatory constraints on the model and technologies utilized. Although some technologies or business models may seem best suited to a locality, existing policies or regulations may make them cumbersome, if not impossible to deploy. In most cases, policies and regulations are binding constraints that narrow the options for interventions, especially those deployed by non-governmental entities. Narrowing down the field of options to those that are practical in the existing policy environment can be a helpful exercise in practicality. On the other hand, understanding what policies or regulations stand in the way of adopting an appropriate technology or business model can guide cooperative policy-makers and regulators as they conduct reform and remove structural barriers.
- 5) **Sustainability:** This requires an understanding of the service's revenue model and of any potential subsidy (one-time and/or recurring). This dimension is closely linked to that of financial viability; it pertains to the interplay between the potential solution's revenue model, the expected level of uptake (and revenue) in the target locality, and the appropriateness of the expected revenue for covering the network's operating expenses

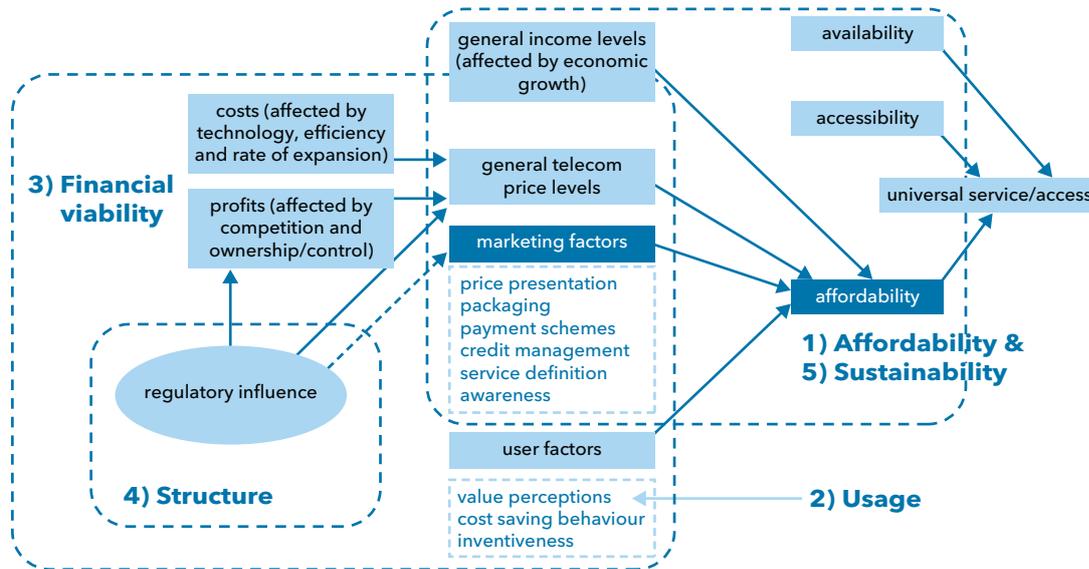
(at a minimum). For commercial for-profit entities, there is the additional question of whether an acceptable level of profit within a reasonable timeframe is possible given the potential solution. Not-for-profit entities, on the other hand, may consider utilizing some form of subsidy to help support the network when available. The question then is how reliable the subsidies are, how essential they are to the survival of the potential solution, and whether alternatives to the subsidy are possible in case they disappear. Answering these questions is essential to determining the long-term sustainability of the intervention.

Figure 31. Components in selecting a sustainable, affordable last-mile connectivity solution



The five factors in selecting an affordable last-mile connectivity solution map to other frameworks of universal access components (see, for example, Figure 32). Regulatory influence is the starting point for economic viability, mirroring the layered intervention approach beginning with market-expanding interventions that increase market efficiency. However, a government may want to provide universal access even when the profitability threshold is not achieved, such as with policy and regulatory interventions such as subsidies, tax alleviations, and free or low-cost licensing.

Figure 32. The components of an affordable last-mile connectivity solution related to other frameworks



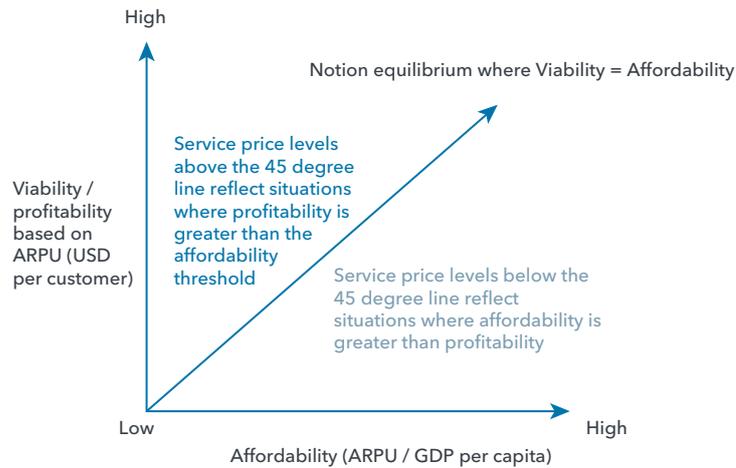
Source: Adapted from C. Milne, Improving Affordability of Telecommunications: Cross-Fertilization between the Developed and the Developing World (15 August 2006), TPRC 2006. Available at SSRN: <https://ssrn.com/abstract=2104397>

3.1.1 Financial viability versus affordability

It is worth stressing that the financial viability of establishing service (considered from the point of view of the investor, whether the project is a commercial investment or a subsidized deployment) is different from the affordability of the service provided (considered from the point of view of individuals in the prospective underserved locality). While financial viability is dependent on revenue generation, presumably from paying consumers, it is irrelevant – in terms of financial viability – whether these customers are higher or lower income, or if they are businesses and organizations instead of users. What matters is that the revenues generated can cover the costs of deployment. Affordability, particularly broadband affordability gauged on the basis of 2 per cent of monthly GNI per capita, on the other hand, is shaped by the consumer profile. So, whereas a deployment may be financially viable from the perspective of a service provider, in that it provides connectivity to higher-income consumers (or businesses), that particular deployment would not be serving an affordability goal.

The difference is depicted in Figure 33, which shows that a service may be highly viable / profitable (in the eyes of a service provider), but low in affordability (for the average consumer).

Figure 33. Financial viability versus affordability



The distinction between financial viability and affordability underscores the nature of the relationship between the five dimensions. Selecting the appropriate solution involves finding the intervention that has the most ideal overlap in terms of reaching the desired targets for each dimension. In practice, of course, it is rarely the case that one intervention fits the situation perfectly. Often there will be several interventions that have varying degrees of dimensional overlap, based on the differing compromises they make with regard to certain targets. What is most appropriate will depend on which set of compromises is most acceptable vis-à-vis the intervening body’s goals for closing the access gap. Alternatively, such a situation may make the case for deploying multiple complementary interventions alongside each other.

3.2 Identify the components of an appropriate last-mile connectivity solution (Step 3b)

3.2.1 Affordability

As the focus of this Solutions Guide is to encourage last-mile connectivity solutions that deliver affordable Internet to unserved and underserved communities, designing potential solutions begins with identifying what price levels of service would be considered affordable.

One approach would be to identify affordability thresholds of 2 per cent of monthly GDP per capita, as well as 5 per cent for sensitivity analysis, using national averages. A more granular approach would consider regional or local average income levels, which can be obtained from national statistical agencies.

These affordability figures would then serve as a guidepost for determining which types of service would be deemed affordable, keeping in mind that the 2 per cent of monthly GDP per capita is for 1 GB of mobile data. (For the discussion of affordability thresholds, see Introduction, 5 Background, motivation and objectives).

The focus on affordability (and on the other critical components highlighted in the selection model, particularly sustainability) emphasizes the importance of ensuring that members of the locality or community – the new service’s potential customers – play a role in determining how the new service is established. The process of designing the last-mile connectivity solution

should include participatory multi-stakeholder mechanisms to surface and take into account a wide range of perspectives.

Ultimately, the question of affordability is perceptual, as it involves the value that users ascribe to connectivity relative to the monetary cost they pay for the service. Identifying what price level is affordable therefore must also involve an understanding of what services users will or can expect to use the connectivity for, and how valuable it is to members of the locality – again pointing to the need for a participatory mechanism that promotes understanding of the needs and preferences of the locality.

Affordability is critical to the success of an intervention, as it determines whether connectivity will have an impact on the target locality. As such, general market rates are of little significance – just because everyone else pays for connectivity at a certain rate does not mean users in the target locality will be willing to do so as well. Targeted interventions that are able to set price levels specific to the target locality should take this into account; commercial entities offering branded services may have more difficulty adjusting rates, something that should be taken into account when choosing a solution.

3.2.2 Usage

An ex-ante determination of usage for last-mile connectivity service will significantly impact the calculations of the type of service that could be established and what the costs and pricing of that service will be. It may be that the QoS (and thus general usage) should be determined by whatever the market can support; or, usage could be more prescriptive in that specific activities are required for the last-mile connectivity service, such as providing connectivity for healthcare services (telemedicine), distance learning or government services.

As noted in Section 2.3.1 (Usage characteristics), general connectivity service features a wide range of usage levels that are usually constrained by QoS and the price of connectivity. If specific sectoral applications are the focus of the connectivity service, then the QoS that the network needs to support will be determined by the QoS thresholds needed for those applications and services. Particularly for target localities that are totally unserved, network considerations such as bandwidth per user and overall QoS may be more or less than that of the general market. A participatory mechanism involving many (if not all) stakeholders might also be useful in this regard.

For underserved communities, users are more likely to have a feel for the extent of the access gap in their locality, in terms of what they can and cannot do with existing connectivity. One difficulty with totally unserved communities is that they may not have existing usage patterns and therefore may not have as keen an understanding of what level of connectivity is most appropriate for them. This is another reason why prescriptive usage might be a more useful gauge of usage for those target localities, at least when it comes to essential digital services such as telemedicine and education.

That being said, a participatory approach can be useful in either situation, and there are no hard and fast rules for determining the actual or potential usage levels in a given locality. Determining usage is important for choosing the appropriate business model and technical solution and must be given due consideration during the selection process.

3.2.3 Financial viability

The financial viability of different forms of service provision depends on a number of factors. Affordability thresholds (if applied) and usage requirements (if applied) from the previous sections can serve as inputs for calculating financial viability. They can also be left out, depending on the ultimate goal of the intervention. Financial viability depends on a number of enabling factors and binding constraints, some of which are articulated here.

It is essential to estimate the potential demand for connectivity service in order to determine whether the service will generate sufficient revenue to cover capital investments and ongoing operating expenses. On the supply side, service options will be determined by environmental / geographic limitations, technical considerations, pricing (of backhaul) and regulatory requirements and limitations.

The core components of estimating financial viability include estimating demand, which involves determining the local per capita income (or ARPU), population level and business environment; knowing the cost of the appropriate access network design and technologies, which involves assessing the geographic coverage area, customer population density, electrical grid availability, regulatory and policy considerations (particularly for ISP licensing and spectrum use) and financing options (including cost of capital); and backhaul limitations, involving the distance to the PoP, capacity available and the cost of bandwidth (see Table 27).

Taken together, these factors help paint a clearer picture of what sort of capital and operating expenditure the operating entity should expect, and what level of revenue is needed to ensure the enterprise's viability. For not-for-profit entities working with a limited level of funding, they can also help determine what sort of access network solution is financially viable, given the constraint of not turning a profit.

The access network and technologies themselves mostly pertain to capital investment and are likely to be fixed according to the price of equipment, deployment and licensing, which are mostly set by the market. On the other hand, backhaul limitations and service demand are two sides of the operating expense equation, and may be subject to the particular revenue model the entity chooses. Put another way, capital investment represents the minimum cost of deploying service, while operating expense considerations play into the entity's ongoing ability to keep the network running.

Table 27. Components of financial viability assessments

Considerations of financial viability	Estimating demand	Access network design and technologies	Backhaul limitations
Data components	Per capita income (or ARPU) Community population (or active subscriptions) Census of businesses (enterprise, government, non-profit organizations, etc.)	Geographic area to cover Customer population density Electrical grid availability Regulatory policy considerations (ISP licensing, spectrum use) Financing options (including cost of capital)	Distance to backhaul PoP in some cases Capacity available Cost of bandwidth

3.2.3.1 Estimating demand

Estimated demand for connectivity service is a function of population size and per capita income (or ARPU). The estimated number of potential enterprise customers (above or below expectations for a given population size) will also influence service options, as will the existence of other potential sources of revenue (such as a direct recurring subsidy).

Table 28 provides a guide to the sort of service that is likely to be most financially viable in any given location, given a particular population size and APRU. Actual conditions for specific localities can nonetheless differ from case to case, depending on the intervention’s specific goal: a government that is intent on providing wired service to a low-income, sparsely populated area will not be affected by the commercial considerations that influence the summary of options described below.

For most entities (particularly commercial providers), fixed wired service is appropriate mostly for areas with large populations, even in areas which otherwise have a low ARPU, the reason being the cost of deploying new wired networks and the need for scale in order for wired services to become financially viable. On the other end of the spectrum, a Wi-Fi hotspot service is a low-cost solution that is likely to be viable, particularly as a complementary service to other forms of access, but that needs a viable backhaul solution.

For not-for-profit entities, or entities that would otherwise receive financing or subsidies, the additional funding can help bridge the high capital costs of a particular solution, allowing for its deployment in areas where return on investment is low. For example, whereas a terrestrial fixed wireless technology such as microwave would normally be deployed in high ARPU areas where it is possible to recover capital expenditure, a subsidy could allow an entity to deploy the technology even in medium to low ARPU areas. This demonstrates that financial viability depends on the particular circumstances of the deployment and that appropriate technical solutions require the right combination of funding and network design.

Table 28. Estimating demand by population size and income

	Very small population (< 3 000 people)	Small population (3 000 to 10 000 people)	Larger population (> 10 000 people)
Lowest income (ARPU < USD 3/ month)	Limited cellular data (2G, 3G); limited Wi-Fi hotspot data service (could be supported by satellite)	Limited cellular data (2G, 3G); limited Wi-Fi hotspot data service (could be supported by satellite)	Cellular data (2G, 3G, 4G); Wi-Fi hotspot data service (could be supported by satellite) or fixed wireless (terrestrial or satellite); fixed wired services (FTTH, cable, copper)
Low income (ARPU between USD 3 and 10/month)	Limited cellular data (2G, 3G); limited Wi-Fi hotspot data service (could be supported by satellite)	Cellular data (2G, 3G, 4G); Wi-Fi hotspot data service (could be supported by satellite) or fixed wireless (terrestrial or satellite)	Cellular data (2G, 3G, 4G, 5G); Wi-Fi hotspot data service (could be supported by satellite) or fixed wireless (terrestrial or satellite); fixed wired services (FTTH, cable, copper)
Higher income (ARPU above USD 10/month)	Cellular data (2G, 3G, 4G); Wi-Fi hotspot data service (could be supported by satellite) or fixed wireless (terrestrial or satellite)	Cellular data (2G, 3G, 4G); Wi-Fi hotspot data service (could be supported by satellite) or fixed wireless (terrestrial or satellite); potential fixed wired services	Cellular data (2G, 3G, 4G, 5G); Wi-Fi hotspot data service (could be supported by satellite) or fixed wireless (terrestrial or satellite); fixed wired services (FTTH; cable; copper)

3.2.3.2 Access network design and technologies

The technology options that are viable in the access network are determined by population size, geographic area and topographical features. Small areas with high population density may be served by localized technologies such as Wi-Fi. Wide areas, however, may need cellular network coverage or direct satellite connectivity to the premise. Similarly, mountainous terrain with limited line-of-sight options between radios may require more complex network design and/or the use of non-line-of-sight technologies.

Table 29 provides a brief summary of the technology and service options for given combinations of population size and topography. Areas with flat terrain are the most versatile in terms of the technology solutions available for deployment, given the reliance of some technologies on line of sight. Furthermore, technologies such as mesh Wi-Fi networks are most appropriate for small areas with flat terrain, given the challenges of scaling Wi-Fi to large areas relative to the cost of network equipment.

Of the different access technologies, cellular is viable across any sort of terrain and population density, although the financial aspect of deployment can vary considerably given factors such as terrain, availability of a PoP and population density. For all wireless technologies, the cost of using licensed spectrum resources must be taken into consideration, except for solutions that use only unlicensed bands such as Wi-Fi.

Table 29. Access network options based on area and geographic features*

	Small geographic area, flat terrain	Small geographic area, mountainous terrain	Large geographic area, flat terrain	Large geographic area, mountainous terrain
Relative thresholds	< 10 square km; line of sight possible across most of the terrain	< 10 square km; non-line of sight across most of the terrain	> 10 square km; line of sight possible across most of the terrain	> 10 square km; non-line of sight across most of the terrain
Potential service options	Mesh network of Wi-Fi access points with point-to-point or point-to-multipoint links; cellular	Cellular, satellite	Wide area cellular or satellite solutions; microwave point-to-point or point-to-multipoint links in a wireless mesh	Wide area cellular or satellite solutions

* Table 29 focuses on common wireless technologies. Other emerging technologies can also be considered in specific situations, such as countries that have begun licensing the emerging technologies described earlier.

3.2.3.3 Backhaul limitations

The QoS options (bandwidth throughput measures in terms of download, upload and latency) in the access network are limited by the backhaul available to interconnect the access network to the country’s core network infrastructure. As such, it is critical to identify backhaul options before choosing a technology. Without an adequate source of backhaul, the potential throughput of any access network will be reduced.

In terms of choice of access technology, entities will need to consider what sort of usage is possible with the bandwidth available from backhaul, and design the network using technologies that are up to the task. While some interventions choose to deploy high-capacity wired networks in anticipation of future growth in backhaul availability, such forward-looking deployments are largely the domain of governments or other entities with considerable resources to spare.

For most deployments where funding is a constraint, making the best use of scarce resources means choosing the access network technology based on available backhaul, with moderate consideration for future growth as appropriate. To illustrate, areas where bandwidth is scarce may choose to deploy limited cellular service (such as basic 2G and SMS), taking into account that backhaul will allow only for limited usage. This also affects what the entity can charge users for access to the network, and therefore plays into the overall financial viability of the enterprise.

Backhaul availability also affects the choice of business and revenue model and helps determine whether additional funds (or subsidies) are needed. The cost of bandwidth is a significant recurring operating expense, and understanding whether expected revenues vis-à-vis expected usage will be enough to cover costs is critical to viability. Table 30 describes the constraints presented by various combinations of bandwidth availability and backhaul cost for access networks.

Backhaul constraints can significantly affect which technical and business models are viable and need to be considered in the light of the goals for the access network. A situation where backhaul

only provides low bandwidth at a high price means commercial viability is only possible if the service is targeted towards high-end users, such as businesses and other organizations. If the goal is to provide affordable service to everyone in a locality, this is either not possible given backhaul constraints, or requires the use of subsidies in order to bring the cost of bandwidth per user down to acceptable levels.

The most ideal situation for backhaul is one where bandwidth is plentiful and available at a low price, as this presents the most flexibility in terms of network design and potential usage (and consequently revenue models). It is important to note, however, that for rural deployments with little to no existing connectivity, particularly in remote areas, this situation is bound to be rare. Scarcity normally pushes prices up, and in more mature markets backhaul providers will often have little capacity available for areas where they themselves do not expect significant demand. This is a challenge when it comes to connecting remote, sparsely populated areas at affordable levels; it may require recurring subsidies to bridge a true access gap.

In other situations, improving market efficiency may encourage backhaul providers to expand their networks and make capacity available to new areas. For access networks, this presents an opportunity to obtain bandwidth for delivery to new localities. The challenge here once again is to ensure that backhaul is affordably priced, either through supply-side (such as tax rebates or other forms of incentive to bring the cost of bandwidth down) or demand-side (via subsidies) interventions.

Table 30. Backhaul limitations by capacity (bandwidth and data caps) and pricing

	Low backhaul capacity (bandwidth and data cap)	High backhaul capacity (bandwidth and data cap)
Low pricing	There are few situations in which both capacity and prices are low, as scarce capacity will normally push prices up; this can occur, however, if backhaul capacity is being dedicated to anchor tenants or government services at regulated rates and minor additional capacity is available for commercial arrangements. Such situations can still support basic connectivity services.	High capacity and low prices provide the most flexibility in access network deployment design and impose the least constraint on potential usage by end-user consumers.
High pricing	Low capacity and high prices are the norm in remote and rural areas where there is limited backhaul available in the immediate vicinity. Such situations lead to more limited access network deployment situations, such as high end-user pricing or the need for subsidies.	High capacity at high cost may result in situations where only higher-income consumers are able to afford services, or a public subsidy may be required, unless the access network business and revenue models are able to effectively price discriminate and segment consumers to maximize efficiency.

3.2.4 Structure

The structure of the entity delivering service will be determined by the availability of options in the policy and regulatory market environment (see Section 2.10 Policy and regulatory regimes). The overall policy and regulatory environment for Internet connectivity in any given country will either contribute significantly to enabling and encouraging new service deployment for unconnected communities or act as a gating impediment. Depending on the type of last-mile connectivity intervention selected, and on the overall policy environment, different last-mile connectivity intervention types will face different regulatory issues.

Generally speaking, commercial entities have stricter regulatory requirements than non-commercial ones, and full-service operators (MNOs) have more requirements than ISPs. That being said, policy environments can vary considerably by jurisdiction, and the regulations governing the entity depend on the specific context. For example, regulatory environments in some advanced economies, such as Japan, require only a registration process for Internet-only entities, while in the Philippines a full-service operator requires a legislative franchise from Congress, in addition to other licences, including for spectrum.

For not-for-profit entities, a regular barrier to entry is the grant of licence for the use of spectrum, which in some jurisdictions is available only to commercial entities. In others, provisions exist for the use of spectrum for non-commercial purposes. As a consequence, what technologies an entity intends to use can influence what sort of structure suits its purposes the best.

An entity that intends to redistribute commercially available cellular bandwidth using a Wi-Fi mesh network normally does not need to apply for any spectrum licences, as Wi-Fi uses unlicensed radio frequencies. On the other hand, use of cellular frequencies normally requires an MNO licence, in addition to the licence specific to the frequency used. For not-for-profit entities, one way to avoid having to apply for a spectrum licence is to enter into a partnership with an existing MNO for the use of its frequencies (and normally, access to its network as well). However, this is usually subject to a commercial agreement with the MNO.

Depending on the specific policy environment, the structure chosen may also affect what frequencies (and technologies) it has access to, and at what cost spectrum resources can be obtained. In some jurisdictions, special policies are in place to make it easier for not-for-profit entities or smaller commercial players to obtain spectrum resources at auction, such as via auction credits.

Ultimately, the choice of structure affects not only the regulatory aspect of an operating entity, but its technical and business models as well. As with other dimensions, the most appropriate structure is chosen in the light of the context and the goals of the intervention, keeping in mind the constraints that come with specific structures, particularly when it comes to the use of wireless technologies. Table 31 highlights some of the different regulatory issues that different types of last-mile connectivity interventions may face.

Table 31. Regulatory issues by organizational structure

	Commercial MNO	Commercial ISP	Not-for-profit local mobile network	Not-for-profit local ISP network
Regulatory issues	Commercial telecom operation licences required; licensed spectrum rights required	Commercial ISP licence required	Licensed spectrum rights required (except in partnerships with an MNO); telecom licence may be required	ISP licence may be required

3.2.5 Sustainability

Sustainability in this context goes beyond revenue modelling to consider the intervention's longer-term viability, ensuring that operating expenditures, future growth and upgrades are taken into account. For existing commercial entities, this is usually par for the course when deciding on the feasibility of a new deployment site. For new commercial players or not-for-profit entities, however, ensuring that sources of funding (from revenues and other sources) are able to support long-term operations and growth can be a challenge.

Not-for-profit entities that rely on recurring subsidies especially have to make provision for the possibility of subsidies ending or substantially decreasing. There have been many instances of small access networks that provide access for free ceasing to operate once subsidies dry up. For these entities, some form of usage fee is encouraged as a way to ensure the intervention's viability.

At a minimum, for-profit and not-for-profit entities alike should have sufficient sources of funding to cover recurring operational expenses, chief among them bandwidth, electricity, and regular upkeep and maintenance of network equipment. Some commercial entities are able to justify continued provision of service in an area at a loss as a form of corporate social responsibility, or in order to meet coverage obligation requirements. Not-for-profit entities, which cannot afford to operate at a loss and whose usage fees are not enough to break even, can consider in-kind contributions (network equipment, and in the form of labour for installing and maintaining the network) or ongoing subsidies from the locality or government.

Once the network has reached sustainability for current operations, the question of network growth and expansion arises. For commercial entities, this is normally a response to growing demand from the locality, and expansion of the network is an investment decision with its own business case. For non-commercial entities that provide connectivity for humanitarian or other similar purposes, extending the network's reach may require substantial additional funding not readily available from existing usage fees and subsidies.

One way to address this is through the contribution of equipment from partners or from members of the locality. This assumes that usage fees in the new target area will be sufficient to cover the additional bandwidth required, or that subsidies will also be available for the expansion. The same logic applies to upgrading network equipment or increasing bandwidth, which can be addressed either via higher usage fees or an increase in subsidies. Table 32 highlights the various sustainability issues faced by different last-mile connectivity intervention types.

Table 32. Sustainability considerations by organizational structure

	Commercial MNO	Commercial ISP	Not-for-profit local mobile network	Not-for-profit local ISP network
Sustainability considerations	Commercial operation that must break even (or provide coverage as a corporate social responsibility endeavour or coverage obligation requirement)	Commercial operation that must break even (or provide coverage as a corporate social responsibility endeavour or coverage obligation requirement)	Usage fees may have to be supplemented with in-kind contributions (network installation and operation) or ongoing community or government subsidies	Usage fees may have to be supplemented with in-kind contributions (network installation and operation) or ongoing community or government subsidies

3.3 Draw up a decision matrix for feasible solutions (Step 3c)

The range of options facing any single intervention are extensive and the process of filtering the characteristics of the constraints can be linear (e.g. a decision tree) or iterative (determines a good fit on the basis of all of the inputs and constraints unique to each situation).

Presented below in Table 33 is one such decision matrix that can help filter relevant intervention options based on the situation characteristics and constraints presented above. The affordability and usage criteria may be applied ex ante to the selection process based on the decisions made to limit interventions to those that meet certain thresholds of service price for predetermined service levels.

For the financial viability criteria, structure of potential entities and sustainability, the different characteristics of the four different intervention types will determine what may be the most feasible solution.

However, for any of the intervention types listed below (commercial MNO, commercial ISP, not-for-profit local mobile network or not-for-profit local ISP network), different technologies can be used and, in most cases, multiple technologies can be deployed in different parts of the telecommunication value chain, as well as in different parts of the networks. These hybrid networks based on technology (also known as heterogeneous networks) can also feature various business models. One type of decision matrix for identifying potential intervention solutions is a decision tree (see Annex 3).

Table 33. A decision matrix for identifying appropriate solutions

		Commercial MNO	Commercial ISP	Not-for-profit local mobile network	Not-for-profit local ISP network
Affordability		Ex-ante measure of affordability threshold (such as 2 per cent of monthly GDP per capita for 1 GB of mobile broadband data) applied at national or local level; determination whether this will govern selection process or used just as an external measure of progress			
Usage		Ex-ante determination of usage requirement: will usage be determined by what the market (and financial viability) support, or are there specific services and applications (such as e-government, health or education) that require meeting specific QoS thresholds?			
Financial viability	Estimating demand and financial viability	Small population/ low income Small population/ higher income Larger population/ low income Larger population/ higher income	Small population/ low income Small population/ higher income Larger population/ low income Larger population/ higher income	Small population/ low income	Small population/ low income Small population/ higher income Larger population/ low income
	QoS options (backhaul)	High capacity and competitive pricing Low capacity and high pricing	High capacity and competitive pricing	Low capacity and high pricing	Low capacity and high pricing
	Access network characteristics	Small area/flat terrain Large geographic area/flat terrain	Small area/flat terrain Small area/ mountainous terrain Large area/flat terrain Large area/ mountainous terrain	Small area/flat terrain; Small area/ mountainous terrain; Large area/flat terrain	Small area/flat terrain Small area/ mountainous terrain Large area/flat terrain Large area/ mountainous terrain
Structure		Commercial telecom operation licences required; licensed spectrum rights required	Commercial ISP licence required	Licensed spectrum rights required (except partnerships with an MNO); telecom licence may be required	ISP licence may be required
Sustainability		Commercial operation that must break even (or provide coverage as a corporate social responsibility endeavour or coverage obligation requirement)	Commercial operation that must break even (or provide coverage as a corporate social responsibility endeavour or coverage obligation requirement)	Usage fees may have to be supplemented with in-kind contributions (network installation and operation) or ongoing community or government subsidies	Usage fees may have to be supplemented with in-kind contributions (network installation and operation) or ongoing community or government subsidies

3.4 Consider additional tools to assess solutions (Step 3d)

A range of additional tools are available to support the right-sizing of network deployments and estimating investment needs. The European Commission, for example, uses a decision tree that flows from developing an initial broadband plan to choosing infrastructure types, investment models, business models and financing tools, before ending with an action plan for execution.⁶⁵ Similarly, the World Bank has a decision tree for different scenarios, or levels of engagement, of government intervention in infrastructure deployment.⁶⁶

Other such decision trees are presented in Table 34, in addition to investment modeling tools (reports and spreadsheets) that help estimate the costs of deployment, potential revenue and economic feasibility. ITU's *ICT Infrastructure business planning toolkit*, in particular, presents a range of different economic analyses for estimating the key financial metrics of any potential infrastructure investment such as demand, revenues, capital expenditure, operating expenses, weighted average costs and net present value.⁶⁷

Table 34. Additional tools for assessing solutions (decision support and investment modelling)

Tool type	Tool name	URL	Applicability
Decision support	European Union Investment Modelling	https://ec.europa.eu/digital-single-market/node/77755	Business model selection process
	World Bank Innovative Business Models	http://documents.worldbank.org/curated/en/674601544534500678/pdf/132845-7-12-2018-17-20-11-InnovativeBusinessModels.pdf	Determining public support for core network infrastructure
	Rural Telecommunications Infrastructure Selection	https://pdfs.semanticscholar.org/1b90/b5db52b035292c06d35f95d13cb4ba1e9e5e.pdf	Various criteria for rural last-mile connectivity
	"Closing the Access Gap" report, with key considerations and access models	https://www.usaid.gov/sites/default/files/documents/15396/Closing-the-Access-Gap.pdf	Identifying last-mile connectivity access models
Investment modelling	ITU ICT Infrastructure business planning toolkit	https://www.itu.int/en/ITU-D/Technology/Documents/Publications/ICT%20Infrastructure-business-toolkit.pdf	Network investment requirements
	"Connecting Africa Through Broadband" report model	https://www.broadbandcommission.org/Documents/working-groups/DigitalMoonshotforAfrica_Report.pdf	Modelling national universal access investments
	Internet for All Investment Tool (World Economic Forum)	http://www3.weforum.org/docs/IFA_models_for_year.xlsx	Demonstrates an investment modeling tool used for East Africa
	Last-mile Connectivity Business Modelling Tool (USAID)	http://inclusion.digitaldevelopment.org/resources/last-mile-connectivity-business-modeling-tool	Financial modelling of last-mile connectivity interventions

⁶⁵ European Commission, [Basic business models](#) (webpage, last updated 3 July 2020).

⁶⁶ World Bank, op. cit., note 76.

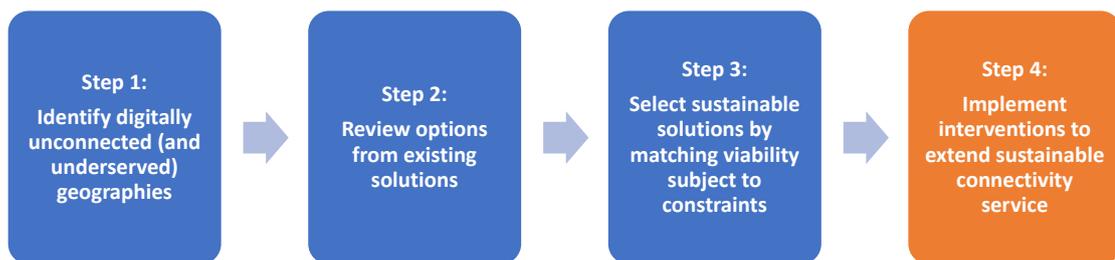
⁶⁷ ITU, *ICT Infrastructure business planning toolkit* (Geneva, 2019).

Chapter 4. Implement interventions to extend sustainable connectivity service (Step 4)



Once viable solutions have been identified, the next step in the process is to determine what additional actions may be required to support their implementation. Step 4 focuses on these supportive actions. Figure 34 situates this step in the overall process and sets out its activities.

Figure 34. Step 4 in the Last-mile Internet Connectivity Solutions Guide.



Step 4 activities to implement interventions to extend sustainable connectivity service:

- 4a - Options for intervention - Introduction
- 4b - Options for intervention - Market efficiency actions
- 4c - Options for intervention - One-time financing (smart subsidy)
- 4d - Options for intervention - Recurring financing/subsidy
- 4e - Examples of options (from case study submissions)

4.1 Options for intervention - Introduction (Step 4a)

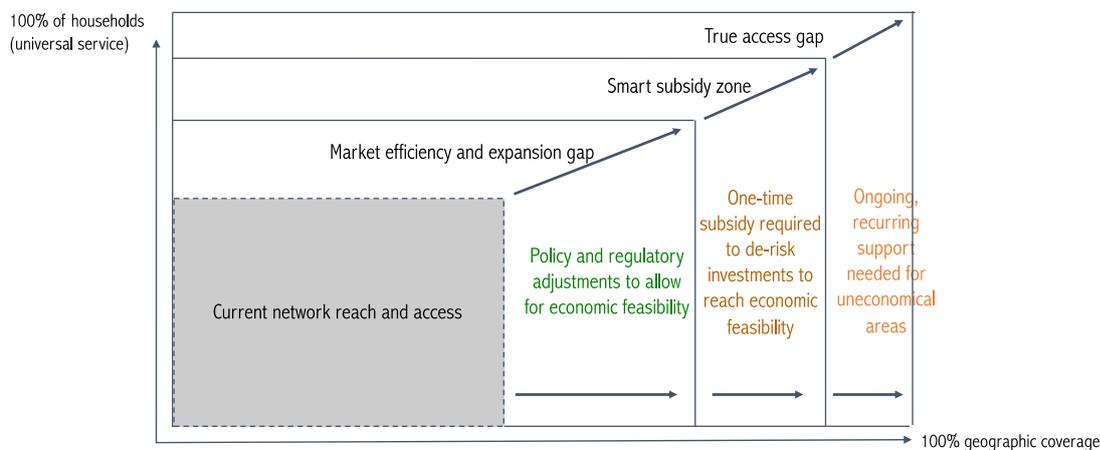
As noted in Section 2.3.3.1 (The rationale for subsidies (none, one-time versus recurring)), there are three general types of intervention to increase universal coverage and service for Internet connectivity. These three categories of intervention are also used in this Solutions Guide to group interventions that encourage last-mile connectivity service deployment (see Figure 35).

The first category involves policy and regulatory interventions that expand economically feasible service provision (described here as market efficiency and expansion interventions). It encompasses actions that address market failure and limit the potential for private sector investment in service delivery.

The second category relates to one-time financing or limited subsidies that de-risk private investment (also described as smart subsidies). It contains a range of one-time public financing measures (and tax incentives) and is described in 4.3 Options for interventions - One-time financing (smart subsidy).

The last category centres on recurring public financing in cases where service provision is not economically feasible, as the market offers insufficient return on private capital investment, and ongoing, recurring subsidies are needed in order to provide service. Section 4.4 Options for interventions - recurring financing/subsidy describes the intervention options available.

Figure 35. Intervention distinctions for the various access gaps



Source: ITU ICT Regulation Toolkit, note 42

4.2 Options for interventions - Market efficiency actions (Step 4b)

Table 35 summarizes a number of policy and regulatory actions that expand economically feasible service provision by encouraging market expansion and deployment and addressing market failure, and their applicability to different last-mile connectivity interventions.

Improving market information data resources on, for example, network coverage, infrastructure assets, population density and income and grid electrification, in order accurately to identify uncovered populations and the solutions they need, is a foundational step towards improving market efficiency. Particularly when underserved and unserved areas remain hidden, existing commercial arrangements can result in market failure. Ensuring that enough information is

openly available for commercial entities to make informed network expansion decisions can help improve coverage and bring connectivity to the last mile.

Authorizing specific licences for rural areas with simplified requirements helps encourage the entry of for commercial and not-for-profit entities alike in underserved and unserved localities. Tanzania's Micro Mobile Network Operator licence, for example, encourages the deployment of cellular service to small populations in rural areas. Such a model is particularly helpful when the regulatory requirements for a full-service operator constitute a structural barrier to entry for new entities.

In a similar vein, authorizing not-for-profit operator licences that do not have the same expensive fees and strict obligations as commercial operators reduces the regulatory barriers to entry, in recognition that such entities do not benefit from the same revenue models as commercial operators. Such incentives could also be offered to enable existing players to extend their networks and services.

Discounting the cost of spectrum licences for rural areas and/or providing a direct allocation for social purposes recognizes that spectrum licensing fees can be a significant barrier to the deployment by small entities of wireless connectivity in the last mile. Particularly for cellular frequencies in auction-based assignment regimes, it can be difficult to recover the cost of licensing spectrum in sparsely populated rural areas, especially when combined with the cost of deployment. Discounting the cost of a licence, providing auction credits for frequencies, or allocating frequencies for social use reduces the financial barrier to deploying cellular technology in areas where they may be technically appropriate, but are rendered financially infeasible by the cost of licensing spectrum.

A similar intervention involves allowing secondary use of spectrum. In areas where an entity with a licence to use certain frequency bands does not use those frequencies, or does not have a network at all, allowing secondary use of spectrum promotes efficient use of scarce spectrum resources. Spectrum sharing helps prevent market inefficiencies involving licensing; in this case, it is necessary to recognize that small entities (particularly not-for-profit MNOs) can make use of frequencies already assigned to another player when that player has not found a commercially viable way to bring connectivity to the target locality.

Authorizing the commercial and non-commercial use of unlicensed and/or licence-free bands opens up the technological options for deployment using wireless technologies. In the case of Brazil, allowing CELCOM, a community cellular network, to use the Special Licence for Scientific and Experimental Purposes to accommodate broadband services and applications helped close the access gap for target localities. Where existing technologies exist to make use of unlicensed and/or licence-free bands to deliver connectivity, allowing players to make use of those technologies opens up options for entities looking to deliver access at the last mile.

In many jurisdictions, spectrum licences are awarded nationally, such that entities may hold the licence for particular frequency bands even in areas where the frequencies go unused. One way to ensure that scarce spectrum resources are used efficiently is to implement and enforce coverage obligations (with QoS requirements) for spectrum licence assignments. By mandating players to deliver a target QoS over a specified coverage area, users are able to benefit more widely from the spectrum resources assigned to MNOs. Such a policy could be complemented

with lower spectrum fees, subsidies or other financial incentives,⁶⁸ and is particularly helpful in jurisdictions where, MNOs concentrate their network build-up (metropolitan centres).

More generally speaking, authorizing innovative uses of communication technology for commercial and non-commercial service deployment creates a technology-neutral policy environment that encourages creative use of available technology for deployment in areas that need them. In many cases, technological solutions exist for the technical problems (such as terrain) preventing access in a locality. Allowing entities to make use of technologies, such as HAPs, to overcome these challenges can help bridge the access gap, especially when more traditional technologies prove insufficient or are not financially viable.

In areas with relatively mature markets, supporting national roaming and infrastructure sharing (of passive and active networks) can help overcome competition issues that prevent affordable last-mile access. For instance, in situations where strong incumbents have distinct networks that cover different geographical areas, a national roaming scheme and infrastructure sharing can help bring competing services to new localities, which will help bring prices down for consumers.

For jurisdictions with few middle-mile players, and especially when middle-mile providers are vertically integrated entities that also offer competing branded services to end users, one way to improve competition is to implement price regulation on middle-mile wholesale broadband capacity, ensuring fair terms for small access ISPs. In leveling the playing field at the last mile, small access ISPs are able to pass down bandwidth savings to consumers in the form of more affordably priced connectivity.

Removing limits on foreign ownership of ISPs and investment restrictions brings several benefits that all work to make the market most efficient. Most immediately, opening up the market to foreign players improves competition, helping to bring access costs down for end users. Authorizing fully foreign-owned ISPs also encourages the entry of foreign talent, which brings with it experience from more mature markets that can translate to smarter deployment decisions. Removing investment limits can also help bring players into the market that are willing to use riskier, less mature technologies than incumbents, fostering innovation in access provision.

A common problem for smaller players that are looking to use cellular frequencies is the high cost of obtaining spectrum resources at auction. Considering alternatives to allocation of spectrum via high-priced auctions allows players with fewer resources to gain access to cellular frequencies, helping them deploy their own mobile networks and improving access to connectivity. Similarly, reducing the spectrum price for existing national operators could allow them to invest more in network deployment and thereby extend their coverage.

More generally, encouraging market competition is an important way to improve market efficiency. Whether through more players, competition, anti-trust regulations or other mechanisms, improving competition helps bring the cost of access down for end users. A more competitive market also presents less of a barrier for prospective new entrants, which may choose to deploy their networks in areas unserved by incumbents, directly increasing access coverage.

Reducing lengthy licensing processes and high regulatory fees for satellite terminals and spectrum not only improves the financial viability of wireless entities, it also helps speed up

⁶⁸ In 2018, Arcep and the mobile operators announced a plan called the "New Deal Mobile" to improve connectivity in France rural area.

deployment and bring connectivity more quickly to localities that need them the most. Long processes and high fees are a barrier to efficient delivery of services, and regulators should look to streamline them when possible in order to improve market efficiency.

Implementing “dig once” regulations that ensure co-deployment of ductwork for fibre deployments when new roads are constructed has a similar effect for wired access networks, or for backhaul provision. A large part of the cost of deploying subterranean wired networks involves the civil works necessary to lay out fibre (or other wired technology). Furthermore, digging up roads entails lengthy bureaucratic processes involving construction permits, rights of way and other similar requirements, and can cause undue obstruction in highly trafficked areas. Implementing a “dig once” policy helps remove these barriers and makes it more attractive for entities to deploy wired networks, whether in urban or in rural areas.

Similarly, easing right-of-way and pole attachment requirements for middle-mile deployment to rural and remote areas increases the financial viability of bringing backhaul to target localities. Particularly when the cost and availability of backhaul is a binding constraint, this intervention can help make access at the last mile more affordable and more available.

Table 35. Market efficiency interventions and their applicability to different last-mile connectivity models

Market efficiency and expansion interventions (non-financial)	Examples	Commercial MNO	Commercial ISP	Not-for-profit local mobile network	Not-for-profit local ISP network
Improve market information data resources on, for example, network coverage, infrastructure assets, population density and income, and grid electrification, in order more accurately to identify populations without coverage and the solutions they need	The GSMA Mobile Coverage Maps can improve the efficiency of MNO infrastructure investment and help other stakeholders to strategically target their activities; Germany's infrastructure atlas, the central information and planning tool for broadband expansion in Germany, contains data from more than 1 500 network operators and the federal, state, district and local authorities; California's order to create a shared database/census of utility poles and conduit; for other open telecom data examples, see Steve Song's Open Telecom Data work	√	√	√	√
Authorize specific licences for rural areas with simplified requirements	Tanzania's authorization of a test for licensing in rural areas of a micro MNO model (see LMC case study); India's experience with Bluetown and permission for wireless ISPs to serve as managed hotspot service providers serving low-income communities (see LMC case study); Peru's example with a rural mobile infrastructure operator licence (see LMC case study)	√	√	√	√

Table 35. Market efficiency interventions and their applicability to different last-mile connectivity models (continued)

Market efficiency and expansion interventions (non-financial)	Examples	Commercial MNO	Commercial ISP	Not-for-profit local mobile network	Not-for-profit local ISP network
Authorize community operator licences that do not have the same expensive fees and strict obligations as commercial operators	Argentina’s 2018 regulatory resolution 4958 giving special dispensation to small local operators; India’s experience with AirJaldi, which began as a small local community operator and then formalized to expand commercial operations to hundreds of thousands of users (see LMC case study)			√	√
Discount spectrum licences for rural areas and/or provide a direct allocation for social purposes	Mexico’s Federal Telecommunications and Broadcasting Law of 2014, which introduced a “social use” concession in spectrum assignments, reserved for the purposes of community, education, culture or science	√		√	
Regulate the price of middle-mile wholesale broadband capacity, ensuring fair terms for small access ISPs	Malaysia’s Mandatory Standard on Access Pricing; Peru’s example establishing asymmetrical interconnection rates (see LMC case study)	√	√	√	√
Remove limits to foreign ownership of ISPs and investment restrictions	Cambodia’s experience of encouraging competition in the ISP market	√	√		
Consider alternatives to allocation of spectrum via high-priced auctions	Cambodia’s experience of reducing operating costs in the ISP market	√		√	
Encourage market competition	Ghana’s experience granting additional licences to ensure no monopolistic provision of service	√	√	√	√
Reduce lengthy licensing processes and high regulatory fees for satellite terminals and spectrum	Geeks Without Frontiers’ Community Connect Best Practices for Satellite Network Operators, Regulators, and Service Providers & Integrators	√	√	√	√
Implement “dig once” regulations that ensure co-deployment of ductwork for fibre deployments when new roads are constructed	United States Federal Communications Commission Broadband Deployment Advisory Committee State Model Code for Accelerating Broadband Infrastructure Deployment and Investment; CTC Net’s Technical Guide to Dig Once Policies and White Paper	√	√	√	√

Table 35. Market efficiency interventions and their applicability to different last-mile connectivity models (continued)

Market efficiency and expansion interventions (non-financial)	Examples	Commercial MNO	Commercial ISP	Not-for-profit local mobile network	Not-for-profit local ISP network
Ease right-of-way and pole attachment requirements for middle-mile deployment to rural and remote areas	One Touch Make Ready (also known as One Touch, and often abbreviated as OTMR) is an item from an order issued by the United States Federal Communications Commission (FCC 18-111) that aims to speed the process and reduce the costs of attaching new network facilities to utility poles, by allowing a single party to prepare the pole quickly, rather than spreading the work across multiple parties.	√	√	√	√
Authorize secondary use of spectrum		√		√	
Authorize commercial and non-commercial use of unlicensed and/or licence-free bands	Brazil's experience allowing CELCOM, a community cellular network, to use the Special Licence for Scientific and Experimental Purposes as provided by the regulator, Anatel (see LMC case study); Brazil's experience allowing the 225-270 MHz spectrum frequency range to be defined by Anatel as an alternative for accommodating broadband services and applications (see LMC case study)	√	√		√
Implement and enforce coverage obligations (with QoS requirements) for national spectrum licence assignments	Austrian 700 MHz 5G licences will include coverage of 900 underserved communities ; Sweden's coverage obligation for 700 MHz ; Brazil's experience ensuring coverage obligations as part of spectrum licensing	√			
Promote innovative uses of communication technology for commercial and non-commercial service deployment	Peru's experience with regulatory policy allowing MNOs to enter into agreements on sharing and working through a wholesale partnership (Internet para Todos) (see LMC case study); Brazil's experience allowing Viasat to offer commercial service on the government network, Telebras (see LMC case study)	√	√	√	√
Support national roaming and infrastructure sharing (passive and active networks)	The United Kingdom's shared rural infrastructure ; Brazil's experience of spectrum sharing	√	√	√	√
Support blanket licensing for end-user terminal equipment	The Satellite Communications Applications Handbook ; ECC Decision (03)04	√	√	√	√

4.3 Options for interventions - One-time financing (smart subsidy) (Step 4c)

Limited concessional financing support can serve to de-risk private sector investment. Examples of specific actions in this regard are summarized in Table 36.

For markets with established players, collecting and distributing universal service funds for one-time subsidies to de-risk deployments encourages incumbents to bring their networks to rural and remote areas. The cost of building out networks to areas with potentially less demand than that covered by the existing network is often unappealing to operators, who see little to no business case in doing so at current cost levels. A one-time subsidy that reduces the cost of deployment can improve the business case for entities and make deployment to the target localities financially viable.

In less mature markets with more systemic risks, allowing and encouraging risk-reducing public-private partnerships encourages new players to enter the market and existing ones to expand their networks. By mitigating their exposure to risk via such partnerships, private entities become more willing to invest their resources in areas – often rural – that might not provide as good a return as their existing coverage area.

In a similar vein, allowing and encouraging blended finance investment structures, pooling commercial capital for project finance with forms of public and/or sub-commercial return-seeking private capital (also known as patient capital) reduces the risk of deploying or expanding networks to low-return areas. Creative funding strategies aimed at mitigating risk can help bridge the access gap caused by demand uncertainty or lagging demand growth in rural areas.

For not-for-profit entities, an important way to reduce the cost of deployments is to authorize flexible in-kind contributions (hardware, software and technical capacity) from the private and public sectors. These entities are often looking to, at most, break even in terms of operating expenses and are not looking for a return on the capital invested. This means that areas that would not normally be attractive to commercial operators are viable localities for not-for-profit entities. The significant hurdle in their case may instead be the cost of procuring and deploying network equipment in order to deliver access. Allowing in-kind contributions reduces costs and encourages the entry of non-commercial players.

In contexts where backhaul is available but last-mile access networks do not operate for reasons of financial viability, implementing tax incentives for last-mile service providers can encourage players to enter the segment and deliver connectivity. By effectively providing a subsidy for the deployment of a network, interventions such as Malaysia's investment allowance incentive on capital expenditure for broadband last-mile service providers incentivize expansion to areas that would otherwise not be commercially viable.

In other contexts, a significant barrier to access may be the high price of access devices. Reducing taxes on mobile handsets and connectivity devices directly improves access in areas where networks already exist. Furthermore, interventions like this help improve potential demand in underserved or unserved areas, as more people will already have devices when connectivity becomes available. This can help make the business case for the entry or expansion of a network to new areas.

Table 36. One-time financing or limited subsidy intervention options and their applicability to different last-mile connectivity models

One-time financing or subsidy intervention	Examples	Commer- cial MNO	Commer- cial ISP	Not-for- profit local mobile network	Not-for- profit local ISP network
Collect and distribute universal service funds for one-time subsidies to de-risk deployments	Rwanda's Universal Service and Access Fund, which focuses on lowering the cost of broadband in rural and urban poor communities, and providing connectivity to essential services; Costa Rica's universal access fund for telecommunications, FONATEL, which led to significant strides towards universal access; Morocco's universal service fund supports its universal access programme to connect remote locations beyond the reach of terrestrial networks (initially 8 000 locations) using satellite in a prepaid business model that is commercially viable (see LMC case study)	√	√	√	√
Allow and encourage risk-reducing public-private partnerships	The United Kingdom's shared rural infrastructure; Georgia's Open Access Fiber Deployment; the Interchange Cable Network 1 (ICN1), connecting Vanuatu to the Southern Cross Cable Network; Peru's example of awarding lowest-subsidy auction funding from its universal service fund to public-private partnership models (see LMC case study)	√	√	√	√
Allow and encourage blended finance investment structures, pooling commercial capital for project finance with forms of public and/or sub-commercial return-seeking private capital (also known as patient capital)	China's experience offering concessional loans for broadband deployment projects in state-level development areas in the western region (see LMC case study); Burkina Faso's experience allowing a partnership between Lux Dev, the government and SES Telecom Services for rural deployment (see LMC case study); Giga initiative which aims to connect every school to the internet	√	√	√	√
Authorize flexible in-kind contributions (hardware, software and technical capacity) to non-commercial entities from the private and public sectors				√	√

Table 36. One-time financing or limited subsidy intervention options and their applicability to different last-mile connectivity models (continued)

One-time financing or subsidy intervention	Examples	Commercial MNO	Commercial ISP	Not-for-profit local mobile network	Not-for-profit local ISP network
Introduce tax incentives for last-mile service providers	Malaysia’s investment allowance incentive on capital expenditure for broadband last-mile service providers; Brazil’s experience granting state tax credits to mobile service providers, to incentivize expansion to areas that are not commercially viable	√	√	√	√
Reduce taxes on mobile handsets and connectivity devices	Kenya’s action to exempt mobile handsets from the 16-per cent value-added tax, resulting in a dramatic rise in purchases and ownership	√	√	√	√

4.4 Options for interventions – recurring financing/subsidies (Step 4d)

Recurring concessional financing support may be required for some deployments, as summarized in Table 37.

For localities where network sustainability is an issue because of market conditions and existing costs, collecting and distributing universal service funds for recurring subsidies to de-risk deployments helps provide access to areas that would not otherwise get connectivity. These areas represent a true access gap; their low population densities and challenging terrain often combine to make operations unviable for commercial operators, even with subsidies for deploying their network. In this case, a recurring subsidy helps cover operating expenses in the locality.

For not-for-profit networks specifically, more flexible and beneficial tax arrangements for non-profit local complementary networks encourage and assist entities with operating networks in rural and remote areas. These locations represent a humanitarian (not commercial) case for providing connectivity, and an intervention of this kind recognizes the public good that these networks deliver to their localities. In more material terms, these tax arrangements lower the cost of operating networks and help subsidize provision of services to end users.

Table 37. Recurring subsidy interventions and their applicability to different last-mile connectivity models

Recurring subsidy interventions	Examples	Commer- cial MNO	Commer- cial ISP	Not-for- profit local mobile network	Not-for- profit local ISP network
Collect and distribute universal service funds for recurring subsidies to de-risk deployments	Malaysia's Universal Service & Access Fund provided support for the deployment of the six main initiatives in the National Broadband Initiative; Gabon's experience using its universal service fund to finance network expansion and operations for 2 700 remote villages in areas deemed too unprofitable for private telephony operators (see LMC case study); South Africa's experience utilizing recurring subsidies from the South African Universal Services Fund to provide free Wi-Fi to rural schools and clinics (see LMC case study)	√	√	√	√
Consider more flexible and beneficial tax arrangements for non-profit local complementary networks				√	√

4.5 Examples of options from case study submissions (Step 4e)

The Last-mile Connectivity Case Studies Database contains a wide range of example solutions, many of which demonstrate one or more intervention options described in the tables above. A number of the case studies are presented in Table 38 and linked to the various intervention options.

Table 38. Examples of options from case study submissions

Examples from the LMC Case Studies Database (submissions)	Intervention option	Details
Morocco - World Telecom Labs	One-time subsidy (universal service fund)	Universal access programme run by the Moroccan national telecommunication regulatory authority to initiate remote locations beyond the reach of terrestrial networks (initially 8 000 locations) using satellite in a prepaid business model that is commercially viable
Tanzania - Amotel (& WTL)	Market efficiency and expansion interventions (appropriate licensing; support from regulator for experimental innovative approaches) One-time subsidy (universal service funds)	Universal service fund financing for a proof-of-concept trial to demonstrate the micro MNO and regulatory approval to operate as an MVNO leveraging MNO partnerships but also the ability to build its own network infrastructure

Table 38. Examples of options from case study submissions (continued)

Examples from the LMC Case Studies Database (submissions)	Intervention option	Details
Gabon - World Telecom Labs	Recurring subsidy (universal service fund)	Tax levied on all telecommunication operators as part of the universal service policy (universal service fund) used to finance network expansion and operations for 2 700 remote villages in areas deemed too unprofitable for private telephony operators
India - AirJaldi	Market efficiency and expansion interventions (allowing community networks, and conversion to commercial networks); one-time subsidy (grant funding)	AirJaldi began as a community network and was allowed to operate in the regulatory policy environment. After growing to a considerable size, it was able to convert into a commercial operation to better serve its members/customers. It has also received grants from various groups, including the APNIC Foundation and Microsoft.
Kenya - Mawingu	Market efficiency and expansion interventions (trial licence for commercial use of TV White Space); one-time subsidy (grant funding)	Mawingu received special dispensation from the regulator to trial TV White Space technology and also received grants from different groups, including USAID and Microsoft.
India - Bluetown	Market efficiency and expansion interventions (an unregulated model wherein an aggregator (Public Data Office Aggregator) provides last mile Wi-Fi infrastructure and small entrepreneurs set up Public Data Offices in local areas for customer access, using existing passive assets (towers) Recurring subsidy (subsidized backhaul from the government)	Wireless ISP serving as a managed hotspot service provider in low-income rural communities
South Africa - Brightwave	One-time subsidy (Microsoft Airband initiative) Recurring subsidy from the South African Universal Services Fund of the Universal Service and Access Agency of South Africa (USAASA)	Commercial ISP providing free Wi-Fi to rural schools and clinics with subsidized support
Peru - Government policy options	Market efficiency and expansion interventions (regulatory and policy changes including licence obligations, rural mobile infrastructure operator licence, asymmetrical interconnection rates) Recurring subsidy (universal service funds awarded via lowest subsidy auction in a public-private partnership model)	Policy options enacted by the government of Peru to expand connectivity to underserved areas. The geographical barriers of the Andes and the Amazon, widespread poverty, limited literacy, poor Internet access and insufficient competition are the most significant barriers, making broadband Internet access in Peru one of the slowest and most expensive in the region. Improved rural connectivity has always been a goal for regulators and policy-makers. Peru's Telecommunication Investment Fund offers a successful example of a universal access fund adopting an innovative approach to achieving access in rural areas, now widely replicated: the lowest-subsidy auction. Using this financial scheme, together with flexible regulatory policies and low-cost technologies, can help achieve that goal.

Table 38. Examples of options from case study submissions (continued)

Examples from the LMC Case Studies Database (submissions)	Intervention option	Details
Brazil - CELCOM community cellular network	<p>Market efficiency and expansion interventions (CELCOM uses the Special Licence for Scientific and Experimental Purposes provided by Anatel with respect to legislation issues)</p> <p>Recurring subsidy (financed by the institutions involved)</p>	<p>This case study concerns cellular community networks in isolated and sparsely populated regions of Brazil, with a focus on very-low-income communities and the Brazilian Amazon. It describes the technologies adopted for three pilot projects in communities located in the Amazon region, together with techno-economic aspects.</p>
Brazil - Government policy options	<p>Market efficiency and expansion interventions (spectrum auction obligations)</p> <p>Recurring subsidy (transfer of funds by the states by granting state tax credits to mobile service providers, limited to the proven amount invested by the company)</p>	<p>Brazil's experiences implementing public policies to incentivize service providers to deploy networks in areas that could be deemed not commercially viable, including rural and remote areas</p>
Peru - Internet para Todos	<p>Market efficiency and expansion interventions (regulatory policy that allows partner MNOs to provide commercial exclusivity in target areas, right-to-use spectrum, licences, etc., and existing wholesale relationships)</p> <p>One-time subsidy (with some direct foreign investment (Inter-American Development Bank, Development Bank of Latin America) so perhaps some one-time subsidies in terms of concessional financing)</p>	<p>Internet para Todos connects MNOs to less financially attractive areas in an open business model; it offers its infrastructure to MNOs so that they can reach low-density areas; local communities, entrepreneurs and other telecom operators are invited to join and co-build the network; any MNO could extend its services to low-density areas using Internet para Todos infrastructure, or deploy and operate next-generation cellular and transport telecommunication networks; partner MNOs provide commercial exclusivity in target areas, right-to-use spectrum, licences, etc., and existing wholesale relationships</p>
Brazil - GESAC (Telebras and Viasat)	<p>Market efficiency and expansion interventions (an innovative agreement allowing Viasat to offer commercial service on the Telebras network and commercialize capacity, as Telebras is the contracting party for federal government programmes, such as GESAC and the partnership pays Telebras a share of revenue from Viasat's commercialization of the capacity)</p> <p>Recurring subsidy (government funding for school connectivity)</p>	<p>Faced with more than 15 000 public schools without high-quality broadband, the Brazilian government turned to satellite as the technology of choice and launched the Programa Governo Eletrônico - Serviço de Atendimento ao Cidadão to connect its schools. The programme, better known as GESAC, has been an unqualified success, with 2 million schoolchildren connected in just 9 months.</p>

Table 38. Examples of options from case study submissions (continued)

Examples from the LMC Case Studies Database (submissions)	Intervention option	Details
Mexico - Community Wi-Fi (Viasat)	No direct policy or subsidy intervention observed, as the focus is on sustainable commercial service, but improved electrical grid infrastructure and subsidy could be considered to de-risk deployments.	The "Community Wi-Fi" model harnesses a commercially successful methodology for connecting the unconnected, particularly in areas that had long been considered uneconomical for terrestrial operators. The programme has also been undergoing trials across Viasat-2 coverage and is being expanded to many Central America and Caribbean countries in the 2020-2021 timeframe. Community Wi-Fi will scale and roll out globally with the ViaSat-3 constellation, beginning in 2021.
China - Government policy options	<p>Market efficiency and expansion interventions (the public authorities can demand that property developers lay fibre-optic cable in newly built residential buildings as last-mile connectivity; the government negotiated joint construction and sharing with operators and formed a new company to implement it)</p> <p>Recurring subsidy (universal service funds and subsidy programme to improve broadband connectivity)</p> <p>Subsidy - The government has a subsidy programme for operators rolling out fibre-optic and 4G infrastructure in target areas.</p> <p>Concessional loan and financing - Concessional loans are available for eligible broadband development projects in state-level development areas in the western region.</p> <p>Tax incentives - Tax incentives exist for the construction and operation of broadband networks.</p>	To improve ICT development, in August 2013 the State Council issued the "Broadband China" strategy to drive all-round broadband advancement, speed up broadband construction, and build safe and universal next-generation national information infrastructure. To foster the long-term development of broadband, the "Broadband China" strategy is linked to the Twelfth Five-Year Plan of the information and telecommunication industry.
Brazil - Private LTE networks at 250 MHz for IoT / agriculture	Market efficiency and expansion interventions (regulations for the 225-270 MHz frequency range (the so-called 250 MHz band) have been defined by ANATEL as an alternative to accommodate broadband services and applications and thereby exploit the premium radio frequency propagation characteristics of lower frequency bands to increase cell coverage, a crucial aspect when it comes to providing services in rural and sparsely populated areas.	LTE 250 MHz technology has been developed by CPQD in the AgroTICS project, based on a partnership with São Martinho S/A and Tropic, funded by BNDES and focused on increasing the efficiency of sugar and ethanol production through the use of ICT. LTE 250 MHz technology is designed for agribusiness applications. It provides a feasible means of increasing coverage via a low-cost and interoperable solution that can be applied in the access and transport networks using a proposed new 3GPP profile applying LTE technology in 250 MHz to a long range and large-scale production. The solution can be replicated in Brazil and other countries according to each telecommunication regulatory agency's rules and decisions.

Table 38. Examples of options from case study submissions (continued)

Examples from the LMC Case Studies Database (submissions)	Intervention option	Details
Ghana - Ruralstar (Huawei)	Market efficiency and expansion interventions (introduction of technological improvements and improved market information)	Huawei's RuralStar is a lightweight rural network coverage solution supporting 2G, 3G and 4G connectivity. It has the potential of a lightweight rural infrastructure option to extend rural coverage in a commercially sustainable manner. Development of improved mapping (GSMA Mobile Coverage Maps) leads to analysis of how millions of uncovered people could be reached in a commercially viable manner using technological innovations, such as Ruralstar.
SES Telecom Services in Burkina Faso	Financial intervention (public-private partnership including Lux Dev, the development agency for Luxembourg, for funding; the government of Burkina Faso for funding and project ownership on the ground; and SES Telecom Services for deployment)	Integrates the country's existing terrestrial wireless and fibre-optic networks with the O3b MEO satellite system to create an end-to-end hybrid communication network. The hybrid ecosystem includes five O3b MEO terminals, 65 towers and 114 point-to-multipoint radio base stations to create a significantly faster, broader and more reliable communication network serving 43 provinces and 19 million potential users through the Burkina Faso Administration. Services include: e-government, e-health and e-education applications; Internet broadband connection for civil servants; exchange of government data; creation of a data centre, SES local office; maintenance by ANSIP; data management and capacity building (training of ANSIP staff and local service providers).
Intelsat Community Wi-Fi for a refugee camp	Financial intervention (full recurring subsidy from Intelsat and UNHCR, with Intelsat funding the pilot programme at Ampain until UNHCR can secure alternative funding)	In 2016 UNHCR and Intelsat jointly developed an Internet access pilot programme for the Ampain refugee camp in Ghana. The camp is home to approximately 3 500 people. The ICT centre at Ampain provides camp inhabitants with computers to access Coursera online courses. In the last year a total of 280 online courses were completed by 220 camp inhabitants. A broad roll-out of Internet access to 100 camps could result in 2 400 refugees acquiring new skills every month, or 28 800 per year.
South Africa Internet for All (Intelsat)	Financial intervention (public-private partnership under the South African Internet for All in the form of a pilot project between the Department of Telecommunications and Postal Services, its social partners and the World Economic Forum, including a strategic partnership with Intelsat and local service providers)	Intelsat has developed a pilot programme aimed at testing commercial and social scenarios that may affect the roll-out of the Internet for All programme to rural areas in developing countries. The pilot is typically rolled out to five sites across a country and runs for six months while information is collected from each site. This information informs the project report, which is the ultimate pilot output. Intelsat provided capital investment for the pilot project. When the programme is rolled out more broadly, the capital investment will have to be funded by the government or by direct foreign investment. The payments from end users should be sufficient to cover operating costs and provide a modest income for the small, medium or micro-enterprise looking after the environment.

Table 38. Examples of options from case study submissions (continued)

Examples from the LMC Case Studies Database (submissions)	Intervention option	Details
Teleglobal-Bakti Project (SES)	Financial intervention (universal service fund subsidy, as SES and Teleglobal's cooperation is part of BAKTI's multi-pronged approach to universal connectivity involving the Palapa Ring of submarine cables to connect Indonesia's major islands, the interim lease of 50 Mbit/s of satellite capacity (of which SES-12 is a part), and the construction and launch of a new multi-functional satellite to provide 150 Gbit/s of connectivity around the country)	Under a new agreement signed in 2019, Teleglobal and SES Networks will be participating in the Ministry of Communication and Information Technology's universal service obligation project, via its universal service agency (Badan Aksesibilitas Telekomunikasi dan Informasi, or BAKTI), to provide broadband Internet access and mobile backhaul services to up to 150 000 sites in remote parts of the country using 1.3 GHz of capacity on SES's new HTS, SES-12, operating in a GEO.
Hughes Express Wi-Fi in Mexico	No direct policy or subsidy intervention observed, as the focus is on sustainable commercial service, but innovations include a strategy to approach the new Wi-Fi retailer, with a user guide, onsite training and help desk; new strategies with the partner, Facebook Connectivity, to improve the end user's experience with new customer apps and enhanced retailer app; assistance and support to the end users from the local retailer; and success factors (choose the target market wisely; cater to low ARPU customers)	Hughes Express Wi-Fi helps to connect people who cannot afford a monthly subscription and require pay-as-you-go, by offering affordable data-pack prices using their bring-your-own-device Wi-Fi mobile gear (phones/tablets/notebooks) equipped with any type of operating system (Android/IOS/Windows/Linux). The service is made inexpensive thanks to bite-sized usage plans, as low as USD 0.50 for 100 megabytes or up to one hour of use. Hughes Community Wi-Fi solutions include a very-small-aperture terminal and Wi-Fi equipment that extend the signal across a 50- to 80-metre radius with low-cost mobile phones; with a high-profile phone, the reach is improved 100 per cent. Once a site is deployed and set up with the hotspot, the local community of users benefits from high-speed Internet access.

Conclusion and next steps



This Solutions Guide aims to inform the design and implementation of future interventions that seek to address gaps in sustainable Internet service. It presents a wide body of experience, from Chapter 1 (Identify digitally unconnected (and underserved) geographies), to the many last-mile connectivity case studies shared in Chapter 2 (Review options from the classification of existing solutions). Chapter 3 (Select sustainable solutions by matching viability subject to constraints) highlights how different constraints and considerations will inform what types of intervention may best fit unique situations, and Chapter 4 (Implement interventions to extend sustainable connectivity service) describes various policy and direct interventions that can be leveraged. While the information presented here is not exhaustive - many situations call for hybrid solutions combining technologies and business models - the goal is to begin the process of addressing shortfalls in sustainable, affordable service.

The Annexes that follow provide additional resources to support specific interventions. Potential further next steps for engagement include the use of more sophisticated software-supported decision tools, such as those being developed within the overall Last-Mile Connectivity Toolkit programme.

Annex 1: Examples of network mapping

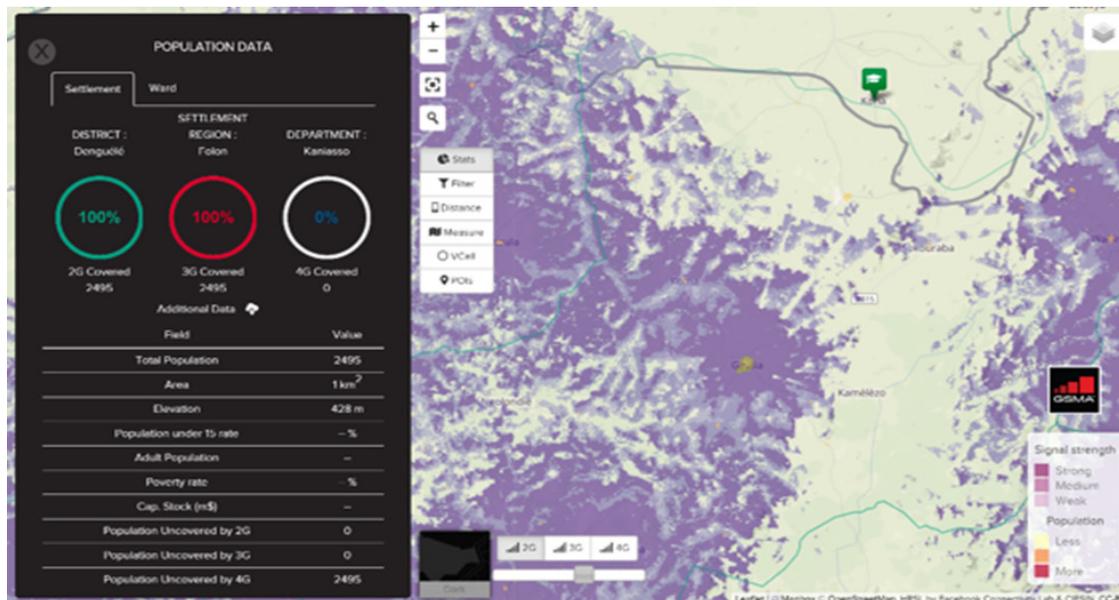
The following cases describe different mapping platforms and their use in network deployment and analysis.

GSMA Mobile Coverage Maps

GSMA created the [Mobile Coverage Maps platform](http://www.mobilecoveragemaps.com/) (<http://www.mobilecoveragemaps.com/>, see Figure A1.1 for an example map) to address the lack of reliable and accurate coverage data in emerging markets. The interactive maps allow users to:

- gain an accurate and complete picture of mobile coverage in a given country for each generation of mobile technology (2G, 3G and 4G);
- assess the coverage status for every population settlement in the country, no matter how small or remote;
- simulate the deployment of new mobile sites and estimate the population covered.

Figure A1.1. GSMA Mobile Coverage Map: example



To be relevant and accurate, and provide actionable insights, the coverage maps are based on first-hand high-granularity data. To achieve this, GSMA collects network information (such as the location of antennas and height of towers) directly from mobile operators and estimates the combined coverage of all the mobile operators in the market using a standard propagation model. The coverage data are then overlaid with high-resolution population data developed by Facebook Connectivity Lab and CIESIN. These data estimate human population distribution at a hyperlocal level, based on census data and high-resolution satellite imagery. Finally, the maps integrate other socio-economic indicators and key buildings such as schools, hospitals and medical centres. The online platform currently hosts eight maps: Ghana, Côte d'Ivoire, Liberia, Nigeria, Rwanda, Tanzania, Uganda and Zambia, with further countries to be added in the coming months.

The coverage maps have a number of use cases, but the main one is planning for rural infrastructure. For this, GSMA has developed algorithms that use the underlying data in the maps to generate optimal deployments that maximize population coverage while minimizing

costs. GSMA thus helps mobile operators identify rural areas where they can extend coverage in a commercially viable way. It also helps the public authorities prioritize their connectivity efforts by identifying areas that require some form of subsidy or concession to lower the cost of deployment (e.g. import duties relief).

Beyond optimizing investment in infrastructure, third parties are using the Mobile Coverage Maps through the GSMA's open and free online platform. For example, private companies are identifying the areas where they can use digital channels to reach rural customers; researchers are measuring the impact of connectivity on the rural economy; and humanitarian organizations are adding connectivity as an input in their intervention plans.

Masae Analytics

<https://www.masae-analytics.com/>

Context: Telecom operators need to identify areas where it makes economic sense to install new base stations in order to expand their reach. As they expand into rural areas with lower population densities, locations have to be chosen surgically, in order to maximize the size of the newly covered population and return on investment.

Methodology: Masae Analytics developed an algorithm combining both granular population density open data and coverage information to detect the most promising zones ("white spots") where new base stations should be installed (see Figure A1.2). The algorithm simulates, for all points in the country, how many additional people would be covered by a hypothetical new base station, thanks to convolution techniques. It then selects zones where this number is the highest and ranks them for prioritization.

Deliverables:

Interactive online secured platform displaying all relevant layers and functionalities:

- operator's coverage map (2G/3G/4G);
- estimated competitors' coverage map (if available in open data);
- granular population layer (typically high-resolution settlement layer by CIESIN and Facebook or WorldPop data);
- white spots identified by Masae Analytics, along with number of newly covered people and sociodemographic information depending on available data;
- filtering tools;
- Excel files export functionality, for instance to focus on the white spots detected in specific regions and rank them by descending potential.

Impact: MNOs with which Masae Analytics has worked have managed to increase their return on investment and deployment-related capital expenditure.

Figure A1.2. Masae Analytics algorithm with granular population density open data and coverage information to detect the most promising zones (“white spots”) for the installation of new base stations



A second example from Masae Analytics includes cases whereby Masae is increasingly working with investors, off-grid start-ups and utilities around the access to energy/access to connectivity nexus.

Methodology: By intersecting coverage maps, electrical grid data, population layers and socio-demographic data in a given country (see Figure A1.3), Masae Analytics algorithms can detect and cluster different areas of interest depending on the aims each tech player wants to achieve. The pay-as-you-go solar industry, for instance, needs to target populated off-grid zones with decent connectivity that allows mobile money payments to go through MNOs and thus prioritize uncovered areas with grid access to deploy new base stations. Mini-grid players will focus on areas with no grid connection, the presence of a base station (which could serve as a potential anchor tenant) and a significant, densely concentrated population.

Deliverables:

Interactive online secured platform displaying all relevant layers and functionalities:

- estimated coverage maps and base station locations (if available in open data);
- available grid maps, or estimated grid thanks to nightlights satellite imagery (e.g. VIIRS DNB Nighttime Lights and Facebook research’s Pathfinder open-source algorithm to model grid access footprint);
- granular population layer (typically high-resolution settlement layer by CIESIN and Facebook or WorldPop data);
- zones of interest identified by Masae Analytics along with relevant information on them (additional served population, distance to grid, distance to coverage, etc.);
- filtering tools, Excel files.

Impact: Energy providers use the Masae Analytics tool to prioritize areas in terms of market attractiveness and to identify priority cities for maintenance/spare parts hubs.

Figure A1.3. Intersecting coverage maps, electrical grid data, population layers and socio-demographic data in a given country to detect and cluster different areas of interest



HIP Consult

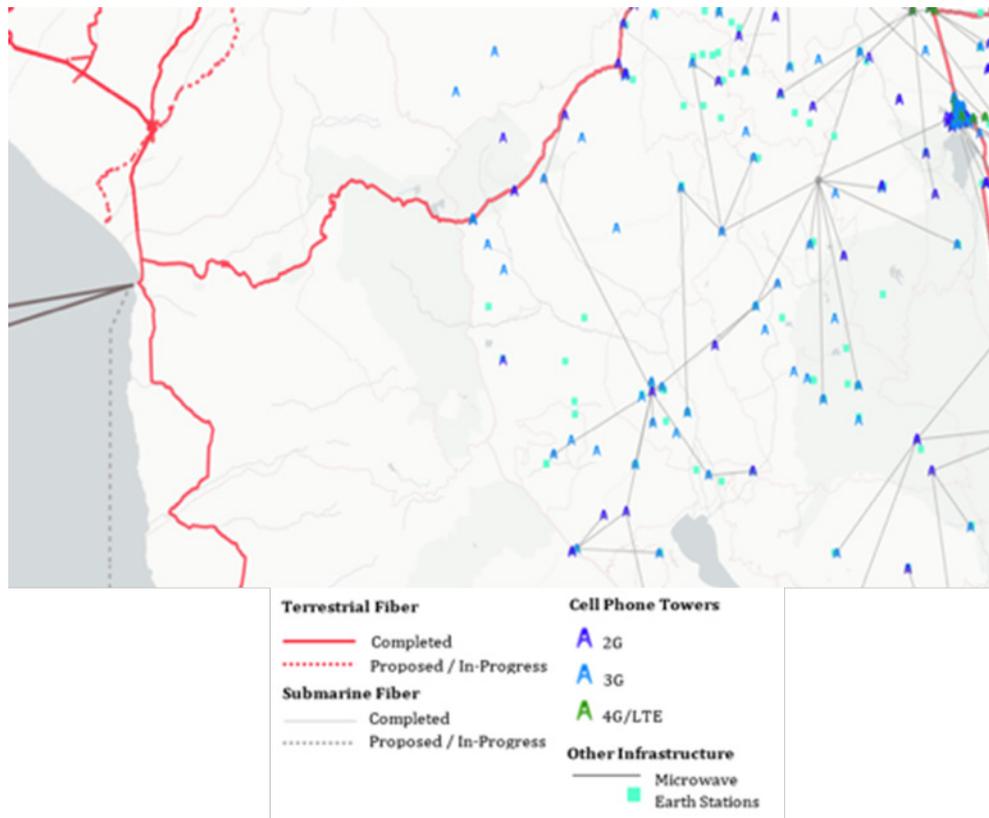
<https://www.hipconsult.com/>

Even as efforts to digitize economies gain attention and pick up pace globally, requisite broadband connectivity remains far from ubiquitous in most developing and many mature markets. Identifying coverage gaps and prioritizing where fibre-optic and other connectivity assets should be deployed begins with having a comprehensive view of where it already exists. It is for this reason that HIP Consult, an advisory firm specializing in emerging market digital infrastructure and services, created InfraNav, a data visualization and analytics platform designed to map, contextualize and optimize network assets (see Figure A1.4).

InfraNav has been developed to deliver and scale the process of infrastructure mapping and analytics. Following several years of research, curation and validation of fibre networks, data centres, Internet exchange points and other ICT assets, InfraNav's GIS database of digital infrastructure spans more than 100 countries in Africa, Asia, Latin America and elsewhere, and the platform's intelligence continues to grow. A key challenge in many markets is that network information is incomplete or not readily available. InfraNav's mapping processes include steps to capture and consolidate data and apply quality-control techniques.

To contextualize infrastructure, InfraNav layers demand considerations such as population density, economic activity, institutional presence and development indicators in areas with existing or contemplated networks. This enables a deep dive into potential bottlenecks and opportunities at a localized level. In addition to broadband networks, InfraNav also includes other supply-side datasets, such as power transmission and other rights of way, to inform possible, often lower-cost options for network expansion.

Figure A1.4. A sample of InfraNav ICT infrastructure data, including fibre-optic routes, cell towers, microwave links, and earth stations



In addition to facilitating transparency and insight into digital infrastructure landscapes, InfraNav also supports network planning and provides metrics for measuring key performance indicators. An example of the former is an algorithm to identify and prioritize quick wins for reaching unserved and underserved populations (see Figure A1.5). An example of the latter is a dashboard to baseline the status quo and track progress over time.

InfraNav’s standardized datasets and proprietary analytics offer digital ecosystem stakeholders such as policy-makers and regulators, investors and service providers the ability to better understand an operating environment, set targets and optimize investment.

Figure A1.5. Fibre network with power grid overlay can identify routes for expansion



Optimizing broadband evolution

More efficient allocation of capital ideally leads to a lower overall cost structure for the sector, and results in the margins of commercial viability being pushed further out to former frontiers. Providers benefit in that resources are freed up that might otherwise have been used for deployments that closely replicate those of their competitors. These resources can be better spent on developing higher-margin value-added services, and national development initiatives gain a lift if broadband coverage and affordability improve. Customers across all segments benefit from more targeted and relevant propositions as the ecosystem becomes more robust.

Increased transparency can also lead to disintermediation of the value chain for a healthier wholesale market. Many markets have seen cycles of acquisition and spin-offs as operators strive to dominate and then realize that it may not be viable to carry a bloated balance sheet with too many network services. Data centres are just one recent example, with global carriers having built their own before seeking partnerships with specialists or investors.

Likewise, aggregated GIS analytics across network operators allow service providers to see where they may be better off leasing capacity from others and to realize the “silicon economics” of increased asset utilization. Operators can then focus their capital expenditure on the gaps that are most relevant to their competitive positioning. Such improved network planning ideally then leads to a range of technologies and value propositions localized for conditions on the ground.

Identifying digital infrastructure gaps and investment opportunities

The International Finance Corporation Digital Infrastructure Initiative, a global undertaking spanning more than 50 countries across Africa, Asia and Latin America, aims to increase access to, and uptake of, broadband Internet and other digital services in underserved markets.

To support this initiative, HIP Consult has employed InfraNav, in conjunction with market, competitive and regulatory analyses, to identify ICT infrastructure gaps and investment opportunities in over 20 countries in Africa and Asia. This approach has proved to be both insightful and efficient in prioritizing potential investment across infrastructure layers and minimizing redundant infrastructure deployment, in both urban and rural areas.

For example, Ethiopia's overall broadband penetration is quite low, with less than one third of the population estimated to be living within 5 km of a fibre network. Given the country's large population (over 100 million) and capacity for digital service adoption, this would suggest a significant need for additional connectivity infrastructure and a potentially attractive opportunity for investment, which could then be considerably de-risked if informed by localized supply and demand factors.

Yet many potential investors, whether private sector, development finance institutions or government agencies, have traditionally struggled to diagnose market gaps in the absence of maps and other tools to assess underlying existing infrastructure. This is one reason why these market diagnostics have produced valuable input for investment planning, providing the ability to consider how the existing infrastructure aligns with potential demand, and where more expansion may be required and warranted. Equally, these insights into past deployments can then be combined with regulatory and competitive environment analyses to begin evaluating other underlying barriers that may need to be addressed to spur uptake and demand.

Geo-analytics for connecting schools and hospitals in Paraguay

HIP Consult leveraged InfraNav to help the Inter-American Development Bank bolster the availability, quality and affordability of broadband Internet access in Paraguay, with a particular focus on rural areas.

By visualizing and contextualizing connectivity and socio-economic data throughout the country, InfraNav identified and prioritized particular geographic zones for potential domestic fibre expansion. In parallel, InfraNav was also used to identify multiple potential cross-border connections and inform the decision as to whether and where to deploy another international link. The project also employed spatial clustering, route planning and optimization algorithms to prioritize infrastructure investment for hospitals, schools and government buildings. Finally, various clustering methods were applied to qualify areas suitable for private sector investment versus those that might require public sector intervention. Within this "intervention zone", high-impact clusters of schools, hospitals and other infrastructure were identified.

Fraym

<https://fraym.io/>

As more companies, governments and multilateral organizations invest in communication infrastructure and unlock value in the market, it is becoming increasingly important to locate demand and optimize resource allocation. Hyper-local geospatial data offer an innovative way to answer these questions and provide guidance on where to upgrade and expand network services.

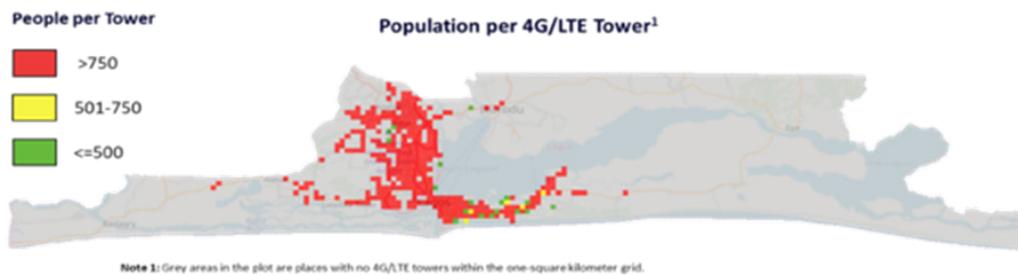
Geospatial solutions can easily reveal areas where connectivity is not available or is of poor quality. In a mobile market report published by Bain & Company, Fraym weaved together satellite imagery and geospatial data to produce a granular view of network coverage and quality in Nigeria's Lagos State. Fraym mapped 4G tower locations and calculated the number of people per tower within a one-square kilometre grid (see Figure A1.6). The hyper-local map shows that 4G network services are of poor quality in most parts of Lagos, suggesting a large service gap for investments and interventions to fill.

Using the granular geospatial information, the private and public sectors are able to identify underserved areas and make informed strategic plans. On the one hand, companies can

target areas where investment meets high demand and shows robust financial returns. On the other hand, governments and multilateral organizations can provide loans, subsidies and other incentives to develop communication networks in less well-off communities, ensuring that people at the bottom of the pyramid benefit from affordable quality connections.

Hyper-local geospatial data offers reliable and actionable insights to private and public players, enabling them to develop appropriate strategies to accommodate needs. As the public and private sectors gain better knowledge of where to invest and intervene, they become better equipped to reduce connectivity gaps and benefit local communities effectively.

Figure A1.6. 4G tower locations and number of people per tower within a one-square kilometre grid



Granular geospatial data support project monitoring and evaluation by showing the impact of investments on access to communication technologies. In collaboration with Harith General Partners, Fraym used geo-tagged household surveys to analyse Internet access and usage before and after the deployment of the Main One Cable, a 7 000-km submarine cable that connects West African countries to the rest of the world. Analysis of geo-tagged data shows significant improvement in Internet access rates and usage of online services across cities with Main One access, thus indicating that the strategic investment brought about an improvement.

VanuMaps™

<https://www.vanu.com/solutions/coverage-mapping/>

VanuMaps is an essential element of Vanu's strategy to cover off-grid markets. VanuMaps uses a combination of data sources to map existing network coverage, assess the business potential of uncovered areas and efficiently plan new networks to cover those areas.

VanuMaps starts with site location data. Such data can be accessed from a variety of different sources, but the best usually come from operators, since they can provide data with respect to antenna height, antenna tilt, azimuth, output power and other elements that may otherwise be difficult to ascertain. The data are then used, along with other datasets and a combination of propagation models, to generate coverage predictions. The predictions take into account topographical information, which is essential for an accurate understanding of coverage.

After the coverage model is generated, VanuMaps analyses uncovered areas and determines the population residing there. The output of this analysis is used to generate a preliminary assessment of the population that can be covered via a network operating in the area, including the preliminary estimate of covered subscribers. The proposed additional network coverage is then fine-tuned to take advantage of topographical features and to assess connectivity between sites for backhaul purposes. Once finalized, VanuMaps uses the proposed site coverage data

to generate revenue predictions based on prevailing ARPU, local and regional factors, market share and other variables.

This approach to assessing coverage allows Vanu to project the economic performance of sites in advance of survey activities. By focusing on the most promising sites, it can improve operator return on investment and reduce the time cost and risk of entering new markets.

Vanu used VanuMaps extensively to plan its deployments with South Africa's MTN. In November 2019, MTN and Vanu announced that Vanu was the winner of the MTN Rural request for proposals. Under the request, MTN plans to deploy as many as 5 000 sites in rural markets. Vanu has worked closely with the MTN teams to identify prospective site locations and maximize the impact of this important MTN initiative.

Vanu also recently used VanuMaps to help a system integrator assess site locations selected by an MNO and suggest new sites that are likely to generate significantly more revenue. This is especially important to the system integrator because it is financing the site construction and its repayment security will be enhanced if the value of the sites is greater.

Finally, Vanu recently worked with an MNO to assess a number of planned sites. After assessing the population distribution and terrain using VanuMaps, it recommended a different network build plan. By changing the site location and construction on a number of sites, the operator was able to cover more people in the same and surrounding areas with less capital and less operating expenditure.

Off-grid markets present many challenges because they tend to offer less revenue potential and higher costs. However, they also represent an opportunity to grow subscriber bases and, potentially, make significant positive contributions to the lives of those who are unable to access digital communications and services. VanuMaps helps MNOs better serve those off-grid markets that are most in need of connectivity.

Annex 2: Reference documents and additional resources

Network infrastructure mapping

Fibre (undersea and terrestrial)

[ITU - Broadband Maps](#)
[Telegeography - Submarine Cable Map](#)
[African Terrestrial Fibre Optic Cable Mapping Project](#)
[The Connected Pacific](#)

Satellite coverage

[SatBeams coverage maps and charts](#)
[LyngSat Maps](#)
[IntelSat Coverage Map](#)
[Iridium Coverage Map](#)
[Inmarsat Coverage Map](#)

Base station locations and coverage

[GSMA - Mobile Coverage Maps](#)
[Open Telecom Data - Tower location \(Various countries\)](#)
[OpenCellID](#)
[OpenSignal](#)

Wi-Fi coverage

[Mozilla Location Service \(MLS\)](#)

Spectrum

[Open Telecom Data - Spectrum allocations \(Africa\)](#)

Sociodemographic, environmental and geographic data

Population density

[JRC's Global Human Settlement Layer population](#)
[WorldPop - University of Southampton](#)
[Landscan - Oak Ridge](#)
[CIESIN's Gridded Population of the World \(GPW\)](#)
[CIESIN / Facebook High Resolution Settlement Layer \(HRSL\) Map](#)

Electrification

[Gridfinder](#)
[World Bank / Facebook Model](#)

Other mapping resources

References/how-to

[World Bank - Broadband Mapping](#)
[Jon Brewer - Using GIS to Deliver Universal Broadband](#)
[UNICEF - Project Connect](#)

Modeling radio frequency propagation

[SPLAT](#)
[CloudRF](#)

Technical references

Networks

[Telecom Network Planning for evolving Network Architectures - Reference Manual](#)
[Wireless Networking in the Developing World](#)

[Building a Wireless Community Network in the Netherlands](#)

[Planning of Wireless Community Networks](#)

[ITU Infrastructure Portal](#)

[How to work with MNOs \(UNHCR\)](#)

[Community Networks through comics](#)

[Ericsson FWA Handbook](#)

[EU Comparison of wired and wireless broadband technologies](#)

Financing

[ICT Infrastructure business planning Solutions Guide 2019](#)

[EU Broadband Investment Guide](#)

Demand-side issues

[NTIA Considerations for Digital Inclusion Efforts](#)

Policy and regulatory recommendations

[ICT Regulation Toolkit](#)

[Alliance for Affordable Internet Good Practices Database](#)

[Community Networks in Latin America](#)

[OECD Telecom Topics Reports](#)

[Dynamic Spectrum Alliance Regulations](#)

Case studies

[LMC Case Studies Database](#)

[School Connectivity Projects Database](#)

[1WorldConnected](#)

[APC Report](#)

[Microsoft Airband Initiative](#)

[UNHCR Collaboration for Connectivity](#)

[EU Broadband Handbook](#)

[Satellite Impact Around the World \(Global Satellite Coalition\)](#)

Other resources

[World Bank Broadband Strategies Solutions Guide](#)

[Digital Interoperable Building Blocks \(Content, Applications and Services\)](#)

[BCG Economics of Bringing Broadband to Rural US](#)

[US NTIA Resources](#)

[US NTIA Webinars](#)

[World Bank Cross-Sector Infrastructure Sharing Solutions Guide](#)

[World Bank Cloud Readiness Assessment Solutions Guide](#)

[The Solar Energy Handbook \(Moving Energy Initiative\)](#)

[NGO Guide to Energy Solutions \(NetHope\)](#)

[UNHCR Connectivity for Refugees](#)

[The Digital Transformation of Education \(Broadband Commission\)](#)

Additional reports referenced and consulted

[Collaborating for Connectivity \(UNHCR, 2020\)](#)

[Digital Access in Africa \(Caribou Digital, 2019\)](#)

[Connecting the Unconnected - Tackling the Challenge of Cost-Effective Broadband Internet in Rural Areas \(Fraunhofer FIT, 2019\)](#)

[Closing the Coverage Gap: How Innovation Can Drive Rural Connectivity \(GSMA, 2019\)](#)

[Becoming Broadband Ready - A Toolkit for Communities \(Next Century Cities, 2019\)](#)

The Mobile Economy 2019 (GSMA, 2019)

Bottom-up Connectivity Strategies (APC, 2019) Digital Dividend: Insights for Spectrum Decisions (ITU, 2018)

State of Mobile Internet Connectivity 2018 (GSMA, 2018)

Innovative Business Models for Expanding Fibre-Optic Networks and Closing the Access Gaps (World Bank, 2018)

Rural Connectivity Innovation Case Study: Using light sites to drive rural coverage - Huawei RuralStar and MTN Ghana (GSMA, 2018)

Community Networks in Latin America: Challenges, Regulations, and Solutions (Internet Society, 2018)

Global Information Society Watch 2018: Community Networks (APC and IDRC, 2018)

Rural Connectivity Innovation Case Study: Cellcard Cambodia (GSMA, 2018)

Powering Last-Mile Connectivity (Facebook / Bloomberg New Energy Finance, 2018)

Spectrum management principles, challenges and issues related to dynamic access to frequency bands by means of radio systems employing cognitive capabilities (ITU, 2017)

Evolving spectrum management tools to support development needs (ITU, 2017)

A Wireless Network Infrastructure Architecture for Rural Communities (Osahon & Emmanuel, 2017)

Closing the Access Gap: Innovation to Accelerate Universal Internet Adoption (USAID, 2017)

Last Mile Connectivity in Emerging Markets (Developing Telecoms, 2016)

Unlocking Rural Coverage (GSMA, 2016)

Business Models for the Last Billion: Market Approaches to Increasing Internet Connectivity (USAID, 2016)

Harnessing the Internet of Things for Global Development (ITU & Cisco, 2015)

Rural Coverage: Strategies for Sustainability (GSMA, 2015)

Benefits and Costs of the Infrastructure Targets for the Post-2015 Development Agenda Post-2015 Consensus (Copenhagen Consensus Center, 2014)

Computing for Rural Empowerment: Enabled by Last-Mile Telecommunications (Various, 2013)

Rural Telecommunications Infrastructure Selection Using the Analytic Network Process (Various, 2010)

Connectivity in Emerging Regions: The Need for Improved Technology and Business Models (CMU, 2007)

Improving affordability of telecommunications: cross-fertilization between the developed and the developing world (Claire Milne, 2006)

Community-Based Networks and Innovative Technologies: New Models to Serve and Empower the Poor (UNDP, 2005)

Annex 3: Applying the Solutions Guide to concurrent multiple-site deployments (network design)

While the Solutions Guide is primarily focused on designing connectivity deployment to an individual site, the steps presented in the Solutions Guide (see Figure A3.1), coupled with the reference information and the decision matrix, can be utilized to design a multi-site network deployment.

Figure A3.1. The four steps presented in the Last-mile Internet Connectivity Solutions Guide



Step 1 - Step 1 remains the same.

Steps 2 and 3 - As multiple sites will need to be connected, it may be that no one connectivity solution will be able to connect all sites, in which case a hybrid solution may be required to match the varying constraints with potential solutions. This hybrid solution will require exploration of various important factors besides location, including the number of sites to be connected, the usage requirements (and bandwidth needs) of each site, topology and environmental conditions, differences in the sites' socio-economic characteristics, and how that may affect affordability and sustainability. The network design will have to take into account the shortest possible path to connect the different nodes.

Step 4 - In this case, the set of implementation options remains the same but will need to account for multiple deployments across potentially different types of technology.

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