The Last-Mile Internet Connectivity Solutions Guide: Sustainable Connectivity Options for Unconnected Sites

Disclaimers

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All errors, omissions and inconsistencies are the authors' alone.

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 46.4 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".

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.

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.

Introduction: Navigating the Solutions Guide

The Toolkit is divided into four main steps, preceded by the Introduction, and followed by additional material in the Annex.

Step 1: Identify digitally unconnected (and underserved) geographies

→ **Step 2:** Review options from existing solutions

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

→ **Step 4:** Implement interventions to extend sustainable connectivity service

Each Step includes Sub-Steps, for example:

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

For ease of navigation, the bottom of each page includes a look back to the overall Table of Contents. The relevant current section of the report is highlighted in orange.

Introduction: Definitions – Describing a Telecommunications Network

There are multiple ways to describe the different elements of a telecommunications network and different sources sometimes utilise different labels. For the purposes of this Solutions Guide, the follow terms are utilised:

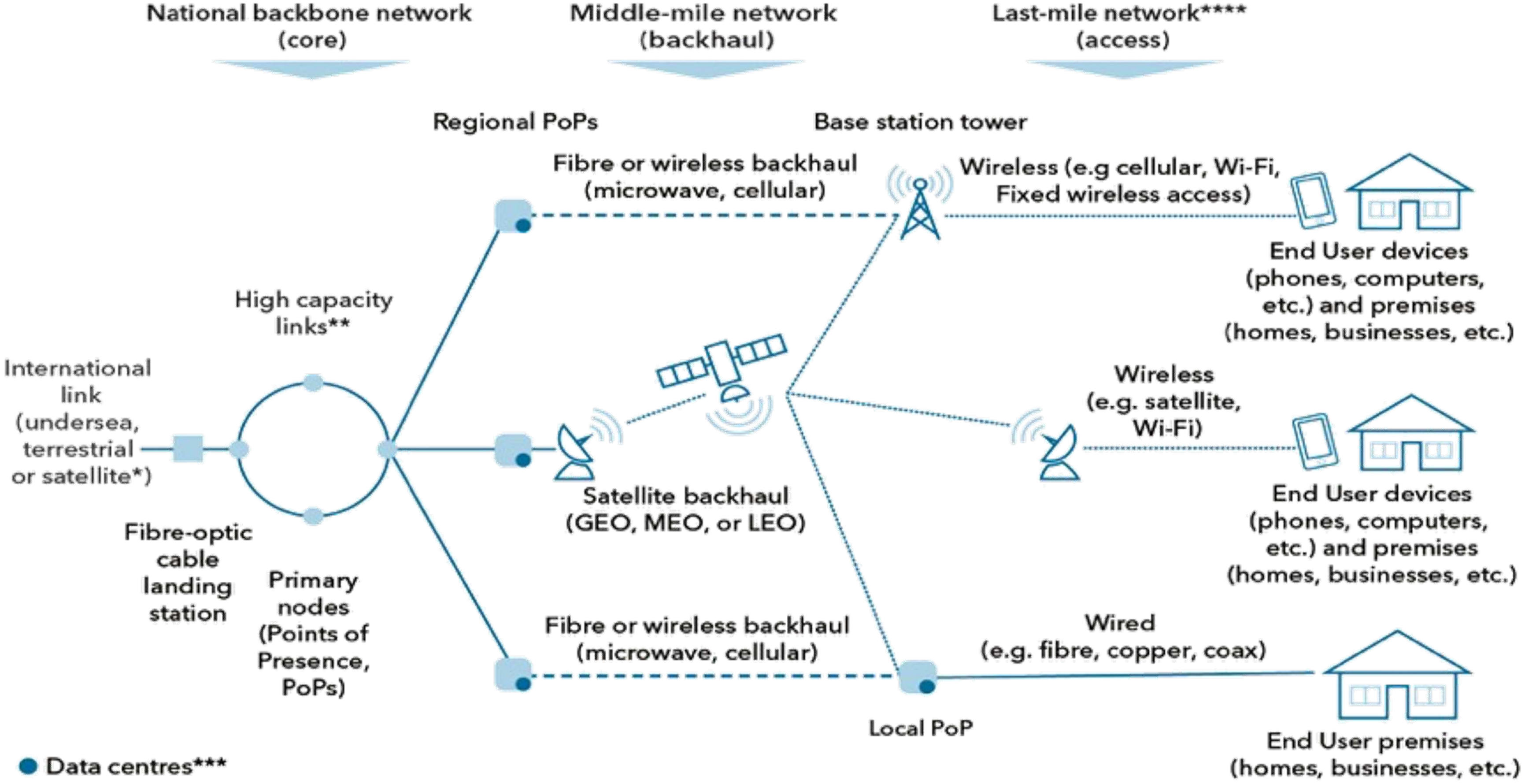
National backbone (or core) network: This connects international Internet traffic (usually through undersea or terrestrial fibre-optic cables) via submarine cable landing stations (or terrestrial gateways for land borders) to the national high-speed, high-capacity backbone network connecting the country's 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.

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.

Introduction: Definitions – Describing a Telecommunications Network

Figure 2: Telecommunications 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 fiber optic links (terrestrial and undersea) but in few country cases, national backbone networks utilize wireless microwave and satellite; *** Data centers 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.

Introduction: Definitions – Describing a Telecommunications Network

Table 1: Telecommunications 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, others); wired (fibre, copper, coax, others)

Introduction: Background, Motivation and Objectives

The global focus on universal connectivity is driven in part by the fact that, despite the meteoric growth of Internet use and broadband connectivity, 49 per cent of the world's population, or 3.7 billion people, were still offline and excluded from the benefits of the global digital economy at the end 2019. Offline populations are particularly concentrated in least developed countries, where only 19 per cent of individuals were online in 2019. Regionally, less than half the populations of Africa and Asia-Pacific are online (29 and 45 per cent, respectively)

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

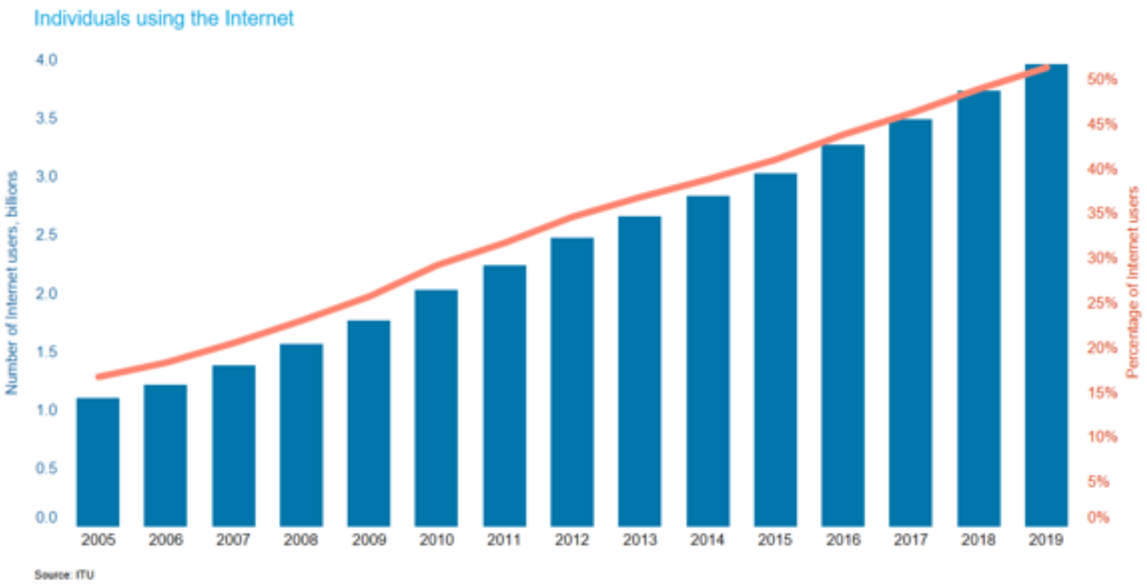
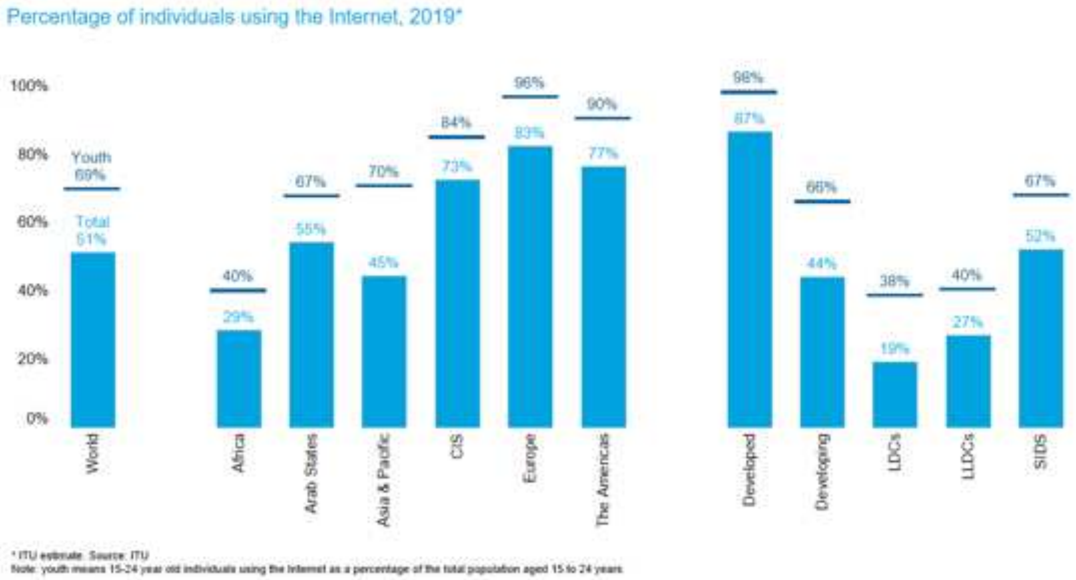


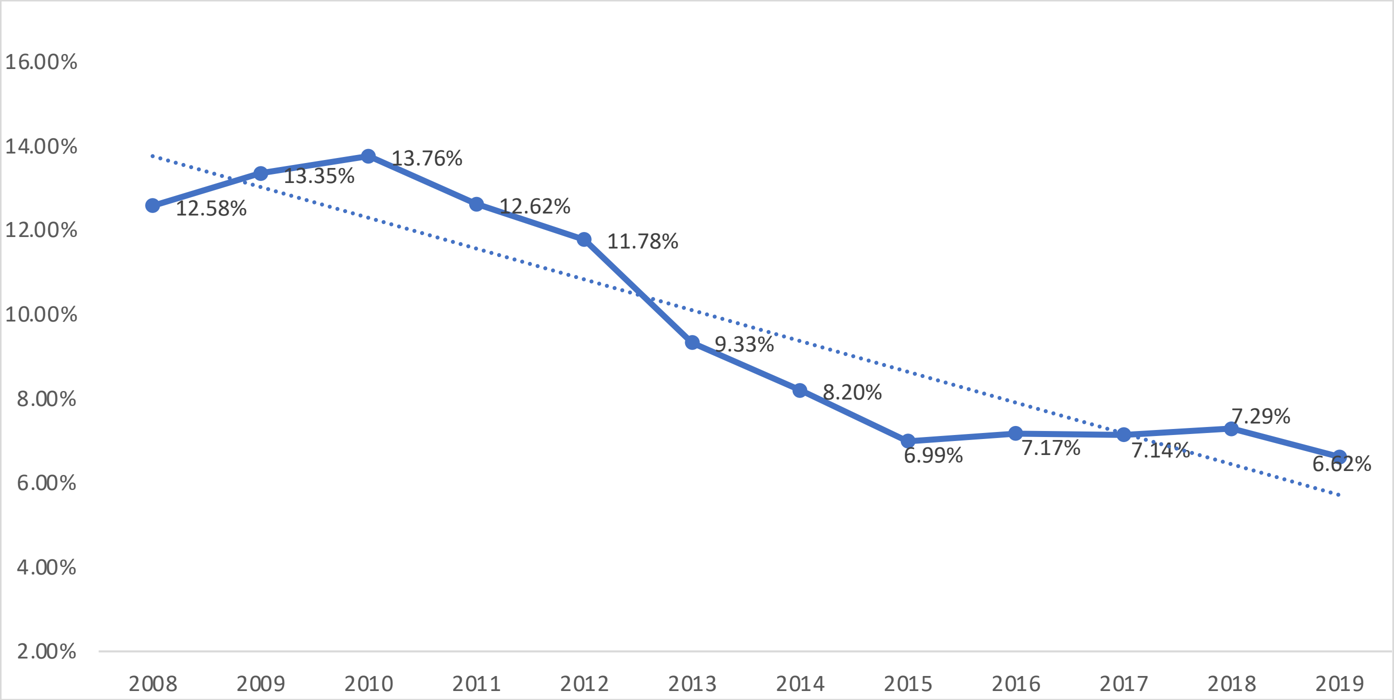
Figure 4: Percentage of individuals using the Internet, by region and development status, 2019



Source: https://itu.foleon.com/itu/measuring-digital-development/internet-use/

Introduction: Background, Motivation and Objectives

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

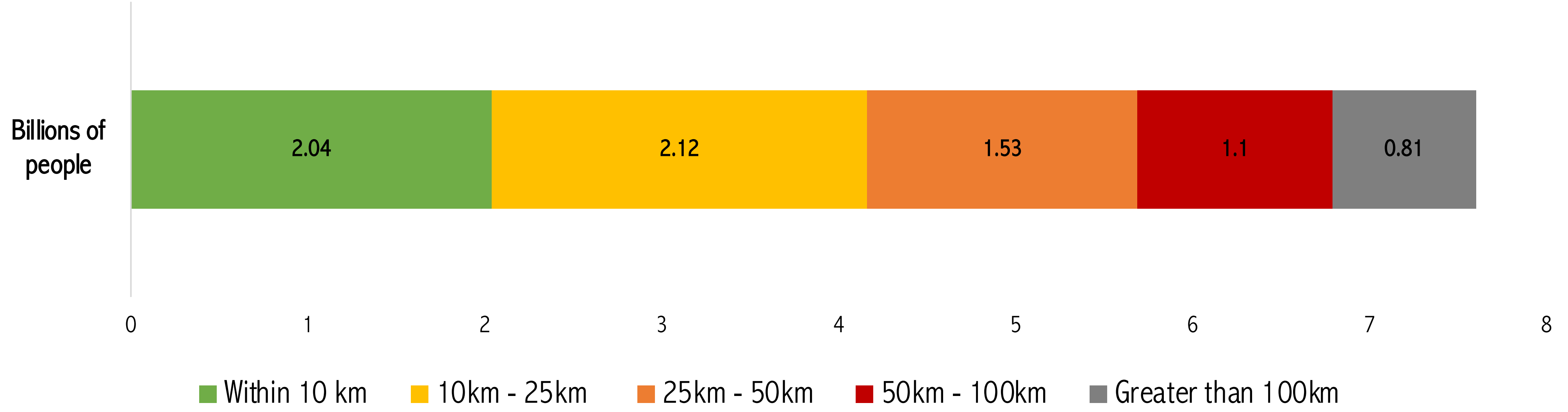


Source: Calculations based on "end-2020 estimates for key ICT indicators" from ITU data in *ICT Facts and Figures 2020*

Introduction: Background, Motivation and Objectives

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. 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.

Figure 6: Population within reach of fiber, March 2019



Note: Not cumulative; figure depicts population within category not inclusive of lower thresholds
Source: International Telecommunication Union (ITU)

Introduction: Background, Motivation and Objectives

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 level whereby entry-level broadband services in developing countries should cost less than 2% of monthly Gross National Income (GNI) per capita. See figure below. The 2% 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% of GNI** and a more granular and targeted focus on lower income groups may be necessary. That is why this Solutions Guide focuses on interventions that provide affordable service.

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

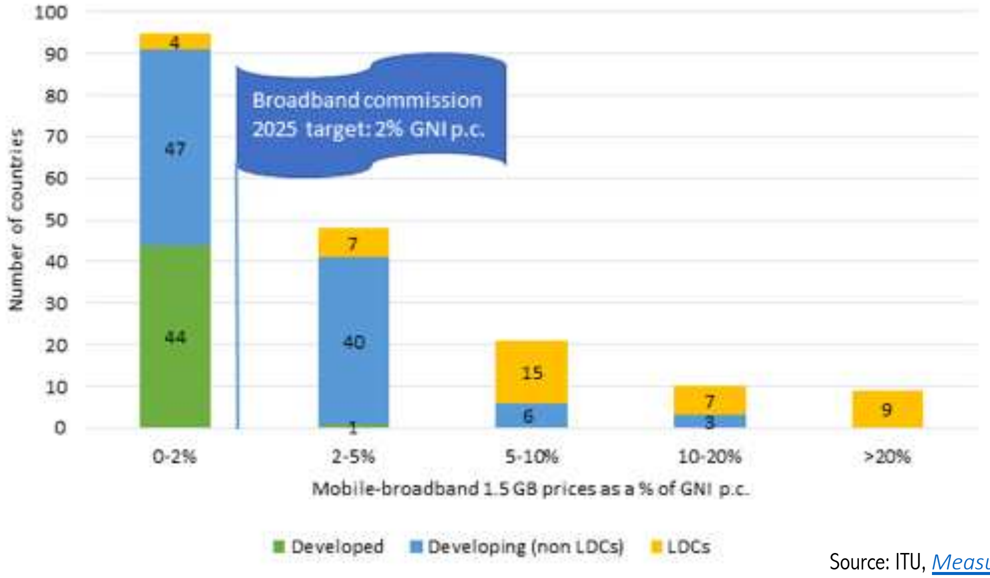
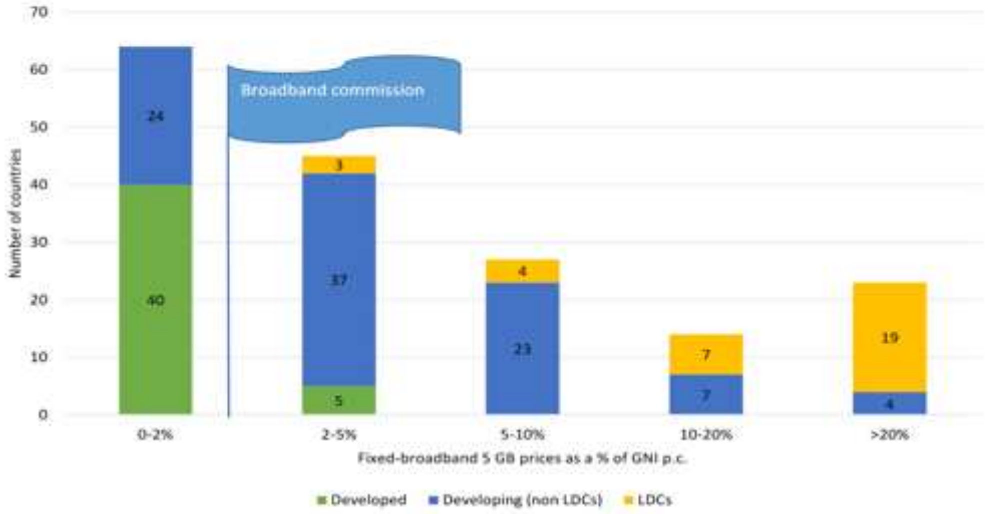


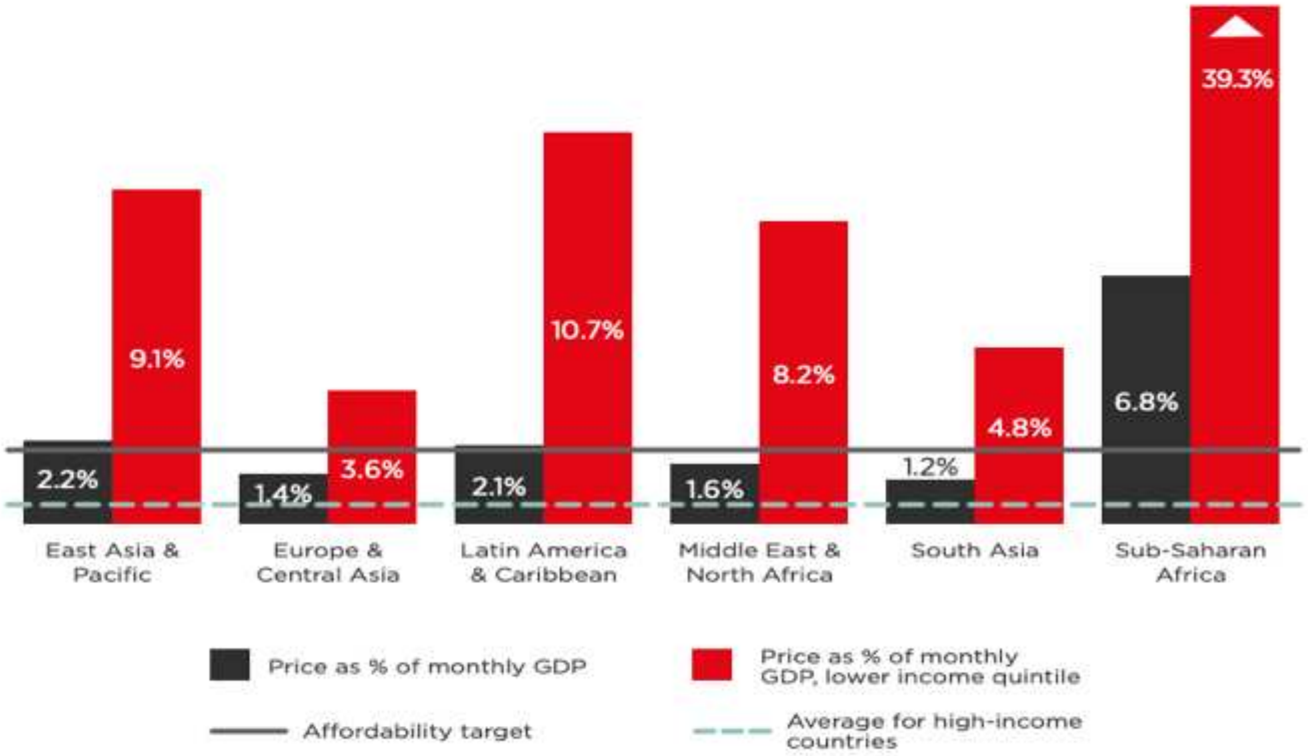
Figure 8. Number of countries having achieved the Broadband Commission targets for computer-based fixed-broadband services (5 GB per month), 2020



Source: ITU, *Measuring Digital Development: ICT Price Trends 2019*

Introduction: Background, Motivation and Objectives

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 Tarifica. 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

Introduction: Steps in the 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 – Adopt 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)

Step 1: Identify Digitally Unconnected Communities

Step 1:
Identify digitally unconnected (and underserved) geographies

Step 2:
Review options from existing solutions

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

Step 4:
Implement interventions to extend sustainable connectivity service

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

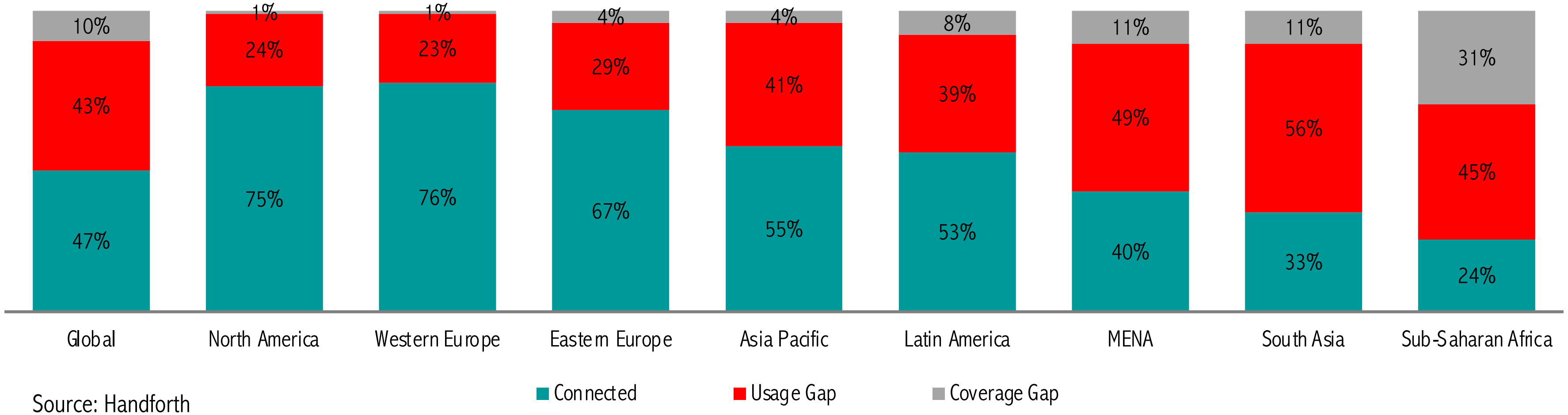
Step 1a: Understand background challenges in mapping

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, the ITU estimates that just over 2 billion people reside within at least 10 kilometers of high speed fiber optic cables. However, in terms of cellular connectivity, GSMA estimates that 90 percent of the world's population live within the coverage areas of mobile data network operators. See the figure below. 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.

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.

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



Source: Handforth

'Coverage Gap' refers to those who do not live within the footprint of a mobile broadband network

'Usage Gap' refers to those who live within the footprint of a mobile broadband network but are not using mobile internet.

'Connected' refers to those who have used internet services on a mobile device (consuming mobile data).

Step 1b: Select a Top-Down and/or Bottoms-Up mapping approach

There are two main approaches to begin geographically mapping 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. The figure 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: Differentiating between two different 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 a multipronged 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 collected via census
- Includes relevant geographic and environmental conditions

Step 1b: Select a Top-Down and/or Bottom-Up mapping approach

In addition to the two main approaches, there are at least four different types of connectivity maps covering different elements and aspects of connectivity service. Those are Demand Mapping, Infrastructure Mapping, Investment Mapping and Service Mapping and their components are highlighted in the table below.

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

Demand mapping	Infrastructure mapping	Investment mapping	Service mapping
• Demand for bandwidth • Quality of service • Willingness to pay • Required services	• Telecommunication structure • Other relevant infrastructure (utilities) • Construction works (roads, buildings)	• Segmenting infrastructure by investment sources • Private / funded • Planned / realized	• Bandwidth & Access Technology (level of service availability) • Provider • Data volume usage, take-up • Price

A standard process of map developing can incorporate three stages: 1) Data Collection; 2) Data Processing; and 3) 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 for appropriate audiences at relevant levels.

Table 3: Common process for all types of broadband mapping

Data collection	Data processing	Data publication
Choice of - Data sources; - Information to be collected; - Spatial level of data collection; - Data supply process/frequency	- Quality checks (additional manual checks/ user feedback); - Data conversion; - Additional data spatial integration	Choice of - Data access level; - Spatial level of publication; - Publication format

Source: World Bank, Juan Navas-Sabater

Step 1b: Select a Top-Down and/or Bottom-Up mapping approach

Once a review of the two overall 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. The table below summarizes the pros and cons of both approaches.

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

	Top-down approach	Bottom-up approach
Pros	• 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.)	• 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	• 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)	• 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

Step 1b: Top-Down Infrastructure Mapping Examples

Table 5: Top-down infrastructure mapping: examples

Map name	Geographic coverage	Network type	Publicly available or commercial service	Data downloadable to 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/

Step 1b: Top-Down Infrastructure Mapping Examples - Countries

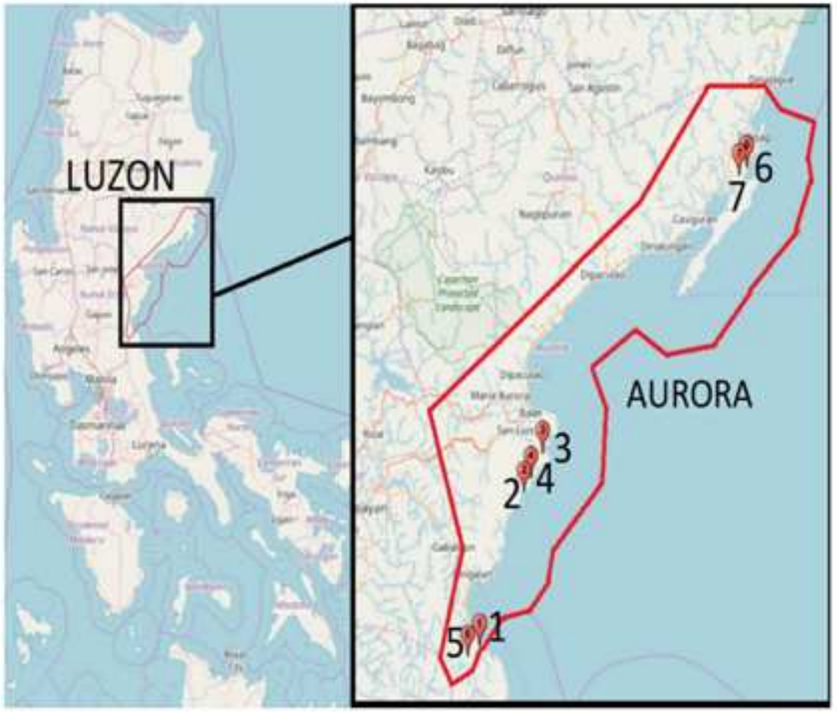
Table 6: Top-down country mapping: examples

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/

Step 1b: Top-Down Infrastructure Mapping Example – PCARI VBTS

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.

Box 2 figure: VBTS deployment sites



- Isolated coastal communities in coves
- Access is mainly by boat
- No concrete road network
- Off-grid power
- No cellular signal but some residents have cellphones
- 80% of land area are protected areas
- Mainly agricultural towns
- Access to social services limited to basic level services

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

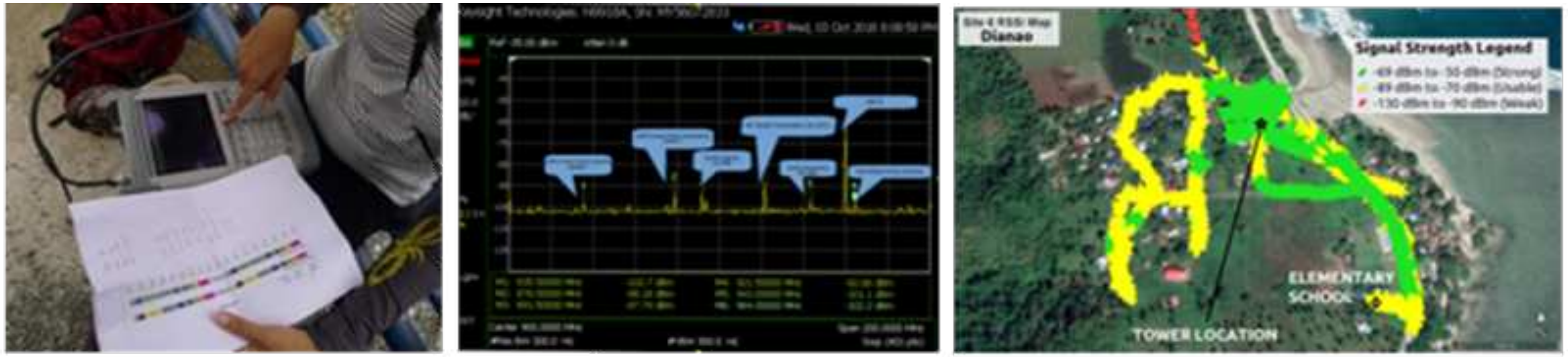
Step 1c: Mapping Key Elements – Other Network Infrastructure

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/)

Step 1c: Mapping Key Elements – Examples

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



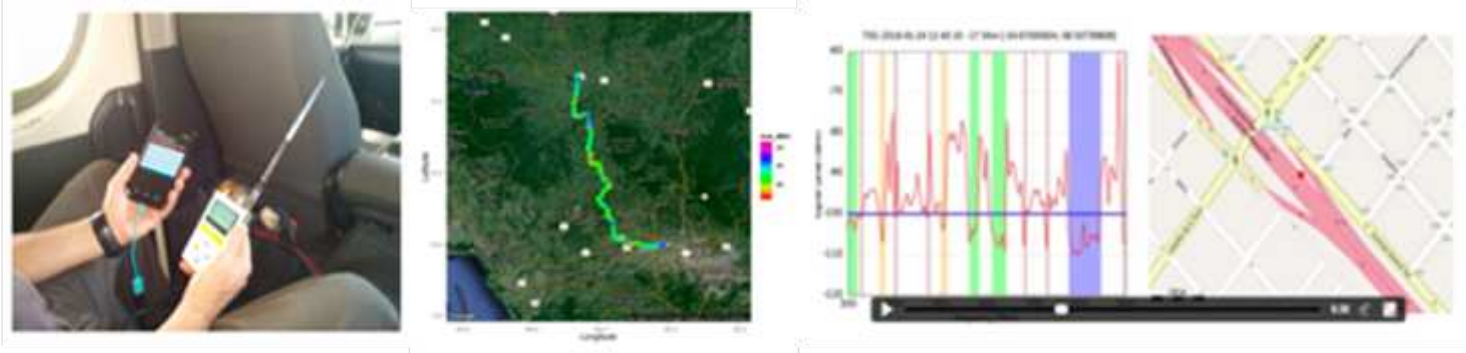
Spectrum Scanning using a portable spectrum analyser.

Sample Spectrum utilisation analysis done post-scan.

Sample RSSI Mapping using Network Monitor Lite.

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

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



RFTrack system portability

Example driving route

Video with spectrum measurements

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

Step 1c: Mapping Key Elements – Examples

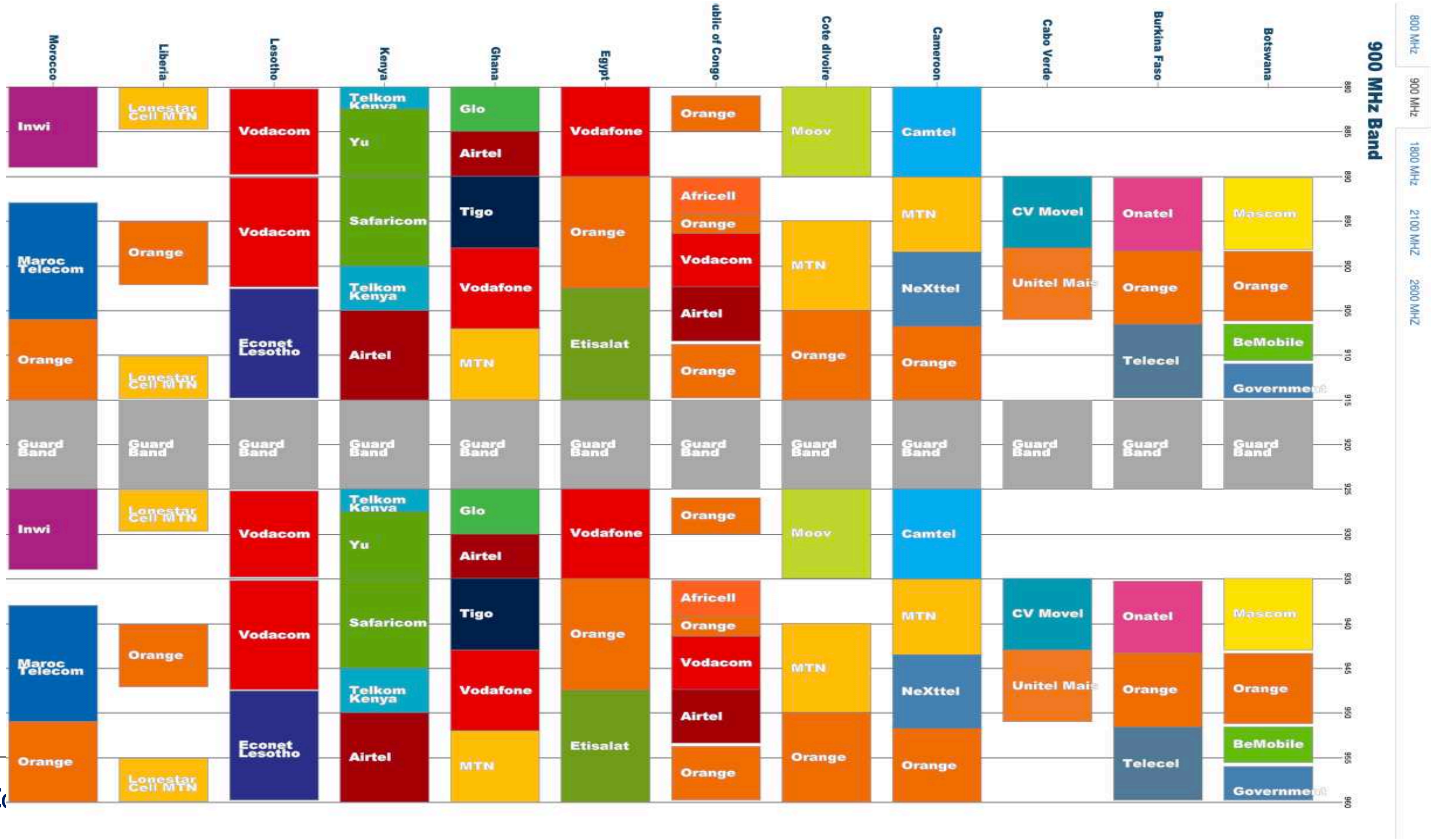
Figure 16: Example of a national frequency allocation table: Moldova

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

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 AMATEUR-SATELLITE 5.216	**144 - 146 MHz** AMATEUR AMATEUR-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

Step 1c: Mapping Key Elements – Examples

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/

Step 1c: Mapping Key Elements – Socio-Demographic Data

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

Step 1c: Mapping Key Elements – Constraints on Technology Options

Other geographic elements and infrastructure assets are useful to incorporate in order to capture a more complete picture of opportunities and constraints.

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 locality's accessibility and 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

Step 2: Review options from the classification of existing solutions

Step 1:
Identify digitally unconnected (and underserved) geographies

Step 2:
Review options from existing solutions

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

Step 4:
Implement interventions to extend sustainable connectivity service

Step 2 activities to review the range and classification of 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

Review Step 2a: The Last-Mile Connectivity Case Studies Database

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 and APC / IDRC GIS Watch 2018. The database is a live document and will be continually updated as more case studies are submitted.

Table 10: Category 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; degree 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

Review Step 2b: Categorization / typology of interventions

The review of 123 different interventions presented in the Last-Mile Connectivity Case Studies Database showed that interventions differed along two axes:

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,

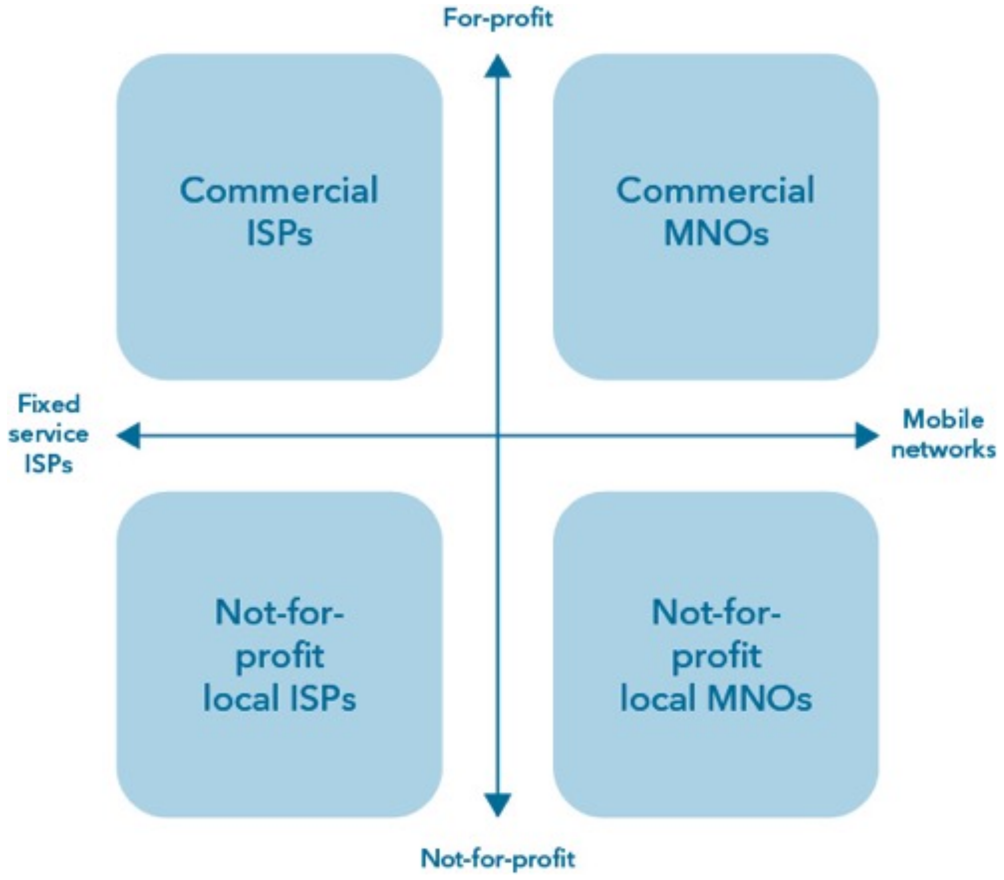
b. General **internet service providers (ISPs)** that utilized a range of different technologies, both fixed and wireless, to provide data-focused services.

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 type of network and profit considerations



Review Step 2b: Categorization / typology of interventions

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). The categorization is shown below.

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

Review Step 2b: Categorization / typology of interventions

Table 12: Characteristics of the different 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; in some cases, Wi-Fi	Fibre; microwave; satellite	Licensed spectrum; radio certifications; franchise; right-of-way and pole attachment agreements; national, regional and local business licences	Ruralstar 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		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; Tecnologías Indígenas 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, Altermundi, 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

Review Step 2c: Characteristics & Trade-offs of Organizational Interventions

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 below, are discussed in further detail in this section (2c).

Those characteristics are:

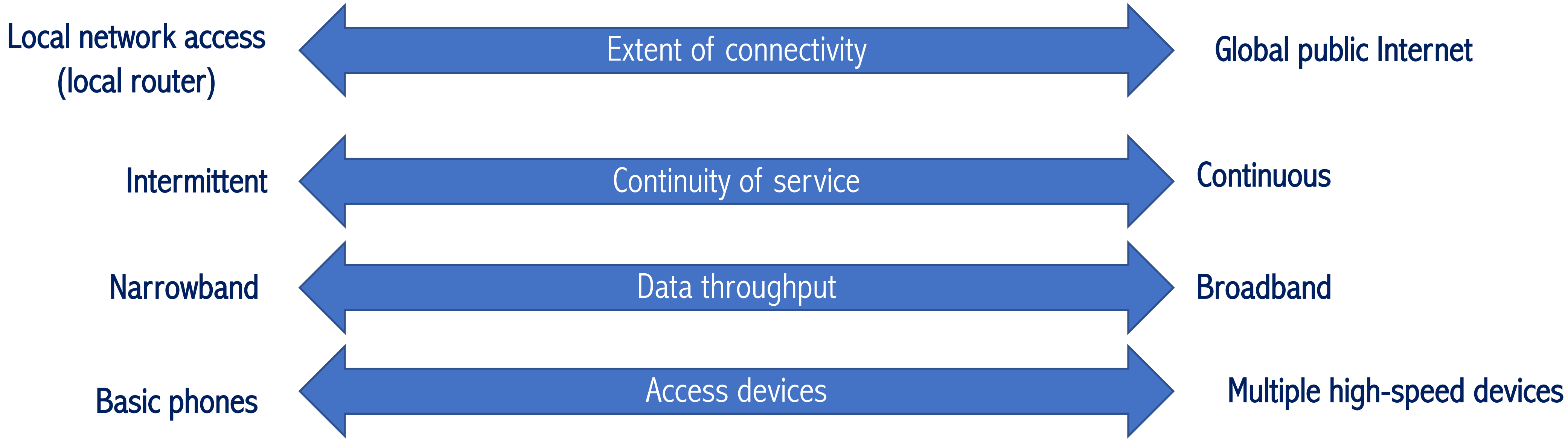
- **Usage:** the intended usage of the connectivity services and the corresponding technical requirements. The intended usage influences the intervention's operational and technical choices, most obviously when it comes to the level of QoS to provide;
- **Business Models:** how the operating entity organizes its operations, constructs its organizational structure, and establishes and maintains its commercial relationships;
- **Revenue Models:** whether the operating entity covers the cost of service provision by collecting revenue and/or by alternate means, including subsidies and in-kind support;
- **Access Network Technologies: t**he 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;
- **Backhaul Technologies:** the choice of backhaul technology or mix of technologies to provide bandwidth capacity can have a big impact on the QoS provided to users;
- **Policy and Regulatory Regimes: d**ifferences in the policy and regulatory environment that act as enablers, or constraints, for different types of business models, revenue models, technology uses and operational entity.

Review Step 2c: Characteristics & Trade-offs of Organizational Interventions

Usage Characteristics

Usage characteristics and constraints differ widely based on a range of constraints. For example potential usage of connectivity can be limited by:

Figure 20: differences in usage characteristics



Review Step 2c: Characteristics & Trade-offs of Organizational Interventions

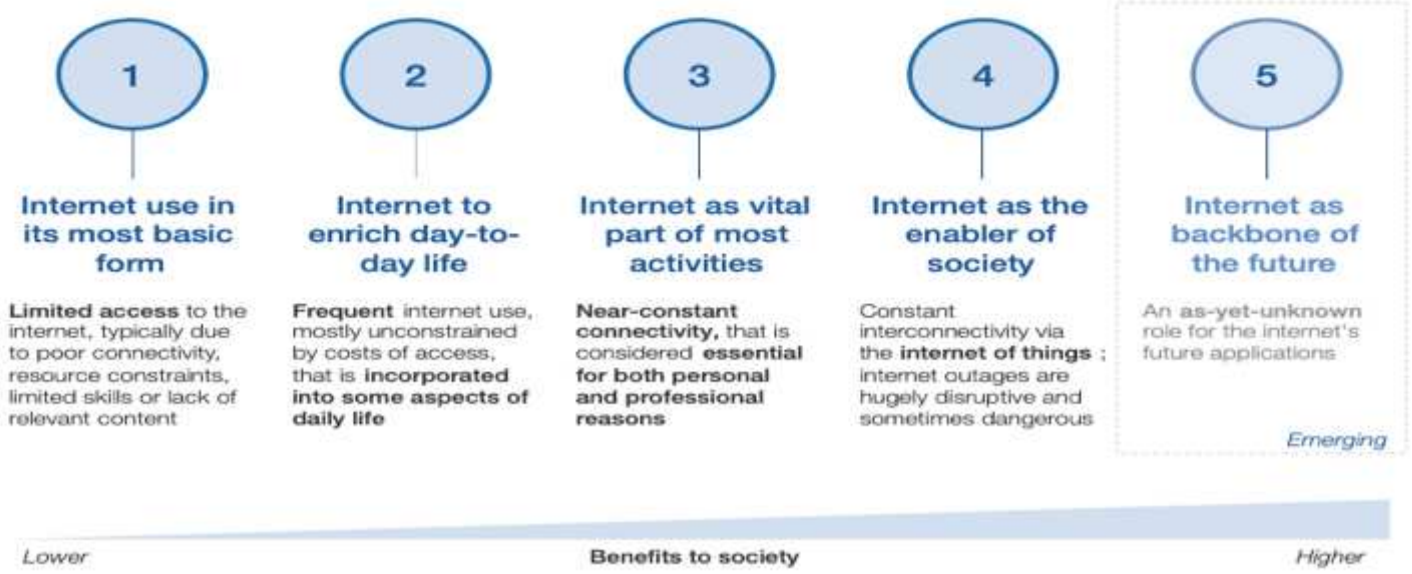
Usage Characteristics (continued)

One notional categorization of usage levels has been presented by the WEF's Internet for All 2018 report on "Financing Forward-Looking Internet for All".

Note:
D/L speed=download speed;
U/L speed=upload speed;
Gbps=gigabits per second;
Kbps=kilobits per second;
Mbps=megabits per second; ms=millisecond;
MB=megabyte;
GB=gigabyte;
TB=terabyte;

Source: WEF, "Financing Forward-Looking Internet for All; The Boston Consulting Group estimates

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



	Level 1	Level 2	Level 3	Level 4	Level 5
D/L speed	512 Kbps	2-3 Mbps	25 Mbps	100 Mbps	1 Gbps
U/L speed	64 Kbps	512 Kbps	10 Mbps	100 Mbps	1 Gbps
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

Review Step 2c: Characteristics & Trade-offs - Usage

Differences in Usage: Education Sector

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

Source: adapted from State Educational Technology Directors Association

Note: 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.

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

Review Step 2c: Characteristics & Trade-offs - Usage

Differences in Usage: Healthcare Sector

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: https://www.healthit.gov/faq/what-recommended-bandwidth-different-types-health-care-providers

Review Step 2c: Characteristics & Trade-offs – Business Models

Business Models

From our LMC Case Studies Database we observed six business models providing some level of service in the local access last-mile network.

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

Business models	Description	Partnerships / business agreements	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	

Review Step 2c: Characteristics & Trade-offs – Revenue Models

Revenue Models

In the access network, we observe four main revenue models, with variations within each one with a particular focus on opex management.

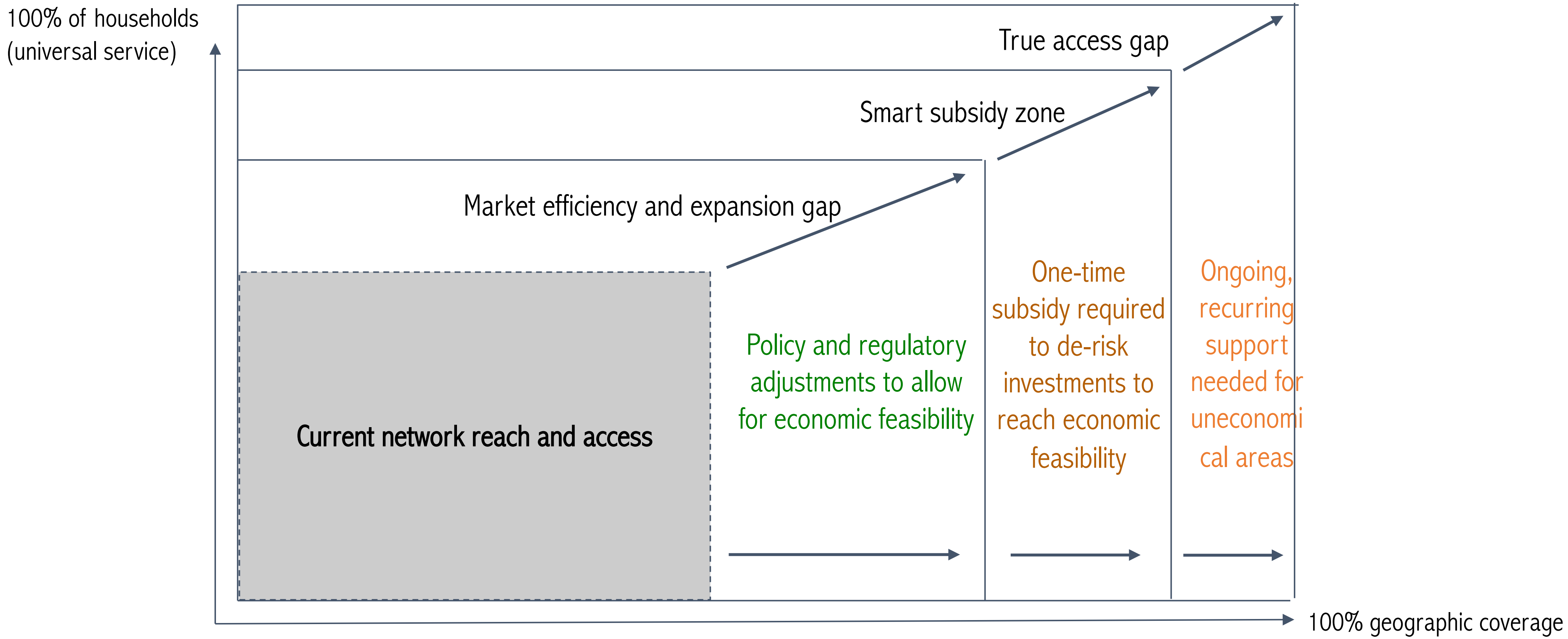
Table 16: Revenue models in last mile retail services

Revenue models	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

Review Step 2c: Characteristics & Trade-offs - Subsidies

Subsidy – The rationale for subsidy (none, one-time or recurring)

Figure 22: Intervention distinctions for the various access gaps



Source: ITU ICT Regulation Toolkit.

Review Step 2c: Characteristics & Trade-offs – Common Access Network Technologies (Wireless)

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

Note with the evolution of 4G and 5G, throughput can reach up to 1 Gbps

Sources: 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

Review Step 2c: Characteristics & Trade-offs – Common Access Network Technologies (Wireless)

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)	
Recognized radio interfaces	Standard	Commercial name	Standard	Commercial name
	1. IMT-2000 CDMA Direct Spread	*W-CDMA UMTS FDD, E-UTRA FDD* (UMTS/HSPA/LTE family; 3GPP) *UTRA*	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 TDD* (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

Review Step 2c: Characteristics & Trade-offs – Common Access Network Technologies (Wireline)

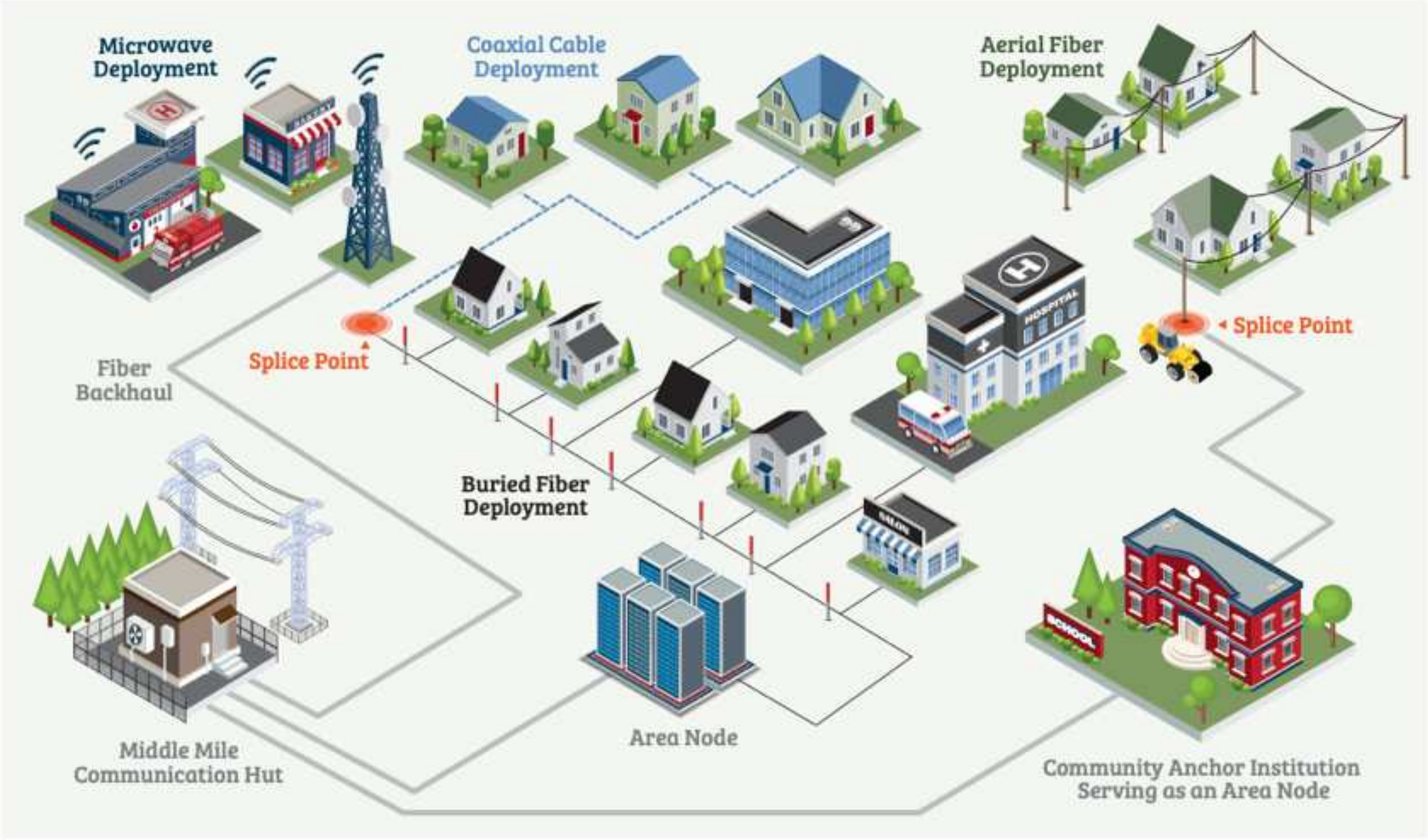
Table 19: Comparison of common wired access network technologies

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

Sources: 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

Review Step 2c: Characteristics & Trade-offs – Depicting Common Access Technologies

Figure 23: Common network deployments



Note: Excludes a number of access technologies such as satellite andDSL

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

Review Step 2c: Characteristics & Trade-offs – 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.

Spectrum Regime: Unlicensed spectrum bands - ISM, 2.4 GHz, 5 Ghz, 6 Ghz (Wi-Fi 6)

Coverage area: 100s of meters for local area access points; 10s of km for Point to Point (PtP) and Point to Multipoint (PtMP) radios

Device costs: Low: Access Points (even Enterprise grade outdoor) < $300; PtP and PtMP < $500

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

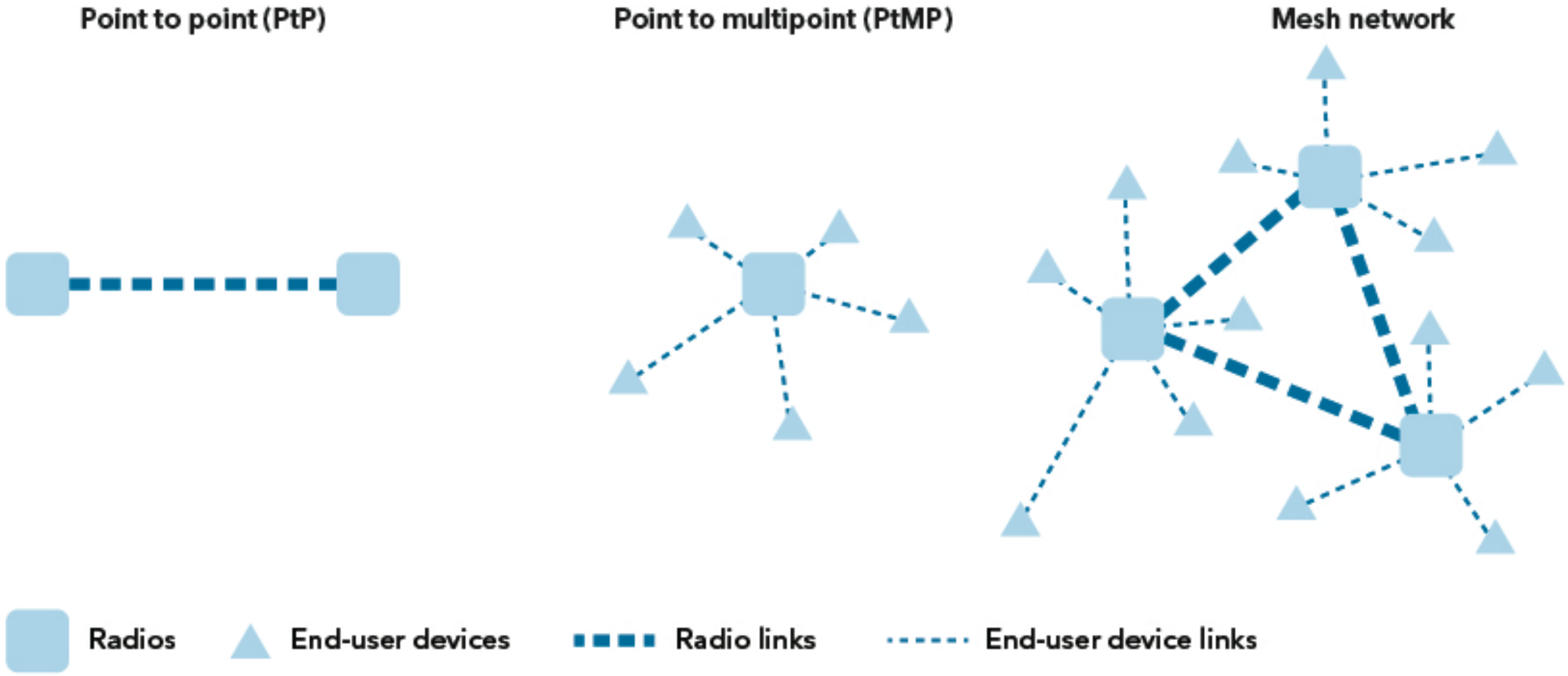
IEEE 802.11 Protocol version	Year deployed	Spectrum frequency band(s), Ghz	Maximum data rate (Mb/s)
802.11ax ("Wi-Fi 6")	2020	2.4 Ghz, 5 Ghz, 6 Ghz	9,600 Mb/s
802.11ac	2014	5 Ghz	6,900 Mb/s
802.11n	2009	2.4 Ghz & 5 Ghz	600 Mb/s
802.11, (a), (b), (g)	1997 – 2003	2.4 Ghz & 5 Ghz	2 Mb/s to 54 Mb/s

Sources: Various

Review Step 2c: Characteristics & Trade-offs – Wi-Fi (cont.)

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. Below are just a few common design for Wi-Fi network deployment that incorporate multiple access points.

Figure 24: Examples of Wi-Fi network topologies



Other network typology definitions, such as from the EU, include:

Tree (all traffic aggregated upwards in hierarchically);

Ring (each node connected to two other nodes)

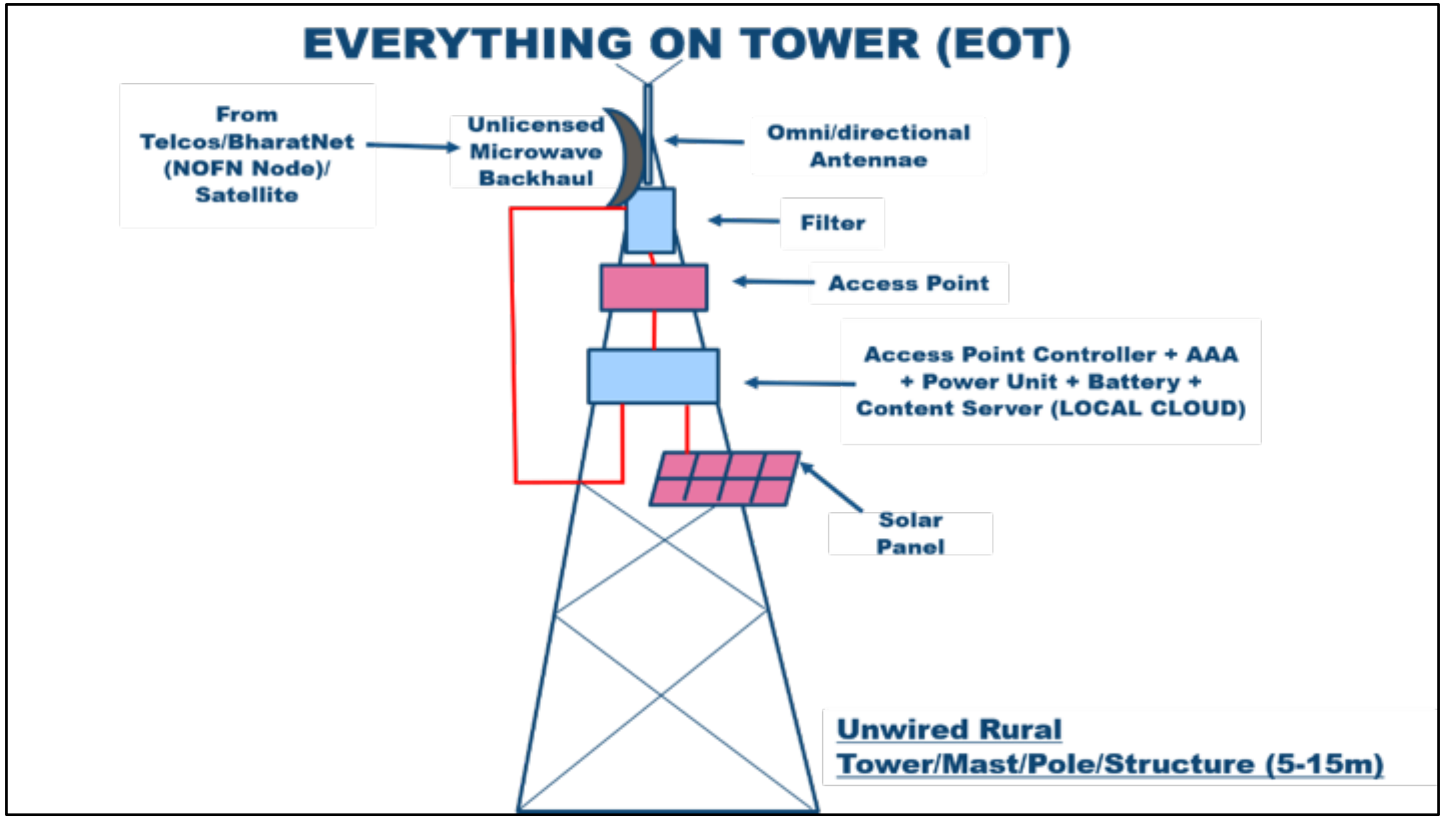
Meshed (each node connected to several nodes for redundancy); and,

Star (each node connects to a central node)

Note: Additional network typologies can be found at https://ec.europa.eu/digital-single-market/en/network-and-topology

Review Step 2c: Characteristics & Trade-offs – Wi-Fi Access Network (India)

Box 3 figure: No number or caption in master document



Source: direct contribution by Satya N. Gupta (Bluetown India)

Review Step 2c: Characteristics & Trade-offs – 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.

Spectrum regime: Various licence bands that are allocated and assigned (through auctions and "beauty contests")
Coverage area: Wide area or metropolitan area; 10s of kilometres
Device costs: Low to medium for access devices; infrastructure equipment varies (cellular base stations from USD 20 000 to USD 100 000)

Table 21: Comparison of various y 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
Note: Rates are based on technical standard maximums

Review Step 2c: Characteristics & Trade-offs – Mobile (cont.)

The coverage areas of different cellular technology deployments are impacted by a wide range of factors, including the spectrum band utilized, 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: 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.

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

Frequency (MHz)	Cell radius (km)	Cell area (km2)	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)

Note: 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.

Review Step 2c: Characteristics & Trade-offs – Mobile Cellular Example

Box 4 figure: Remote Africa Mobile Networks AMN small site deployments

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

Review Step 2c: Characteristics & Trade-offs – 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. 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.

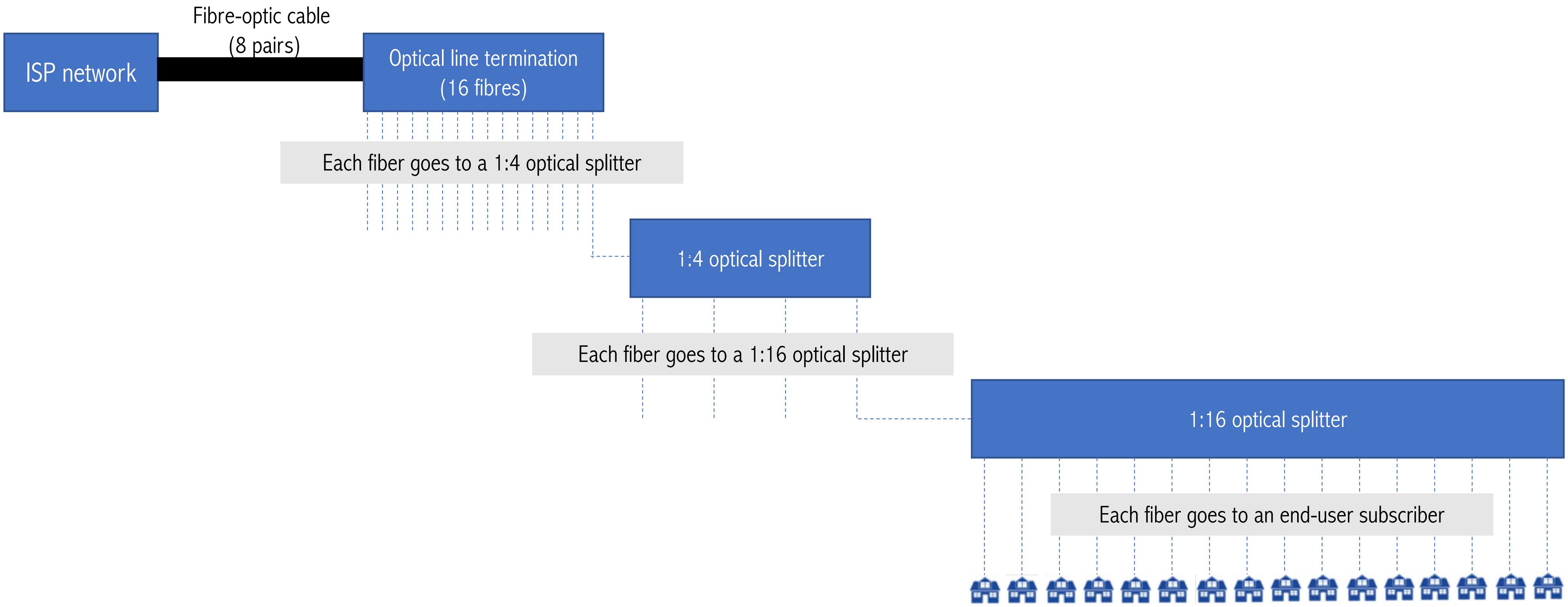
Spectrum Regime: Not Applicable (Wired technology)
Coverage area: Wide area, though requires physical installation
Device costs: High, for the active network equipment and civil works component of deployments

Note however that with Wave Division Multiplexing (WDM), using multiple frequencies of light on a fiber, the capacity of optical fiber can continuously be upgraded with improved technology. Passive Optical Network (PON) technology, particularly the Gigabit PON (GPON), is increasingly being deployed as a way for optical fiber technology can reach the end-user premise (home or office) in a more affordable manner as the active network equipment extends only to a central exchange. See figure on next slide.

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. In estimates for cost structures of fibre deployments, on average around 45% of network operations relate directly to deployment costs (recovery of capital expenditure) reflecting their capital-intensive nature. 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 "policy , easing rights of way , or the One-Touch Make-Ready pole attachment).

Review Step 2c: Characteristics & Trade-offs – Optical Fiber (cont.)

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



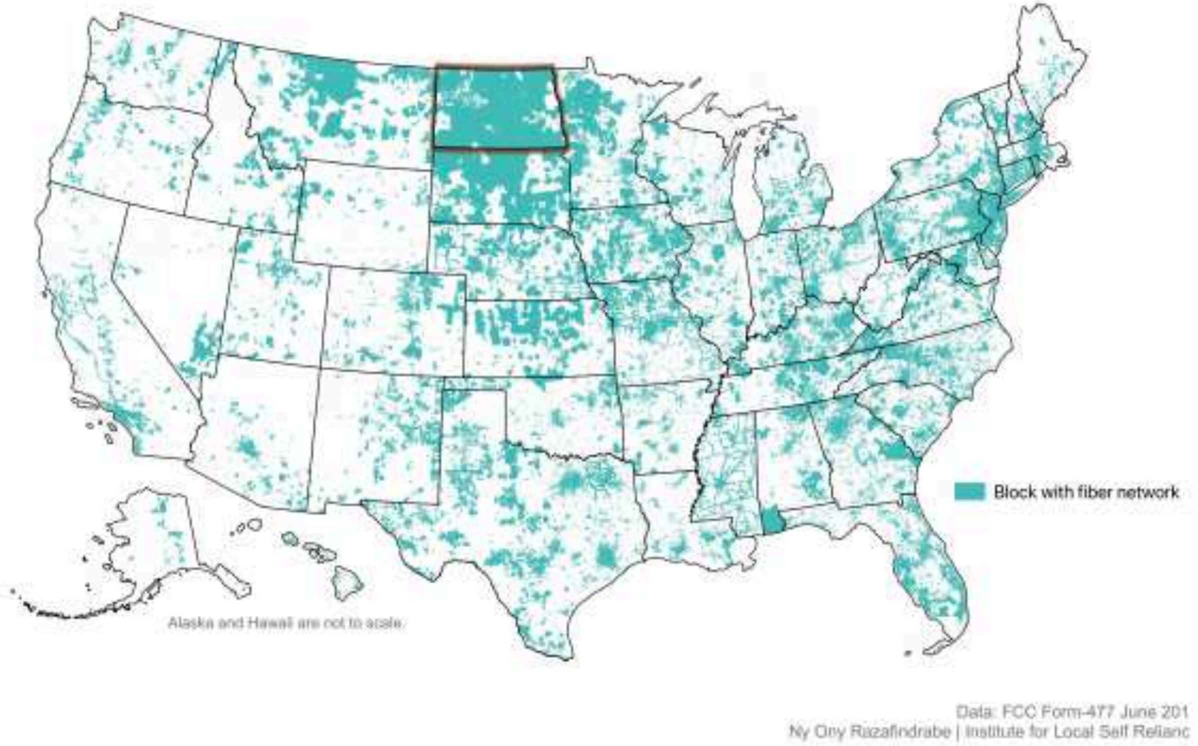
Sources: Adapted from Brewer et al, "From Analog to Digital"

Review Step 2c: Characteristics & Trade-offs – Optical Fiber Examples

Box 5 figure: Example of Guifi.net aerial fiber deployments

Source: presentation by Ramon Roca, 14 November 2019

Box 6 figure: 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)

Review Step 2c: Characteristics & Trade-offs – 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. Satellite connectivity is utilized for a range of different deployment scenarios in support of last-mile connectivity, such as in providing mobile backhaul, community Wi-Fi and in direct broadband satellite-to-the-premises. Satellites are usually grouped into three different categories: Geosynchronous Earth Orbit (GEO), Medium Earth Orbit (MEO) and Low Earth Orbit (LEO) with varying characteristics (see below).

Spectrum Regime: Licensed
Coverage area: Very wide area
Device costs: VSAT terminals for the end user premise are lower cost, whereas bandwidth pricing through satellite can be higher. (Note that new satellite network deployments require significant capex investment which includes the satellite, launch and ground station hub)

Data rates are increasing with next generation GEO satellite (High Throughput Satellites, HTS), new MEO and emerging LEO deployments. The latter, LEO, have a particular advantage of lower latency, though deployments have shown that GEO latency is acceptable for VoIP and video calls and MEO latency is within range for MNO 4G deployments.

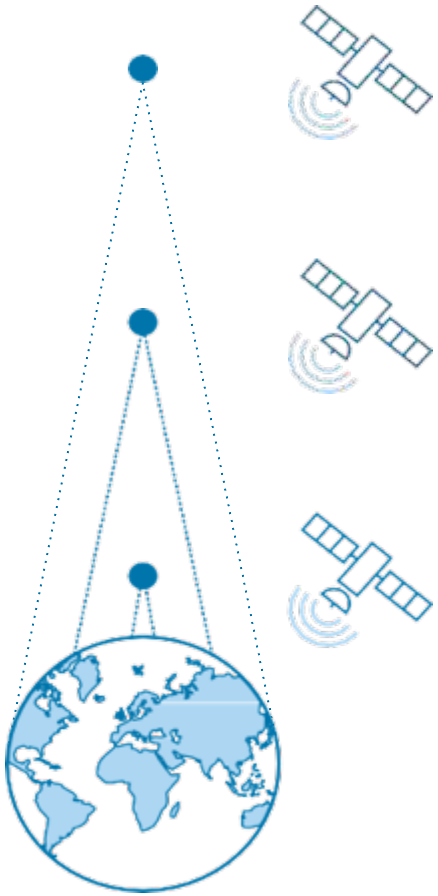
Table 23: GEO, MEO and LEO satellite characteristics

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	~477ms	3*	approx. USD 100 to 400 million	15 to 20 years
MEO	2,000 to 35,786 km**	127 minutes to 24 hours	~27ms to ~477ms	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	~2ms to ~27ms	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.

Review Step 2c: Characteristics & Trade-offs – Satellite (cont.)

Figure 26: Illustrative comparison of GEO, MEO and LEO satellite characteristics including coverage areas



GEO satellites at altitudes of 35,786 km Full orbital period of 24 hours
Latency (round-trip) of approx. 477 ms

MEO satellites at altitudes of 2,000 km to 35,786 km Full orbital period of 127 minutes to 24 hours Latency (round-trip) of approx. 27 ms to 477 ms

LEO satellites at altitudes of 160 km to 2,000 km Full orbital period of 88 to 127 minutes
Latency (round-trip) of approx. 2 ms to 27 ms

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

Review Step 2c: Characteristics & Trade-offs – Satellite (cont.)

Figure 27: Impact of latency on select applications and services

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:

Fibre · Cellular · Public Wi-Fi · Satellite

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
V2V and V2X	Depends on application	Few	Cellular, Public Wi-Fi, Satellite
Mobility connectivity (In-flight/maritime/Cars /train)	Depends on application	Many	Cellular, Satellite
IoT	Depends on application	Very Few	Fibre, Cellular, Public Wi-Fi, Satellite

Source: EMEA Satellite Operators Association

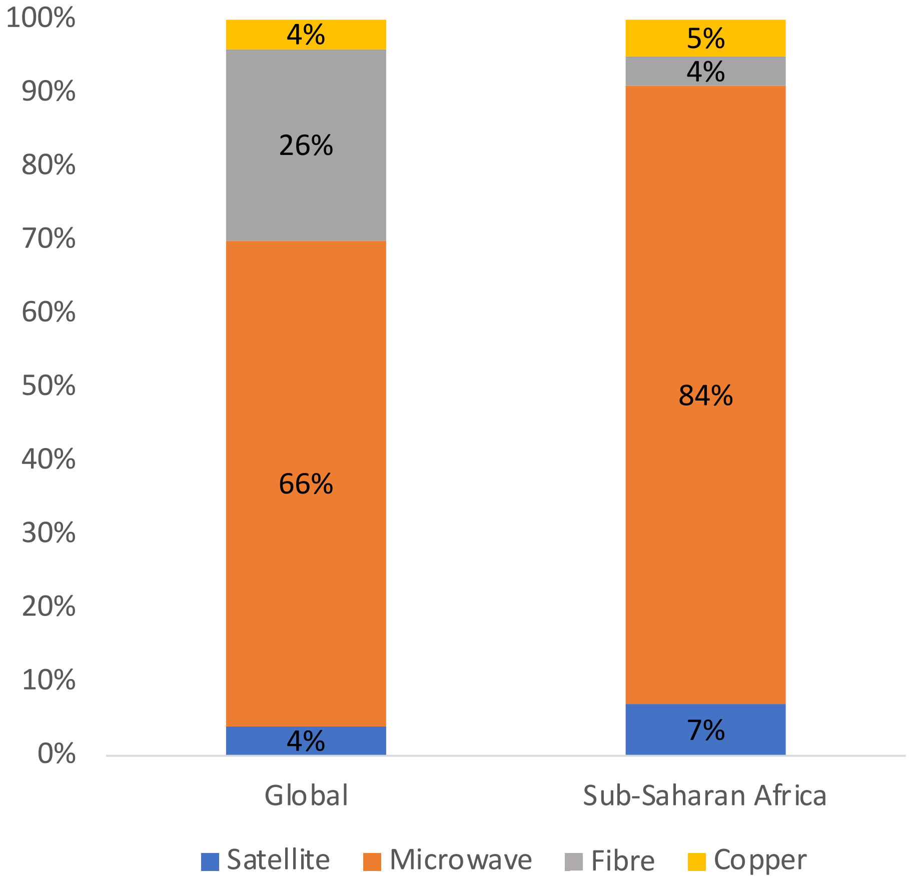
Review Step 2c: Characteristics & Trade-offs – Backhaul Technologies

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 kilometers in a single hop, and multiple hops are utilized in backhaul transmissions.

Note 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.

Figure 29: Backhaul for mobile voice and data by method, global and sub-Saharan Africa (2017)



Source: Handforth

Review Step 2c: Characteristics & Trade-offs – Backhaul (cont.)

Table 24: Comparison of 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)

Review Step 2c: Characteristics & Trade-offs – Emerging Technologies

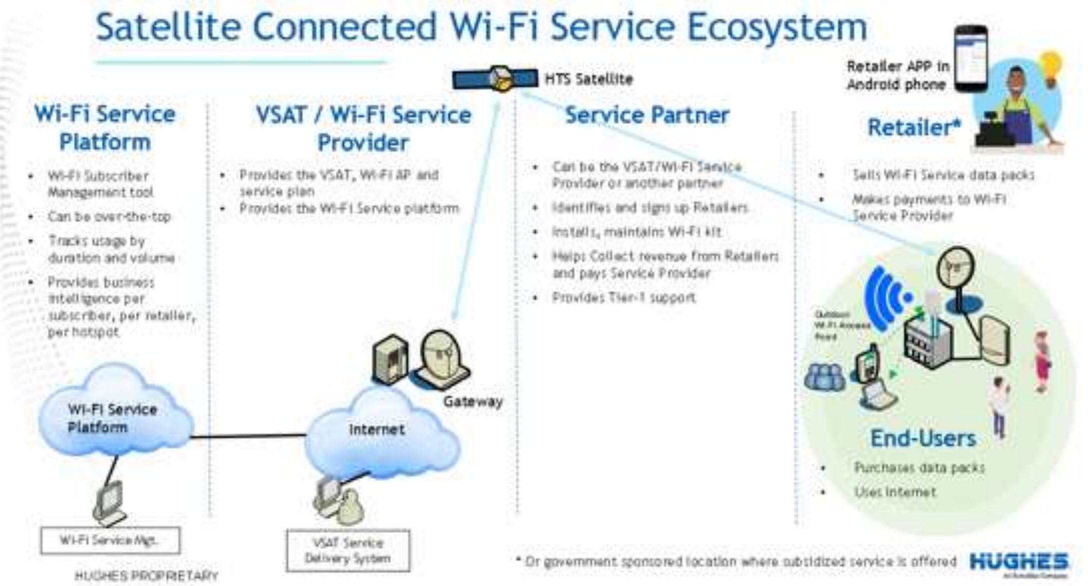
Table 25: Comparison of emerging technologies in connectivity

Technology	Wired or wireless	Potential throughput / QoS	Range	Infrastructure required	Suitability for rural deployments	Spectrum licensing requirement	Backhaul suitability	Access device type
HAPS	Wireless	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
Millimeter wave		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
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

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. Wimax deployments appear to have peaked globally and are on the decline. Whereas TV White Space is still at a nascent stage of ecosystem growth and deployment.

Review Step 2c: Characteristics & Trade-offs – Hybrid Solutions

Box 7 figure: Hughes satellite-connected Wi-Fi service ecosystem



Box 7 table: Hughes express Wi-Fi data packages

Data Packs

Package	Data (In Megabytes)	Price (Pesos)
1 hour	100	$10
1 day	250	$30
3 days	500	$60
1 week	750	$90
Month	1000	$120
Month	2000	$220
Month	4000	$440

Source: https://www.hughes.com/expresswifi/mexico

Review Step 2c: Characteristics & Trade-offs – Policy & Regulatory Regimes

The overall policy and regulatory environment for Internet connectivity in any given country will contribute significantly to either 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.

Policy and regulatory action 1: Identify the country's overall ICT regulator environment by reviewing ITU's generations of ICT regulation (See ITU's *Global ICT Regulatory Outlook 2020*)
The latest data from ITU's Regulatory and Market Environment group can help to determine how a specific country ranks in terms of overall ICT regulatory maturity.

Policy and regulatory action 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 countries 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 database. 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.).

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

Review Step 2c: Characteristics & Trade-offs – Policy & Regulatory Regimes

Table 26: Comparing intervention 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	✓		✓
	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 subsidiaries		✓	
	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	✓	✓	

Review Step 2c: Characteristics & Trade-offs – Policy & Regulatory Regimes (cont.)

Table 26: Comparing intervention 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	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	✓	✓	
	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	✓	✓	
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	✓		✓

Review Step 2c: Characteristics & Trade-offs – Cybersecurity

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 records being breached. Many users in low- and middle-income countries connect to the Internet through their phones; however, GSMA Intelligence 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, 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 businesses 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 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.

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 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 principles 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.

Step 3a: Select Sustainable Solutions by Matching Viability Subject to Constraints

Step 1: Identify digitally unconnected (and underserved) geographies → **Step 2:** Review options from existing solutions → **Step 3:** Select sustainable solutions by matching viability subject to constraints → **Step 4:** Implement interventions to extend sustainable connectivity service

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

3a – Select an affordable last-mile connectivity solution

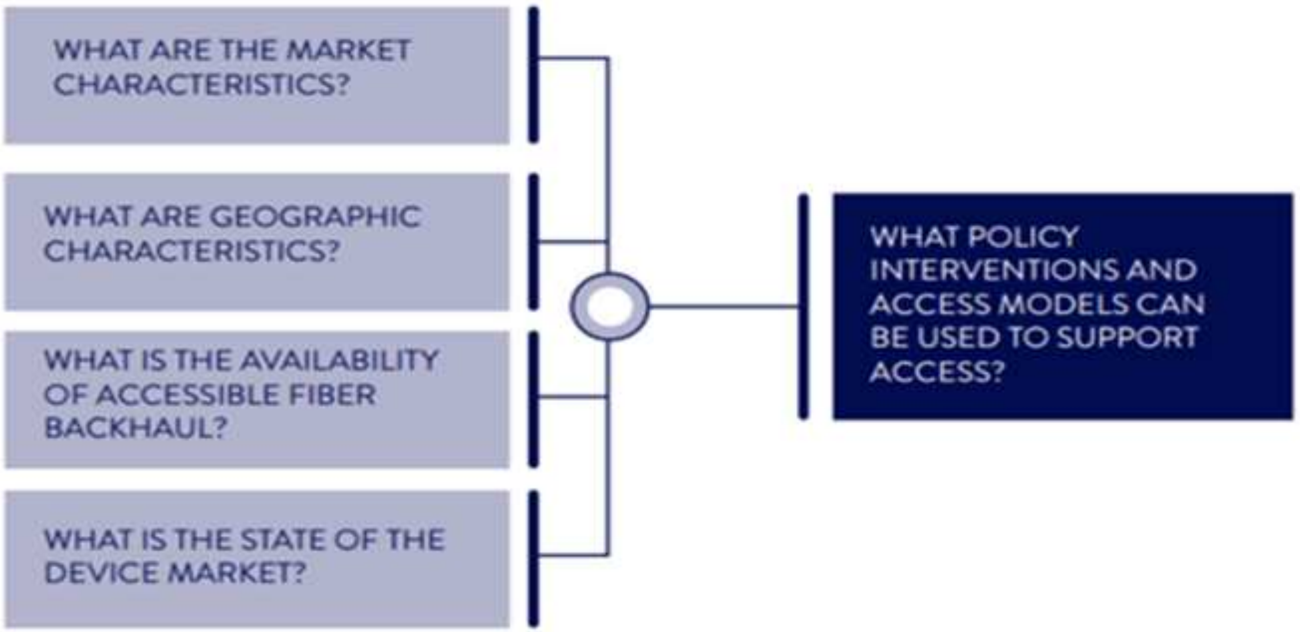
3b – Identify the components of an appropriate last-mile connectivity solution

3c – Draw up the decision matrix for feasible solutions

3d – Consider additional tools to assess solutions

Selection Step 3a: Selecting an Affordable Last-Mile Connectivity Solution

Figure 31: Access models grouped by challenge (USAID)



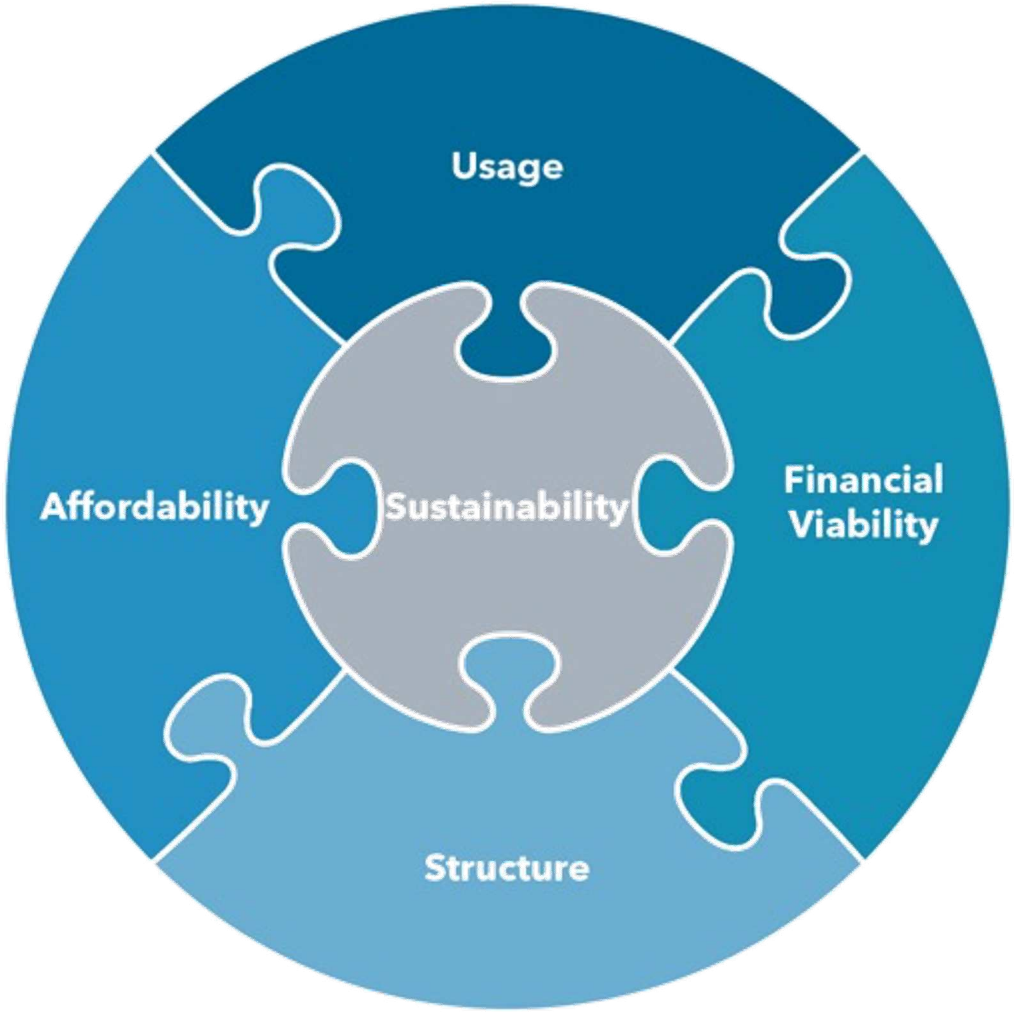
Source: USAID et al.

Selection Step 3a: Selecting an Affordable Last-Mile Connectivity Solution

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 the figure to the right, 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.
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.
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.
4) **Structure** – This involves articulating the service delivery business model and identifying any regulatory constraints on the model and technologies utilized.
5) **Sustainability** – This requires an understanding of the service's revenue model and of any potential subsidy (one-time and/or recurring).

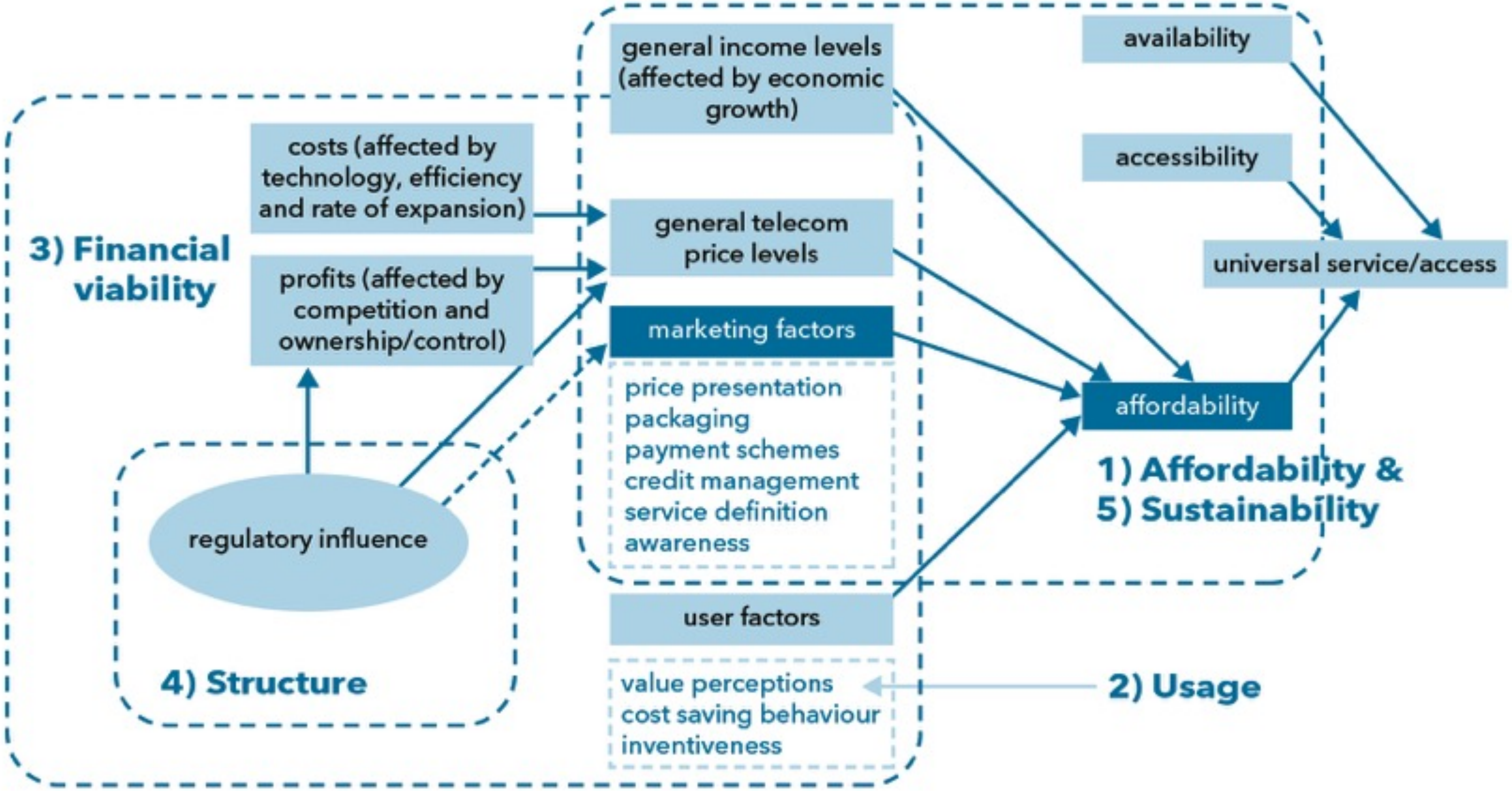
Figure 32: Components in selecting an affordable last-mile connectivity solution



Selection Step 3a: Selecting an Affordable Last-Mile Connectivity Solution

The five factors in selecting an affordable last-mile connectivity solution map to other frameworks of universal access components in the figure below. 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 33: The components of an affordable last-mile connectivity solution related to other frameworks



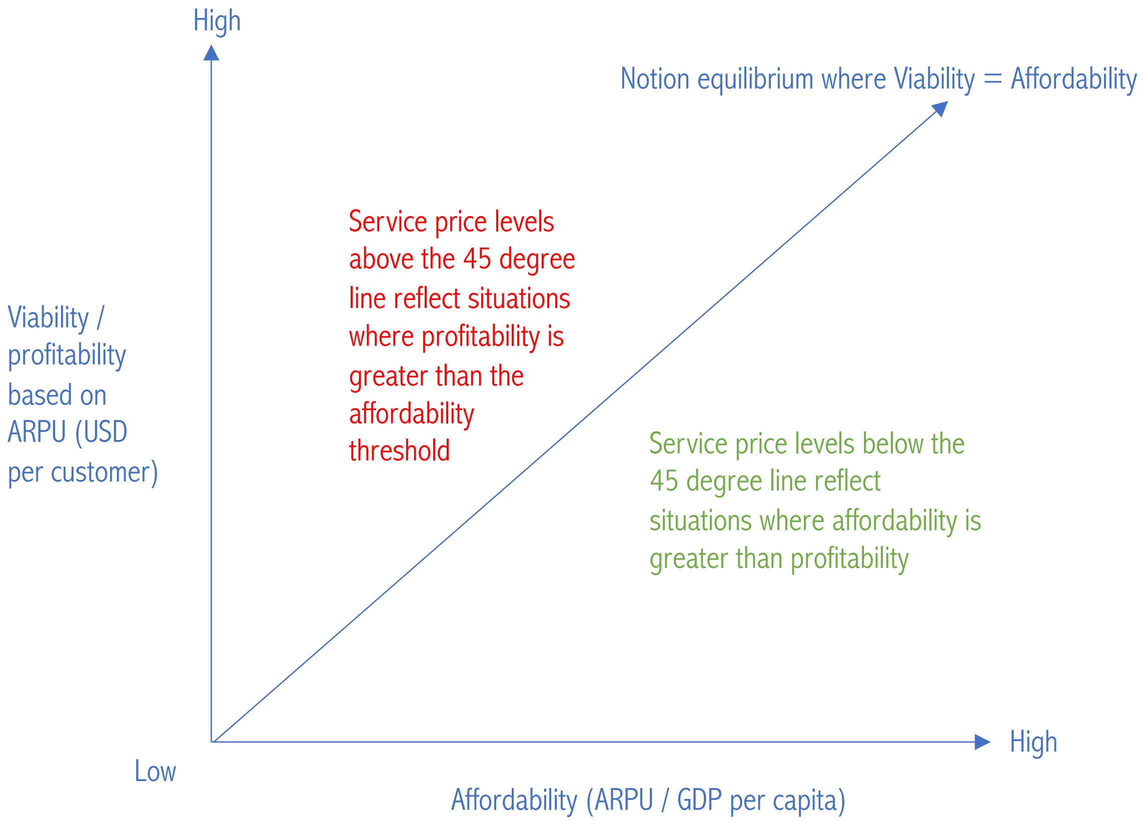
Source: adapted from C. Milne, Improving Affordability of Telecommunications: Cross-Fertilization between the Developed and the Developing World (15 August 2006), TPRC 2006. Available at SSRN: https://ssrn.com/abstract=2104397

Selection Step 3a: Selecting an Affordable Last-Mile Connectivity Solution

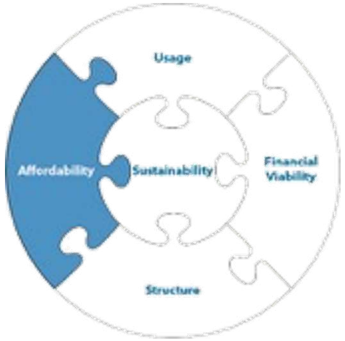
Financial viability versus affordability: It is worth stressing that the financial viability of establishing service (considered from the point of view of the investor, whether the project is a commercial investment or a subsidized deployment) is different from the affordability of the service provided (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 the notional figure to the right, 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 34: Financial viability versus affordability



Selection Step 3b: Components of an Appropriate Affordable Solution



Affordability

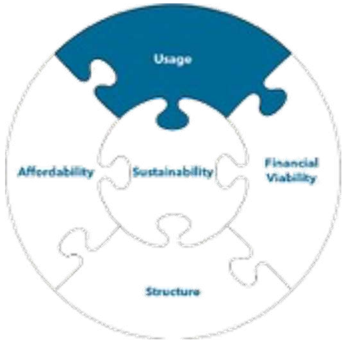
As the focus of this Solutions Guide is to encourage last-mile connectivity solutions that deliver affordable Internet to unserved and underserved communities, designing potential solutions begins with identifying what price levels of service would be considered affordable.

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 the discussion of affordable service in the Introduction: Background, motivate 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.

Selection Step 3b: Components of an Appropriate Affordable Solution

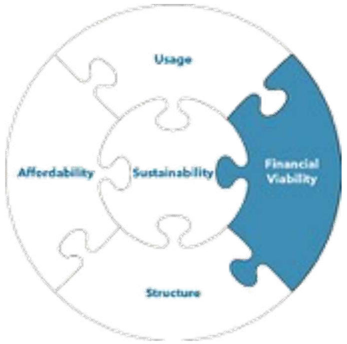


Usage

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, government services, etc.

As noted in Step 2, 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.

Selection Step 3b: Components of an Appropriate Affordable Solution



Financial Viability

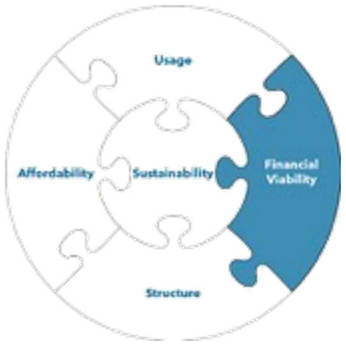
The financial viability of different forms of service provision depends on a number of factors. Affordability thresholds (if applied) and usage requirements (if applied) from the previous sections can serve as inputs for calculating financial viability. They can also be left out, depending on the ultimate 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.

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

Selection Step 3b: Components of an Appropriate Affordable Solution



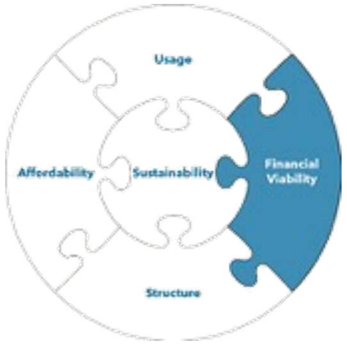
Financial Viability: Estimating Demand

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: 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)

Selection Step 3b: Components of an Appropriate Affordable Solution



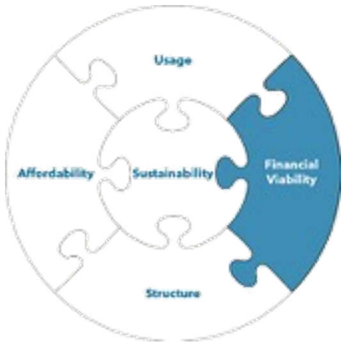
Financial Viability: Access Network Design and Technologies

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: 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

Selection Step 3b: Components of an Appropriate Affordable Solution



Financial Viability: 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.

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.

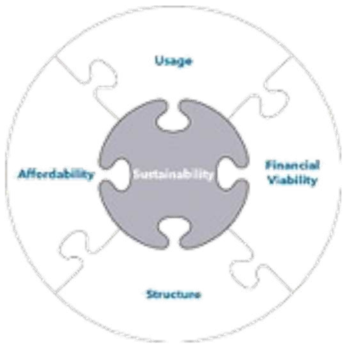
Structure

The structure of the entity delivering service will be determined by the availability of options in the policy and regulatory market environment (see section in Step 2 discussing different categorical classifications). The overall policy and regulatory environment for Internet connectivity in any given country will contribute significantly to either 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.

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

Selection Step 3b: Components of an Appropriate Affordable Solution



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.

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

Selection Step 3c: A Decision Matrix for Appropriate Solutions

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).

Table 33: A decision matrix for 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

Selection Step 3d: Additional Tools to Assess Solutions

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

Step 4: Implement interventions to extend affordable connectivity service

Step 1:
Identify digitally unconnected (and underserved) geographies

Step 2:
Review options from existing solutions

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

Step 4:
Implement interventions to extend sustainable connectivity service

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)

4a: Options for interventions - Introduction

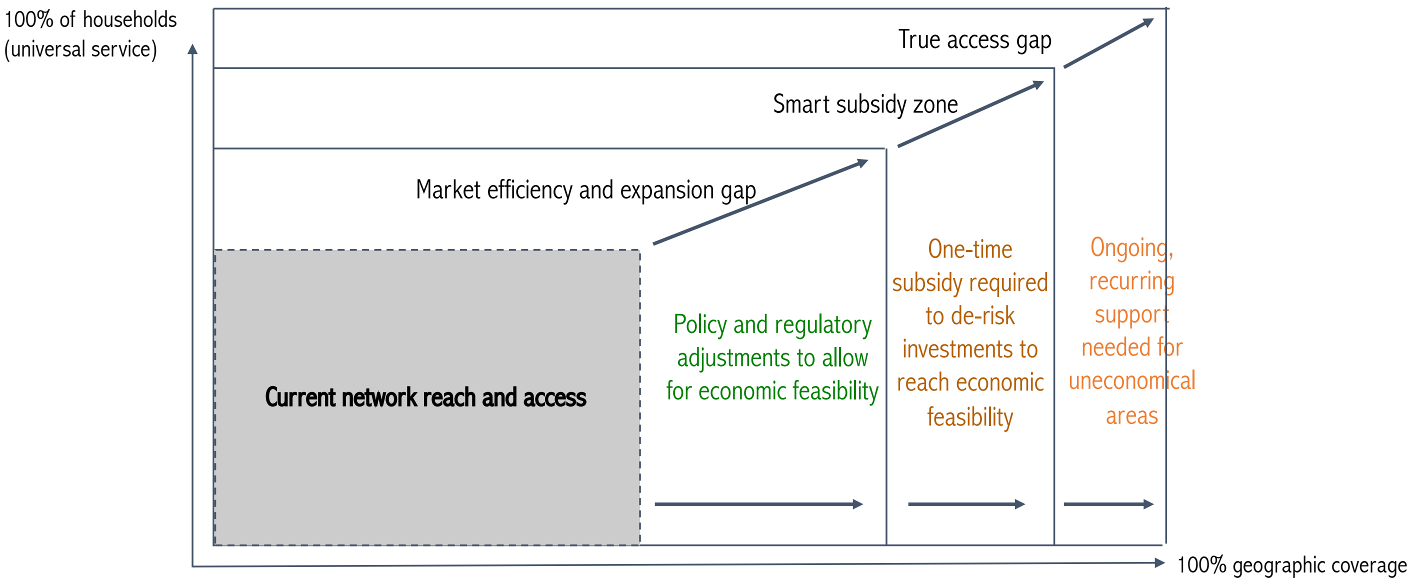
As noted above on slide 44, there are three general types of interventions to increase universal coverage and service for internet connectivity. These three categories of interventions are also utilized in this Solutions Guide to group interventions that encourage last-mile connectivity service deployment. This includes:

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 Step 4c.

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. Step 4d describes the intervention options available.

Figure 36: Intervention distinctions for the various access gaps



Source: ITU Regulation Toolkit

4b: Options for interventions – Market efficiency interventions (1/3)

Policy and regulatory actions that expand economically feasible service provision by encourage market expansion and deployment by addressing market failure.

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)	✓	✓	✓	✓

4b: Options for interventions – Market efficiency interventions (2/3)

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
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	✓	✓	✓	✓

4b: Options for interventions – Market efficiency interventions (3/3)

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
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: 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	✓	✓	✓	✓

4c: Options for interventions – One-time financing (subsidy) (1/2)

Limited concessional financing support can serve to de-risk private sector investment (as described as a smart subsidy).

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	Commercial MNO	Commercial 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)	✓	✓	✓	✓

4c: Options for interventions – One-time financing (subsidy) (2/2)

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	Commercial MNO	Commercial ISP	Not-for-profit local mobile network	Not-for-profit local ISP network
Authorize flexible in-kind contributions (hardware, software and technical capacity) to non-commercial entities from the private and public sectors				✓	✓
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	✓	✓	✓	✓

4d: Options for interventions – Recurring financing (or subsidy)

Limited concessional financing support can serve to de-risk private sector investment (as described as a smart subsidy).

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

Recurring subsidy interventions	Examples	Commercial MNO	Commercial 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				✓	✓

4e: Examples of options – Submissions to the case study database (1/9)

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
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.

4e: Examples of options – Submissions to the case study database (2/9)

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

Examples from the case study database (Submissions)	Intervention option	Detail
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 (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.

4e: Examples of options – Submissions to the case study database (3/9)

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

Examples from the case study database (Submissions)	Intervention option	Detail
Brazil – CELCOM community cellular network	Market efficiency and expansion interventions (CELCOM uses the Special Licence for Scientific and Experimental Purposes provided by Anatel with respect to legislation issues) Recurring subsidy (financed by the institutions involved)	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.
Brazil - Government policy options	Market efficiency and expansion interventions (spectrum auction obligations) 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)	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
Peru – Internet para Todos	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) 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)	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

4e: Examples of options – Submissions to the case study database (4/9)

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

Examples from the case study database (Submissions)	Intervention option	Detail
Brazil – GESAC (Telebras and Viasat)	Market efficiency and expansion interventions (an innovative agreement allowing Viasat to offer commercial service on the Telebras network, commercializing 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) Recurring subsidy (government funding for school connectivity)	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.
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.

4e: Examples of options – Submissions to the case study database (5/9)

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

Examples from the case study database (Submissions)	Intervention option	Detail
China - Government policy options	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) Recurring subsidy (universal service funds and subsidy programme to improve broadband connectivity) Subsidy – The government has a subsidy programme for operators rolling out fibre-optic and 4G infrastructure in target areas. Concessional loan and financing - Concessional loans are available for eligible broadband development projects in state-level development areas in the western region. Tax incentives - Tax incentives exist for the construction and operation of broadband networks.	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.

4e: Examples of options – Submissions to the case study database (6/9)

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

Examples from the case study database (Submissions)	Intervention option	Detail
Brazil – Private LTE networks at 250 MHz for IoT / agriculture	Market efficiency and expansion interventions (Regulation for 225-270 MHz frequency range (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 Tropico, 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.
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.

4e: Examples of options – Submissions to the case study database (7/9)

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

Examples from the case study database (Submissions)	Intervention option	Detail
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 the 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.

4e: Examples of options – Submissions to the case study database (8/9)

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

Examples from the case study database (Submissions)	Intervention option	Detail
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 will inform 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.
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.

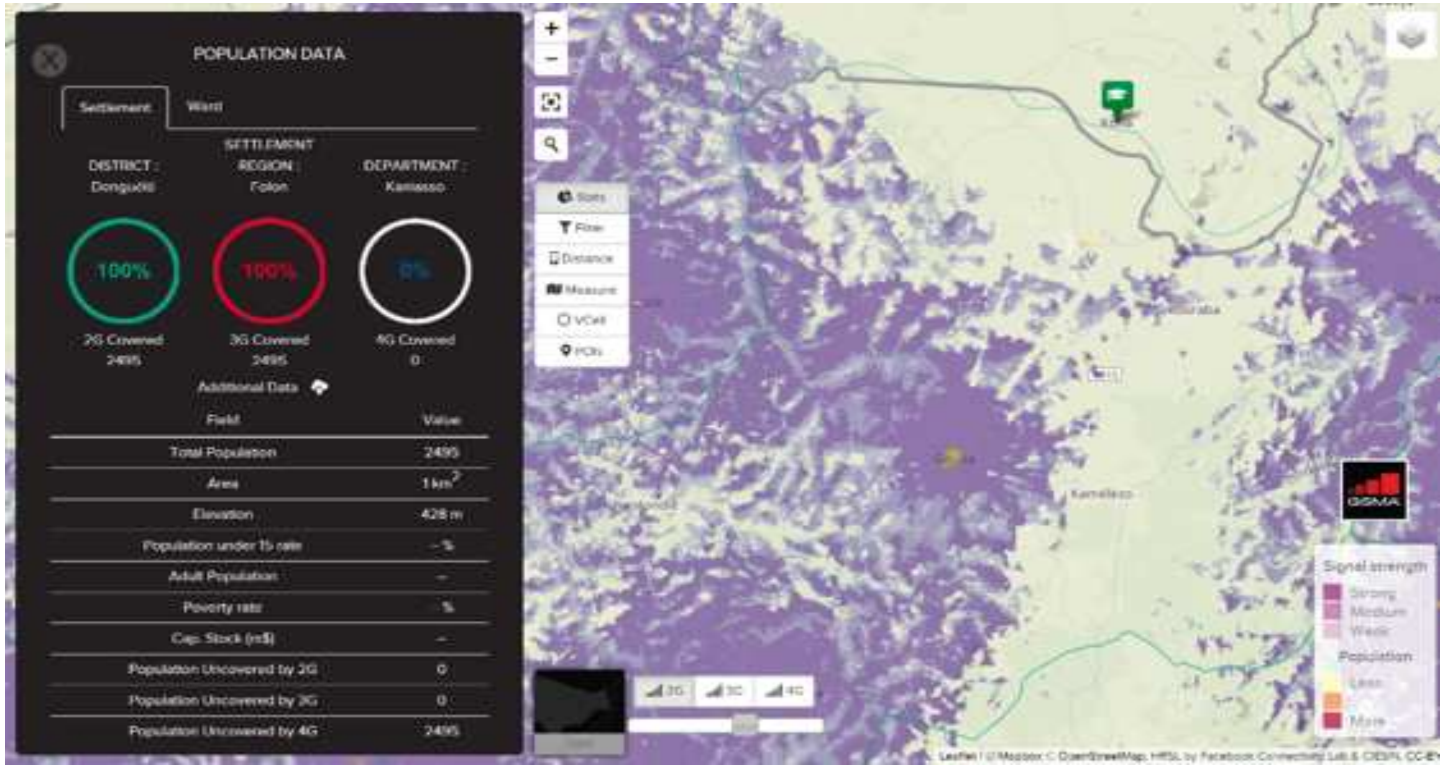
4e: Examples of options – Submissions to the case study database (9/9)

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

Examples from the case study database (Submissions)	Intervention option	Detail
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-meter 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.

Annex 1: Examples of network mapping

Figure A1.1: GSMA Mobile Coverage Map: example



Source: http://www.mobilecoveragemaps.com/

Annex 1: Examples of network mapping

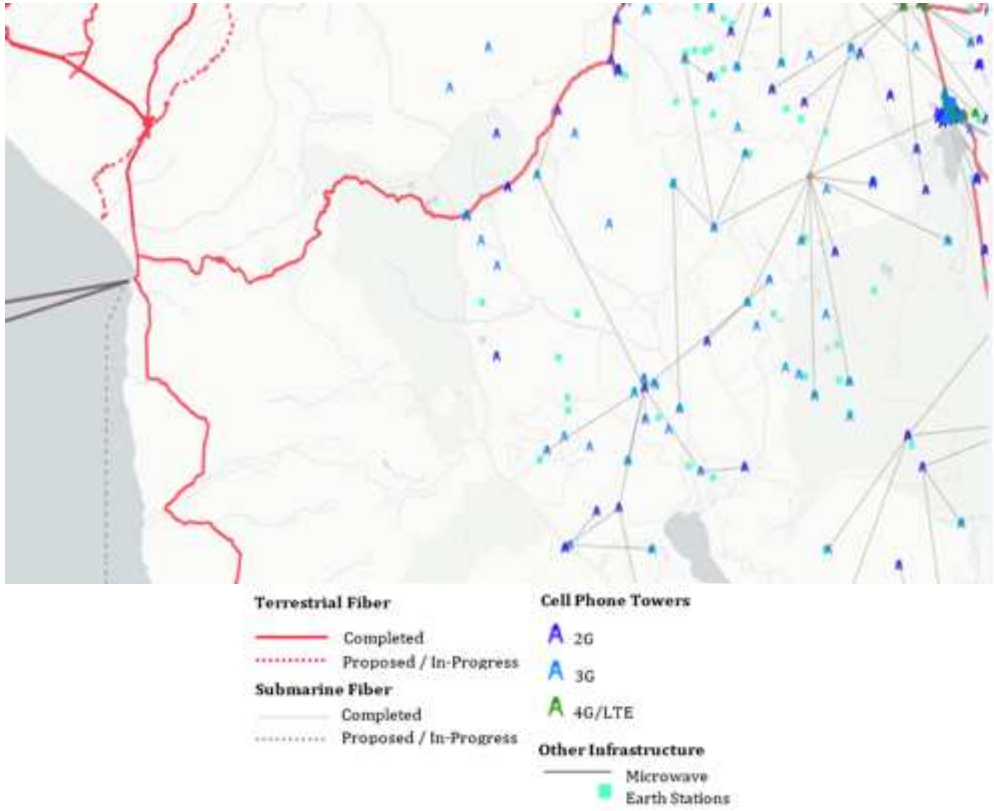
Figure A1.2. Masae Analytics algorithm with granular population density open data and coverage information to detect the most promising zones ("white spots") for the installation of new base stations

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

Source: https://www.masae-analytics.com/

Annex 1: Examples of network mapping

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



Source: https://www.hipconsult.com/

Annex 1: Examples of network mapping

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

Figure A1.6. Satellite nightlight imagery as a proxy for economic activity

Source: https://www.hipconsult.com/

Annex 1: Examples of network mapping

Figure A1.7. Fibre proximity grid with urban clusters can yield fibre proximity of key places.

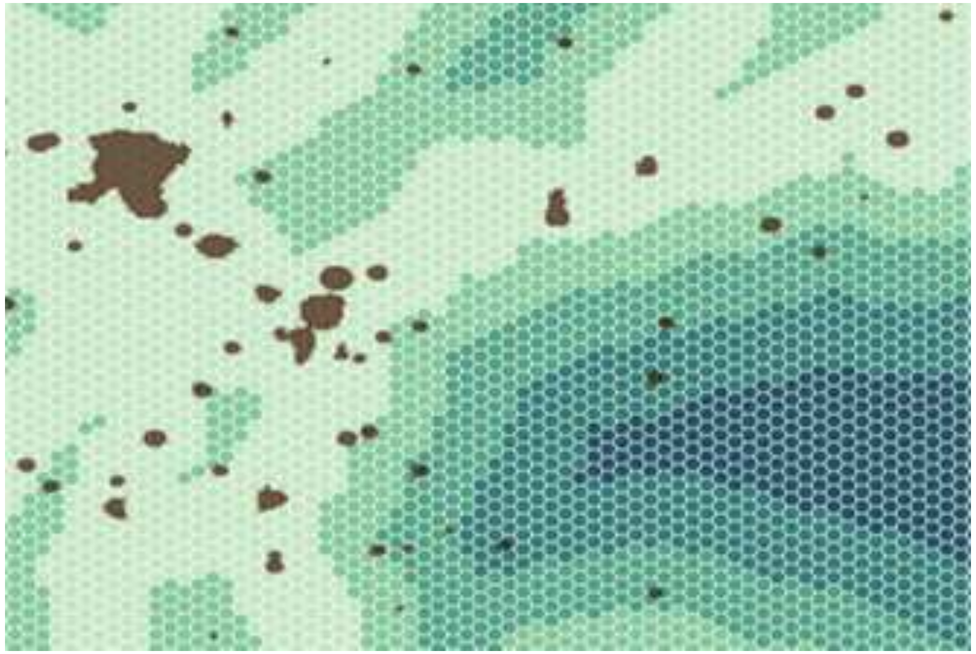
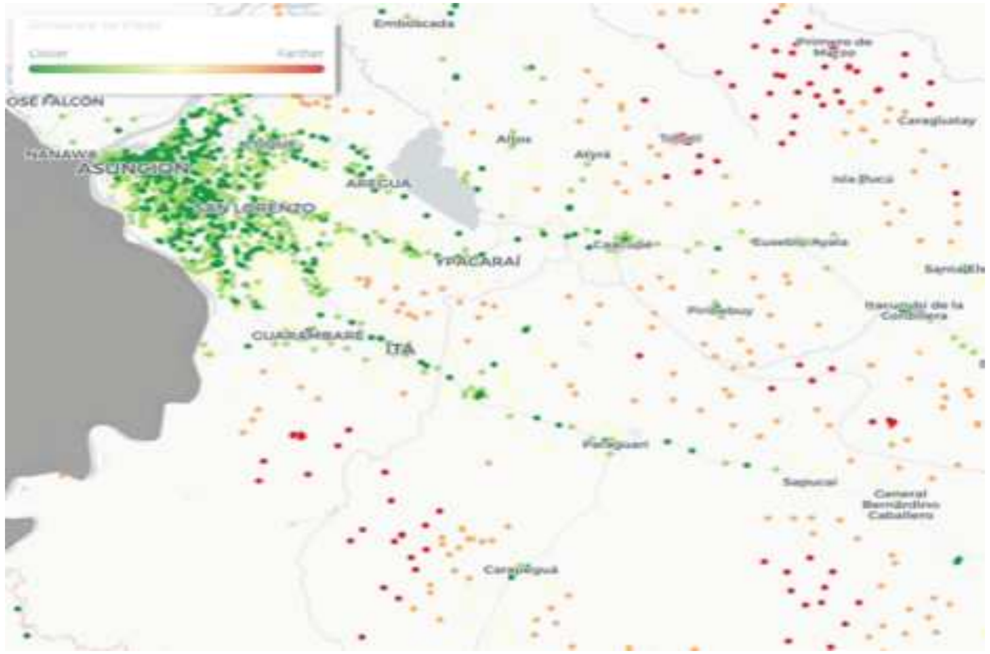


Figure A1.8. Schools visualized by distance to fibre, to assess school density and fibre proximity



Source: https://www.hipconsult.com/

Annex 1: Examples of network mapping

Figure A1.9. 4G tower locations and number of people per tower within a one-square kilometer grid

Source: https://fraym.io/

Annex 2: Additional Resources for Mapping

Network Infrastructure Mapping

Fiber (Undersea & Terrestrial):
ITU – Broadband Maps: https://itu.int/go/Maps
Telegeography – Submarine Cable Map:
https://github.com/telegeography/www.submarinecablemap.com
African Terrestrial Fiber 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 stateion 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)

Socio-Demographic, Environmental, 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 Resources:

References / How-to:
World Bank – Broadband Mapping
Jon Brewer – Using GIS to Deliver Universal Broadband

Modeling Radio Frequency Propagation
SPLAT
CloudRF

Annex 2: Additional Resources (Technical References, Policy, & Case Studies)

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
A4AI Good Practices Database
Community Networks in Latin America
OECD Telecom Topics Reports
Dynamic Spectrum Alliance Regulations

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

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)

Annex 2: Additional Reports Referenced and Consulted in the Literature Review

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)
Digital Dividend: Insights for Spectrum Decisions (ITU, 2018)
State of Mobile Internet Connectivity 2018 (GSMA, 2018)
Innovative Business Models for Expanding Fiber-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)
Bottom-up Connectivity Strategies (APC, 2019)
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)