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BACKGROUND PAPER

Digital Dividends

The Economics and Policy Implications of Infrastructure Sharing and Mutualisation in Africa

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Abbreviations

CAPEX: Capital Expenditures
OPEX: Operational Expenditures
IBP: Internet Backbone Provider
ISP: Internet Service Provider
RPNP: Receiving Party Network Pays
ARPU: Average Revenue per User
NGAN: Next Generation Access Network
LLU: Local Loop unbundling
SLU: Sub local loop unbundling
MSC: Mobile Switching Centre
HLR: Home Location Register
VAS: Value added systems
PPP: Public Private Partnership
MVNO: Mobile Virtual Network Operator
DTT: Digital Terrestrial Television
SBC: Service based competition
FBC: Facility based competition
LRIC: Long Run Incremental Costs
CAGR: Compound Annual Growth Rate
APT: Asia-Pacific Tele-community
M2M: Machine to machine
IoT: Internet of Things
LEO: Low Earth Orbit
NGN: Next Generation Network
DTT: Digital Terrestrial Television
OTS: Over the top services
CEPT: European Conference of Postal and Telecommunications Administrations
ITU: International Telecommunication Union
EASSY: Eastern Africa Submarine cable
IFC: International Finance Corporation
WACS: West Africa Cable System
BOFINET: Botswana Fibre Networks
VULA: Virtual unbundles local
VDSL: Very high bit rate Digital subscriber line
MSC: Mobile Switching Centre
HLR: Home Location Register
VAS: Value added system
DFI: Development Financial Institutions
SOE: State Owned Enterprise
IMT: International Mobile Telecommunications
ECC: Electronic Communications Committee

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Executive summary

The appeal of broadband is gaining momentum on the political scene. In developing countries, governments know the importance of broadband for development and promoting broadband as a way to boost knowledge in society has now entered the political agenda.

Infrastructure sharing is one of the main trends in broadband infrastructure deployment. In developing countries, particularly in sub-Saharan Africa, there is a trend for governments to back infrastructure sharing projects as a way to reduce costs in network deployments, expand coverage, reduce the rural-urban digital divide, and accelerate broadband take-up.

Traditional infrastructure sharing models, such as regulated access to the so-called "last-mile" network or site sharing agreements among mobile operators, have given way in recent times to new designs. The mutualisation model, where a common facility is operated by all market participants, and the cooperative model, where the telecommunication infrastructure is housed or jointly constructed with other linear infrastructures, are the two most popular designs.

Mutualisation has become a prominent new telecom infrastructure design in Africa since 2009 when undersea cables were constructed that integrated Africa into the fiber optics international connectivity networks. The requirement to connect national backbone networks to the new undersea cables continued the trend, and currently mutualisation is occurring to deploy mobile access network as well.

These changes pose regulatory challenges and questions. Whether or not the monopoly provision of infrastructure can coexist with competition in the retail markets is still unknown. But if future investments in network quality and new technologies will occur under the mutualised infrastructure paradigm, this question must be answered.

The mutual construction of undersea cables has been driven by market forces and supported by national and international public institutions, with guaranteed competition from the multiple cable systems. For national backbone mutualisation, the most competitive solution is the high participation of all national market agents in the construction and operation of the mutual infrastructure. The most controversial approach is to jointly construct mutualised access mobile networks. This approach poses risks of monopolization of an essential facility, and could discourage investment and innovation in a market where next generation technologies appear quickly.

A regulatory intervention that favors infrastructure sharing can lessen a specific market problem—such as the existence of entry barriers in the access network—but it could create complications to the future market development or distort the functioning of an adjacent one. The consequences of a particular regulatory intervention to encourage or prevent sharing must be analyzed on a case-by-case basis taking into account dynamic aspects such as innovation and future investment incentives.

1. Introduction

The Internet is made up of a hierarchical set of networks that transport the data necessary for telecommunication services. Each network requires building, operating, and maintaining an infrastructure made up of a combination of diverse types of assets. These assets include passive infrastructure assets, such as masts or ducts, active infrastructure assets, such as antennas or transmission components, and intangible assets like spectrum licenses or rights of way. In addition to these assets, network infrastructure relies on services to function, such as connectivity services, including the lease of bandwidth capacity, network management and intelligence services involving routing or quality of connection, and retail customer services such as billing or customer care.

Infrastructure sharing in telecommunications refers to the joint utilization of assets and/or services necessary to provide telecommunication service in order to reduce the costs of building, operating, and maintaining network infrastructure. Sharing can happen in any of the interrelated internet networks and has the potential to re-shape the structure and function of the different telecommunication services markets.

This document explores three models of infrastructure sharing, infrastructure asset sharing, infrastructure mutualisation, and infrastructure cooperation, and the bargaining power of involved agents.

Infrastructure asset sharing happens when two or more competing operators providing a telecommunication service share assets that are required to provide the service. Examples of these include mast, ducts, antennas, transmitters, and also rights of use and spectrum licenses.

Infrastructure mutualisation is a particular type of infrastructure sharing and happens when a common network infrastructure is built, operated, and maintained by a third party, an infrastructure provider, and jointly used by telecommunication service providers. Service providers lease a portion of the mutualised infrastructure and pay a wholesale price for it.

The third model, infrastructure cooperation, arises when telecommunication infrastructure is housed or jointly constructed with other linear infrastructures[1] in order to exploit the potential synergies in the construction, operation, and maintenance of several networks at the same time.

The ownership of a shared asset might belong to one of the telecom operators, be distributed among them, or be property of a third party.

Infrastructure sharing is a crucial element in the organization of the telecommunications industry and has strategic importance for market agents trying to minimize costs and regulators aiming to maximize social welfare. Because of its importance, sharing may result from an agreement between operators or a regulatory intervention. Regulatory intervention has a fourfold justification: market failures in the provision of telecommunications services, the socially desirable redistribution of resources to give access to ICT services to deprived or isolated communities, market agent's rationality, and limited information.

[1] Railways, waterways, pipelines or electricity distribution lines.

For market agents, infrastructure sharing is both an important component of the business model and a strategic behavior in response to a particular market competitive structure, the existing market conditions, the regulatory obligations and/or the existing technology.

For regulators, infrastructure sharing is an opportunity to reduce market failures in telecommunication services markets. The following is a list of existing market failures that can be addressed through sharing:

- the absence of economies of scale and density in the manufacture of network and user devices;
- the presence of high sunk costs associated with the deployment of certain telecommunication networks;
- the occurrence of economies of scope and network externalities in the provision of services and applications;
- the existence of positive externalities linked to the beneficial effects of telecommunication networks on other economic sectors and negative externalities on the environment;
- the existence of services and applications that can be considered as public goods;
- the potential competition problems between the different markets of the Internet ecosystem.

Sharing is associated with reduced capital expenditures (CAPEX), Operative Expenses (OPEX), barriers to entry, and prices as well as increased competition and Internet use. Even with these benefits, infrastructure sharing can be a source of disequilibrium and market distortion, and if imposed externally, may reduce incentives to build new infrastructure, adopt new technologies and stifle market innovation. Infrastructure sharing, therefore, is a trade-off between expected faster and cheaper network expansions and the potential disincentives to innovation and investment in new technologies.

In developing countries, particularly in Africa, there is a trend for Governments to back infrastructure sharing projects to reduce costs in network deployment, expand coverage, reduce the rural-urban digital divide, and accelerate broadband take-up. In Africa, where rural population ranges from 40% to 70% of total population, rural Internet access is particularly important.

Expanded access to broadband is a crucial element in global development. The internet is an important delivery tool for development projects and essential services to the world's poorest, such as education and healthcare. Internet access increases opportunities for women, improves environmental sustainability, and enhances government transparency and accountability. Furthermore, broadband use is associated with positive spillovers, such as higher economic growth, enhanced productivity and a boost to employment. According to the World Bank (2009), a 10 percent increase in broadband penetration in developing countries is associated with a 1.4 percent increase in GDP per capita.

In order to facilitate broadband expansion, The World Bank has supported several infrastructure sharing projects in Africa through Public Private Partnerships (PPP) under the principles of open access, non-discrimination and low-cost pricing. Examples are the construction of shared towers underpinning the mobile access and backhaul networks and projects to fill backbone infrastructure gaps by developing mutualised backbone networks. The World Bank has also backed projects to facilitate access to undersea cables and eliminate coordination failures that hinder infrastructure sharing benefits by strengthening institutions.

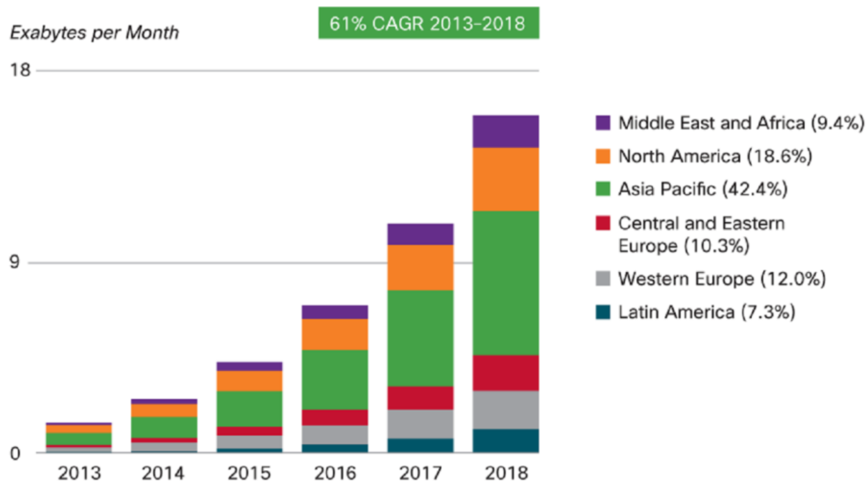
This paper analyses the policy implications and economics of infrastructure sharing, and suggests recommendations to enable effective infrastructure sharing for broadband development. The report is structured as follows: Section 1 defines infrastructure sharing and explains why this topic is important for African countries and for the World Bank. Section 2 describes new technologies and demand trends and their effect on infrastructure sharing models. Section 3 identifies key elements of the internet supply markets and of the internet ecosystem that may affect infrastructure sharing. Section 4 analyzes the economic theory behind infrastructure sharing, including agents involved, incentives agents have to share, and which factors explain agent´s behavior. Section 4 also analyzes the three models of infrastructure sharing and offers examples of existing World Bank projects in this space. Section 5 identifies the market and regulatory failures that can be reduced by infrastructure sharing, how economic theory justifies public intervention for infrastructure sharing, and finally presents case studies in infrastructure sharing. Section 6 offers a study of the existing theoretical and empirical analysis about market distortions related to infrastructure sharing and suggests possible solutions to mitigate these distortions. Section 7 offers policy recommendations and Section 8 concludes.

2. Demand trends, new technologies and the impact on infrastructure sharing

Network infrastructure deployment and sharing are encouraged in a country by the demand for fixed and mobile broadband connectivity, the type of data services used and the capacity of existing and expected future technologies to absorb traffic demand. This section describes new technologies and demand trends that could shape market agents and incentivize infrastructure sharing.

The exponential increase in the demand for data in recent years is the result of three main concurrent demand trends. First, the rapid popularization and proliferation of smart mobile devices (smartphones and tablets) and wireless Internet data cards for computers is putting pressure on wireless broadband networks. According to Cisco (2014), broadband traffic is expected to increase by an 11-fold expansion between 2013 and 2018, with a total CAGR growth of 61 percent. Africa and the Middle East are leading this growth with a CAGR of 70 percent, a 14-fold increase.

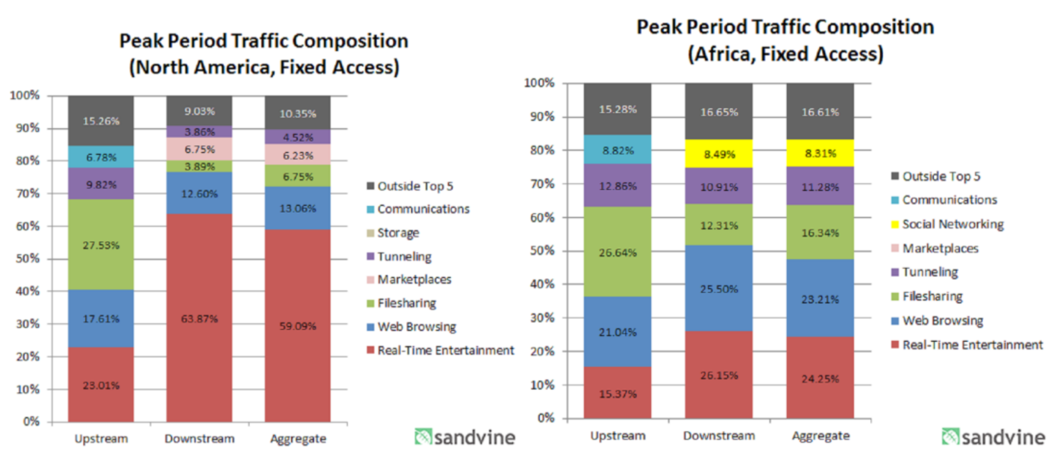
Global Mobile Data Traffic Forecast by Region



Source: Cisco (2014). Visual Networking Index, global mobile data forecast

Second, the demand for multimedia content and applications is pressuring mobile and fixed infrastructures. In the US, Netflix and Google are responsible for about 50% of downstream traffic in fixed networks during peak internet usage hours. In Africa, multimedia applications are taking off at a slower pace, and web browsing is still an important source of traffic generation. Low average mobile connection speed, which is more than three times slower in Africa than in North America (529 Kbps to 1,728 Kbps), and the lack of fixed internet connection infrastructures limits the expansion of multimedia applications.

Peak traffic composition in North America and Africa in fixed networks



Source: Sandvine (2014). Global Internet Phenomena Report.

Finally, the nascent development of the Internet of things (IoT) is responsible for the growth of Machine-to-machine traffic (M2M) for applications such as smart security systems, smart metering of utilities in buildings, or healthcare monitoring. The emergence of connected wearable devices including smart watches, smart glasses, and smart clothes is also part of the revolution of connected “things.” These devices are also adding pressure on data networks; M2M traffic is expected to grow at a 43 percent CAGR between 2013 and 2018.

In addition to demand growth, new technologies are shaping incentives to share network infrastructures. New innovative access technologies reduce the need to share access network assets and the multicasting feature of next generation networks could shift the optimal fixed network interconnection point. Finally, congestion control technologies reduce network occupancy and diminish the incentive to deploy and share facilities. New approaches to spectrum sharing are spurring new forms of sharing infrastructures.

One example of innovative access technology is the constellation of Low Earth Orbit (LEO) satellites using simple and easily reachable orbits to provide Internet coverage over a wide area. Google has bet on this technology by spending US$500 million to buy Skybox Imaging[2], a satellite company, to improve Internet access and disaster relief assistance.

A different innovative access technology approach is the use of drones to provide internet connectivity. This can minimize costs if the drones are powered by solar energy and fly as close to the ground as possible to maximize signal strength and reduce transmission power. This access network connectivity solution has drawn the attention of Facebook and Google for its ability to provide low-cost Internet access. In March 2014, Facebook bought Ascenta[3] and in April 2014 Google acquired Titan aerospace[4], both drone manufacturing companies.

Project Loon[5] is an idea floated by Google with the goal to increase internet access connectivity in rural and remote areas by connecting internet-enabled balloons with each other and with an earth station to provide connectivity. In a test program, solar powered balloons offered a 3G equivalent speed of connection over an area of 1250 square kilometers.

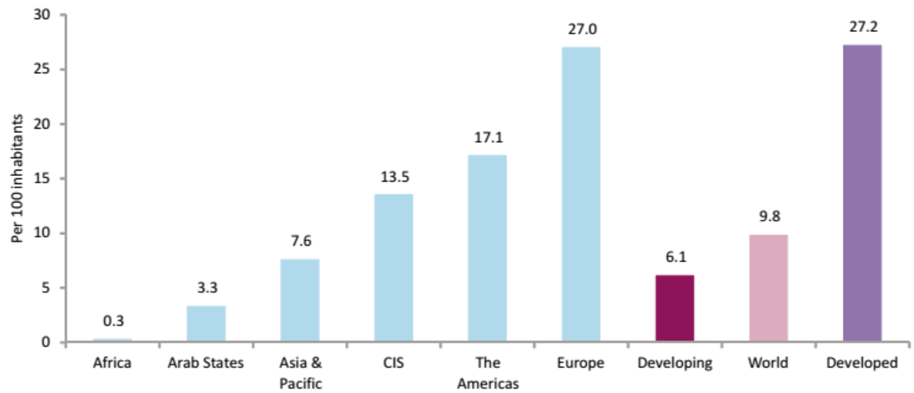
A different technology with potential to shape infrastructure sharing incentives is multicasting capability, available in fixed Next Generation Networks (NGN). This technology allows simultaneously transmitting of video to multiple consumers, carried as a single stream with much less bandwidth. With this approach, the resulting occupied bandwidth of multimedia linear content applications, such as television, is equivalent to the demand of only one consumer. Multicasting shifts the efficient interconnection point to where operators who lack access infrastructure interconnect, and increases the incentives to share a larger network segment to more efficiently occupy the network.

The expansion of wireless broadband through new spectrum sharing technologies is one of the most cost-efficient routes to provide internet access; and in the developing world, given the very low penetration rates of fixed access networks, wireless broadband is the most likely way. The

[2] The business Insider, http://www.businessinsider.com/google-skybox-imaging-2014-6
[3] Bloomberg, http://www.bloomberg.com/news/2014-03-27/facebook-seeks-to-spread-web-via-drones-and-satellites.html
[4] Bloomberg http://www.bloomberg.com/news/2014-04-14/google-acquires-drone-maker-titan-aerospace-to-spread-web.html
[5] Google, http://www.google.com/loon/

most salient example is Africa, where the average fixed access network penetration rate is only 0.3%.

Fixed (Wired) broadband subscriptions per 100 people by region and level of development, 2013



Source: ITU (2013 a). Measuring Information Society.

The so-called TV White Spaces in the Ultra High Frequency (UHF) band are one of the possibilities identified for efficient spectrum sharing. White Spaces are portions of the radio spectrum allocated to the Digital Terrestrial Television (DTT) broadcasting service no longer being used in a specific geographic location. These frequencies can be used for wireless broadband connectivity or other radio-communication applications, using new technologies such as cognitive radio devices or geo-location databases, provided that they do not cause harmful interference to the broadcasting primary service. Cognitive radio devices are gadgets able to dynamically detect the most suitable available frequency band in a particular geographical area at a particular time. These devices are able to dynamically change the transmission and reception parameters depending on the radio electric environment. Geo-location databases maintain a permanently updated database of available frequencies to share in a particular area and moment. The radio-communication services using the TV white spaces work on a non-protected basis and therefore, whitespace users cannot make claims against potential interference problems caused by the broadcasting primary service.

Other technologies that reduce incentives to share infrastructures by reducing network traffic also exist. Protocols that control congestion at the end point assume no network support to quality of service and use packet losses as a signal of congestion to decrease self-sending rate, reducing network congestion, improving jitter and yielding a fair allocation of network elements. Peering also reduces the traffic packages susceptible to be sent through the internet backhaul and backbone networks. Additionally, content delivery networks, such as Akamai, store content coming from remote servers in local servers to reduce the transit traffic exchanged among distant internet networks.

3. Internet supply markets and the Internet Ecosystem

The supply of Internet connectivity depends on interactions among different networks, each requiring an infrastructure with a combination of diverse assets. There is a set of services associated to each network that can be bought and sold in wholesale and retail markets.

The aim of this section is to identify the elements of the internet supply chain that could be shared, describe the internet ecosystem, and discuss the interrelations between these elements. This section is not intended to be a thorough analysis of infrastructure sharing in terms of effective competition, since this analysis must be undertaken in each particular country and is a continuous process that must be re-evaluated as technology evolves and the competitive environment changes.

Supplying internet services requires the use of networks. For each network or network segment, the following applies:

- one or more relevant internet supply markets may need ex-ante regulation
- network facilities can exist that require mandated sharing because of the particular competitive situation
- significant market power in service provision and sunk costs in network deployment that make the duplication of a network unfeasible could coexist

The elements defined below describe the components of the internet supply chain and the internet ecosystem.

1. <u>Telecommunication networks</u>: The networks involved in the supply chain to provide telecommunications services can be classified into international connectivity networks that carry traffic between countries and continents, regional and national backbone networks which distribute internet traffic to a particular region, access networks that connect people and businesses to the internet, and backhaul networks that transport traffic from access to backbone networks.

2. <u>Infrastructure assets for telecommunication networks</u>: Tangible and intangible infrastructure assets exist in telecommunication networks. Active infrastructure assets are tangible assets used in the transmission, reception or transformation of telecommunication signals. Examples include transmitters, receivers or antennas. Passive infrastructure assets are tangible assets that are necessary to support active assets; examples include masts, ducts, dark fiber or sites. Intangible assets are those that do not exist physically but are necessary to provide a telecommunication service, with the most common examples being licenses granted for the use of spectrum or the rights of way to build a telecommunication infrastructure.

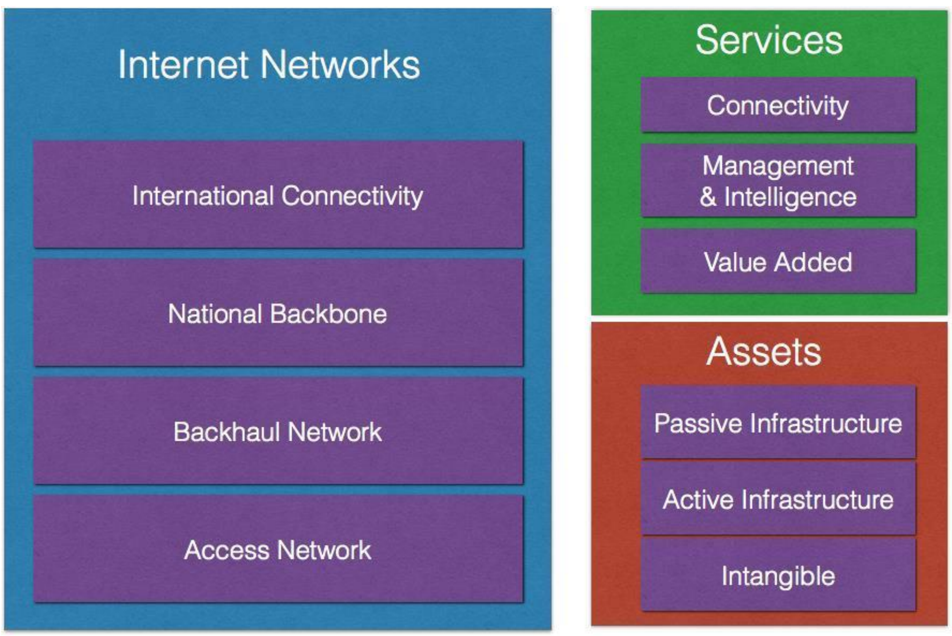
3. <u>Services for telecommunication networks</u>: Wholesale and retail connectivity services transfer data over telecommunication networks from the origin to the destination. Network management and intelligence services process data packages to offer, for example, different degrees of quality by reducing jitter or latency in data transmissions, or the encryption of data packages to secure the information contained. Finally, there are value added services in the commercialization of connectivity services, customer care, or billing. Connectivity service providers can be classified in three different levels:

- Internet Service Providers (ISPs) offer retail connectivity services and connect households and businesses to the internet. An Access Service Provider (ASP) is a special type of ISP that owns the last mile infrastructure of the access network and directly connects final users to the internet. Some ISPs share last mile infrastructure with an ASP in order to offer retail connectivity services.

- Internet Backbone Providers (IBPs) offer transit and routing services to other backbone or access providers within a country.

- International Internet carriers are IBPs that provide international connectivity between countries using undersea and terrestrial fiber optic cables and satellite connectivity.

Internet networks and related assets and services



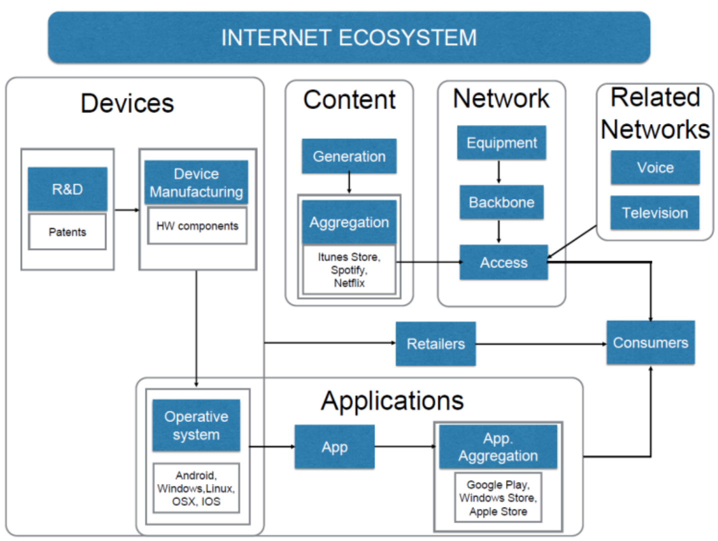
Source: Author.

4. Markets for connectivity services: The set of services within a particular network and the economic transactions among the different service providers make up the markets for connectivity services. There are economic transactions among connectivity service providers, among users and access providers, among access and backbone providers and among backbone providers in different wholesale and retail markets.

The supply chain for the provision of internet connectivity involves the interaction between wholesale and retail markets. The retail price of internet is influenced by the competitive interactions of wholesale markets and the horizontal and vertical relationships that occur throughout the complete value chain. Infrastructure sharing could change the competitive dynamics of the markets by altering the interactions between markets and market agent behavior. The main types of markets involved in the provision of connectivity services are described below:

- Downstream ISP retail markets offer fixed or wireless internet connectivity of different bandwidths and technologies to residential, government, or business clients.
- Upstream ISP wholesale markets offer services to ISPs to interconnect different access network segments. For fixed internet connectivity, ISPs could own a physical network segment, or, more commonly, lease the access network of the access provider to reach their customers. For mobile internet connectivity there is a rising trend of sharing passive infrastructure assets to expand coverage in a cost-effective way. Two examples of these markets are the wholesale physical access at a fixed location, which offers an interconnection point to a segment of the access network (the local loop), and the wholesale interconnection to the complete access network (the denominated bit-stream access).
- Upstream transit markets offer wholesale internet transit telecommunications services to internet service providers or internet backbone providers, such as routing or interconnection services. Transit interconnections allow traffic exchange with remote networks not directly accessible from the local ISP's network.

5. <u>The internet ecosystem elements and markets</u>: The internet ecosystem is the set of assets, services and associated markets that interact with or use internet telecommunication networks. Over the top services (OTS) and applications that use the internet as a platform to provide content, e-mail, search, cloud data storage, are all elements of the internet ecosystem. Network equipment and user terminals, manufacturing markets, operative system markets, content and application aggregation markets, spectrum markets and markets for other telecommunication services that can be bundled with the retail Internet access, such as mobile and fixed voice communication services and cable television, are related markets in the ecosystem.



Source: Author

4. Analysis of infrastructure sharing models

Infrastructure sharing is a crucial element in the organization of the telecommunications industry, but sharing also is important for market agents trying to minimize costs and regulators aiming to maximize social welfare. Regulatory interventions can help overcome market failures in providing services and achieve the socially desirable redistribution of ICT resources,–e.g. universal service obligations. Regulations can also overcome constraints derived from market agent's rationality and limited information.

Existing literature has analyzed the share of different assets in the diverse networks that make up the Internet with game-theoretic models e.g. the share of spectrum and active infrastructure assets in the mobile access network, Lee et al (2008) and Bublin et al (2008), or the housing of the telecommunication infrastructure assets with other linear infrastructures, such as energy and transportation infrastructures, see Zhang et al (2005).

Infrastructure sharing contains three interrelated dimensions: commercial, regulatory and technical. Each of these dimensions can be analyzed from a static and dynamic perspective because markets evolve and technology changes.

The <u>commercial dimension</u> of infrastructure sharing refers to the strategic behavior of an operator in reaction to competitive market structures, market conditions, regulatory obligations and existing technology. From the perspective of the operator's strategic behavior, infrastructure sharing is worthwhile if it supports the operator's competitive advantage. According to Porter (1991), a company has the competitive advantage if it produces at a lower cost than its rivals or if it offers differentiated products and commands a premium price that exceeds the extra cost of differentiation. Telecommunication operators can achieve this advantage by reducing capital expenditures and operating expenses by sharing infrastructure. However, if increased coverage allows an operator to charge a premium price, not sharing infrastructure may be the more attractive strategy.

The design of an infrastructure sharing strategy depends on four main factors - the market's competitive structure, market conditions, network symmetry, and regulator behavior - each described below in detail.

1. Market's competitive structure: In highly competitive markets, the focus of the differentiation strategy changes from competition in network coverage to competition in service provision, which makes infrastructure sharing more attractive. In high technology markets, shorter technology life cycles, the commoditization of network equipment, and less capital expenditure needed to adopt new technologies shifts the incentives of operators toward sharing <u>passive and active</u> infrastructure. By contrast, in emerging markets where telecommunications is not yet liberalized, operators are more interested in differentiating products by expanding coverage, and infrastructure sharing will be limited to passive network components, such as towers, ducts and rights of way.

2. Market conditions: Network infrastructure deployment is a low return investment in areas with a low population density or income level. Under these circumstances, there is greater incentive to reduce capital and operating expenses through infrastructure sharing. In fact,

sharing may be the only feasible way to deploy infrastructure under such budgetary constraints.

3. Network symmetry: Operators with similar rollout cycles, known as symmetric network, have incentive to share and merge networks and deconstruct redundant sites to compete in service provision. In this environment, sharing can reduce capital expenditures and operating expenses, which allows providers to add network capacity in congested areas with limited space and free up capital for other strategic investments. However, if networks are asymmetric, the largest network operator will be reluctant to share in order to keep the competitive advantage.

4. Regulator behavior: An operator’s incentive to share infrastructure is influenced by expectations about future regulator behavior. If an entrant operator has the initial benefit of access to the incumbent infrastructure from mandated sharing and expects such regulation to continue, the operator may delay investments in new technologies. Friederiszick et al (2008) and Grajek et al (2009) analyze the relationship between the intensity of regulation and investment in infrastructure and find that a higher intensity of regulation discourages entrant’s investments in new infrastructures. This aspect will be further analyzed in subsequent sections.

Infrastructure sharing is also influenced by <u>a regulatory dimension</u> when regulators mandate infrastructure sharing to provide competitive access to infrastructures, reduce market failures and increase social welfare. To illustrate, mandatory sharing and price regulation is common when the high sunk costs of network infrastructure deployment of essential facilities threatens retail competition by encouraging monopolization. Regulators can also enable infrastructure sharing agreements by making regulatory changes that obstruct potential sharing contracts. Furthermore, state aid can sometimes be used to promote the development of shared telecommunication infrastructures under PPP models.

As markets and technology evolve, regulation must also change. According to Hasbani et al (2012), the regulator´s role evolves as market structure progresses. In early stages of liberalization, infrastructure sharing needs explicit involvement of the regulatory authorities, while in mature markets, infrastructure sharing can be reached through collaboration among market participants.

Finally, there is a <u>technical dimension</u> to infrastructure sharing, such as the technically available options to implement a regulatory or market strategy. Technological progress has modified incentives for sharing and changed which assets are suitable to share.

There are three different types of sharing strategies: infrastructure assets sharing, infrastructure mutualisation, and infrastructure cooperation. Each strategy has different shared assets and bargaining power of involved agents.

- **Infrastructure assets sharing strategy** is adopted when two or more telecom operators in the same market share an asset that is necessary to provide a final service. Examples of network assets suitable for sharing are masts, ducts, antennas, transmitters or rights of use. Infrastructure asset sharing can occur through negotiations between interested parties, which results in a leasing or a cost sharing agreement, or through a regulatory provision.

Regulations to encourage or mandate sharing can introduce competition in retail markets, reduce the rural-urban digital divide, and reduce the environmental footprint of network deployment.

- **Infrastructure mutualisation strategy** occurs when a common infrastructure is built, operated, and maintained by an infrastructure provider, and jointly used by telecommunication service providers, with each leasing a portion of the mutualised infrastructure and paying for it at a wholesale price. Infrastructure mutualisation can be driven by markets or promoted by governments when the private sector does not have the incentives or resources. Public Private Partnership (PPP) approaches with different degrees of ownership and risk sharing may be used to build the infrastructure under open access, non-discrimination and low-cost pricing principles. In this model, the infrastructure provider is normally not allowed to participate in the retail market. In certain occasions, governments offer the exclusive exploitation of the infrastructure as an incentive to invest in the deployment of the network infrastructure.
- Examples of possible PPP models are 1) the cooperative model, where infrastructure and service providers jointly build and operate the infrastructure with a government subsidy, 2) the equity model, where the government obtains equity in exchange for its contribution, 3) the concession model, where the government issues a public tender to select a private operator to build and operate the infrastructure, and 4) the management contract where the government issues a public tender to select a private operator to build, operate, and commercialize the infrastructure
- **The Infrastructure cooperation strategy** refers to housing or jointly constructing linear infrastructures [6] for efficiency gains in capital expenditures and operating expenses. Infrastructure cooperation occurs when utility operators (railways, waterways, pipelines or electricity distribution) share rights of way with broadband operators, or when telecommunication operators that provide different services share the same physical infrastructure. The existence and exploitation of synergies in the coordinated construction, operation, and maintenance of linear networks [7] underpin the cooperation strategy. Cooperation differs from mutualisation because agents are not competing in the same market and, as a result, are more willing to share.

Infrastructure assets sharing, mutualisation and collaboration can be used in any internet network supply chains. Next, we analyze fixed and mobile access, the backhaul network, and international and national backbone network infrastructure sharing strategies.

1. Infrastructure sharing in the international and national Backbone networks

The internet backbone refers to the set of networks that transport and route traffic internationally and distribute the traffic within a country. Different backbone infrastructure asset sharing, mutualisation, and cooperation models are described below. This models are important to the retail price of broadband.

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[6] Linear infrastructure systems can be defined as a set of coupled layers of a generalized transportation network with passenger, freight, data, water and energy flowing in each layer Zhang et al (2005).
[7] Telecommunications, transportation, energy and water.

1.1. Infrastructure asset sharing in the backbone network

Infrastructure asset sharing among backbone providers occurs when an IBP accesses or interconnects its network to another national or international IBP network. IBPs offer transit and routing services to ISPs or to other IBPs,[8] with two types of transactions:

- Transit payment transactions - These payments are made under the principle of Receiving Party Network Pays (RPNP). For example, given X, Y and Z IBPs, RPNP is a payment method where X pays Y a price either to reach the content directly connected to Y's network or to route X's traffic to a different network Z.

- Peering or "Bill and Keep" transactions - Peering is a contract where there are no payments among IBPs under the assumption that the amount of traffic originating in X and terminated in Y is roughly the same as in the reverse direction.

Backbone providers can rely on transit agreements based exclusively on peering, transit payments, or any mix of the two. IBPs are classified in tiers of network providers (tier 1, tier 2 or tier 3) according to the intensity of peering transactions. Tier 1 providers exclusively use peering agreements, while tier 2 providers sign peering and transit payment agreements (settlement-based interconnection). Tier 3 providers, ISPs are an example, mostly use transit payment agreements.[9]

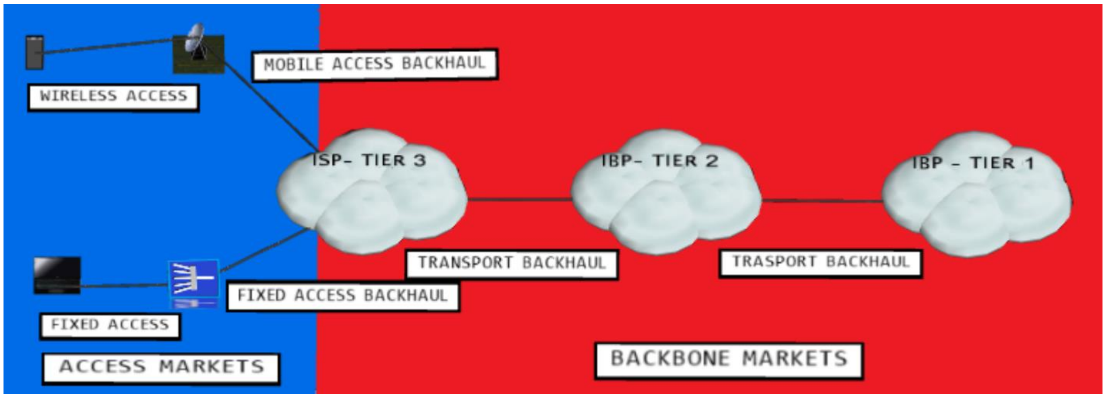
The factors explaining why an IBP signs a peering or a transit contract are the type of traffic that users consume and the cost of carrying traffic within each network.[10] The cost of carrying traffic is closely related to the geographic coverage of the IBP network. The classification of IBPs in tiers is useful for understanding the competitive dynamics of backbone markets because the intensity of peering defines the IBP's bargaining and market power.

A 2005 study on the economics of the Internet backbone found that the following set of conditions must exist to prevent Tier 1 market monopolization: 1) common interconnection standards and protocols, 2) incentives to maintain the interoperability among IBP's, and 3) demand for universal connectivity.[11]

Network externalities in the provision of backbone services also increases the risk of monopolization for both tier 1 and tier 2 provider markets. A tier 1 IBP can leverage market power either by increasing interconnection prices selectively to tier 2 rivals or by degrading the interconnection quality of competing networks. Multi-homing interconnection, which occurs when a tier 2 IBP interconnects with several tier 1 IBPs at the same time, can overcome this problem. Multi-homing increases the tier 1 IBP price elasticity of demand and limits the ability to increase prices.[12] The figure below illustrates the tiered internet network system.

[8] IBPs can also connect content providers and business through leased lines-. Some IBPs are vertically integrated and jointly offer ISP and IBP services.
[9] Mitchell et al (2007).
[10] Economides (2005).
[11] *ibid*
[12] ibid

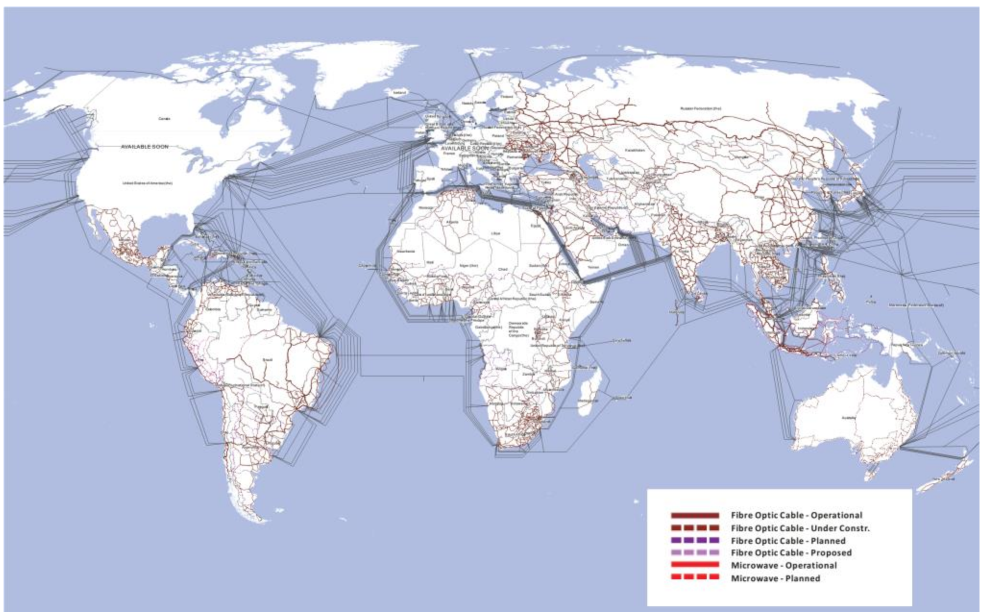
Schema of Internet networks and the classification of IBPs in tiers



Source: Author

The investment in backbone networks is featured by the existence of substantial sunk costs. There are several financing mechanisms used to finance national and international backbone networks. Some projects have received The World Bank's support in sub-Saharan Africa, public subsidies are the main mechanism in the Commonwealth of Independent States (CIS), and in Latin America, public-private partnerships and private entrepreneurship mechanisms have expanded networks to over two-thirds of the population.

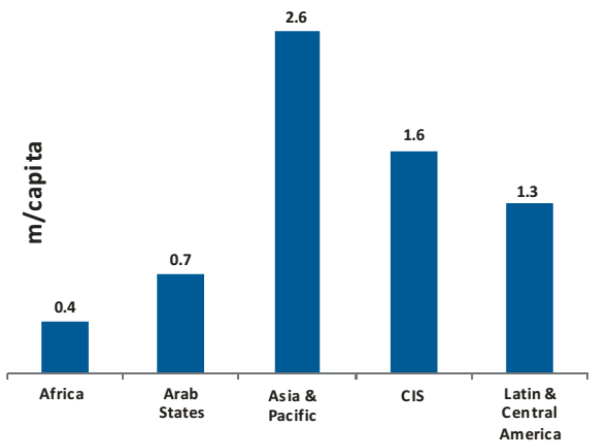
Map of world terrestrial optical fiber lines and microwaves transmission networks for the Internet Backbone



Source: ITU (2013 b). Trends in telecommunication reform. Data collection in progress: www.itu.int/itu-d/tnd-map-public/

But sub-Saharan Africa still falls short of other developing regions in route-meters per capita and population residing near a backbone network. There are 6.5 times fewer backbone network route-meters per capita in SSA than in the Asia & Pacific region, and half as many as in the Middle East.

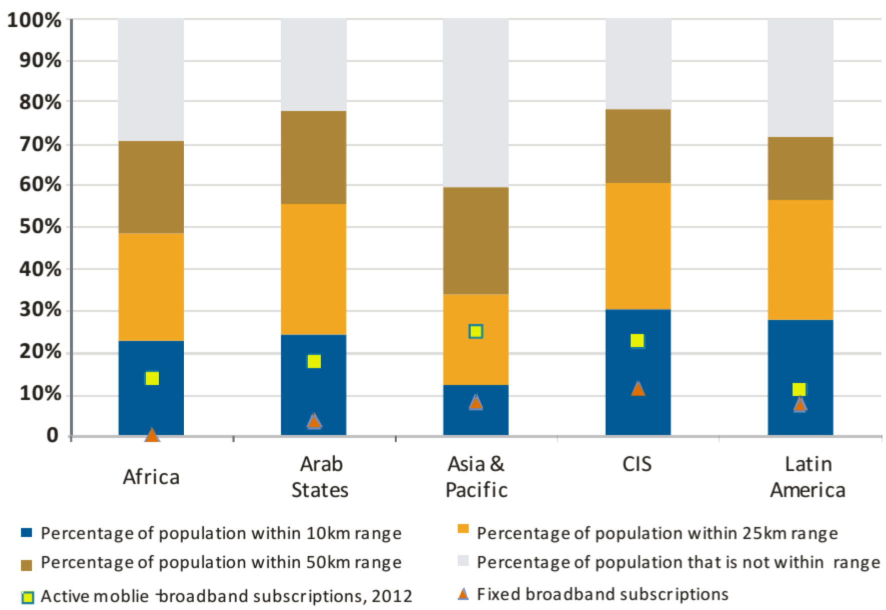
Fibers and microwaves routes in miles per capita



Source: ITU (2013 b). Trends in telecommunication reform

Additionally, 30% of the population in sub-Saharan Africa is completely out of the range of a backbone network, compared to 20% in the Middle East and 40% in the Asia & Pacific region.

Backbone connectivity in different regions



Source: ITU (2013 b). Trends in telecommunication reform

The interconnection among national and international backbone networks is important to the retail price of broadband. In order to lower the prices of international connectivity, The World Bank has supported several international IBP multi-homing projects in Africa, such as a project to deploy international submarine cables along the eastern and western coasts of Africa and a project to develop missing links in national backbone infrastructures to connect backbone networks to international connectivity providers. This strategy has improved Africa's international connectivity balance of payments as compared to the rest of the world.

1.2. Infrastructure mutualisation in the backbone network

Mutualisation in the backbone network occurs when all market agents share a single backbone network infrastructure and the infrastructure operator offers open and non-discriminatory access to all retail market participants[13]. Apart from offering access, the operator engages only in the wholesale market and does not compete directly in the retail market. The mutualisation of backbone networks usually occurs in regions that lack sufficient private funding to invest in telecommunication network construction. Additionally, such mutualisation agreements usually include exclusivity given to the infrastructure provider in order to create investment incentives. There are several Public Private Partnership (PPP) approaches, each with different degrees of ownership and risk sharing that can be used to develop mutualised backbone infrastructures.

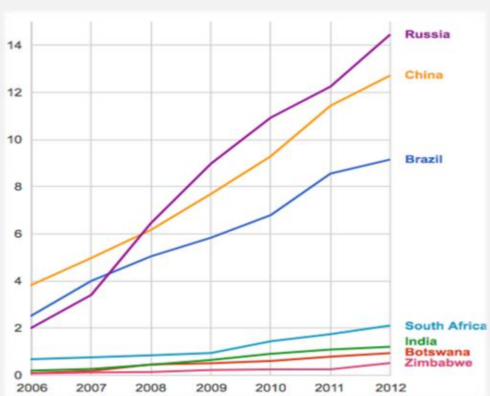
Box 1: Infrastructure mutualisation of backbone and backhaul networks in Botswana and backbone infrastructure competition in South Africa

Botswana and South Africa are examples of how a lack of competition in international and national backbone networks curbs internet expansion. Although new undersea cables partially solved the problem for both countries, Botswana turned to the mutualisation of the national backbone infrastructure while South Africa relied on constructing a second backbone network.

Before 2009, South Africa was connected to international internet networks by only one undersea cable, the SAT-3, which was owned by the incumbent operator, Telkom. For Botswana, a landlocked country, international connectivity historically came through South Africa or via expensive satellite connections. As a result, South African international connectivity competition problems affected Botswana's international connectivity markets.

In 2009, internet penetration in South Africa and Botswana was well below the average for upper-middle income countries, largely due to the lack of competition in international backbone networks. Even Zimbabwe, with a GNI per capita more than ten times less, had a higher internet penetration rate than South Africa or Botswana. Broadband penetration rates in 2009, below 1% in both countries, were also much lower than countries with similar economies.

Broadband penetration rate per 100 people in selected countries

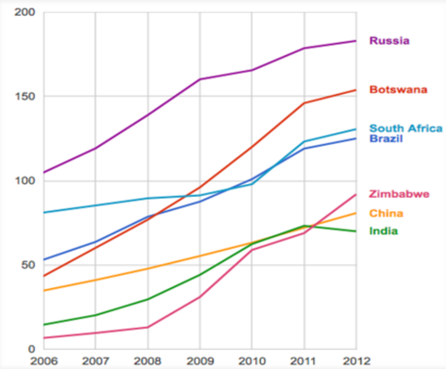


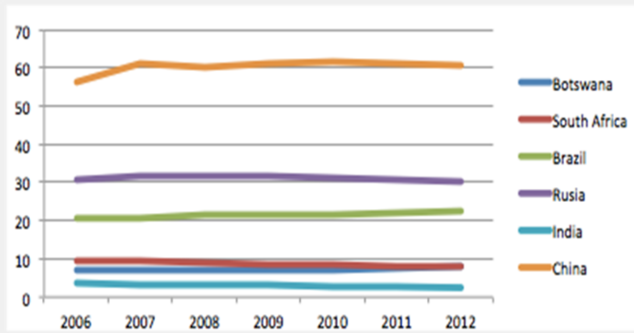
Source: ITU. ICT Eye http://www.itu.int/net4/itu-d/icteye/

[13] The mutualized infrastructure can be passive, only the dark fiber, or include also the active network elements.

Despite the low internet and broadband penetration rates, Botswana and South Africa have remarkable potential for broadband growth, based on fixed and mobile telephone subscription rates which can be used as a proxy for the potential for broadband penetration. Mobile telephone subscriptions in South Africa and Botswana are among the highest in the region; Botswana approached a subscription rate of 160% while South Africa reached 150% in 2013. Fixed telephone subscription rates were around 10% in both countries.

Mobile-cellular subscriptions per 100 people (LHS) and Fixed telephone subscribers per 100 people (RHS)

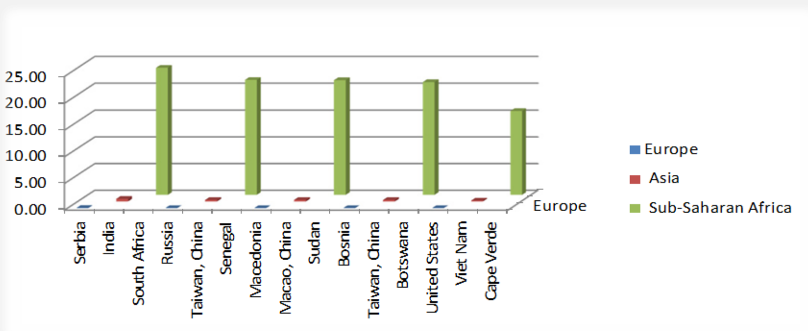




Source: ITU. ICT Eye http://www.itu.int/net4/itu-d/icteye/ (LHS) Author using data from ITU ICT statistics (RHS)

Before 2009, the share of international connectivity in both Botswana and South Africa exceeded 20%, compared to the sub-Saharan African average of around 15%. Compared to other regions, this is extremely high; the share of international connectivity in US and Europe is around 0.03% and between 0.18 and 0.49% in Asia.

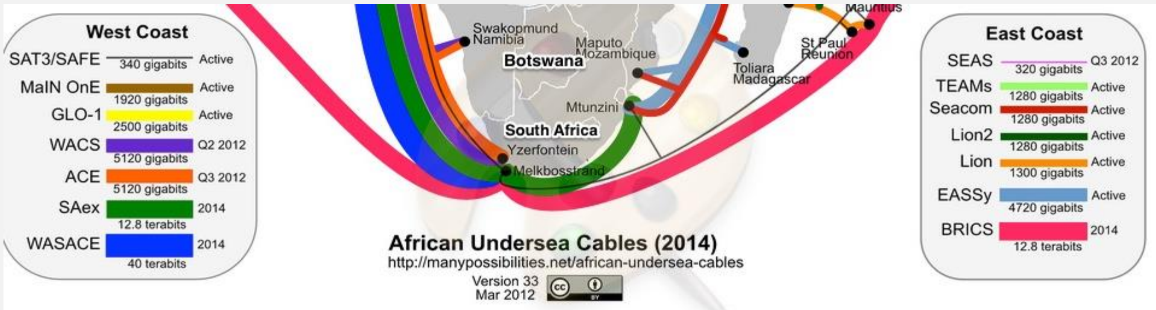
Cost of leasing 256 Kbit/s of bandwidth capacity as a proportion of the tariff charged to customers for the top five countries in Asia, sub-Saharan Africa and Europe



Source: ITU (2013 c). Study on International Connectivity in Sub-Saharan Africa

New international undersea cables in South Africa improved the situation between 2009 and 2010. These cables enabled network capacity expansion and increased competition in the international connectivity markets. In 2009, the privately financed SEACOM cable landed in South Africa. The EASSy cable (partially funded by IFC), the MainOne and the WACS cable landed in 2010. Botswana benefited from these new cables because BOFINET (Botswana´s wholesale backbone network provider) connected its backbone network to the EASSy and WACs cables.

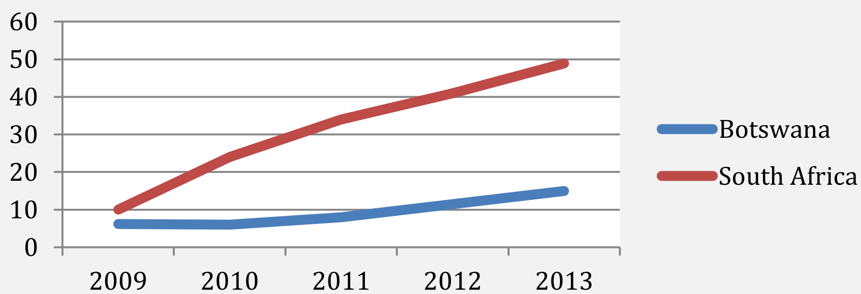
International backbone connectivity in Southern Africa 2014



Source: Modified from. Many possibilities.net.
Available at: https://manypossibilities.net/african-undersea-cables/

With new undersea cables and the subsequent increased availability of bandwidth, the price of international connectivity fell by up to 70% and set the stage for internet expansion.

Internet penetration Rate per 100 people in selected countries



Source: Author using data from ITU ICT statistics

However, lower international connectivity prices were not fully translated into retail broadband prices, which remained high. For example, the price of leasing bandwidth capacity from London to South Africa, thousands of kilometers away, was more affordable than the price of connecting the landing station to the capital through the national backbone. The new challenge was now how to promote lower prices into the national backbone, backhaul and access networks still owned by a monopolist.

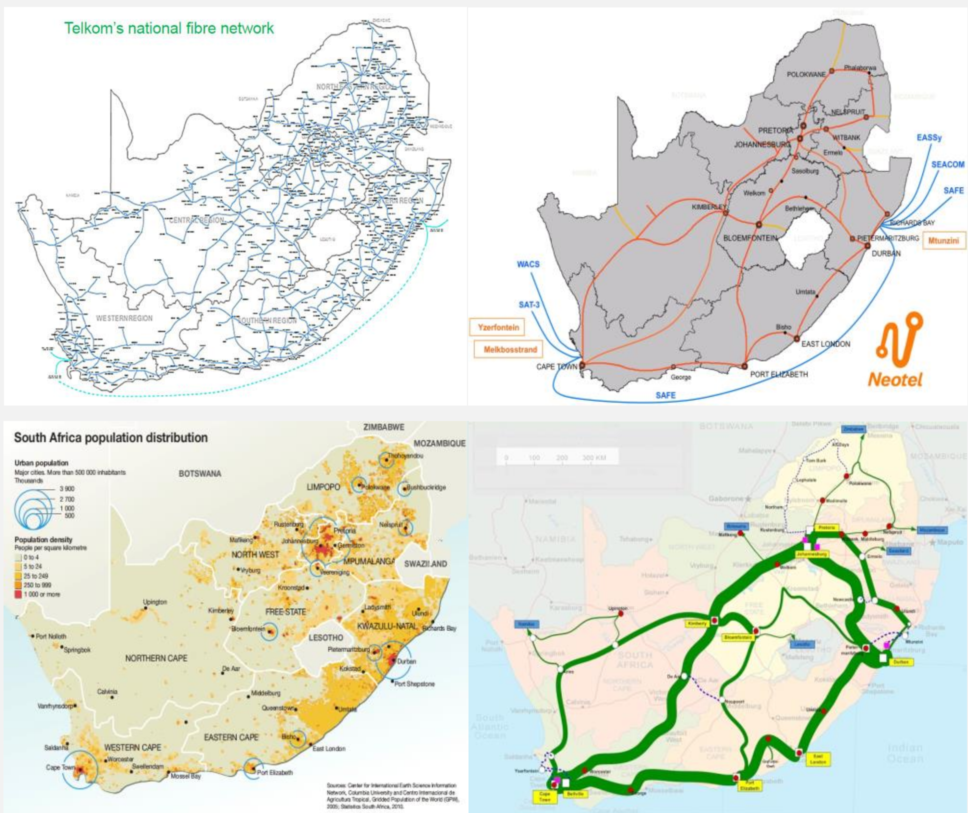
Although the starting point for these two countries was similar, Botswana and South Africa used different strategies to increase competition in backbone networks and lower prices. Botswana privatized the incumbent backbone infrastructure while South Africa is creating a secondary backbone network.

In Botswana, the regulator[14] has historically relied on sharing to promote competition and network expansion. From the beginning of the telecommunication sector liberalization in 1996, the regulator promoted infrastructure sharing, including enacting mandatory sharing of mobile access and backhaul network infrastructures and national roaming regulation. Currently, the regulator has privatized the incumbent's[15] backbone network in order to mutualise its use. After the mutualisation of the backbone infrastructure, the incumbent and other ISPs will access the backbone network under the same conditions and open access principles.

South Africa has developed a different strategy to increase market competition. To compete with Telkom, the largest backbone network provider in the country, existing fiber optic networks, previously deployed by Eskom Enterprises and Transnet Limited along electricity transmission lines and the railway system, were connected to create a new infrastructure. New fiber optic networks were added to the existing network segments to create a second backbone network. These fiber lines were transferred from Eskom and Transnet to Broadband Infraco, a state-owned enterprise and Broadband Infraco granted access to its backbone network under open access and non-discriminatory principles. A new company, Neotel, entered the wholesale market using Infraco's network and is currently developing additional backbone and backhaul infrastructures.

In spite of a second backbone network, competition in South Africa is still nascent. Telkom's network is 10 times longer than the new competitors' infrastructure and the second backbone is only available in densely populated areas. As of March 2013, Telkom owned a fiber network with 147,000 Km compared to only 15,000 km on Neotel's network.

Backbone networks in South Africa: Telkom, Neotel, Infraco, and population distribution in 2011



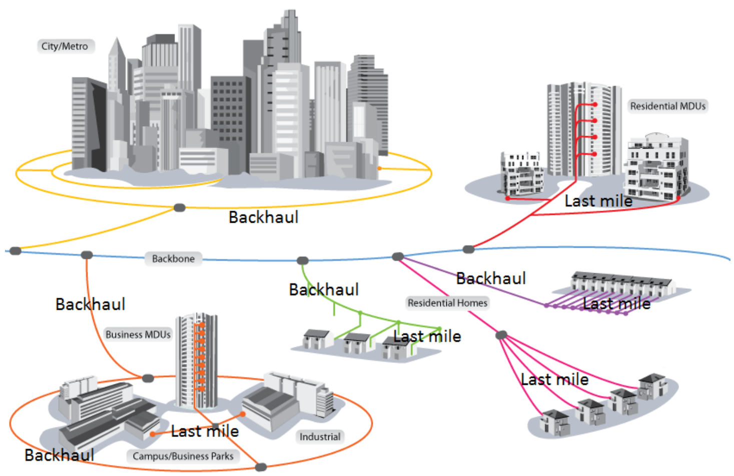
Source: Network diagrams: http://mybroadband.co.za/news/broadband/42651-fibre-in-sa-an-eye-opener.html and http://mybroadband.co.za/news/telecoms/80239-telkoms-unrivalled-fixed-line-network.html. Population density http://www.grida.no/graphicslib/detail/south-africa-population-distribution_dbae

[14] Botswana Communications Regulatory Authority (BOCRA)
[15] Botswana Telecommunication Corporation (BTC)

2. Infrastructure sharing in the fixed access network

The fixed access network usually features tree topology architecture with branches that come together in interconnection points where traffic is aggregated. The so-called “last mile” segment is the final link of the access network that goes to the final user.

Internet backbone and access network (backhaul and last mile)



Source: Modified from: http://telcoxchange.com/blogs/blog/How_To_Buy_Last_Mile

The last mile segment is the highest-priced component of the fixed access network. The construction of the last mile involves high sunk costs, which lead to high and non-transitory barriers to entry, lack of infrastructure-based competition and high prices in the broadband retail market.

Retail market competition has traditionally been achieved through regulations that force incumbents to share last mile infrastructures. Incumbents are obliged to offer connectivity services in different interconnection points at regulated prices, for example, with local loop interconnection. This model allows a certain degree of facility-based competition because the entrant is required to build the network segment to reach the local loop. A different option is bit-stream interconnection, which is the interconnection to the complete last mile network. In this case, only service-based competition occurs.

Connecting an entrant to the last mile link requires technical coordination among the incumbent and the entrant. As a result, there is a trade-off between increased competition and higher coordination complexity; closer interconnection points to customers require more complex incumbent-entrant technical coordination.

An operator’s strategic behavior towards sharing, however, depends on the degree of network rollout symmetry. When the access network is owned by a monopolist, as in the case of xDSL technologies over the copper line, complete asymmetry takes place. When the last mile access infrastructure has not yet been built, as in the case of Next Generation Access Networks (NGAN), complete symmetry occurs.

Next generation access networks have certain properties that define the optimal interconnection point. The multicasting feature available in NGAN shifts the effective interconnection point from the customer to the edge of the access network. Multicast is a cost effective and efficient video delivery system enabling simultaneous transmission to multiple users carried as a single stream. An additional feature of NGAN is the use of IP services routers. This aggregates a large number of access connections onto a small number of physical interfaces, which reduces the aggregation of hierarchical levels and increases efficiency.[16]

Unfortunately, in Sub-Saharan Africa, fixed access networks are sparse and growth is slow. The number of fixed-broadband subscriptions per 100 inhabitants in the region is below 1% and growing slowly because of the strong competition with mobile broadband.[17] Additionally, network deployment requires heavy investment because of high operating costs, and theft of copper wires is routine.[18]

2.1. Fixed access network infrastructure sharing

Infrastructure sharing strategies take three main forms: full unbundling, line sharing, and virtual unbundled local access. Additionally, some regulators also recognize the right of every network provider to share the access to the preexisting in-building passive physical infrastructure if duplication is impossible or economically inefficient[19].

i. Full unbundling is a sharing approach where all market participants share the same copper access line at a regulated price. This is the traditional model used to introduce competition in the last mile access network using xDSL technologies. This solution is technologically neutral and allows entrants to choose from different xDSL technologies, but it requires a high degree of incumbent-entrant technical coordination and, in some cases, the low quality condition of the copper wires prevents implementation.[20]

There are two variations on full unbundling, local loop unbundling (LLU) and sub local loop unbundling (SLU). In the former, interconnection is at the exchange point of the incumbent operator. In the latter, interconnection is closer to the customer at the cabinet. SLU entails higher investments than LLU but allows entrants to provide VDSL high-speed internet by connecting fiber optic links to the cabinet.

ii. Line sharing is the share of the higher frequencies of the copper wire to provide broadband. The incumbent continues offering phone calls in the low frequency spectrum of the copper wire but the higher frequencies are available for the entrants to offer broadband services. Line sharing is not technologically neutral because all operators must use the same access technology, but it requires less incumbent-entrant coordination than full unbundling.

iii. Virtual Unbundled Local Access (VULA) is a type of NGAN shared access where a single fiber is virtually unbundled (electronically, not physically) and made available to all operators.

[16] See Alcatel (2012)
[17] ITU ICT statistics. http://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx
[18] Williams et al (2008).
[19] Directive 2014/61/EU; article 9. http://eur-lex.europa.eu/legal-content/FR/TXT/?uri=CELEX:32014L0061
[20] Gabelman (2001).

VULA is a wholesale product in between the traditional concept of LLU and bit-stream access in which the interconnection occurs locally, it is service agnostic and able to support multiple services, and it is uncontended. [21] VULA allows for control of connection quality, multicasting capabilities, access, and of the customer borrowed equipment.

2.2. Fixed access infrastructure mutualisation strategies

Infrastructure mutualisation strategies apply not only the share of the last mile network but the complete access network. There are two main strategies, bit-stream and next generation bit-stream mutualisation.

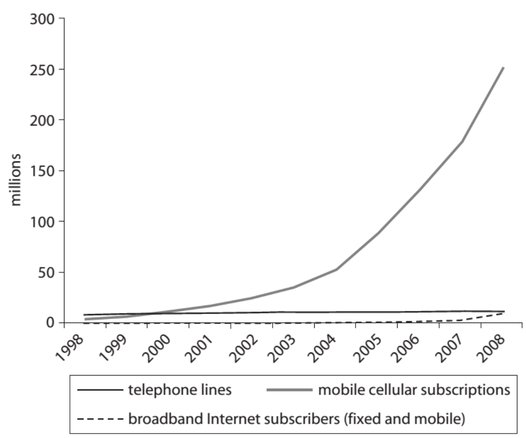
i. Bit-stream access occurs when the incumbent offers the entrant a share of the total network capacity. The incumbent keeps full control over the access network and decides when to invest, how much to invest and what technology to use.

ii. Next generation bit-stream is the virtualization of the access network. The incumbent offers different interconnection points at metropolitan, regional or national levels. Next generation bit-stream is flexible for subscriber and service management.

3. Infrastructure sharing in the mobile access network

The most affordable way to provide broadband in rural areas is to construct a wireless access network using frequencies below 1 GHz. Wireless access is one of the potential solutions for the last mile connectivity problem and is particularly important in developing countries because of the lack of fixed infrastructures.

Telecommunication subscribers in sub-Saharan Africa, 1998-2008, fixed and mobile subscriptions



Source: Williams M. et al (2011). Africa's ICT infrastructure Building on the mobile revolution.

Competition is limited by the availability of spectrum in suitable bands because the number of mobile operators is constrained by the spectrum allocated to broadband. To overcome this, mobile

[21] Ofcom (2010)

operators either multiply base stations (infrastructure-based competition) or share towers (asset sharing). Asset sharing is more common in mature and highly competitive mobile markets.

From the mobile operator's strategic standpoint, mobile broadband is a vertically integrated industry that requires acquiring the right spectrum frequencies, planning network deployment to ensure that capacity meets demand, acquiring sites, building physical infrastructure, operating and maintaining the network, and providing final services to the customer.

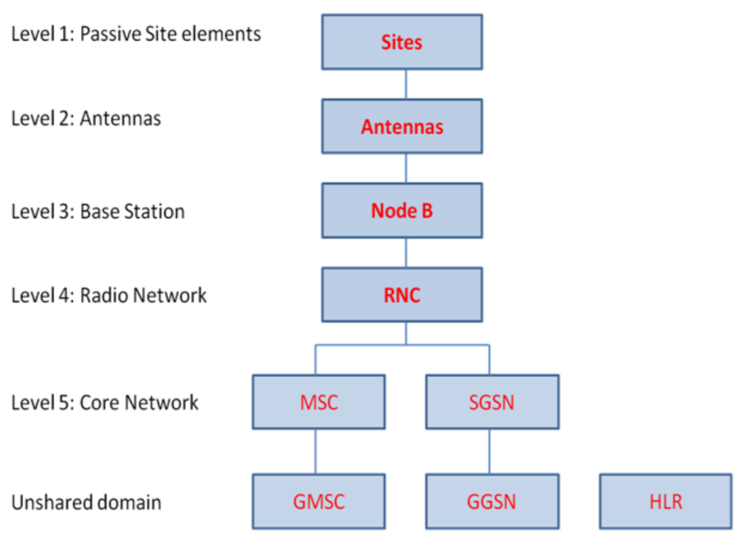
Sharing is an important strategic decision that involves a vertical disintegration process. Operators look at sharing as a trade-off between the release of economic resources for strategic investments and a twofold loss, the forfeiture of the possibility to compete in network quality and coverage and the inability to control network technological migration.

Base stations, the fundamental element of the wireless access network, have active and passive components, both of which can be shared in different circumstances. Active components are those necessary to generate, transport, transmit or receive a telecommunications signal, while passive components do not intervene in radio communication transmissions.

Sharing active components is technically complex because of operational adjustments needed to adapt different network technologies and standards; however, it is easier if the networks are deployed at the same time because both networks can use the same technology.

From a regulatory point of view, passive sharing is technologically neutral while active sharing can pose neutrality concerns.

Infrastructure sharing levels in the mobile access network and backhaul



Source: Meddour et al (2011). On the role of infrastructure sharing for mobile network operators in emerging markets.

3.1. Infrastructure assets sharing in the mobile access network

According to GSMA (2008), mobile access network infrastructure sharing can adopt the following forms:

i. Site Sharing: Two or more operators use the same site but each installs separate facilities, including masts, antennas, cabinets, backhaul, power supply shelter and air conditioning. In urban areas, where the number of available sites is scarce, site sharing is a potential solution.

ii. Tower Sharing: Each operator installs separate antennas on a shared physical mast, antenna frame or rooftop. This strategy has cost savings advantages; a 2008 GSMA study of the Indian mobile market found that tower and site sharing reduced capital and operating expenses by 30%.[22] But, Capex savings are lower if operators must first dismantle an existing mast and construct a new one.

iii. Radio Access Network (RAN) sharing: Mobile operators share all the access network facilities including radio, mast and backhaul equipment, but maintain separate logical networks and spectrum licenses. RAN sharing requires operational coordination among operators sharing a base station and is typically adopted in mature markets with downward ARPU. RAN is also common in rural and remote areas because of reduced operating costs and increased coverage. In a typical European mobile operator, RAN can reduce capital costs by up to 20%.[23] From a regulatory point of view, EU and US regulators consider RAN a competitively neutral way of sharing.

Box 2: Madagascar. Passive infrastructure sharing in remote and rural areas

Madagascar is a low-income country with around 23 million people, two-thirds of whom live in rural areas, and ICT is underdeveloped. In 2011, the country was 144th out of 155 countries in ITU's ICT development index and 24th out of 36 African countries. Affordability and access are the main barriers to ICT development in this country; mobile cellular networks cover roughly 60% of the population and the cost of ICT goods and services is approximately 65% of the GNI per capita.

The World Bank's Regional Communications Infrastructures program aims to expand coverage and accessibility to rural areas and increase mobile subscriptions in Madagascar. To achieve these goals, The World Bank is financing the construction of the base station (e.g. the mast and the power supply system) for 65 telecommunication towers in remote areas, 44 in the southwest and 21 in the southeast. These regions were chosen based on lack of coverage and potential profitability for mobile providers. Once construction is completed, mobile coverage is forecasted to reach more than 2 million people, about 9% of Madagascar's population.

The project has been financed with a cooperative Public Private Partnership. While the Government has contributed a subsidy granted by public tender, it does not have ownership over the infrastructure. The private companies awarded with the subsidy, Towerco of Madagascar, Camusat, Telma and Orange, are responsible to build, own and operate the infrastructure under open access, with non-discriminatory and low-cost pricing. A total of $15m USD, 40% of the necessary funds, was granted on a reverse subsidy auction, the remaining 60% has been provided by the private sector.

The towers will be shared by all mobile operators under open access principles and have been dimensioned to support at least three access network elements and the microwave backhaul network elements. The tower can also host additional infrastructures such as an extra operator or a broadcasting infrastructure, depending on the weight of the additional infrastructure.

[22] The research studied the Indian mobile market

Currently, over 70% of the towers have been successfully constructed in the southwest region and the first tower in the southeast was recently inaugurated. Although The World Bank has financed other mutualisation projects, the Madagascar case is innovative because it is the first project focused exclusively on passive infrastructure. Madagascar's passive infrastructure sharing is an example of how to reach the benefits of infrastructure sharing in countries where political crisis make it difficult to enact the regulatory change required for active infrastructure sharing.

3.2. Infrastructure mutualisation in the mobile access network

i. National roaming (or geographical sharing) occurs when competing operators have complementary infrastructures in different regions and agree to share networks to expand coverage to the entire country. National roaming accelerates the rollout of a new network and it is typically used for a limited period of time in order to expand network coverage with limited cash flows. From the regulatory point of view, national roaming is usually accepted, provided that network deployment is in the early stages or a new technology is being launched. The demand for new technology is low when it is released, but once it increases, the operators usually deploy a nationwide network to meet demand. Under certain circumstances, for example in markets with low ARPUs or in rural areas, there are commercial and regulatory advantages to maintain national roaming,

ii. Core Network Sharing is when operators share part or all of an entire core network, including the core transmission ring, the Mobile Switching Centre (MSC), the Home Location Register (HLR), the billing platform, and the Value Added System (VAS). Practical examples of core network sharing are limited and the associated capital and operating cost reductions of a core network sharing model are not known. This model is difficult to implement, primarily due to the necessary coordination of technologies and standards and the decrease in product differentiation options that occur when strategic commercial information is shared among operators.

iii. The Mobile Network Virtual Operator (MNVO) model occurs when MNOs sell unused network capacity to a competing operator that then commercializes the excess capacity. The owner of the infrastructure shares the complete access network, core network, backbone, and the spectrum license.

iv. Network outsourcing is a sharing model where companies outsource part or all of the mobile access network infrastructure. An infrastructure provider builds and manages the network and leases it to several telecommunication operators. The benefits of renting the infrastructure increase as the tenancy ratio increases, however, in some cases, a mobile operator can sell part of its network to an infrastructure company and the operator remains the exclusive user of the infrastructure.

The backhaul of the mobile access segment connecting the base station with the mobile operator core network can also be mutualised. This is the usual case in 4G/LTE networks where traffic expansion requires this mutualisation in order to absorb the traffic from the base station.

Box 3: Rwanda, the mutualisation of the national backbone, the international bandwidth capacity and the LTE access network

In the last decade, Rwanda's economy has grown at rates close to 8%; but, despite these improvements, Rwanda is still a low-income country with around 45% of people living below the poverty line. Rwanda's government is committed to developing the ICT sector to spur economic growth by transforming the economy, moving from agriculture to services.

The World Bank is supporting this goal with USD 24 million with the Regional Communications Infrastructure Program. This program aims to develop ICT sectors by promoting the pooled payment of international bandwidth capacity to lower the cost of connectivity. Tanzania Telecommunications Company Limited, which was awarded the project contract, will provide 1,244 Gbps bandwidth capacity over 10 years, most of which is used by the Government to provide e-governance, e-learning, and e-health services. The excess capacity has been sold to the private sector.

In addition, Rwanda is investing in backbone network expansion. From 2008-2009, the government deployed 2500 Km of fiber optic national backbone network to connect the country to the EASSy and TEAMS undersea cables. The State owns the backbone infrastructure and exclusively uses one of the four ducts, while the remaining cables are available for the private sector. Rwanda has also rolled out fiber along with national electricity, water and sanitation networks to expand backbone coverage and redundancy to insulate the market from common cable cuts.

After completing the backbone network, the Government will deploy a mutualised mobile broadband access network in the frequencies made available by the digital TV switchover, which cover 95% of total population with LTE technology.

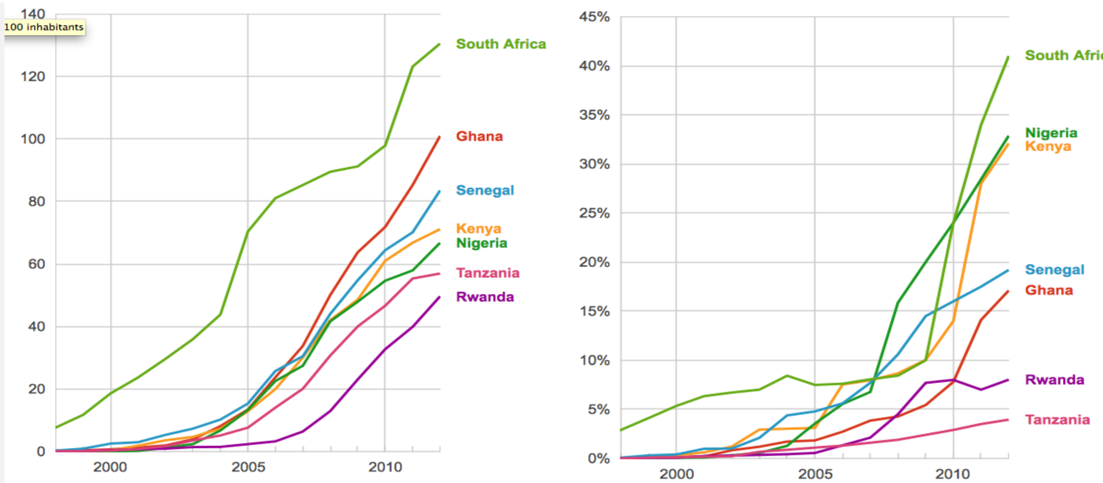
The financial mechanism established to execute the project is a joint venture; the government owns the infrastructure and provides the private partner an equity stake in the joint venture, its national backbone assets, licenses for the exclusive use of the digital switchover spectrum, and the exclusive right to sell the access network capacity at a wholesale price during a period of 25 years. In exchange, the private partner will make all the necessary investments to build the network and will not offer mobile broadband retail services. Existing mobile operators[24] and telecommunication infrastructure companies were invited to participate.

In March 2013, the government announced that they had reached an agreement with Korea Telecom Corporation, under which the latter would invest USD140 million to deploy the LTE access network in three years.

Rwanda has growing mobile telephone and mobile broadband sectors. In 2013, the mobile access market grew sharply with an annual growth rate close to 30% and a penetration rate of 54%, a fivefold growth since 2005. Mobile broadband is also growing; penetration rates reached 25% in 2013, although only 3.3% were active subscribers. The percentage of individuals using the internet by all access means remains low, with only 8% of people and less than 3% of households covered by home internet access. Rwanda's fixed broadband penetration in 2012 was as little as 0.02% and, given the higher penetration of the mobile network, mobile broadband appears to be the most suitable access technology to increase internet use and coverage.

Mobile cellular subscriptions per 100 people (LHS) and percentage of individuals using the Internet in Rwanda and key sub-Saharan African markets (RHS)

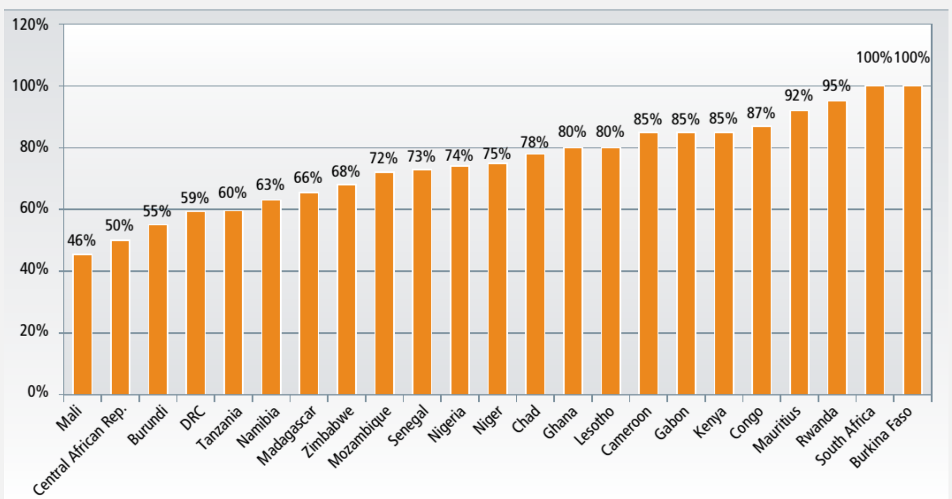
[24] Airtel, MTN and Tigo.



Source: ITU. ICT Eye http://www.itu.int/net4/itu-d/icteye/

Mobile network coverage is a strength of Rwanda's mobile market, with base stations covering 95% of population. Rwanda's coverage stands among the highest in Sub-Saharan Africa, behind only Burkina Faso and South Africa. This may be explained, at least in part, because the population density of the small country is among the highest in the world, which reduces network deployment costs.

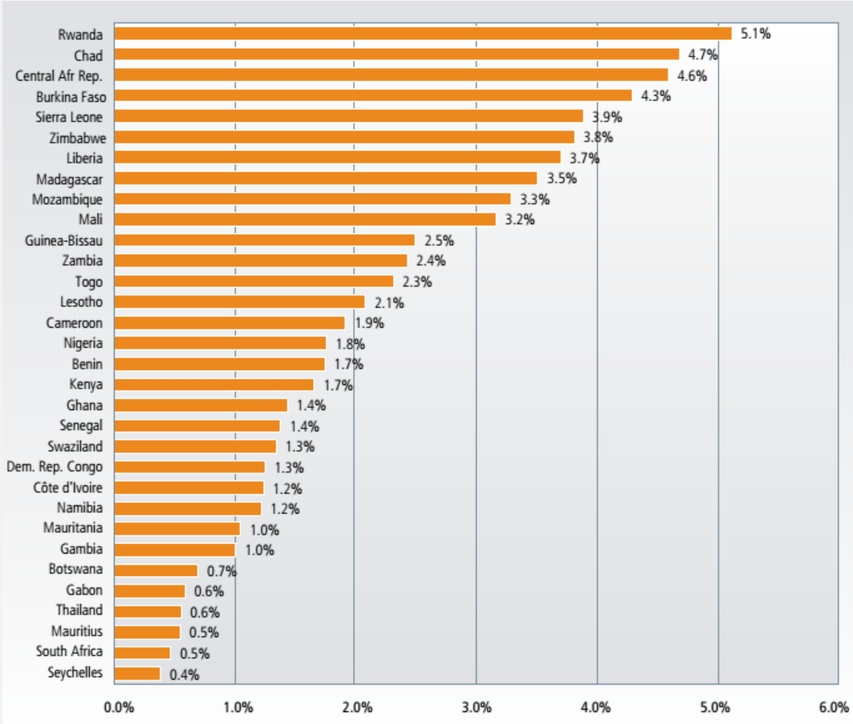
Coverage levels in Sub-Saharan Africa in 2012



Source: GSMA (2012 a) Sub-Saharan Africa mobile Observatory.

According to a study by GSMA (2012 b), the increase in mobile penetration is especially worthwhile for Rwanda's economy. For every ten percent increase in mobile penetration, GDP per capita is expected to grow by 5.1%, the highest return to mobile penetration in Sub-Saharan Africa.

Effect of a 10% increase in mobile penetration on GDP per capita growth in each country



Source: GSMA (2012 a) Sub-Saharan Africa mobile Observatory. Based on GSMA (2012 b) What is the impact of mobile telephony on growth?

Considering the current number of active mobile broadband customers and fixed broadband penetration rates, the government would likely be the main customer of the network backbone, the bulk international bandwidth capacity and the LTE access network. However, this will change if household demand increases in the following years.

The construction of a mutualised LTE access network covering the whole country may pose to reducing impediments to future innovation and investment. In general, subsidies or state aid to build infrastructure should only be used if the private sector lacks the incentives or resources to undertake the necessary investments, if intervention will not distort competition or in cases where market fails.

Technological change and innovation occur faster in mobile access network than in any other network and failing to adapt the access network to new technologies or to compete have deeper implications in retail prices, network capacity, and quality. The global regulatory trend involves more, not less market participation. Concepts such as service and technological neutrality are being incorporated in the regulation of developed countries, including those in the European Union and in the US, for example to allow market agents to select which technology and/or service should be deployed in a spectrum band. The mutualisation of the access network reduces the possibilities of market participation, especially if operators don’t take part in the construction of the mutualised access network.

Allocating at least a portion of the LTE spectrum through market mechanisms (e.g. auctions) could introduce the incentives necessary for the wholesale network operator to provide competitive prices. Moreover, allocating spectrum to a competitor would allow the existence of infrastructure based competition, which is associated with the highest levels of competition.

The PPP agreement is the key element to mitigate potential competition and innovation problems of the mutualised LTE network. The PPP contract should include enough incentives for the wholesale provider to invest in quality of service, network maintenance and innovation. The contract should also include technical and service neutrality considerations since the operators using the mutualised network should agree to change the service and/or technology. To lessen potential coordination problems, mobile operators should also participate in the shareholder structure of the mutualised network company.

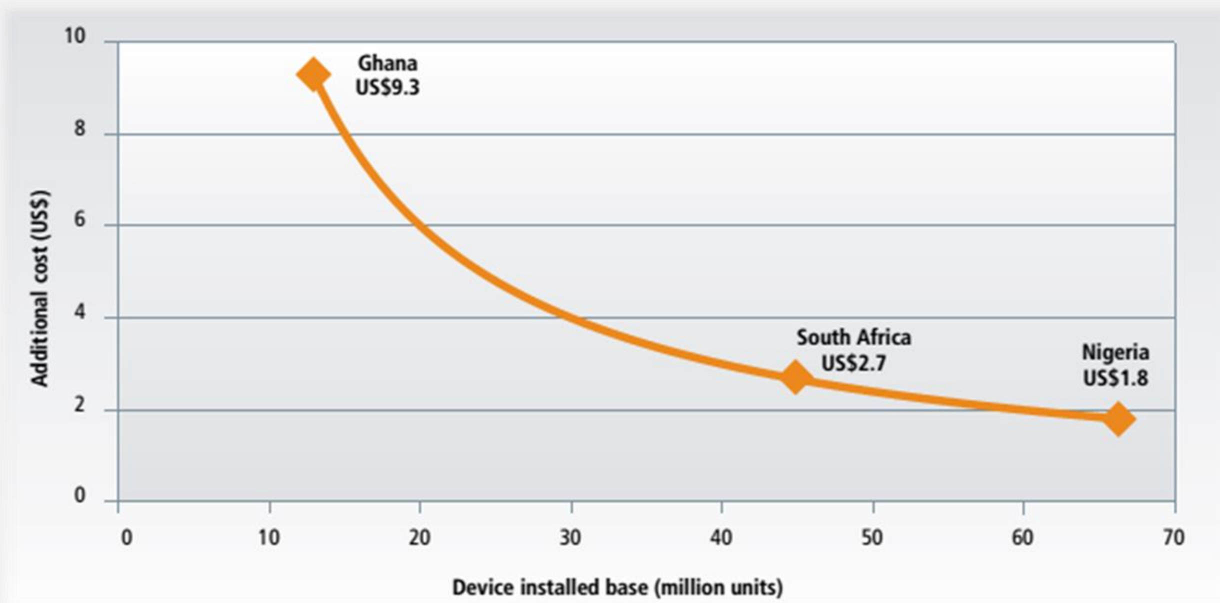
The wholesale network will be an attractive option for mobile operators only if prices are competitive; if the net present value of the cost flow generated by the wholesale prices is higher than the net present value of the cost of providing mobile broadband by re-farming existing 2G spectrum bands, operators will choose to re-farm rather than pay the wholesale price. Re-farming spectrum bands could be a low-cost solution for expanding broadband in developing countries.

Furthermore, the mutualised network should share most existing sites to avoid higher Capex and Opex than faced by current operators. For this reason, passive infrastructure sharing is mandated in Rwanda.

Rwanda has not yet announced the frequency band plan for the wholesale network. Adopting highly harmonized band plans reduces the price of terminals by stimulating demand and taking advantage of economies of scale in handset and network equipment manufacturing. In the case of the 700 MHz band, the Asia-Pacific Tele-community (APT) band plan (3GPP band plan 28) could become one of the most internationally harmonized bands with a potential market of hundreds of millions of handsets. Countries in ITU Region 2 (America) and Region 3 (Asia and Oceania) have already announced the adoption of the band plan, while Region 1 (Europe, Africa and the Middle East) is currently considering the plan.

A 2012 GSMA report estimates that if the 700 MHz harmonized band plan is not adopted, the price of a handset would increase by an additional USD 1.8 in Nigeria to USD 9.3 in Ghana. For countries like Ghana, lack of harmonization cost is huge and represents 18% of the cost of the average smartphone.

Additional device cost in the absence of spectrum harmonization



Source: Image: GSMA (2012 a) Sub-Saharan Africa mobile Observatory.

5. The role of infrastructure sharing to reduce market and regulatory failures in the provision of broadband internet

This section identifies the market and regulatory failures that justify regulating infrastructure sharing, and the circumstances under which this occurs. It also explains the economic theory underlying this justification. A regulatory intervention is not required if market agents agree to infrastructure sharing and private and social welfare are maximized through this sharing. However, if infrastructure sharing increases a market agent's welfare but decreases total welfare, regulatory intervention may be necessary to achieve the social welfare optimal allocation of resources.

The following arguments support regulating infrastructure sharing:

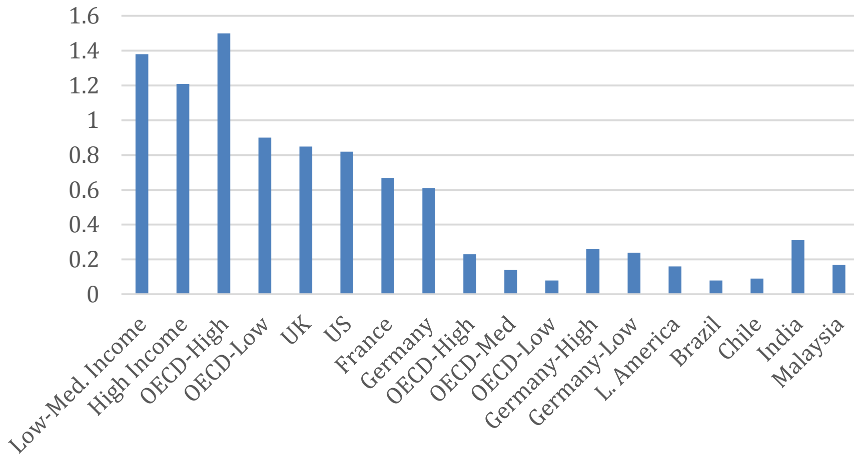
- To leverage positive externalities of internet use by spurring broadband penetration and coverage through infrastructure sharing;
- To reduce the impact of negative externalities, such as the environmental footprint of telecommunication towers;
- To lower the problem of reduced competition in the internet retail market by easing the entrance of new market agents;
- To create more competitive and efficient markets by reducing the existence of coordination failures;
- To leverage potential synergies in the construction of telecommunication and other linear infrastructures by removing existing regulatory failures, including the failure to release spectrum resources;
- To generate positive spillovers from providing wireless broadband by easing technological and service neutrality through reducing potential interferences.

A regulatory intervention to overcome a market failure must be designed carefully so that it does not introduce market distortions or prevent optimal broadband provision for society. Efficiency in telecommunication markets is both static and dynamic, and when designing regulations policy makers must consider both aspects, such as incentives to innovate and invest in future technologies, because they are important to improve total welfare. The following market and regulatory failures can be addressed by regulating infrastructure sharing.

5.1 Leveraging the positive externalities from Internet access by increasing broadband penetration to achieve the social optimum provision of broadband and redistribution policy goals

Broadband access is associated with positive externalities, such as higher economic growth, enhanced productivity, and a boost to employment. According to the World Bank (2009), a 10 percent increase in broadband penetration in developing countries is associated with a 1.4 percent increase on average in GDP per capita.

Contribution to GDP growth 10% increase in broadband penetration in different regions



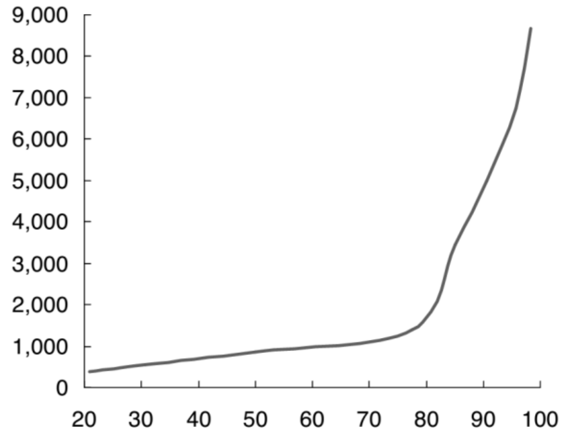
Source: R. Katz (2010) The impact of broadband on the economy: Research to date and policy issues

Government intervention of infrastructure sharing to support broadband expansion is justified if spillover effects contribute to the social optimum provision of broadband. Regulation is required when the private sector lacks incentives or resources to undertake the necessary investments. In this situation, public subsidies are a useful tool, as long as these subsidies do not distort competition and open access is available to all market participants.

There are many infrastructure sharing policies that can maximize total welfare. For example, the government can promote Telecommunication tower sharing to expand the "last mile" network coverage in rural or remote areas, or can use State aid to construct mutualised infrastructures to fill the gaps in national backbone networks. Collaboration among linear infrastructure providers to gain efficiency is another example of an infrastructure sharing policies that can be promoted by the government.

In rural areas, existing literature supports infrastructure sharing and mutualisation as a way to reduce the negative effects of the economies of density. Economies of density occur when a higher number of users in a geographic area lowers the costs to provide services. Dalton and Mann (1988), and Armstrong and Fuhr (1993) suggest mutualisation as a way to reduce the effects of economies of density and a way to avoid excessive network duplication by constructing a common infrastructure in areas where network deployments are less profitable, such as rural or remote areas. Additionally, network deployment in remote areas is associated with higher construction and maintenance costs because of a lack of reliable electricity supply sources. For example, in Mexico, the cost of reaching 80 percent of the population with mobile broadband is three times lower than the cost to cover the remaining 20 percent (see figure below).

Number of sites and population covered using the 700 MHz band in Mexico. Mobile service



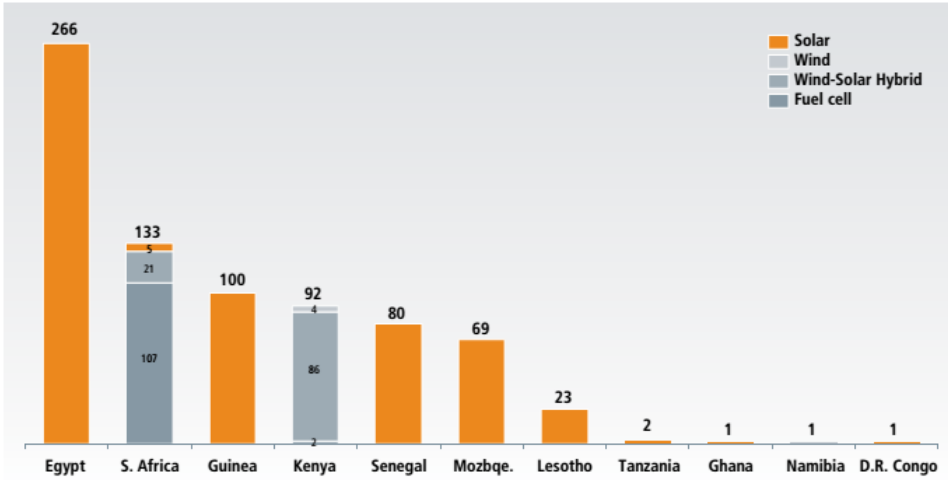
Source: CFT (2013). Telecommunications Federal Commission, Mexico.

Together, economies of density and high sunk costs in network deployment make network expansion in rural and remote areas financially unattractive to providers. Regulatory measures to encourage infrastructure sharing and universal service policies can help expand broadband to these areas. These policies can both expand coverage and unleash the positive externalities of broadband into the economy.

5.2 Reducing negative externalities, such as the environmental footprint of telecommunication towers.

Unfortunately, telecommunications networks also have negative externalities, such as the environmental impact of telecommunication towers. Luckily, these negative effects can be decreased through infrastructure sharing because sharing can reduce energy consumption. According to GSMA (2011 a), of the approximately 165,000 base stations across sub-Saharan Africa, around 79% of stations, do not have a reliable electricity supply and are powered with diesel generators. Infrastructure sharing can help to reduce the number of base stations and thus the environmental footprint of broadband.

Base stations powered by renewable energy sources



Source: GSMA (2011 a). African mobile observatory.

5.3 Lowering the problem of reduced competition in the internet access network by decreasing sunk costs and high non-transitory entry barriers

Telecommunication infrastructure deployment is characterized by high sunk costs, which are particularly important for fixed and mobile access network. Unlike fixed costs, sunk costs are a barrier to market entry and help determine whether a market is contestable, defined as a lack of market entry barriers, lack of costs to exit the market, and equal access to technology for all market participants.[25]

Contestable markets ensure a socially efficient output, avoid duplication of fixed costs and promote technological efficiency. Infrastructure sharing and mutualisation make the market contestable and therefore reduce sunk costs, monopoly rents and market entry and exit barriers.

5.4 Reduction of coordination failures of market agents to leverage the benefits of the exploitation of synergies in the joint construction, operation and maintenance of telecommunication facilities and other linear infrastructures.

The joint construction, operation and maintenance of linear infrastructures (such as telecommunication, transportation, energy and water networks) enables to capitalize on important productive efficiency gains achieved through cost savings and more functioning networks. Economic theory supports the benefits of joint deployment of networks and the interactions among the agents sharing the multi-network infrastructure. Zhang et al (2005) define infrastructure systems as a set of coupled layers of a generalized transportation network where passengers, freight, data, water, and energy flows are the commodities that use each layer. Their study uses

[25] Baumol et al (1982 a) and Baumol et al (1982b).

game-theory to find the equilibrium flow quantity and the optimal budget allocation among layers in a shared common infrastructure hosting different networks (layers).

The joint design, construction and maintenance of networks is a holistic approach to network deployment that reduces operating and capital expenses and increases total welfare. Government intervention to improve market agents' coordination is justified when the agents ignore the synergies of the holistic approach. Regulators can solve coordination failures by taking the following actions:

- Supervising infrastructure deployments to identify potential synergies;
- Creating an environment that encourages companies to leverage the opportunities of infrastructure sharing;
- Communicating the available strategies to unleash the benefits of sharing;
- Conducting the appropriate regulatory changes where needed.

One benefit to the joint construction of networks is that it reduces civil work deployment costs. In the case of fixed broadband, these costs account for 80 percent of the deployment expenses.[26] Moreover, the holistic approach to linear infrastructure deployment reduces market entry barriers, increases competition, and allows for faster deployments and more reliable networks. In developing countries that face budgetary restrictions, solving coordination failures could allow for an otherwise impossible telecommunication infrastructure.

In spite of the advantages of the coordination among linear network providers, there are challenges to overcome in order to leverage the benefits. The most important challenge is the distinct deployment pace of the different networks. While constructing a road might take years, broadband networks can be deployed in months. Accordingly, if both networks are jointly deployed, broadband cannot be used until the road is finished, with a delay of several months. The delay between joint and independent deployment is the opportunity cost to the joint deployment of networks, and includes loss of welfare from externalities and lost consumer and producer surplus. If the present value of the costs incurred in the delay does not exceed the present value of the savings accrued by the join construction, then infrastructure collaboration is the optimal solution; otherwise, the independent construction is a better option.

The benefits of the holistic approach are higher, and the opportunity costs lower, in conflict-affected countries under reconstruction or in countries with a lack of linear infrastructures. For example, providing broadband where electricity is not available has a lower opportunity cost than where electricity is available. Furthermore, cost savings are more significant in conflict-affected countries because more linear infrastructures available to be jointly built are associated with more benefits from economies of scale and cost reductions.

In cases where the telecommunication network already exists, housing a telecommunication network with other linear infrastructures can be used to build a redundant network that increases quality of service at a reduced cost.

[26] http://ec.europa.eu/digital-agenda/en/pillar-iv-fast-and-ultra-fast-internet-access/action-47-member-states-facilitate-broadband

A potential problem, which distorts the benefits of coordinating network providers, can occur when finances come from different sources. Although the public sector usually participates in the design and supervision of all linear infrastructures, different sources of financing make coordination more difficult because public financing is subject to strict internal and external controls and procedures that guarantee fiscal transparency but may delay procurement. For example, transport systems are usually financed with public funds, whereas broadband is normally funded using Public Private Partnerships (PPP). In these cases the role of the regulator as a coordinator of stakeholders and financing sources is of utmost importance.

The benefits of the joint operation of networks can be enjoyed by all stakeholders either through cost reductions or through improvements in network functionality. The possibility to deploy intelligent electricity networks, the reduction of commuting time in transport networks or the efficient monitoring and control of pollution in water networks are examples of the benefits that utilities and transport infrastructures can obtain from housing a telecommunication network.

The following table (next page) shows the interdependencies and cross-benefits of the joint operation and maintenance of networks (source: OECD).

Zhang et al (2005) identify the sources of efficiency gains. They maintain that the benefits of the generalized network are the result of different types of interactions among layers including physical, functional, informational, environmental, market and budgetary interdependencies. The mode of functioning of these interactions is described as follows:

- Physical interactions appear with the share of rights of way or with the overlapping of structural network elements such as nodes (computers, cities, and electricity plants), links (cables, wireless links, electricity wires), and paths.

- Functional interdependencies occur when the construction and operation of one infrastructure relies on other infrastructure support. For example, power supply is necessary in almost any other kind of infrastructure.

- Informational synergies refer to the creation of intelligent infrastructure systems using ICT networks.

- Environmental interdependencies take place when there is a reduction of negative environmental spillovers related to the joint deployment of networks.

- Market interdependencies appear when a single competitive market is created in the regions which are linked by a transportation infrastructure.

- Budgetary interactions happen because public agents are involved in the investment, planning, design, maintenance and management of most linear infrastructures.

Matrix of interdependencies and cross-benefits among infrastructures

Infrastructure	Telecommunications	Electricity	Land transport	Water
Telecommunications		Intelligent electricity networks, including remote metering (better demand management). Greater efficiency in spot and futures markets for electricity. More dispersed electricity consumption patterns.	Telework, teleshopping, videoconferencing, telemedicine – leads in some cases to reduced commuting and other travel. More effective vehicle fleet management. Intelligent highway systems – greater security, less congestion, more sophisticated road network pricing. Faster emergency response to accidents. JIT management and longer supply chains – generating more traffic.	With ICT and sensors – better monitoring and control of pollutants, degraded drainage systems etc., and potential for remote metering (better demand management). Possibly greater vulnerability of installations, requiring back-up and fail-safe mechanisms.
Electricity	Dependence on electricity, vulnerable to outages and voltage fluctuation. Electricity network can be used for transmission of information.		Source of power for trains. Progress in battery technology – greater use of electric and hybrid cars – may mean more charging stations. Wider coverage of household electricity – more dispersed habitat – more travel. Cost factor where road construction crosses underground electricity cables.	Dependence of water and wastewater systems on electricity, vulnerable to power failures. Hydropower plants. More widespread pumping and high-energy treatment of wastewater. Cross-subsidisation between electricity and water – depletion of aquifers and other natural water resources.
Land transport	Increases demand for mobile communications, location-based services, navigation systems, emergency services. May stimulate demand for video conferences. Provides telecoms with right of way to lay communications cable.	Use of trains to transport fuel for energy generation (coal, oil). Modal split in favour of rail results in net increase in use of electricity (consequences for sustainability objectives).		Impact on water infrastructure since this is often built alongside or under major highways. Where transport improves accessibility, new settlements will increase demand for water services. In emergencies, drinking water can be transported to disaster-affected locations.
Water	Extension of water infrastructure to new locations and new housing engenders increased demand for telecommunications.	Extension of water infrastructure to new locations and new housing engenders increased demand for electricity services. Use of waste for energy generation. Required to cool nuclear power plants.	Waterways as alternative to road and rail. Poor water infrastructure poses risks to road and rail infrastructures though flooding, pipe breakages, etc. Cost factor where road construction crosses drainage/ water pipes.	

Source: OECD (2006). Infrastructure to 2030 Telecom, land transport, water and electricity

Box 4: Synergies between telecom and transport networks in South Sudan

After a 20 year civil war, South Sudan finally gained independence from Sudan in July 2011, and four years later, South Sudan is building infrastructure from the ground up.

In 2013 and 2014, the World Bank allocated approximately USD130 million to develop roads, ICT and trade with the goal to improve economic management, governance, and connectivity. Road density in landlocked South Sudan is the lowest in Africa, with only 15 Km per 1000 km2, far behind the 101 km per 1000 km2 average of East African countries. The condition of the electricity infrastructure is not much better, with only 6.67% of urban population having access to the electricity network.[27]

The main obstacle to ICT network development in South Sudan is the lack of national and international fibre optic backbone connectivity; the country does not fibre optic or landline phone infrastructures. In fact, South Sudan failed to connect the capital city, Juba, with fibre optic networks by 2012, a target set by the African Union. The three existing mobile operators (MTN, Vivacell, and Gemtel), and the fifteen ISPs use expensive satellite connections to provide broadband, which makes telecommunications unaffordable. With most linear infrastructure networks yet to be built, South Sudan is a perfect example of how to maximize the benefits of joint construction, operation and maintenance of network infrastructures.

The different pace of construction of networks normally creates an opportunity cost from the delay in network deployment. However for South Sudan, this opportunity cost is low or non-existent because electricity is still inaccessible to the vast majority of the population.

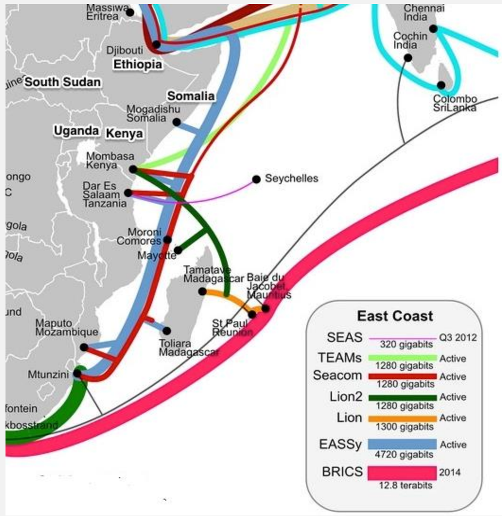
The common origin and destination of networks is an important precondition to realize the benefits of joint network infrastructure construction. South Sudan is a salient example on the common start and end of different network infrastructures. The construction of roads to reach the regional ports of Mombasa and the Port of Djibouti is a priority in the government's transport and trade strategy because the lack of all-weather road corridors increases the transportation costs of freight and inhibits the development of the entire region. These two ports are also crucial in the broadband expansion strategy because the East African and Mediterranean undersea fibre optic cables land in these ports.

The government's strategy to deploy combined networks include three routes: 1) Juba to the submarine cables located in Mombassa (Kenya) via Lokichoggio, 2) Juba to the East African undersea cables in Dar Es Salaam (Tanzania) via Nimule, and 3) Juba to the Mediterranean cables in Djibouti (Ethiopia) via Lugga. The government expects to halve internet retail prices and double the speed of connections with these fibre-optic routes.

The World Bank is financing the construction of the Juba-Kenya highway, with USD80 million of which USD15 million will be used to deploy fibre optics. The fibre optics will be deployed alongside the road using on a Public Private Partnership agreement under the open access principles and will be installed adjacent to the side drains in rural areas and under the pedestrian walkway in urban areas using the rights of way of the road. Fibre optic connection to Mombasa in Kenya is a key element of the development of the broadband strategy because The East African Marine System (TEAMS), the Eastern Africa Submarine Cable System (EASSy) and SEACOM undersea are available in Mombasa.

[27] Source: Interim Strategy note for the Republic of Sudan. The World Bank. Available at http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2013/02/07/000333037_20130207110223/Rendered/PDF/747670ISN0P1290Official0Use0Only090.pdf

East African Undersea Cables (2014)



Source: Modified from https://manypossibilities.net/african-undersea-cables/

5.5 Removing existing regulatory failures, including the failure to release spectrum resources

The regulation of telecommunications services is intended to avoid or eliminate market failures that hinder efficient markets. However, too much or inappropriately applied regulation could actually decrease, rather than increase, total welfare. Problems of regulatory capture, the administrative costs of regulation, and the misallocation of resources due to regulation can outweigh the benefits. Furthermore, inappropriately measuring market conditions and not considering the dynamic characteristics in the economic models used to regulate telecommunication services could negatively impact the investment incentives of regulated firms, which could lower social welfare.[28]

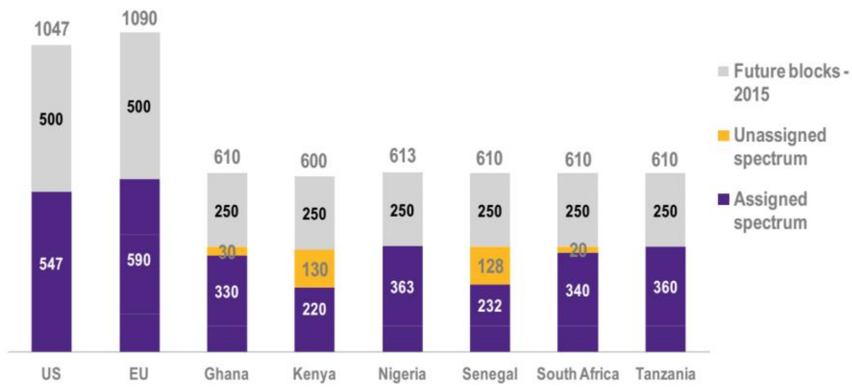
A notable example of regulatory failure is the misallocation of spectrum resources. The traditional practice is for a state agency to allocate spectrum, granting spectrum licenses specifying the service and technology to be used in each frequency band. Any change to license conditions needs prior approval from the regulator. The regulatory failure occurs when the spectrum agency is not able to allocate spectrum such that the spectrum use generates higher social value.

Spectrum management is key to developing broadband in sub-Saharan Africa. On one hand, these countries have the lowest wired internet penetration rates in the world, usually reaching only 1 percent of the population. On the other hand, penetration rates in mobile telephony are comparable to those of the OECD countries, although with considerable disparities. Because of these access differences, broadband in Africa will be provided mainly wirelessly. The take up of mobile telephony can be regarded as the most prominent ICT trend in Sub Saharan Africa; however, in spite of the importance of the spectrum for broadband development, sub-Saharan African countries have assigned considerably less spectrum to the mobile broadband service than the majority of

[28] See J. Alleman and Rappoport (2007) for a more detailed discussion.

developed countries. For example, the US has assigned two times more spectrum to the mobile service than Kenya. The lack of spectrum for mobile is a regulatory failure that poses a major barrier to broadband development and economic growth in sub-Saharan Africa.

Spectrum assigned to IMT mobile services in number of MHz in 2012 and future bands in 2015



Source: GSMA (2011 b). The benefits of releasing spectrum for mobile broadband in Sub-Saharan Africa.

Africa needs to remove the regulatory barriers that prevent optimal distribution of spectrum resources to encourage more innovative spectrum use. New approaches to allocate spectrum are more important and will have a greater impact in Africa than in any other region because of the very low penetration of fixed broadband networks. Existing regulation hinders market transactions that would allocate more spectrum to broadband. Examples of innovative approaches to spectrum management include the authorization of secondary market transactions of spectrum grant permits and the licenses allowing the shared use of spectrum and those authorizing the re-farming of existing mobile licenses in order to provide wireless broadband. These approaches require regulatory changes in the spectrum management regime.

Secondary market transactions include the sale, lease and also the mutualisation of spectrum licenses. In this case, mutualisation occurs when two or more spectrum licensees of the same radio communication service agree to share the rights conferred by their licenses in a geographical area.

Spectrum is shared when two or more two or more different radio communication services use a spectrum band in order to increase the efficiency of spectrum use. Normally, one service has a primary status and the other works in a non-protected basis using the excess capacity of the primary service or in an unused temporal slot. The secondary service cannot cause harmful interference to the primary, nor claim against interference problems.

Several spectrum-sharing technologies have recently emerged, including cognitive radio devices, geo-location databases, and radio-electric beacons. Cognitive radio devices dynamically detect the most suitable available frequency to be shared. These devices are able to change the transmission and reception parameters depending on the radio environment. Geo-location databases maintain a permanently updated database on the available frequencies in a particular area and moment but require querying a database before the device is operated. An additional option for spectrum sharing is with beacon transmission technology, which consists of radio-electric beacons that broadcast the information about the available frequencies in a particular area.

In spite of the enormous progress that has recently been made, there is still a lack of regulatory mechanisms to allow spectrum sharing. An ECC (2009) report suggests a new type of license, somewhere in between the traditional spectrum use licenses and the license exempt regime, to accommodate the shared use of spectrum. Light licenses would be granted under simplified procedures that generally do not require frequency planning or coordination among services. Registering and notifying the regulator would be enough for emission and interference control under this approach.

Light licensing of shared spectrum uses and traditional licensing

Individual authorization (Individual rights of use)		**General authorization** (No individual rights of use)	
Individual license	**Light-licensing**		**License-exempt**
Individual frequency planning / coordination Traditional procedure for issuing licenses	Individual frequency planning / coordination Simplified procedure compared to traditional procedure for issuing licenses With limitations in the number of users	No individual frequency planning / coordination Registration and/or notification No limitations in the number of users nor need for coordination	No individual frequency planning / coordination No registration nor notification

Source: ECC (2009). CEPT Report 132

The common use of spectrum is an additional option with great potential to expand wireless broadband. Common use is a method without individual rights of use - a frequency band is mutualised and does not require a license, but the equipment using the band must comply with standards to avoid harmful interference between devices sharing the band. Wi-Fi is the most well-known example of the common use of spectrum. Additional allocations to Wi-Fi based on long distance Wi-Fi networks (WiLD) have been suggested as a potential way to expand broadband, and is a good option to increase wireless broadband penetration in sub-Saharan Africa.

Re-farming existing frequency bands is also a possible strategy to expand wireless broadband. Re-farming occurs when spectrum license conditions change in order to allow the technology being used by the licensee in a particular frequency band to change. The most common example is 3G or 4G mobile technologies in frequency bands that have traditionally been used by 2G networks. Spectrum re-farming is a low-cost solution to expand mobile broadband, especially in countries with low population density or low levels of telephone service demand. Re-farming has important advantages compared to more traditional 3G deployments. Because cell using 2G frequencies are 2.8 times larger than traditional 3G cells, a 2G broadband network requires 65% fewer sites to cover the same area which reduces the total cost of operation by 60%. In addition, data rates and indoor coverage are higher in 2G networks than those in traditional 3G networks.[29]

Countries such as Denmark, Mauritius, Portugal, and South Korea have launched re-farmed networks using part or all of the 1800 MHz band.[30] Re-farming the 900 MHz band licenses is also a common approach and has been carried out in several countries including Denmark, the Czech Republic and Sweden.

5.6 Creating positive externalities in the provision of wireless broadband by easing technological and service neutrality through the reduction of interferences.

Interferences in radio communication services reduce the economic value of radio spectrum for both license holders and customers. Interferences degrade the quality of telecommunication services and prevent innovative services and applications to emerge. The costly and lengthy service compatibility studies required to guarantee a free of interferences environment among services using adjacent bands, which sometimes take years, reduce innovation and value. In fact, this lack of coordination between spectrum licensees to avoid interferences is the most prominent market failure justifying State intervention in the allocation of frequency bands. However, as noted by R. Coase (1959, 1960), when a state agency administers the allocation of the spectrum, the agency will also face difficulties in efficiently allocating the bands because it lacks the same relevant information about consumer preferences that the market possesses.

The main challenge is to find mechanisms to avoid interference and ensure that market agents participate in spectrum allocations. This is particularly important following the explosion in wireless traffic demand and the subsequent radio frequency scarcity. One suggested possible methods by which the market can undertake participation in frequency allocations is to define license conditions that are use and technology neutral. These types of licenses would allow technology and service changes without the prior consent of the regulator.[31] However, changes are only feasible if they do not cause harmful interference to existing services.

[29] see Nokia (2014)
[30] Additional countries include the Czech Republic, the Dominican Republic, Estonia, Finland, Germany, Hungray, Japan, Latvia, Lithuania, Poland, South Africa
[31] see European Commission (2009)

Preventive mechanisms can help avoid future interferences and ease technical and service neutrality and these can be incorporated in the license definition or adopted in network deployment. The most salient technique to prevent interferences is to define license requirements in terms of interference instead of transmission power and site sharing.

Traditional spectrum licenses are granted for a particular service and technology and specify the maximum power that the license holder can transmit, which helps to prevent harmful interference to other users in the same and adjacent bands. However, as highlighted by Webb (2009), a definition of license rights which specifies the maximum interference that can be caused on adjacent bands rather than specifying the power that can be transmitted, would allow for a more flexible allocation of spectrum. Licenses defined in terms of interference would foster service and technological changes as well as the innovative use of spectrum. Nonetheless, this solution is limited to new spectrum bands since existing allocations have already been planned and devices manufactured under the maximum power approach.

Sharing sites by different telecommunication networks reduces the potential inferences resulting from a change in spectrum use because it facilitates technical and service neutrality by avoiding potential coverage holes caused by a new service using adjacent frequencies.

This type of site sharing is usually a complicated in areas that are density populated because networks can have different densities of transmitter locations. However, in the case of rural and remote areas, site density tends to be similar, which makes site sharing more suitable.

Box 5: The coexistence of digital Television with LTE base stations in the digital dividend

Digital television transmitters and LTE base stations using the digital dividend spectrum band (780-862 MHz) share adjacent frequency bands. Technical studies analyzing radio-electric compatibility between LTE and the reception of digital terrestrial television indicate that LTE stations create 'holes' in the coverage of digital TV, either by interfering reception for TV channels adjacent to LTE frequencies or by overloading or blocking TV receptors so that they lose the ability to receive all television channels (Ofcom, 2009).

Infrastructure sharing, primarily site sharing, can be used to minimize interference among services using adjacent bands, either through co-siting LTE base stations with TV transmitters or co-siting LTE operators' base stations. The impact of co-siting base stations on interference in adjacent channels depends on the dimension of the coverage holes compared to the separation among base stations. When base stations are close to each other, co-siting will have limited effect on interference reduction. For example, co-siting LTE base stations reduced roughly 10% of the number of affected households in a pilot test undertaken in the UK, while[32] co-siting the LTE base station with the TV transmitter eliminated the interference problem in 90% of households in a pilot test conducted in Denmark [33] (Analysis Mason,2011; Ofcom, 2011).

In addition to interference reduction, studies show that increasing LTE base station site sharing is effective at substantially reducing the risk of digital TV receiver overload. The pilot test concluded that site sharing reduced the number of households affected by overloading by 80% (Analysis Mason, 2011).

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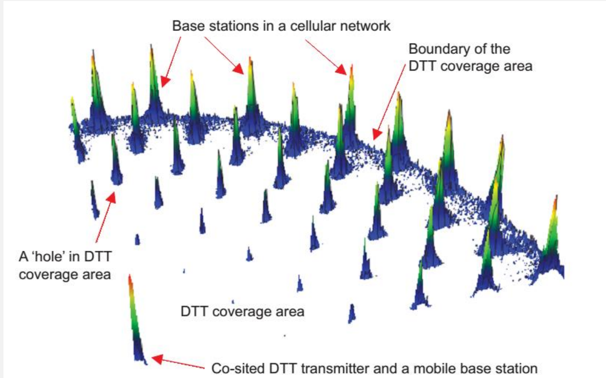
[32] Oxford Digital Terrestrial Television transmitter

[33] North Copenhagen DTT transmitter

Coverage holes caused by LTE base stations into DVB-T coverage



Source: EBU (2011). How can mobile and broadcasting networks use adjacent bands?

6. Market distortions and infrastructure sharing

A regulatory intervention that promotes infrastructure sharing can ameliorate certain market inefficiencies, such as barriers to entry in the access network; but, regulation can also complicate future market development or distort an adjacent market. Regulating telecommunication markets is complex because it is difficult to estimate the net impact of regulatory measures. In ICT regulation, it is almost impossible to regulate the market without also introducing uncertainty in a related market. Policies to alleviate a particular static market challenge may not be able to solve dynamic market problem (eg, creating appropriate incentives to stimulate innovation, investment in network quality and coverage).

Innovation is crucial for telecommunication market evolution, and the effect of policies on market innovation is an important input for market efficiency. Three different types of efficiency are important when analyzing the impact of a regulatory measure on telecommunication markets. Allocative efficiency, or Pareto optimality, occurs when scarce resources are allocated among market agents to produce the maximum possible output; any re-allocation would reduce total output. Productive efficiency occurs when telecommunication services are provided at a minimum cost. Finally, dynamic efficiency balances the short run feasibility of resource re-allocation and the long-term effect on technologies and technological innovation.

The consequences of a regulatory intervention must be analyzed on a case-by-case basis and consider the pre-existing situation, regional situations, potential effects on related markets, and future innovation and investment incentives. But even with full information and thorough analysis, regulation to mandate infrastructure can create market distortions. Potential distortions are described in detail below.

6.1 Infrastructure sharing and the incentives for investment and innovation

Market competition is the cornerstone for the provision of affordable broadband. Although mandated infrastructure sharing can increase competition in the short run by eliminating sunk-costs and non-transitory entry barriers, it can stifle investment and innovation in the long run. Two types of competition exist in the broadband market, and they have different effects on long-term social welfare. Service based competition (SBC) is introduced when new entrants share the incumbent's pre-existing facilities at a regulated price, either through unbundling or bit-stream access. Unbundling refers to the incumbent offering an interconnection point to the infrastructure, while bit-stream access is when the incumbent resells a portion of the total capacity produced. Facility based competition (FBC) occurs when market entrants build new facilities and compete with the incumbent in service provision, network quality and coverage. While SBC promotes competition in the short-run, FBC promotes long-run benefits, and as a result, is more beneficial to social welfare (Borreau et al., 2010).

Existing literature suggests that forcing an incumbent to share fixed access network infrastructure may delay facility based competition and may also decrease investments in service quality (Woroch, 2004; Kotakorpi, 2006; Bourreau and Doan, 200; Hori and Mizuno, 2009). There is also evidence that mandatory sharing can reduce innovation because the incumbent is incentivized to keep leasing prices low to prevent the entrant from adopting innovative technologies (Bourreau and Doan, 2005).

Other studies, however, suggest that mandatory sharing does not stifle all investment. Vareda (2007) shows that although mandatory sharing does reduce quality upgrades, it actually increases the incentive to invest in cost reduction strategies in service provision. Gayle and Weisman (2007) conclude that the policy decision to mandate unbundling, not the regulated wholesale price of a shared network, reduces the incumbent's investment incentives. They find that the price increase of interconnection to the unbundled network only boosts incentives to invest if prices maintain the entrant's efficient make or buy decision.

Nitsche and Wiethaus (2011) analyze the effect of regulation on investment and consumer welfare, focusing on four types of infrastructure sharing: fully distributed costs, regulatory holidays, and risk-sharing and long run incremental costs. In the investment stage, an incumbent invests in a non-duplicable infrastructure with uncertain returns, while in the subsequent stage there is quantity competition. Using this methodology, they found that a regime with fully distributed costs or regulatory holidays induces higher investments and consumer surplus as compared to risk-sharing and long run incremental cost regulation.

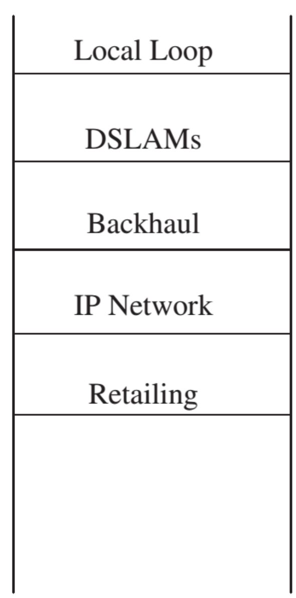
Most of the existing empirical analysis, which focuses on Europe and the US, supports the theoretical results. Wallsten (2006) and Zackaras et al (2005) show that a regulatory measure that mandates infrastructure sharing may promote competition in the short-run while reducing investment incentives in the long-run. Hausman (1998) argues that incorporating the sunk cost character of network deployments in the regulated price may be a solution to increase an entrant's investment incentive. Friederiszick et al (2008) find that fixed network infrastructure sharing discourages entrants' investments in infrastructure but has no effect on the investment behavior of incumbents. They do not find any significant impact, however, of mandatory sharing in the mobile network. They also concluded that higher incumbent investment increases the regulator´s incentive to mandate regulated access. Finally, Ford and Spiwak (2004) find a non-negative impact of access network sharing on investment incentives.

But further research is necessary to convincingly establish the effect of mandatory infrastructure sharing on competition, investment and innovation. Cambini and Jiang (2009) highlight the following areas for further research:

- Theoretical models do not consider the regulatory impact on the overall level of investment and focus instead only on one type of investment (e.g. either investment on enlargement of capacity or in new technology adoption).
- More analysis on how regulatory rules should evolve over time to create investment incentives is needed.
- No analysis has yet been carried out yet in cases where several wholesale access possibilities exist, for example local loop, bit-stream and sub-loop unbundling.
- No analysis is available on the impact of types of sharing such as mobile access and backbone network mutualisation on the incentives for investment and innovation.

There are, however, possible mechanisms to create incentives so that entrants depart from service based competition to facility based competition. Cave (2006) suggests creating a ladder of investment for entrants, which consists of increasing the regulated access price over time to encourage entrants to move from SBC to FBC. The suggested “ladder” has 5 steps; 1) copper loop or shared loop access, 2) DSLAM access located at the local exchange, 3) ATM backhaul access, 4) IP network access, access to the World Wide Web via transit or peering services, and 5) retail functions, such as marketing, billing, helplines, etc.

The ladder of investment (Ladder of replicability for broadband)



Source: M.Cave (2006). Encouraging infrastructure competition via the ladder of investment.

The main objective of the ladder of investment is to increase the regulated price so that entrants have adequate investment incentives. Cave (2006) proposes the following regulatory steps to implement the ladder of investment:

- Deciding which of the supply chain network products are non-replicable.
- Ranking the replicable components;
- Identifying where all firms are located on the ladder, both incumbent and entrants;
- Identifying investment potential of actual and new entrants;
- Choosing a mode of intervention, either raising regulated prices or withdrawing mandatory access policy;
- Calibrating the intervention permanently;
- Making pricing policy credible to avoid moral hazard problems.

Cave also asserts that the price of entrant access to the incumbent network should include Long Run Incremental Costs (LRIC), common costs, and the opportunity cost of delaying investment. Without opportunity costs included in the equation for access prices, prices will not be set at an appropriate level to incentivize the entrant to invest in network deployment. Instead, the entrant instead will continue to buy regulated access to avoid uncertainty and sunk costs.

Oldale and Padilla (2004) question the ladder of investment theory because of the many examples of regulators and industry stakeholders who have acted on expectations that turned to be wrong. Regulators should have the information, time, and competence to micro-manage the evolution of a market from service-based to facility-based competition for the ladder to create investment incentives, but this information often does not exist.

Cave (2010) re-analyzes the ladder of investment to study its efficiency in NGAN. He concludes that regulators should take into account that Next Generation Access Network costs are not sunk costs, that the monopoly suppliers need an incentive to invest, the access price, and the access point to the unbundled network.

Pindyck (2007) outlines a different option for entrant access pricing. Because entrants do not bear the sunk costs of network deployment, there is an asymmetric allocation of risk and the return to providing the service does not properly accounted for that risk. He argues that incumbents should be compensated for the asymmetric risk they bear and suggests including a price for that risk in the wholesale access price.

6.2 Infrastructure sharing and distortions in the Internet ecosystem markets

In addition to skewing incentives, infrastructure sharing can distort or modify internet ecosystem markets. For example, the share of a particular type of equipment reduces the demand for the manufacture of this equipment, such as if mobile operators agree to share the antenna system and then the demand for antennas is reduced. In the same way, changes in the internet ecosystem can modify the incentives to share infrastructure. For example, bundling telecommunication services can change the demand for infrastructure due to the existence of economies of scope, which occur when the joint provision of services reduces the average cost of producing those services. Under economies of scope, the price of a bundle of services is lower than the sum of the prices of producing each service independently. Commercial bundling of telecommunication services such as fixed and mobile broadband, telephone and internet television modify the incentives to share and build infrastructures because the demand for services also affects the need to supply infrastructure.

Bundling also alters market competitive dynamics because of the competitive interrelations among services; the provider of service bundles may gain significant market power because of the competitive advantage of producing services at lower cost. Rivals could be forced to offer a similar bundle in order to keep their business. Bakos and Brynjolfsson (1999) maintain that a new provider may be able to profitably enter a new market, capture incumbent's market share and drive the incumbent out of business by adding a new good to an existing bundle.

Additional interactions among the Internet ecosystem markets that can shape infrastructure sharing incentives are as follows:

- The demand for infrastructures and the demand for services are closely interrelated. Emerging new content and "over the top" services of internet networks like IP television and streaming services is increasing demand for network capacity and broadband infrastructure. Equally, the demand for internet services is driven by network capacity and availability.

- The shared use of spectrum can enhance competition by increasing the number of wireless broadband operators and modify the demand for infrastructure.

- The existence of economies of scale in the deployment of networks is responsible for the emergence of infrastructure companies that build towers to host several telecommunication networks. These operators offer leasing, operation, and maintenance and sometimes network planning to telecommunication service operators. The bigger the scale of the infrastructure operator the higher the incentives to share sites and expand networks.

7. Policy Recommendations for regulators and policy-makers

Policy recommendation 1: *Enable commercially driven infrastructure sharing when it does not distort competition.*

Commercially driven sharing agreements should be encouraged because of the positive spillovers of broadband expansion, provided that these agreements do not harm competition.

Policy recommendation 2: *Regulators should reduce coordination failures to promote infrastructure collaboration among linear infrastructures providers.*

The regulator can identify synergies that exist in joint infrastructure deployment, communicate the benefits to stakeholders, and enact the appropriate regulatory changes to create an environment that promotes infrastructure collaboration. The regulator can also coordinate the generalized linear network. Housing telecommunication networks is worthwhile even if telecommunication infrastructure is already built because a duplicated network can create backup networks, which improves service reliability and introduces competition in monopolized markets.

Policy recommendation 3: *Subsidies and state aid to support mutualised network infrastructure deployment should only be granted in cases where markets fail or externalities occur.*

Government subsidies for constructing mutualised infrastructures must be limited to instances where the subsidies will support clear and transparent policy goals, such as filling in infrastructure gaps, increasing coverage in rural or remote areas, or providing access to international connectivity links.

Government intervention should only be used if the private sector lacks incentives or resources to undertake the necessary investments, if intervention will not distort competition, and finally, if mutualized infrastructure will lead to the social optimum provision of broadband. Additionally, access to a mutualised network must be open to all market participants and must be provided under non-discriminatory principles.

Rather than relying on state aid, infrastructure users can finance, construct and operate a mutualised network. This strategy is highly recommended because it reduces public expenditure and also creates incentives to invest in quality of service, network maintenance and innovation. The price of accessing the mutual network should be regulated to avoid infrastructure owners' incentives to collude or limit the capacity of new entrants to access the market.

Policy recommendation 4*: Mandated sharing is the last resort to reduce bottlenecks when infrastructure competition is not possible, and/or agreements among stakeholders are difficult to reach.*

A regulatory intervention supporting infrastructure sharing can be useful to lessen specific market problems, but regulation can also complicate future market developments or distort the functioning of adjacent markets. Regulatory interventions must be analyzed on a case-by-case basis, taking into account dynamic aspects of the market such as innovation and future investment incentives.

For example, some countries include sharing obligations in the regulatory framework to aid broadband expansion; and while such provisions may be justified, there must also be an analysis of the impact of sharing on investment incentives. Furthermore, the regulator should take into account that the enforcement of the interconnection requirements might be complicated by a lack of resources and limited available capacities.

Policy recommendation 5*: Political economy matters. Simple solutions that do not require complex regulatory changes are effective in most cases.*

Regulatory reform in countries in political crises are complex and potentially fruitless. Promoting sharing models that can be adopted without regulatory reforms and with demand side policies, such as passive infrastructure sharing, can be a successful approach because the benefits of sharing can be realized without using complex regulatory interventions.

Policy recommendation 6: *Demand side policies are important, and connectivity prices can be reduced by aggregating demand.*

The design of a public tender to select an international connectivity provider for the supply of bulk bandwidth capacity for a long-term period, e.g. 10 years, is a simple and effective practice that reduces connectivity prices.

Policy recommendation 7: *Public Private Partnerships (PPP) are a sound tool to promote ICT sector investment from the ICT demand side.*

Providing e-services, such as e-governance, e-learning, or e-health, and promoting e-banking services and secure e-commerce through PPP agreements are examples of how governments can stimulate demand to achieve development objectives. Demand side policies can increase of the incentives for network investment in the supply side.

Policy recommendation 8: *A sound competition regulation requires monitoring interactions between the Internet supply chain and the markets of the Internet ecosystem.*

Regulatory provisions must adapt to changes in the markets of internet ecosystem. For example, bundling strategies or economies of scale in infrastructure sharing deployment change the competitive dynamics of broadband markets because dominance in one market can be propagated to adjacent ones. Regulators should act accordingly to avoid cross subsidies, price squeezing, or mergers and acquisitions that distort competition. Regulators may identify the problems and impose conditions to mergers and acquisitions or the price of bundled products to prevent the appearance of anti-competitive behavior or impose fines and remedies to correct distortions that already exist.

Policy recommendation 9*: It is important to tackle spectrum bottlenecks with additional allocations to mobile broadband and to enable authorization methods to give mobile broadband access to underutilized spectrum*.

The Radio-communication Bureau of the International Telecommunication Union (ITU), the UN specialized agency for telecommunications, estimated between a 1,280 and 1,720 MHz need for additional spectrum for mobile broadband by 2020 (ITU, 2007). Current spectrum allocations in sub-Saharan Africa only allocate about 400 MHz to mobile broadband (e.g. 363 MHz in Nigeria and 220 MHz in Kenya). Even with planned future allocations, the amount of spectrum will not exceed 600MHz, around one third of the forecasted needs. Several regulatory provisions should be taken in order to increase spectrum allocation for mobile broadband:

- Make additional allocations to the mobile service in available bands.

- Design a new licensing spectrum regime to allow innovative approaches such as the licensed or authorized shared access to enable the shared use of underutilized spectrum. [34]
- Allow secondary market transactions of spectrum including the sale, lease and the mutualisation of spectrum licenses.
- Enable technology and service neutrality, for example, re-farming 2G licenses would help introduce 3G and 4G mobile technologies in existing spectrum allocations.

8. Conclusions

Governments are now placing a higher priority on broadband infrastructure to improve e-governance, e-learning, and e-health services, and infrastructure sharing is one trend that can help expand broadband networks. For governments, sharing is an opportunity to expand the knowledge society faster and at lower costs.

Traditionally, infrastructure sharing was associated with regulated access to the last-mile network over the copper line, which occurred after the market liberalization in the late 90's. With the advent of mobile telephony, mobile operators voluntarily shared both infrastructure assets, such as masts, and intangible assets, such as rights of way, to reduce network deployment costs. Asset sharing was especially useful in rural or remote areas where service provision was typically less profitable. At first, operators shared passive infrastructure assets when coverage was a competitive advantage, but once all competitors reached a comparable coverage they began to share active infrastructure assets and even outsource their network to infrastructure companies.

The traditional model of asset sharing is now complemented by two new types of infrastructure sharing: infrastructure mutualisation and infrastructure collaboration. Mutualisation is the share of a common infrastructure by all service providers, while collaborative infrastructures house different networks or are jointly constructed with other linear infrastructures, such as electricity lines or roads.

Infrastructure mutualisation in Africa came in three waves. The process began with undersea cables connecting Africa to the fiber optic international connectivity networks. The EASSY undersea cable, for example, that was put into operation in 2010, was deployed under the mutual agreement of 20 African and 4 international telecom operators, and it received support from the IFC and other Development Financial Institutions.

Network mutualisation continued with connecting national backbone networks to the new submarine cables. Different approaches were adopted in several countries, for example, Rwanda created a State Owned Enterprise (SOE) to operate the mutualised backbone while Burundi operated the mutualized backbone through a consortium of mobile operators.

[34] Licensed shared access (LSA) and Authorized Shared Access (ASA) are authorization procedures that allow the use of a spectrum band by two different services. The regulator establish specific rules and conditions to avoid interference among services sharing the band.

In countries where the backbone network already existed, mutualisation was used to break monopolies. In Botswana, for example, the government undertook the structural separation of the incumbent operator to create a new SOE. In a different approach, South Africa leveraged the existing fiber optic cables along with railways and electricity lines to create a new backbone provider to compete with the incumbent operator.

A new mutualisation model is taking place in the mobile access network. The governments of Kenya and Rwanda are planning to construct a common LTE network in order to offer wholesale mobile access to existing mobile operators.

Each of these mutualisation models poses difficult regulatory challenges. Whether or not monopoly provision of infrastructures can coexist with retail competition is still unknown, and further research on the potential disincentives to invest in network quality and new technologies is needed.

The construction of a mutual undersea cable infrastructure is less controversial than backbone and access network mutualisation. Multiple market agent participation and different cable systems guarantee competition because the possibility to connect to several cable systems eliminates the dependency on one provider.

Literature on the effect of backbone mutualisation on investment and innovation incentives is scarce. However, the literature on access network mutualisation is abundant and the results may be similar. In the last case, literature describes reduced incentives to invest and innovate. The participation of all market agents in the construction and operation of a mutual backbone reduces the risk of monopolization. The creation of a SOE to operate the backbone seems to pose a step back in the process of market liberalization although in some cases this might be the only possible solution if it is not possible to reach an agreement among market agents.

The joint construction of a mutualised access LTE network is the most controversial approach because it is in the access network where technological change and innovation is faster. The global trend implies that more, not less, market participation will enable market decisions on which technology and/or services should be deployed. Technology and service neutrality should be the rule in the access network, but mutualisation of the access network reduces the possibilities of market participation.

Highways constructed to foster trade and connect people have frequently the same destinations and origins than information "highways." This fact, together with the cost reductions associated to the exploitation of synergies in the construction operation and maintenance of the infrastructures, made the collaboration among different linear infrastructures providers worthwhile. The infrastructure collaboration model is useful in three different scenarios:

- Post-conflict countries or countries with underdeveloped linear networks benefit the most from infrastructure collaboration because the opportunity cost of a delay in broadband expansion is smaller.

- There is still room for housing telecommunication infrastructures in countries where a telecommunication network already exists because a second network can improve quality of service and reduce service disruptions.

- Infrastructure collaboration can be used to duplicate infrastructures to increase competition in backbone networks and reduce the incumbent's market power.

The uptake of wireless access deployments is another important trend in the development of advanced ICT networks in Africa. Wireless connections are crucial to network development in Africa because of the low penetration of wired lines. Soon, broadband in Africa will be synonymous with wireless broadband. The good news is that wireless broadband can use existing mobile telephony infrastructure. Some countries, such as Botswana or South Africa, enjoy mobile penetration rates above the OECD average of around 150%.

Infrastructure sharing is an opportunity if used correctly and is commercially driven; however, it can also be a considerable risk if poorly implemented. In the access network, sharing passive assets is the least risky measure to be adopted since it poses fewer problems to competition and does not require regulatory changes.

The need for wireless broadband spectrum in sub Saharan Africa is greater than in any other region in the world. But the allocation of spectrum to mobile broadband in sub-Saharan Africa is on average only a third of the forecasted need in 2020. Innovative approaches to spectrum management and licensing are important to expand broadband, and African regulators must undertake the technical and regulatory changes to unleash the potential of wireless broadband in their countries. Shared and common use of spectrum are important options to spur broadband development, but they are not the only options. Re-farming existing spectrum bands for mobile broadband, especially in the 900/850 MHz bands, is also a low-cost option for expanding broadband in Africa.

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