Unclassified **DSTI/ICCP/CISP(2013)4/FINAL**

Organisation de Coopération et de Développement Économiques
Organisation for Economic Co-operation and Development **18-Feb-2014**

English - Or. English

DIRECTORATE FOR SCIENCE, TECHNOLOGY AND INDUSTRY
COMMITTEE FOR INFORMATION, COMPUTER AND COMMUNICATIONS POLICY

DSTI/ICCP/CISP(2013)4/FINAL
Unclassified

Working Party on Communication Infrastructures and Services Policy

INTERNATIONAL CABLES, GATEWAYS, BACKHAUL AND INTERNATIONAL EXCHANGE POINTS

JT03352652

Complete document available on OLIS in its original format

English - Or. English

FOREWORD

This report was presented to the Working Party on Communication, Infrastructures and Services Policy (CISP) in June 2013. It was made public by the Committee for Information, Computer and Communications Policy (ICCP) in December 2013. The report was prepared by Mr. Rudolf van der Berg. The econometric analysis on website hosting was done by Mr. Piotr Stryszowski. It is published under the responsibility of the Secretary-General of the OECD.

The data on website hosting was contributed by Pingdom. Mr. Magnus Nystedt of Pingdom is thanked for gathering the data and working with the OECD team.

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MAIN POINTS

This report focuses on the development of backhaul and cross-border networks, which enable local networks to connect to the wider Internet. These local networks may cover a city, a region or even a country. To connect their networks to other networks around the world, operators need access to regional and international high-speed networks. The level of investment required in these networks varies and can be very different from region to region. In some parts of the world, the investment made around the turn of the century was characterised by a “boom and bust”, which fuelled an expansion in backhaul links and datacentres. Since that time, investment has taken place at a more measured pace, reflecting growing demand from liberalised markets and leading to further expansion in areas such as mobile and broadband Internet access.

Fibre networks form the basis of backhaul networks, with some niche applications for microwave and satellite. A fibre pair can carry as much traffic as all geosynchronous satellites combined together. A single duct of fibre can carry all traffic in the world. In most OECD countries backhaul networks have become interconnected meshes crossing borders and complimented by multiple Internet Exchange Points (IXPs) and direct interconnections between networks. This allows traffic to be rerouted when necessary and provides competition and alternative paths. In many developing nations, backhaul networks have the shape of a river system, where first mile tributaries bring the data into ever widening backhaul connections that end in an international submarine fibre. Network resilience in these areas could benefit from regional and cross-border meshes of connectivity.

Some in the Internet technical community have expressed the view that the number of exchange points around the world has not yet reached a sufficient scale and that expansion should be proceeding at a faster pace. The issue here is not just the traditional challenge of establishing IXPs in countries where they do not currently exist, though that remains a priority. These commentators expect a need for a significant increase in the number of IXPs, in the next decade, from the current 20 major locations to a future with 200 such locations. The basis for this assessment is the increased use of fixed and wireless broadband access throughout the world. A significant proportion of the users of these connections are in countries and regions that are under served. Much of their traffic will be sourced or routed from outside their region if IXPs are not available for content and services providers to further localise this traffic. This results in higher costs for transit.

Most OECD countries currently have robust backhaul and co-location markets on the main routes in their country. Liberalisation of markets enabled competition to achieve this situation and prices for backhaul continue to decline. There are challenges, however, in regional and remote areas where there is insufficient competition for backhaul. There are also indications in some countries that there may be insufficient competition in backhaul markets where the majority of the most accessed websites, designated under their country code top level domain, are hosted at a foreign location. This requires ISPs in these countries to purchase more international access, which reduces the resilience of networks and weakens the position and effectiveness of IXPs in their own country.

In many countries around the world, insufficient competition is the root cause of the lack of affordable backhaul. The availability of submarine fibre technology has brought prices down in coastal countries where competitive operators are able to bring this capacity to the market. The challenges can be greater for landlocked countries without co-operative neighbours for access to landing stations and other necessary infrastructure. However, the report also notes that landlocked countries are behind coastal neighbours in liberalising their telecommunication market. Countries could greatly improve the functioning of their markets by removing specific licenses for specific functions in the backhaul market, such as regional, national and international licenses and licenses for landing stations.

INTRODUCTION

In the Seoul Declaration on the "Future of the Internet Economy", ministers undertook to support making the Internet economy global and highlighted the need to:

- Support expanded access to the Internet and related ICTs, especially for people in developing countries.
- Recognise the importance of a competitive environment for the successful growth of the Internet economy and the opportunities this can bring for development, particularly for people and regions with the most limited economic means.[1]

In order to achieve this goal, the infrastructures connecting countries needs to be of high quality and available at competitive prices. The review of the Declaration for the Future of the Internet Economy (OECD, 2013) the Seoul Declaration OECD(2008) concluded that the availability of high-speed international submarine cables had increased in recent years. As of 2012, most countries and regions in the world were connected to submarine fibre cable networks, increasing the available capacity to their countries and lowering latency for international traffic. The review concluded that future work should focus on how both reliability and competition in international connectivity could be improved.

This report focuses on backhaul and cross-border networks, which enable local networks to connect to the wider Internet. These local networks may cover a city, a region or even a country. To connect their networks to other networks around the world, operators need access to regional and international high-speed networks (submarine fibre optic or satellite). Going forward, the level of investment required in these networks, varies and can be very different from region to region. In some parts of the world, the investment made in such networks was characterised by a boom and bust in the lead up to the turn of the century. This largely coincided with the "dotcom bubble".

After being constrained by monopolies, the initial years of liberalisation were accompanied by over supply on some routes. On others, the demand itself was constrained by on-going monopoly power over gateways or the local access networks in a particular country. Further liberalisation has contributed to addressing this situation by generating new demand. The expansion of mobile penetration is one example of where market liberalisation brought new demand for international connectivity. More broadly, the changes that the Internet has enabled, like the creation of new industries in areas such as the outsourcing of services, generated new demand for international connectivity.

There are now signs of new infrastructure being deployed in Africa, Latin America, the Caribbean and the Asia-Pacific region. Terrestrial networks are expanding in countries, submarine cables are connecting countries and continents. Some of the new cables will follow traditional routes and others plot new paths of connectivity, such as two proposed cables between Latin America and Africa. At the same time there are new cables proposed on the trans-Atlantic routes to connect financial markets, on novel routes. In addition, complimenting the increase in global connectivity, satellite operators have also deployed new and more efficient broadband capable solutions.

In some countries, excess capacity through the use of dark fibre on alternative networks, such as electricity or railway networks, is being used as an effective addition to infrastructure. Nevertheless, there is still insufficient competition in some regions to facilitate competitive pricing and to allow for international Internet traffic backhaul. There are also challenges in linking available capacity to Internet exchange points (IXPs), either because they do not exist or because authorities impose restrictive regulation in areas such as gateways to international facilities, the use of alternative networks and dark fibre, or competitive backhaul from satellite and submarine-cable landing stations.

Defining backhaul networks

First (or last mile) networks carry telecommunication data from the customer to an antenna or local switch. Backhaul networks carry the traffic of the first mile networks (DSL, cable, mobile) towards central switching locations and to their final destinations. Backhaul networks can cover a city, a region or a country and are known under different specific names. Historically, the terms used for backhaul networks have included 'trunk networks', inter-local or long distance networks. Other commentators use terms such as "middle mile", "metro", "core", "submarine", "backbone" and "international network". These terms do not, however, necessarily specify any specific network length or particular technological deployment. What is termed as a metro network in one context, for example, may be considered to be part of a backbone or core network in another. The size of countries and their geographic distribution varies significantly. As a result a transnational network, for one network operator, may cover a fraction of the national network for another. This document, therefore, uses the term backhaul network as a general term to refer to these situations. Where necessary it is more specific, based on the use of particular facilities. An example could be using mobile backhaul for traffic from cellular antennas to the rest of the network.

The term backhaul is not limited to public networks. Private networks may also use the term to denote an inter-office network on a city, regional, national or international scale. In a liberalised market these networks may deploy and purchase connectivity in much the same way as public networks do.

A further term frequently used in relation to backhaul is that of leased lines. The main distinction is that the line is leased from a third party rather than self-deployed. The type of network a leased line supports is dependent upon the situation. It may, for example, describe a first mile solution to connect antennas in mobile networks or offices to backhaul networks, using connections such as fibre, a wavelength, E1/T1 and similar connections. A leased line may also denote a backhaul link that connects various branches that are connected via first mile connections. It may also be the full link between two or more locations, independent of the underlying networks. The use of the term is often dependent upon the user of the network. A business-to-business ISP may use the term leased line for the last mile and the term backhaul for that part of the network that carries the traffic further into its network. An end-user may call any connection between one or more offices a leased line or backhaul.

Technologies used for backhaul networks

Fibre has become the predominant technology for backbone networks. The abundance of bandwidth it offers has changed the underlying economics of providing backhaul networks. To illustrate this, an example can be used. Using commercially available equipment a single fibre pair can carry 160 wavelengths at 40 Gbit/s carrying 6.4 Tbit/s. Some ISPs, as a rule of thumb, use the figure 200-500 Kbit/s to estimate the interconnection capacity they need per customer. This means, in terms of backhaul, that a single fibre pair could carry the interconnection needs of 12.8 to 32 million broadband customers. A single fibre pair could, therefore, be overcapacity for almost any network, except for all but the very largest networks. In practice, Dense Wavelength Division Multiplexing (DWDM) technology that allows the use of these high capacities is costly and it is less expensive to use more fibres, which means it is only used on specific routes or for submarine fibre. Networks will also keep capacity available for backup; therefore not all possible capacity will be used.

In the 1980's copper backhaul cables were quickly replaced by fibre. This was in large part because of the bulk of a copper line. These networks used four copper wires for 24, 30 or 64 Kbit/s lines and repeaters every few kilometres. Today, a single fibre cable, no thicker than a centimetre, will carry 96 or 144 fibres, though fibre counts over 800 per cable are possible. These cables are fed into ducts or strung over poles and some ducts can carry several cables. On land routes, network operators may have installed 10 or 20 ducts, often leaving several empty and there may be competing networks on the same route between two cities. The theoretical capacity on most routes therefore is measured in Petabit/s. For submarine fibre, much lower fibre counts are used, often limited to four or eight pairs of fibre.

Whereas in the 1990s backhaul networks used dedicated technologies, such as Asynchronous Transfer Mode (ATM) and Synchronous Optical Networking (SONET) and Synchronous Digital Hierarchy (SDH), today most Internet backhaul networks are built on the Ethernet suite of standards. This was originally designed for offices and data-centres. The speeds of 1 Gbit/s and 10 Gbit/s are now those most commonly used, with 100 Gbit/s becoming more and more available. Ethernet became dominant because the high volumes used in data-centres created a high volume market that overshadowed the demands generated by the traditional telecom voice market. The Ethernet standard was expanded such that it could support the requirements of carrier networks. SONET/SDH still remains central in backhaul and interconnection for telephony services.

Modern fibre networks offer an additional level of flexibility through optical routing. Optical routing allows the network to route wavelengths irrespective of the content in the wavelengths. Academic research and education networks, that used it for high bandwidth applications, first used this feature. The benefit to this approach, was that they were not constrained by the overhead imposed by multiple protocol layers. Multiple protocol layers are necessary to allow flexible intra and inter-domain switching and routing. In academic settings, researchers know the origin of data and where it needs to be sent for further processing and can pre-configure these routes in the intermediary equipment. By using optical routing networks they do not need to use Ethernet or the Internet Protocol to send these data. This feature is now integrated into more and more commercial networks. This enables networks flexibility in choosing physical routes and fibres for routing their traffic. In turn this enables savings in the number of ports necessary to provide “fail-over” from one fibre to another. It does, however, come at the cost of additional complexity in managing a network, because possible routes have to be pre-configured.

Fibre networks are increasingly used for the backhaul necessary for mobile networks. The data demands of 3G and 4G networks make existing copper and wireless backhaul less competitive. LTE+ can deliver up to 3.3 Gbit/s per antenna, which is at the far end of what wireless solutions can deliver. LTE+ will also allow two antennas to send data to the same device, when it is at the edge of both networks. This will greatly increase the possible bandwidth at the edges of cells. It does, however, require adequate timing data to be sent, which requires signalling of timing information between the controllers of the antennas. This requires fibre to be rolled out deeper into the network.

Today, copper networks are used for the first part of the backhaul of mobile telephony networks. Using Time Division Multiplexing up to 44 Mbit/s can be delivered. Some forms of VDSL2+ may also provide bandwidth up to the 100 Mbit/s needed for wireless backhaul networks, if telephony wires are available at the site, though this is not commonly used. With vectoring and the “G.fast” version of VDSL even higher speeds can be achieved. These higher speeds can only be achieved over distances shorter than 450 metres. Therefore, copper connections are reaching the peak of their possible capacity with 3G and 4G mobile data networks needing bandwidth in excess of these rates over longer distances.

Wireless networks are the other mainstay for providing backhaul. Wireless is used where fibre does not reach a location or as a temporary solution until it is rolled out. The three main variants are: satellite, wireless optical, microwave and millimetre wave point-to-point connections and femtocell/Wi-Fi offload. Satellite supports the widest reach, but at a higher cost. Microwave and millimetre wave point-to-point connections are used in many locations to reach mobile base stations. In contrast, femtocell/Wi-Fi offload has the shortest reach, but the lowest associated cost, as it uses an existing broadband connection.

Satellite networks were the backbone of the intercontinental telephone network from the 1960s to the 1980s. Since that time fibre cables have supplanted the use of satellites on routes with the highest traffic volume. The main drawbacks of satellite over fibre are the high latency, limited capacity and shared nature of satellite communications. A latest generation satellite in geostationary orbit can handle up to 8 760 Mbit/s. There are 400 satellites in geostationary orbit offering a maximum of 3.5 Tbit/s across the globe (the equivalent of interconnection for up to 17 million wired broadband customers). However, much of the capacity is currently used for television broadcast. A geostationary satellite is orbiting at 36 000 km. A roundtrip will take around half a second. In some parts of Africa, access to satellite backhaul can be as expensive as USD 6000 per Mbit/s/month, at least 60 times higher than an expensive submarine fibre connection and 2400 times more than a link between New York and Sao Paulo. The main reason for the higher price does not appear to be related to network costs. Rather, it seems to be the scarcity of capacity in certain locations meaning that higher prices can be charged.

At the time of writing, O3B Networks is set to launch the first satellite in a constellation of eight satellites. These satellites will operate at 8 062 km some 75% lower altitudes than geosynchronous satellites, which will result in much lower latency. The satellites are aimed at providing backhaul services in areas that are currently not reached by fibre networks. Likely customers are mobile networks and larger corporations. The constellation will deliver 84 Gbit/s between 45 degrees north (United States, except northern states, Southern-Europe and Asia south of Russia, Kazakhstan and Mongolia) and south (Australia, New Zealand, Africa and South America). One location will be able to send 600 Mbit/s and receive 600 Mbit/s.[2] A special tracking dish and not a traditional stationary dish, will be necessary, because the satellites are not stationary, but will orbit around the world four times per day. The service expects to be able to offer more bandwidth to more customers at a lower price than current satellite systems.

Microwave, millimetre wave and optical transmitters are used extensively by mobile networks to link antenna locations. Wireless networks can scale up to 1-2 Gbit/s for a location. The technology is constrained by the need for line of sight between a sender and a receiver to achieve high speeds or operate at much lower speeds for non-line of sight. The weather can also affect the performance of this technology. Microwave backhaul is therefore generally a short to middle range solution.

In 1969, the use of microwave networks became the first deregulated form of backhaul, when the United States Federal Communications Commission (FCC) granted a license to Microwave Communications of America (later MCI). Microwave was overtaken for long distance backhaul by fibre, which offered higher bandwidth and did not need line of sight. In recent years, however, microwave backhaul has witnessed somewhat of a resurgence because of the benefit it offers to high-frequency trading (HFT).[3] The speed of light in air is close to that of the speed of light in vacuum (300 000km/s). The speed of light in fibre is only two-thirds of that (200 000 km/s). This reduces the time it takes for a signal to travel between New York and Chicago from 6.55 milliseconds, using fibre, to 4.25 milliseconds using microwave. This makes a significant difference for HFT.

Operators use Wi-Fi and femtocell as “offload options” to reduce the demands on mobile networks. They make use of unlicensed Wi-Fi spectrum or their own licensed 2G/3G/4G spectrum. This type of approach is also known as heterogeneous networking. The goal is to relieve demands on the operator’s mobile first mile and backhaul networks. There are still relatively few networks that currently actively, and on a large scale, make use of operator provided Wi-Fi offload, though the number is increasing.[4] One notable exception is Iliad’s Free Mobile in France. It uses its large broadband networks with over five million customers as a Wi-Fi offload network. If customers have a mobile phone that supports SIM-based authentication (EAP-SIM), the offload is seamless. Network operators around the world have introduced femtocells, but they are mostly sold or leased to ameliorate a lack of capacity in and around the home. Users, of course, do actively use Wi-Fi offload. Mobidia calculates from their measurement, for a range of countries, that on average, between 50% and 80% of data traffic for Android mobile phones is offloaded over a user's private Wi-Fi.[5]

Data centres and Internet exchange points, essential for backhaul

Data are generated at the end-points of a network rather than within the networks themselves. An end-point could be an end-user at a residential or commercial location. Another end-point is the data centre where the servers, storage, routers, switches and DWDM equipment are housed. Many large companies have an in-house data centre. Other companies buy space in a data centre as a service from a third party. Backhaul networks aim to be in data centres because that is where the customers are located. Equally a data centre will try to attract a number of backhaul networks into the facility for resilience, preferably on physically separate routes, so that customers have a greater choice in using a network. Since the turn of the century, energy efficiency has increasingly become a primary focus of all co-location facilities. The energy density of modern servers can be up to 40 kW per 19-inch cabinet peak load. Such density requires efficient cooling, which in itself may cost more in terms of energy than running the server itself. The costs of energy are today the majority of the costs in operating a data centre, more than the location or the connectivity to the data centre.

A classification of data centres could be:

- In-house data centres are the data centres of an organisation. These are often located in the same office building as the entity concerned. Some large corporations may have dedicated data centres, generally located with their IT-department. These data centres are conveniently located so that staff are able to visit the servers and networking is mostly local. The drawback of these data centres is that they are often lightly utilized in terms of space. As processors have become more efficient than servers take up less space. McKinsey estimates that servers are only utilised at 10% capacity.[6] As a result these types of data centres are often also energy inefficient. They use up a lot of energy, which increases operational costs.

- Third party data centres, also known as co-location facilities. This type of data centre is shared by a number of parties. The owners of these types of facilities compete on location, available space, interconnection facilities and energy efficiency. These datacentres are, therefore, optimized to deliver customers the peak load they demand and at the same time be very efficient with cooling the building, for example, using outside air or water from a lake instead of an air conditioner. Their site is often close to locations with many companies, which means they are situated around large cities, national capitals and financial centres. This also means that the price per square metre and energy costs are likely to be high. There are many datacentres in Manhattan for example.

- Internet industry data centres are data centres of companies such as Amazon, Google, Facebook and Microsoft. The data centres are massive dedicated facilities, designed to work as one single computing infrastructure. As a result everything in the datacentre can be optimised to increase computing power and utilisation and use the least amount of energy. The servers may not come from traditional server vendors, but may include custom designs at the size of the rack, to optimise the computing power versus the cooling needs of the data centre. They may even be on wheels, in order to make it easier to receive and place them and, during their lifetime, to reorganise and relocate the servers across the data centre. Some data centres may even follow the moon, operating only at peak capacity at night, shutting down certain jobs and moving them to another site in the world when temperatures rise. These sites are generally far away from large cities, in locations where land, energy and cooling are inexpensive. An example is Facebook's facility in Luleå, Sweden, which came online in June 2013. It is located in the north of Sweden, because of the year-round low temperatures and the abundance of dependable hydro-electrical power.

For many customers a co-location facility has to be carrier-neutral. This means that every backhaul network is welcome to enter the facility and sell services. Historically, the facilities of incumbent telecom operators have not generally been carrier neutral. These locations might allow networks to come into the facility and interconnect with the incumbent, but they might not allow these networks to buy and sell connectivity in competition with the incumbent operator.

Historically, it is at these carrier neutral data centres that Internet exchange points (IXPs) emerge. It is possible to directly interconnect with other networks that are present at a facility. Given that so many content and backhaul companies are present at the facility a central platform can be established more economically. Many networks will combine direct interconnections and a connection to the IXP. At the same time, carrier neutral data centres endeavour to get IXPs into their new facilities, because this means that interconnection with many networks is possible. In North America most IXPs are commercial entities of some form or another. In other countries, IXPs are not-for-profit entities - they are often associations made up of public and private networks. Equinix, the world's largest data centre and colocation facilities provider also operates an IXP in 19 of the cities it is in or partners with the local IXPs. It sees these partnerships as an essential part of its strategy.

In 2012, the OECD published a report on Internet traffic exchange, demonstrating how well the market for Internet traffic exchange functioned.[7] The model of peering and transit has created a dynamic market where a few simple rules create complex but efficient behaviour. While every network is free to choose its own strategy, on average many participants in the market choose a co-operative strategy for commercial reasons, where they exchange traffic via peering and thereby reduce transit costs for both networks. The effect has been that prices of Internet transit can be 100 000 times lower than that for regulated voice interconnection.

For peering and transit to function effectively, backhaul networks, co-location and Internet exchange points are essential. In the aforementioned report undertaken for the OECD, the 4 300 surveyed networks peered on average with 30 networks. In many cases it could also be significantly more. This cannot work efficiently without those networks being able to self-provision connectivity to a peering location and to be able to peer there independently from third parties (i.e. their traffic is carried by them, not by a transit provider). Without interregional and inter-country backhaul the networks cannot reach the exchange and are reliant on buying transit locally from networks, giving them less flexibility.

The economics of Internet backhaul are such that with ever increasing traffic levels, networks are seeking to deploy more local Internet exchange points. In the past, Internet exchanges were located in capitals or major financial centres. There were few local IXPs. In Europe, Germany, Sweden and The Netherlands were exceptions. In recent years, however, there has been a surge in the number of local Internet exchange points. For example, Manchester, Lyon, Turin and Zurich all now have local IXPs. The money saved by peering is used to acquire more customers, increase the quality of the network or to extend the network to new regions and connect to networks and customers in those regions.

Some in the Internet technical community have expressed the view that the number of exchange points around the world has not yet reached a sufficient scale and that expansion should be proceeding at a faster pace. The issue here is not just the traditional challenge of establishing IXPs in countries where they do not currently exist, though that remains a priority. These commentators expect a need for a significant increase in the number of IXPs in the next decade, from the current 20 major locations to a future with 200 such locations. The basis for this assessment is the increased use of fixed and wireless broadband access throughout the world. A significant proportion of the users of these connections are in countries and regions that are underserved. In some cases a significant proportion of their traffic will be sourced from outside their region if IXPs are not available for content and service providers to further localise this traffic. The high penetration of IXPs in Europe could serve as a model that could be used elsewhere.

The cumulative effect of more people and devices online, with more use of data, will increase the demands on regions without efficient IXPs. In much of the OECD area, with high broadband penetration rates, Internet traffic growth can be in the range of 20-40% year on year. In those countries traffic growth will come from higher smartphone penetration, M2M and the increasing use of fixed broadband connections for video services and so forth. Outside the OECD area, however, relative growth rates are likely to be much higher as many users get their first broadband connections. Rather than this traffic traversing the world's largest IXPs it would be preferable for it to be exchanged locally, which can be done either directly or via an IXP, or it will place strains on the international backhaul available in these countries.[8] Since the second half of the 1990s, it is for this reason that OECD countries have advocated the development of local IXPs.

Many major content providers and content delivery networks, such as Google, Netflix and Akamai, will deploy local caches into the networks of ISPs, some of whom will form strategic alliances with market CDN services. This is a natural outcome of a competitive market. There are likely to be more ISPs in those locations that could benefit from these caches. However, because the caches are deployed in a specific network, instead of available via an IXP, other networks in the same region cannot connect to the caches. These networks, therefore, will have to route traffic via their backhaul links and incur costs as a result. Developing local IXPs should encourage content providers and CDNs to also connect to these IXPs.

Locating datacentres outside OECD countries has proven to be challenging for some providers. The barriers can be of a practical and regulatory nature. An example of a practical hurdle is obtaining an adequate and stable power supply. On the regulatory side, the failure to liberalise telecommunication markets or the development of insufficient competition remain major barriers in many countries. If the market for backhaul and co-location is dominated by an incumbent telecommunication carrier, which does not allow independent co-location facilities to emerge, there is a significant obstacle to the development of the Internet in that country. Further regulatory challenges can be in the areas of obtaining permits or the development of associated policies such as in data protection. As a consequence, there is a barrier to overall social and economic development.

INTERNET BACKHAUL: BOOM, BUST AND CONTINUED GROWTH

This section reviews some of the experience gained from the first decade following widespread market liberalisation with respect to Internet backhaul. This period included the so called "dotcom bubble" and is relevant to today's market because of some of the domestic and international cable infrastructure developed at that time. For the most part, this infrastructure represented an overlay for existing routes with a significant expansion of capacity. This capacity ran ahead of new demand, which eventually began to materialise with the expansion of broadband access. This demand did not come soon enough, however, for many of the market entrants were subsequently bankrupted or were taken over by other firms. The firms buying these facilities, many of which came from outside the OECD area, benefited from gaining assets at fire sale prices and some of these assets still influence international backhaul prices on these routes.

A question can be raised, however, for regions and routes that were not the focus of the initial race to roll out new international undersea cables, as to whether this period has had an on-going influence on their development. Certainly, it led to a dramatic drop in the price for international backhaul on major routes between OECD countries, an effect that is still evident today. The same can also be said for those countries that benefited from being on those routes that also liberalised access to those facilities. The real change in the market, therefore, was the ability for ISPs to provision their own end-to-end networks on domestic and international routes. In other words, there had always been ample capacity but it had been rationed by entities with monopoly power over its distribution.

Some may pose the question as to whether other regions in the world can compete with infrastructures that were built on some routes during a period of "irrational exuberance" leading to the dotcom crash in 2001. In other words, they ask whether facilities obtained at bargain prices following bankruptcies are still distorting current markets, by lowering the prices in those regions. This is, however, to misunderstand the nature of liberalised communication markets, which allow all players to provide end-to-end infrastructure, peer with others or to purchase transit from others where this is not economic. The key challenge for those locations not connected by facilities installed leading to the dotcom crash is: *i)* how to gain competitive backhaul to those facilities; and *ii)* how to exchange local traffic locally through the creation of local IXPs and encourage the production of local content.

This is a fundamentally different challenge from traditional telecommunication networks in which each country had a monopoly provider(s), for specific geographical areas, and governments mandated the domestic or international exchanges of traffic. Nonetheless, it is worth recalling how public switched telecommunication networks (PSTNs) dealt with backhaul in relation to telephony and how this changed after liberalisation. At the same time, it can be noted that in domestic markets, liberalisation quickly brought new players into the market either because they had existing backhaul facilities for their own purposes or because the barriers that existed internationally were not in place.

For PSTNs, backhaul networks were better known as inter-local or long distance networks. The traffic in a telephone network was primarily local traffic reflecting economic and social patterns and this largely remains the case today. PSTNs were, as a result, focussed on facilitating local traffic with more limited capacity for inter-local traffic. A large proportion of inter-local traffic was inter-branch, business-to-business and business-to-consumer telephony and data traffic handled within in the same company due to their monopoly. In this environment, inter-local traffic was regarded as a luxury and as an element to which price differentiation could be applied, including for the customers of other entities and those with greater demand (e.g. business users).

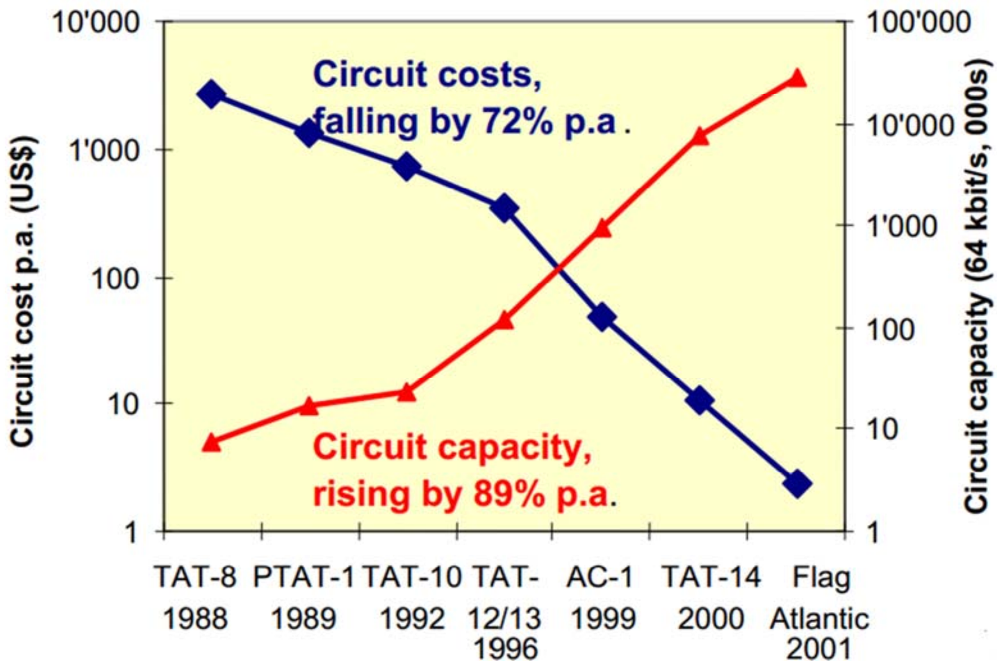
In domestic markets liberalisation enabled new entrants to provide backhaul even if telecommunication markets were not their primary business. Some market players such as railway, energy and oil companies had existing fibre assets along their networks for private use. In Spain, for example, Adif, a railroad company, now leases capacity on its network to British Telecom, Cableuropa, Cogent, Colt, Islalink, Jazztel, Orange, Telefónica, Vodafone, VSNL among others. Following liberalisation in Spain, and other OECD countries, the use of these assets were quickly deployed to include providing private networks for business users and competitive services in areas such as voice and data traffic.

When the Internet was commercialised, ISPs were quick to take advantage of the facilities that had been developed in liberalised telecommunication markets (e.g. leased lines for backhaul). As a result, much of the necessary infrastructure already existed to offer dial-up Internet services and direct data connections for larger users. In other words, ISPs could get local telephone numbers and modem banks to support dial-up and backhaul could be provided via leased lines. Though originally designed to provide private networks for large business users, these facilities were quickly repurposed for use by ISPs.

The take-off of the Internet was undoubtedly a result of a number of factors. The advent of cost effective multimedia computers that showed colourful and interactive content over the World Wide Web was undoubtedly one element. Another element, less often noted, was the liberalisation of markets that enabled existing and new players to take advantage of the potential massive increase in technical capabilities of backhaul fibre networks. This was then possible at the domestic and international level including opening these markets for new investment. Technically, the tremendous increase in backhaul capacity came from being able to put multiple signals on the same fibre. In 1996, Ciena introduced one of the first commercial dense wavelength division multiplexing (DWDM) systems on the market that used 16 wavelengths on a fibre pair. By 1999, some 96 wavelengths were possible. In other words, where players had first bought a fibre pair between two locations, their potential capacity increase by 96-fold in a period of three years.[9]

The huge increase in technical capacity changed the underlying economics of backhaul networks. In 1995, for example, a network owner might have designed and built a link consisting of 10 ducts with 3 ducts filled with 96 fibres on a route between two cities. Each fibre pair could do no more than the technical limit of a single wavelength on a single fibre and this would have been the basis on which the business case was constructed. In just four years the potential capacity of that line increased 96-fold. As a result the price of capacity dropped. In 2000, an analysis was undertaken at the International Telecommunication Union (ITU) that provided an indication of the effects these changes had made on the availability and price of trans-Atlantic 64 Kbit/s circuits (Figure 1).[10]

Figure 1. Price and capacity of trans-Atlantic submarine fibre over time



Source: Tim Kelly, ITU, 2000.

Concurrent with the increase in fibre cable capacity, there was also an influx of capital in the backhaul market. For reasons that go beyond the scope of this document, capital markets made almost unlimited funding available for backhaul infrastructure. Certainly, the existing players were driven by demand from their customers to offer end-to-end services or see their competitors do so. For markets where there were geographical (regional or international), or other splits (local, long distance), there was a need to develop facilities to meet market demands. Finance was made available to some entities that still had significant market power through controlling local access to customers or through government ownership and, thereby, considered as safe investments (i.e. predating the too big to fail situation in a different sector a decade later).

This capital was used to rapidly build up networks between the major cities in many OECD countries. The civil engineering costs of a network are such that expanding the number of ducts and fibre cables in a duct, are only a small cost to the network. Most of the costs are in the civil engineering necessary to rollout the cable. A common lead-time, from planning to fulfilment, was one to three years. After 1999, the result was a major increase in the number of players and capacity came on stream with a dramatic downwards pressure on prices for connectivity between the major cities.

The boom in investment in new networks, was further fuelled by erroneous statistics cited by some players at the time about Internet traffic growth. Some reports mentioned a doubling of traffic every 100 days or a 1200% growth per year.[11] These data were misleading, because even though they may have been correct for some networks, during a short time, they were not correct for the entire Internet and all networks.[12] This contributed to capital markets and some network operators overinvesting in capacity. In some cases, the investment was on the same routes.

Many industry players expanded the reach of their networks by swapping capacity with out of region networks though this, of course, added to competitive pressure on prices. Where some networks had the funds to build out their networks between large cities in different countries, other networks were only able to invest in a particular country or region. These smaller players co-operated across borders by swapping capacity on each other's networks, using so-called Indefeasible Rights of Use (IRU). The IRU would give the other party unrestricted and indefeasible right to use one, a pair or more strands of fibre of a fibre cable for a period of 15 to 25 years.[13] Regional networks, such as Telia and Telecom Italia expanded across Europe and North America using IRUs. Global networks such as Cogent relied on them for regional coverage (Box 1).[14] Each IRU and fibre swap however created more competition in locations on both ends of the network, as DWDM allowed a close to unlimited capacity to a single provider.

The expansion of access to passive infrastructure, fibre, IRUs and DWDM also stimulated the growth of IXPs, especially across Europe. Where originally an ISP had to buy transit in the location where the network terminated, it became possible to extend the network to a location with many other networks, through the use of fibre or DWDM. At these locations networks could buy transit from multiple networks, which pushed prices down. At these locations IXPs were established. Here networks could meet, exchange traffic and avoid paying for expensive transit. This put further downward pressure on transit prices.

Box 1. Use of IRUs and future renewal

The extensive use of IRUs can be demonstrated by a quote from the 2004 10K form of Cogent deposited at the United States Securities and Exchange Commission:

Inter-city Networks

The North American portion of our inter-city network consists of two strands of optical fibre that we have acquired from WilTel Communications and 360 networks under pre-paid IRUs. The WilTel fibre route is approximately 12 500 miles in length and runs through all of the metropolitan areas that we serve with the exception of Toronto, Ontario. We have the right to use the WilTel fibre through 2020 and may extend the term for two five-year periods without additional payment. To serve the Toronto market, we lease two strands of optical fibre under pre-paid IRUs from affiliates of 360networks. This fibre runs from Buffalo to Toronto. The 360networks IRUs expire in 2020, after which title to the fibre is to be transferred to us. While the IRUs are pre-paid, we pay WilTel and affiliates of 360networks to maintain their respective fibres during the period of the IRUs. We own and maintain the electronic equipment that transmits data through the fibre. That equipment is located approximately every 40 miles along the network and in our metropolitan aggregation points and the on-net buildings we serve.

In Spain we have approximately 1,300 route miles of fibre secured from La Red Nacional de los Ferrocarriles Espanoles (now Adif – OECD). We had the right to use this fibre pursuant to an IRU that expired in 2012. In France, the United Kingdom, Belgium, the Netherlands and Switzerland, we have approximately 5 400 route miles of fibre secured from Neuf Telecom and Telia. We have the right to use the Neuf Telecom fibre pursuant to an IRU that expires in 2020. In Germany and Austria, we have approximately 1 800 route miles of fibre secured from MTI and Telia. We have the right to use the MTI fibre pursuant to an IRU that expires in 2019. We have the right to use all of our Telia fibre pursuant to an IRU expiring in 2011 with an option to extend to 2019."

Going forward some commentators have expressed doubts whether networks will be willing to extend the IRU contracts as it might remove competitors from the market.[15] Current holders of fibre are reported to be less willing to enter into IRUs and fibre swaps. This could lead to a consolidation in the market, though the calculations made by these players will be dependent on how much competition is available. One point that is clear from the Cogent filing (Box 1) is the significant changes to players in the market since 2004. For example, Wiltel's assets are now held by Level 3 and 360networks assets are held by Zayo, both competitors of Cogent.

In the OECD area, between 2000 and 2004, 114 communication companies went into bankruptcy, from which 35 new companies emerged.[16] Some notable names were Teleglobe, Flag, KPN-Qwest, Tyco, Enron, Worldcom and Versatel. The assets of these networks, datacentres, ducts, fibres and IRUs were bought by new and existing players for a fraction of their original costs. These players continued to compete in the same markets, but with lower costs. This has driven prices to marginal cost for backhaul networks on those routes built out in the earlier period. On the other hand, it has supported the growth in data-rich applications and the expansion of the demand for broadband access.

The type of networks that had the greatest chance of surviving the "burst of the bubble" had large numbers of private customers. The networks least likely to survive were the networks focusing purely on backhaul and transit for other ISPs. As pure intermediaries, these transit networks were always at risk of their customers whether they are ISPs, content providers or private networks, finding another supplier or an alternative route, via a direct interconnection or an IXP. A network that is a customer is able, through a few agreements for wavelengths or dark fibre, to become a full competitor. The intermediary has to consistently drop charges for the use of its network, to discourage its customers to find alternatives. Even if it does this conscientiously it can find that the organic growth of the network of its customers allows the customer to bypass the supplier. At the same time, many customers prefer to outsource these functions and they will continue to do so to the most efficient intermediaries.

The current market for backhaul networks in the OECD

Over the past decade the backhaul market has undergone consolidation and rationalisation across the OECD area. Many networks were bought and sold for pennies on the dollar. Networks that had a large consumer broadband customer base were able to buy additional capacity and to become wholesale players themselves. While many national incumbents wrote off huge losses on their investments, they were able to carry them, because backhaul was only part of their business. As noted earlier, it was also the case that some had backing through public ownership. Other incumbents, such as Telefonica and Telmex, who had not been part of the initial "gold rush" extended their networks into areas outside their traditional regions.

In the United States, new players such as Zayo emerged. Between 2007 and 2012, Zayo bought 21 smaller players and distressed assets to create a new business. Operators with headquarters outside the OECD area entered the market, especially Indian networks. Players such as VSNL and Reliance became large participants in the submarine fibre sector as did companies from China in the Asia-Pacific. The market continues to consolidate, notably with the merger between Level 3 and Global Crossing and Vodafone's purchase of Cable and Wireless Worldwide. The market for submarine fibre will be discussed in the section on backhaul networks outside the OECD. This section will concentrate on terrestrial networks in and between OECD countries.

Today the market between large cities in OECD countries is generally extremely competitive. Industry sources state that it is possible to buy 10 Gbit/s wavelengths between major cities in Europe for prices as low as USD 915 per month, with the United States offering similar prices.[17] As a result Europe and North America can boast an excellent mesh of connectivity between large cities with adequate back-up capacity and differentiated routes for resilience. Networks have, however, learned from past experiences and are said to be more reluctant to sell an IRU for a fibre pair or duct to a competitor or potential competitor.

The increase in capacity and decline in prices of backhaul connectivity has also proven to be a boon to content providers. Hosting and data centre providers expanded their networks to enable their customers to benefit from better interconnection to networks. The same has been true for large content providers, such as Google and Facebook, who own extensive networks, data centres and points of presence (POP) throughout the world. In 2012, Facebook bought a European ring to support its data centre operations, which are located in Sweden. Google announced it would open a POP in South Africa and a data centre in Chile. Both Google and Facebook have bought into submarine fibre networks in the Asia-Pacific region, where capacity is said to be more expensive than Europe and the United States. All major Internet companies either have their own facilities or rent capacity in data centres and on networks in major countries in the world. According to the website "PeeringDB", where Internet companies, data centres and IXPs register their details, some content providers are in 20 to 70 locations worldwide.

It can, of course, cost much more to reach locations outside major cities in OECD countries. In many areas only an incumbent network provider provides access to these locations. In some locations, such as in business parks, local and regional governments have worked together on bundling demand for fibre networks. By bundling the demand of a business-park or village, the customers can either build a network out to a regional point of presence, where there are a number of networks located, or conversely build a network that other networks want to build out to with their facilities. This has proven to be not just a first-mile solution, but also an option to bring backhaul into a region, as access to a network opens up possibilities to ISPs and mobile networks that want to deliver mobile broadband.

Despite local market initiatives, regulators have found a position of dominance with incumbent operators in supplying regional backhaul. This is the case, for example, in Australia and in many countries in the European Union area. It is very challenging to compare the regulated wholesale prices across countries. This is because regulators use different methodologies in setting prices and ISPs may buy core network connectivity between major cities from a different network than the connectivity into smaller towns, which they need to buy from an incumbent operator. Nonetheless, there are some indications for regulators for the costs of backhaul. For example a report for Ofcom quoted prices of between USD 15 000 in London and USD 120 000 in remote areas per year for a 10 Gbit/s connection.[18] The regulated price in Australia for an inter-capital 600 km 1 Gbit/s link is USD 640 000 per year.[19] according to the DTCS FAC calculator of the Australian regulator ACMA.[20] This is not an apples and apples comparison with the prices in the United Kingdom.

Not all interventions in OECD countries may be interpreted as stimulating the rollout of backhaul networks. In the United Kingdom, for example, some believe an application of a tax has a restrictive effect on deployment of backhaul networks. The charge is sometimes known as the "fibre tax", but is actually one methodology adopted for the application of property taxes (or business rates as they are better known in the United Kingdom) to networks. Note that this application is not unique to telecoms networks but is also in force for electricity, gas and water distribution infrastructures. In general, the approach adopted is to estimate the rental value of the asset in the free market, and charge the owner a fixed proportion of this value. Relevant authorities charge long distance network operators, based on the number of lit fibres that they have and on the length of those fibres, in line with the market price for "dark fibre". The charges can be quite substantial. A 100-km network of two fibres would be charged USD 77 000 per year. Activating another two fibres on the same route is another USD 36 000 per year. Subsequent charges decrease with distance and the number of fibres. It is, therefore, often more economical to deploy DWDM equipment on a route. Though DWDM equipment is expensive, in this case it is reportedly often more profitable to use all available colours in the spectrum to expand capacity.

In the United Kingdom, the tax means that any network that has already deployed several fibres already on a route has an advantage when there is demand to activate new fibres. In the example given above, a network that was already paying tax for two fibres, could undercut a competitor by USD 31 000 per year all else being equal. Purchasing two fibres on an existing route means that the company will pay tax according to the scale for two fibres, without other fibres of other networks counted. Some of the incumbent networks, however, do not pay tax on this basis, but a lump sum per year. The effect on the market is that the tax implications of deploying a new backhaul link are less substantial for an incumbent network, than for a new entrant.[21]

Statistics on local co-location markets

A question that arises, when considering backhaul markets, is the location of content. Pingdom, a Swedish uptime analytics firm, evaluates the hosting market in all countries of the world. In 2013, the company published an article about the location of domains in the Alexa one million (a list of the top 1 million sites of the world) are co-located.[22] On request for this document, Pingdom re-analysed the data it had collected to see how many of the sites under a country's top-level domain, such as .au for Australia, .be for Belgium, were actually hosted in the country.[23]

For this analysis, the generic top-level domains were omitted from the list, as there is no reliable public data as to where the domains are registered. Out of the one million top sites, 948 000 were scanned, 474 000 were generic top-level domains, 40 000 had no identifiable host country and 3 700 had no identifiable domain, just an IP-address. The remaining 429 000 domains were analysed and of 309 000 their hosting country identified. For each country the number of domains hosted in the country were identified. In addition, for each ccTLD the alternative countries where content was hosted was recorded. This provides insight into which countries are most popular for hosting content independent of where it is from.

These data, from Pingdom, have been further examined for correlations with other factors (Annex 1). The main conclusion is that for mid-income countries, the percentage of ccTLDs domestically hosted is correlated with the reliability of the electricity supply of that country. This correlation holds even when it is corrected for other variables. There are no time series available, so causation cannot be derived. As energy supply is essential to data centres this is not a surprising result but, nonetheless, has implications for policy makers. It underlines the importance of considering local energy supplies when developing initiatives to enhance local backhaul and data centre markets.

The resulting data provides one potential indicator into how well the countries co-location and backhaul market functions. Each of the sites under a country's top-level domain has identified itself with that country. If the market for co-location and backhaul functions efficiently in the country, than it would be likely that content could be hosted domestically. If a larger portion of sites is hosted outside the country, it could indicate that the local market for hosting and co-location is not functioning efficiently. One caveat should be mentioned in relation to the United States, where for historical reasons most use is made of generic top-level domains. The ccTLD.us is also a valid top-level domain in that country, but it is very lightly used. For completeness it is mentioned here.

There are some further caveats with the data. In some cases there may be a national and an international site for the content. For example, it might be the case that a newspaper has a site hosted in the country, for all web requests coming from the country and an international site located close to where the diaspora of that country lives. The local site will likely not show up as the query was run from Sweden. Similarly, some of the largest sites in the world use content delivery networks (CDNs) to distribute their data. These sites show-up as hosted outside the country, though for visitors in the country, they may be local.

Table 1. Sites hosted in country

Name	Hosted in Country	Total Sites	Sites in Country	cctld
Korea	97%	1750	1693	.kr
Germany	92%	25469	23306	.de
Japan	91%	14188	12964	.jp
Czech Republic	90%	4736	4258	.cz
Hungary	84%	2619	2197	.hu
Israel	84%	1302	1088	.il
Estonia	83%	456	378	.ee
Netherlands	82%	7937	6532	.nl
Turkey	81%	2095	1693	.tr
Slovenia	78%	518	403	.si
United States	78%	2709	2100	.us
Denmark	76%	2735	2072	.dk
Finland	76%	1444	1098	.fi
France	74%	10820	8021	.fr
Iceland	72%	193	138	.is
Norway	72%	1930	1389	.no
OECD	72%	164740	118479	
Poland	71%	14235	10176	.pl
Sweden	71%	3541	2522	.se
Italy	68%	8158	5513	.it
New Zealand	66%	1106	730	.nz
Australia	65%	7914	5140	.au
United Kingdom	64%	17532	11206	.uk
Switzerland	62%	2849	1755	.ch
Ireland	60%	1070	638	.ie
Slovakia	60%	1628	984	.sk
Chile	58%	1231	713	.cl
Portugal	54%	1347	729	.pt
Spain	50%	6129	3049	.es
Austria	49%	2614	1280	.at
Luxembourg	49%	174	85	.lu
Belgium	46%	2635	1213	.be
Canada	45%	4138	1873	.ca
Mexico	22%	3566	776	.mx
Greece	19%	3972	767	.gr

Source: OECD, Pingdom, Alexa

The countries above the OECD average in general conform, with expectations, hosting most of their sites in their country (Table 1). Countries with the lowest proportion of their most popular ccTLD hosted domestically include Greece, Mexico, Canada, Belgium, Luxembourg, Austria, Spain and Portugal. For higher income countries, such as most OECD countries, energy reliability is less of a factor because it is readily available in all these countries and there may be other factors influencing their local markets. The position of Greece can perhaps be explained by looking at the local Internet Exchange Point, GR-IX. It has 12 members, only ISPs and telecom companies. It seems possible, therefore, that the market for co-location in Greece is unfavourable and content providers have not chosen a domestic location to host traffic. Greek content is hosted in the United States (31%), Germany (26%), Greece (18%), United Kingdom (9%) and The Netherlands (6%).

The factors at work in Greece are likely to be similar for Mexico, combined with the proximity to the United States, which has a well-functioning co-location and backhaul market. This has been exacerbated by Mexico being the only OECD country not to have an IXP. Policy makers are aware of this deficiency and the Mexican government has announced plans for the establishment of a domestic IXP. The strength of the market in the United States is also evident in the position of Canada. Nonetheless, in September 2012, a review undertaken for the Canadian Internet Registration Authority identified weaknesses in the exchange of domestic traffic in that country. It identified how this situation could be addressed by the establishment of further IXPs in Canada.[24] While proximity to efficient IXPs in neighbouring countries (e.g. Belgium and Austria, who are close to high scoring countries like Germany and The Netherlands) is clearly a factor, improvements could likely be made in these markets.

The market for backhaul outside the OECD

Overall the inter-city backhaul market, in most OECD countries, provides the needs necessary to market players. It is in rural and remote regions that all stakeholders still face challenges. Outside of the OECD, however, backhaul markets are still developing. These markets need backhaul as they expect to connect more fixed and mobile broadband users, who once they are connected, are increasingly likely to have a similar consumption patterns to consumers in OECD markets. At present, however, many of the backhaul facilities in these countries are not tightly integrated mesh networks, but rather more resemble river systems. At the coast, for example, an international submarine fibre lands and from here the network spreads out throughout the country, gradually thinning out in capacity.

International backhaul networks were the first places for the exchange of traffic for ISPs located outside the United States. Over time this situation has changed, first in OECD countries and then around the world as more IXPs were established to exchange domestic traffic. Nonetheless, as a significant number of countries either do not have an IXP or for whatever reason it is not used efficiently, this traffic is still exchanged outside their borders. At the same time, networks in neighbouring countries often do not exchange traffic directly but rather transit through IXPs in locations such as Europe and the United States. In this section the markets outside the OECD will be discussed. It begins with submarine fibre networks, which are often the international communications lifeline of countries.

Submarine fibre networks

Submarine fibre optic cables are the preferred technology for carrying data over large distances in and between countries separated generally by oceans or large expanses of water. They are deemed less prone to failure than over-land cables, where excavation is a major source of outages, despite risks such as damage from a fishing trawler, anchor, earthquake or undersea volcano. In addition, they are capable of carrying enormous amounts of data. A single intercontinental submarine fibre can potentially carry more data, with less delay than could be achieved by combining all the world’s active geostationary communications satellites together. Some countries are connected to only one submarine fibre, which then becomes a single point of failure if there is no overland option. When this cable is cut, or offline for maintenance, the country is effectively disconnected from the Internet economy with all the ramifications that entails (Box 2).[25]

Box 2. The impact of submarine fibre disruption

Submarine fibre disruption is common. At least twice a week there is a disruption in a cable somewhere in the world. Most of the time nobody outside telecommunication companies notices. When countries cannot reroute their traffic over other submarine cables, business and consumers are severely affected.

Benin the only cable serving in 2012 at the time severed and cut the country off the global Internet for two weeks. Many people in Benin felt the outcomes of this disruption. Western Union, which is important for the transfer of money inside and remittances from outside the country, was not able to operate. Its systems are located outside the country. Remittances from outside Benin are a major source of income for the economy, bringing USD 250 million per year into the country. Two weeks without Internet meant up to USD 10 million were not received by the economy. Or, the equivalent of 150 000 Beninese not receiving the nation's average weekly income. Banks were not able to operate and international trade came to a standstill.

Though there are limited news reports to support this, it is likely that least developed countries suffer in other ways from the impact of submarine fibre disruption. Healthcare professionals will not be able to access online resources, purchasing of spare parts will cease, many other activities will be impacted, because submarine cables support almost all forms of interaction of the country with other countries in the world.

Current submarine fibre systems are designed with capacities of 80 channels of 40 Gbit per channel for 3.2 Terabit per fibre pair. Many existing systems can be upgraded to 100 Gbit/s channels, 500 Gbit/s super-channels and optical component manufacturers expect 1 Tbit/s channels to be available by 2020, allowing a single fibre pair to carry up to 100 Terabit/s.

The first intercontinental submarine fibre was the trans-Atlantic TAT-8 cable installed in 1988. It could carry 591.2 Mbit/s. Since then investment in submarine fibre has averaged from USD 1 billion to USD 2 billion per year. From 1997 to 2002 there was a significant increase in investment in submarine fibre networks. The peak year was 2002 when new systems worth over USD 12 billion came into service across the world, though the decisions to invest were taken in the lead up to their installation.

The boom was stimulated by liberalisation of telecommunication markets across OECD countries, with 1998 being a key year for a number of European countries, such as France and Germany. Accordingly, the race was on to provide customers with end-to-end service, over an operator's own trans-Atlantic capacity that was previously provided jointly, with traffic theoretically handed over at midpoints. The enthusiasm for the rapid growth of the Internet added to a perception that there was demand for the new cables. While demand did indeed spiral so did the capabilities of the new cables to carry larger amounts of data, together with competition applying market discipline to prices for the first time.

The increases in technological capabilities of submarine fibre - new technologies that allowed multiple channels and faster speeds - was such that many of the cables built before 1997 were decommissioned after 2002 as they could not compete in the new environment. Moreover some of the new entrants, driven by an excess of supply relative to demand, were forced to sell systems at "fire sale" prices. As a result, on the trans-Atlantic route, capacity installed during that period has proven to be sufficient to meet all requirements. Indeed, no new cable has been added on this route since 2003 despite the growth of the Internet and demand for content from companies that originate in the United States. In large part this is attributable not only to any over-build of capable capacity around the turn of the century but because this content is distributed around the world much more efficiently that it was a decade ago.

There are signs, however, that the market for new undersea cables on this route is once more starting to gain momentum. This is not so much driven by demand for capacity but rather the speed at which data can be transported and other new uses. Between 2013 and 2014, two new cables are expected to go into service on trans-Atlantic routes. The vaunted attraction of these, so called, Express cables (Hibernia Express and Emerald Express) is that they offer a shorter, more direct route which shaves off a few milliseconds. The reduction of time, even if only by milliseconds, can be a major selling point for financial markets, where High Frequency Trading accounts for an ever larger part of the market and success may depend on the reduced time it takes to undertake transactions. The Express operators aim to run one of the cables via Iceland to offer services to data centres powered by renewable energy. While a number of further cables have been planned or discussed for the North-Atlantic market, there are as yet no confirmed dates for installation.

Low latency is also the driving force behind three proposed cables through the Arctic. These are: Arcticlink, Arcticfibre and Russian Optical Trans-Arctic Submarine Cable System (ROTACS), though not all may be active. The warmer conditions in the arctic, in recent years, have resulted in relatively ice-free routes during the Arctic summer. This potentially makes it more feasible to lay cables. Such cables could significantly reduce the distance from London to Tokyo from the current 22 000 km to around 15 000 km. It could also allow an alternative route from Europe to Asia and from the North American East coast to Asia and connect communities and businesses in northern Canada and northern Russia. The ROTACS cable could be connected with a new Baltic cable that the Finnish government is researching. It is of the opinion that more diversity in routes between Finland and Central Europe is necessary (Box 3) whether such cables will be built is dependent upon demand, financing and other considerations.

Low latency traffic between Europe and Asia is currently transported overland through Siberia. Nevertheless, the majority of traffic between these two regions is carried via the Mediterranean, past the Suez Canal and then around the Arabian Peninsula, passing India onwards to Singapore, China and Japan or vice versa. This route is longer and has experienced challenges from factors such as earthquakes or ships anchors, as well as political instability. Specifically, Egypt has been a concern because of frequent cable failures near Alexandria due to anchors. While some companies are researching alternative routes, the political situation in the Middle East however is making this difficult. For example, the EPEG-cable goes overland and through the sea from Oman, via Iran, Azerbaijan, to Russia and Frankfurt. Another alternative route proposed is via Eilat through Israel.

Before 2002, there were only two active submarine fibres available between Asia and Europe via the Middle East. Since then almost one cable per year has been activated between the Middle East and Asia. A number of these cables connect through to Europe generally via Egypt and sometimes over land. Prices on this route are said to be higher than using a combination of trans-Pacific and trans-Atlantic cables. This leads to traffic between Asia and Europe, which does not have priority, to be routed via North America.

The intra-Asian and Asia to North America trans-Pacific markets are rapidly developing with the economic growth in the region and the increase in the number of users with high-speed broadband access. There are now seven systems active between North America and South East Asia and four new cables are being planned or proposed. Some of these proposed cables are aimed at connecting one rather than a number of countries to North America (i.e. Thailand, Malaysia and China). There are also several proposed systems aimed at meeting demand in between countries in South East Asia. The investors in these cables are not only telecommunication operators, for example: both Google and Facebook have invested with telecommunication operators in submarine fibre networks in the Asia-Pacific region.

In the southern Pacific, Australia is connected to the rest of the world via a number of cable systems. One of these goes via New Zealand, providing their primary international connectivity, to the United States (Southern Cross). A further cable connecting Australia to the United States, does so via Guam (PIPE Pacific Cable or PPC-1). The introduction of the latter cable is said to have contributed to significant reductions in the price for carrying traffic between Australia and the United States, alongside new cable introduced by Telstra.

In July 2012, Pacific Fibre, an initiative to build cable from Australia via New Zealand to the United States, did not proceed, due to finance not being raised. In September 2012, another cable, called Hawaiki was announced, that would connect Australia, New Zealand, via Hawaii, to the United States. It also proposed to reach Pacific islands such as Samoa and Fiji. An alternative proposed cable called Optikor may, however, connect New Zealand to Australia and onwards through existing submarine fibre systems, but its main investor Kordia has so far postponed a final decision.

In February 2013, Telstra, Vodafone and Telecom New Zealand proposed the USD 50 million Tasman Global Access cable to connect New Zealand and Australia. Some suggest the cable may face competition issues, as Telecom New Zealand also own Southern Cross.[26] Several other cables have been proposed to link Australia to Asia and North America. One of these even proposes to connect New Zealand directly to Australia and Chile. Given the large public investment in broadband in Australia and New Zealand entrepreneurs may believe demand will significantly increase for traffic in and out of these countries. On the eastern side of Australia three new cables are proposed to connect with Singapore, promising lower latencies into Asia and Europe.

In South-America, Chile is connected via two international cable systems. One of these systems is part of a ring that spans South-America in both the Atlantic and the Pacific with an overland link from Chile to Argentina. These two cables are the only ones on the Pacific side of South America. On the Atlantic side there are four cable systems that reach North America and one smaller cable that goes from Brazil and Argentina to Europe. In the Caribbean there are many cable systems, some systems stretch over a long distance, such as the Americas Region Caribbean Ring System with 24 landings stations in 13 countries. Others are shorter such as the one connecting Trinidad, Guyana and Suriname.

Box 3. Baltic submarine cable project

The Ministry of Transport and Communications of Finland has explored the opportunity of implementing a new, direct telecommunications connection between Finland and Germany via the Baltic Sea. By establishing a new route, which provides an alternative to the current link running through Sweden, the purpose is to improve the operational reliability of Finland's international data traffic connections. A Baltic Sea cable is also needed to improve the operating conditions of data centres and other cloud computing businesses in Finland.

In mid-2012 an initial examination of the feasibility of a direct submarine cable, between Finland and Germany, was finalised. The length of a cable could be between 900 and 1 300 km, depending on the route chosen. The cost of such a cable was put at around USD 66 million (EUR 50 million). According to the preliminary plans, such a cable would comprise 6-8 fibre optic pairs (each 10 Tbit/s). No decision has yet been made on the implementation of the cable or construction timetable; however, the aim would be to build it in 2014-2015.

A business plan is currently under preparation, looking into different ways of financing the project. No option has yet been excluded. One possibility is the cable would be owned and operated by a state-owned company, and the Finnish Government would contribute to the project by providing a capital injection to this state-owned submarine cable company.

The Ministry of Transport and Communications has also invited comments on the Baltic Sea submarine cable project from all interested parties. The aim is to determine if they are willing to contribute to the funding of the project, or in co-operating in the project in some other way. This request for comments was open to all, including telecommunications operators, data centre operators, cable suppliers, investors and the authorities. The period for comments closed on 22 May 2013.

The project is an important one at the European level. In Russia, plans are being made to build a new submarine cable along the Northern Sea Route. This link would connect Europe and Asia. The Baltic Sea cable and Northern Sea Route cable can be connected to each other via an existing link through Finland. Together, these two cables could provide a new high capacity and low-latency connection between mainland Europe and Asia.

Given the rapid growth of broadband in South-America, several new cable systems have been proposed. Some proposals look at connecting Africa and South America directly and connecting Africa via South America to the United States onward. One proposed cable aims at connecting Brazil, India, China and South Africa. America Movil will activate a cable that connects many of its networks throughout South America. Another cable SEABRAS-1 is expected to be the first cable connecting Sao Paulo directly with New York.

In 2012, the activation of two cables passing the west coast of Africa connected the final countries in continental Africa to submarine fibre systems. Prior to 2002 only South Africa had been connected via such a cable. In 2002, a new cable connected a further eight West-African countries. Sub-Saharan East-Africa (except for Djibouti) saw cables built to it between 2009 and 2010 when three cables connected all countries. That being said, the connections to Somalia and Somaliland, by 2012, had still not been activated. As there is now considerable capacity, no new cables are currently proposed for the Europe-Africa route. Sub-Saharan cables that have been proposed are focused on the route towards the Americas.

The business model of submarine fibre

Submarine fibre networks represent a high initial capital expenditure. Long intercontinental cables can cost between USD 500 million and USD 1 billion, though shorter cables, such as between Australia and New Zealand can cost USD 50 million. If Bangladesh wants to join the 16 country consortium of Sea-Me-We 5 cable, the costs estimated by the Bangladesh Submarine Cable Company Ltd (BSCCL) are USD 48 million. Connecting to Sea-Me-We 4 had cost USD 35.2 million.[27] The financing of such a cable is either done through;

- a single network,
- consortia of telecom operators,
- private (non-telecom) investors,
- supplier financing, and
- government and development bank financing

The two dominant forms of ownership are single networks, consortia and private (non-telecommunication) investors, together representing more than 90% of all investment over time. To develop and maintain a cable, the owner will contract a company to build the link for them and contract a company for the maintenance of the cable, should it break. The owner also commits to financing future upgrades and maintenance. Upgrades are necessary, as even though a cable may be designed for 3.2 Tbit/s, it often only operates at a fraction of that. Therefore, the initial activated capacity on a cable designed for 80*40 Gbit/s, may be 5*40 Gbit/s. Future improvements in equipment may dramatically increase the capacity of cables as has occurred in the past.

Until market liberalisation, only incumbent telecommunication carriers had the ability to invest in a submarine cable. Initially, new entrants had to purchase capacity from these operators until they could rollout their own facilities or purchase capacity from other new entrants. Therefore prices were high and attracted competitors. Private investors entered the market financing new networks, for use by new entrants, competing with the incumbent network. The introduction of DWDM changed the underlying business models and led to an oversupply especially on the trans-Atlantic market, where most investments had taken place. The effect was that several private networks went bankrupt.

A consortium of telecommunication operators is the most common form of financing for a submarine cable. These telecommunication operators will finance part, or all, of the network upfront. The backing of telecommunication operators makes it easier to secure financing from banks and institutional investors should this be necessary. There are a number of common rules in submarine fibre projects that deserve attention with respect to competition.

The rollout of a submarine fibre connection is a rare occasion in most countries. If an entity was not able to join the project at the start, it often cannot join later. Many consortia have a rule of only one network per country and only allow licensed telecommunication operators to join the consortium (not private companies, such as Google or Facebook). Under this model, a single operator per cable can create a monopoly on international connectivity in the country or a duopoly if there are two cable connections. In principle, there is no reason why there cannot be a number of operators per country.

Many cable consortiums have a rule that any change to its governance or any sales to external operators have to be approved unanimously by all operators. Another restriction can be that networks are not allowed to sell capacity in each other's territory. From the perspective of the consortium such rules are meant to increase the value for its members. Some consortia provide access to a consortium via an auction per country with a natural incentive to build-in monopoly power, if it increases the value of bids. The companies initiating a cable often form the start and end of the cable. They may initiate the cable because they wish to be a telecommunication hub. The aim is for an operator to bring traffic from other countries into their region and carry it onwards to the rest of the world. Non-compete clauses, however, may limit the most likely potential competitors in a region. It needs to be noted that not all cable consortiums are the same and that liberalisation has opened up traditional approaches. One sign of this is that companies such as Google and Facebook have each been part of cable consortiums.

The pricing of a submarine fibre is generally done on a "per dedicated capacity per month" basis. Unlike terrestrial backhaul purchased by ISPs, this backhaul is bought on a point-to-point basis. When traffic grows, so does the revenue for the cable owner. As Internet traffic has relatively high growth rates, income from a cable is likely to rise where there is less competition (e.g. on a single cable route). This discourages the growth of traffic to a country. Naturally, competing networks could decide to build a new cable to enter the market and this would bring prices down. Some cable owners, therefore, are said to lower prices over time, by a level aimed at discouraging new entrants, but high enough for them to extract rents. This may decrease the attractiveness for a competitor to enter into a market but market access and demand are likely to be more critical in a new entrant's decision.

A further factor that drives some cable entry is the desire for a network to reduce its own costs. If a network operator views access to international capacity as a bottleneck, for its own growth, it may seek to add a link to larger points of international traffic exchange. In this instance, a company could be just removing a major source of cost rather than generating a high return from the cable. It needs to be remembered that by raising the international costs of its competitors an operator with monopoly power can also charge higher rates to business and consumers for Internet access.

Given the remarkable ability of fibre networks to carry large amounts of traffic a single cable may be sufficient and, in some cases, may benefit a single provider of that service. Single cable outcomes do not bode well, however, for the resilience of any country's network connectivity. The experience of Bangladesh and New Zealand provide recent examples. Both are connected to one system, in Bangladesh consisting of one cable, in New Zealand consisting of two cables (one direct to the United States and one via Australia to the United States). The cable in Bangladesh has been prone to failures disrupting communication services. In 2013, an alternative route overland became an option for linking Bangladesh to the rest of the world via India. Use of such an alternative link would allow for resilience and redundancy. The country's policy is, however, to restrict access to international connectivity to two licences for each of data and voice services through which traffic must pass via an international gateway. The result is a situation where the government owned operator would incur additional costs for use of an overland route but not necessarily generate additional revenue given that a single cable meets current demand, which in itself is constrained by such policies.[28] The two-cable system in New Zealand has not witnessed a competitor emerge. In 2001, on one occasion, the Southern Cross cable in New Zealand experience total disruption of services for 12 to 20 hours.[29] In most cases the two cables of the system can provide back-up for each other in case of failure. However not all customers buy protected service, which comes at a higher price. It is worth noting that the cable has provided sufficient capacity and that market conditions have not attracted new entry that would result in additional resilience for any failure of both links.

Conditions can change quickly with respect to the attractiveness of developing new cables in response to market reform. Africa provides a prime example of where the introduction of competitive markets has driven growth in wireless services. This has created, for the first time, sufficient demand to attract competition in undersea cable connectivity on that continent. Nigeria and Kenya are both now connected through three competing submarine fibre networks. In Nigeria the three largest telecommunication operators each control a submarine fibre. Kenya's favourable market, good governance of networks and position in the region has helped it secure access to multiple cables.

In many countries only a single telecommunication operator is permitted to manage any landing station or submarine fibre link. The result is that this dominant position is abused. A report undertaken by Analysys Mason and the Internet Society, documented that countries are increasingly liberalising the operation of landing stations.[30] It noted, however, that this is still not the case in many countries and provided examples. The report mentioned Cameroon as a country with unclear rules and government monopolies. This has so far delayed the landing of two cables in Cameroon, even though one of the cables is owned in part by Orange Cameroon's parent (Orange France).

A landing station is a structure that houses connection of an undersea cable to the landside network. It contains power equipment that power repeaters along the cable, optical transmission technology specific for the cable and the landside networking equipment. More modern cables may, however, only place power equipment in the landing station and carry the optical signal to a data centre nearby, where the facilities are better and traffic can be split out directly to the receiving networks. Control of landing stations has been a source of monopoly power. An operator of a landing station may impose a high charge on maintaining the landside networking equipment and, from there, forwarding it to a data centre where the receiving networks were located.

There are positive examples of recent developments in Africa. The World Bank has worked with Benin, Gambia, Kenya, Sierra Leone and Liberia to invest in new cables. A condition of this financing was that the government share would only be used to secure the initial investment in the cable. The government's share would later in part be divested to the private sector. This provides cable consortia with some security that the initial investment will be undertaken, but also promotes competition in the market.

Finally, some have proposed alternative financing of international bandwidth (mostly submarine fibre), based on a sending party network pays model. The claim made by some proponents of this model was that they were required to pay for the whole link from their network to major hubs for Internet traffic exchange. A logical weakness with such proposals is that the sending party on the Internet is only the sending party because it received a request from the receiving party. Furthermore it can be argued that communication is two-way or multi-sided where all parties value the communication, because if they did not they would cease the communication. In the same way, the commercial choices to participate in a cable and to allow the landing of a cable are all made by the operators and countries that connect to the Internet. These decisions are made to benefit these operators and countries hence the fundamental principle on the Internet that everyone pays for their own connection.

When an operator establishes a cable to connect to the nearest international location, where it can find a large number of other networks, it benefits from the networks that other operators have built to that location. It can then peer or purchase transit with all the benefits associated with a competitive market place. At the same time, through the creation of domestic IXPs and the participation in regional IXPs, any operator can reduce its costs and improve services for its customers. This has proven to be successful in many countries, especially with the introduction of local caches by companies like Google and Akamai. These store the most popular content in the country locally and distribute it via the IXP. In Kenya traffic on the KIXP grew by 800-900Mbit/s when the Google Global Cache was installed. The main barriers to such 'win-win' developments are regulatory barriers that do not permit such market-based outcomes.

Stimulating terrestrial backhaul in developing countries

Terrestrial backhaul is a critical component of any nation's communication infrastructure. It is preferable if the available networks function as a mesh to provide multiple routes between any two locations. The optimal route would be a direct one, with additional links that do not result in a diminution in performance in the exchange of traffic. Unfortunately, this is not always the case. In the absence of an IXP or competitive domestic backhaul facilities some operators exchange traffic at an international location or even take traffic out from and back into a country – something known as "tromboning".

Experience demonstrates that liberalisation is essential to the development of the telecommunication market. A well-defined neutral role for a regulator in ensuring effective competition between market players, is essential. No single player should be able to control essential facilities without oversight in the absence of sufficient competition. In the case of backhaul a first step is to remove unnecessary barriers in deploying backhaul connectivity.

Historically, many countries had specific licenses for designated roles in telecommunication markets associated with geography. For example, some countries only issued licenses for regional or international services where certain operators could only make offers in that location or market segment. Generally these restrictions have been lifted so that all market participants can offer a full range of services. Some countries do, however, still have licences for international gateways. There is arguably little need in a liberalised market. Nonetheless, the issue here is not that they exist, but that they should be available for any market participant and non-discriminatory. Only with such a license is a network allowed to interconnect directly with foreign networks. Without such licences the ability of operators to flexibly expand their networks are curtailed. For example, a fibre or wavelength swap between two networks in adjoining regions or countries becomes more difficult and often more costly. The experience in the European Union, for example, shows that creating a single market with modest registration obligations lowers barriers to cross borders.

It can be challenging to negotiate rights of way, to pay municipalities fees for civil works and to pay taxes related to deploying a network. Some OECD countries have taken steps that minimise or remove these hurdles, for example, by giving telecommunication networks a blanket right of way. If networks are required to pay taxes to municipalities this should be done in a transparent and non-discriminatory way.

The financing of backhaul networks in some locations will always be challenging. Remote or less populated areas are a prime example. In respect to addressing this issue policy makers have adopted many strategies over the years. A recent example comes from Colombia. The government created a list of unconnected municipalities and public funding for co-financing backhaul when networks were willing to connect these municipalities. The successful tenderer would be the firm that offered to connect the greatest number of municipalities. In this case, the winner of the tender connected 245 previously unconnected municipalities, where the government had expected 70 to be connected.

Brazil has taken a different route than Colombia. It has revived the dormant state incumbent Telebras, which is to operate a wholesale network across the country and connect previously unreached areas. Telebras is also tasked to provide competition to existing network providers, which in the view of the government were expensive and delivered low quality in some regions. Telebras makes use of the networks of the electricity and oil companies to reach these outlying parts of the country. In the case of Manaus, the capital of Amazonas, it opted to connect via Venezuela. It can be said, in principle, that this is an example of how backhaul networks should function if this is the most efficient option and not be restricted by borders. This does, however, need neighbouring countries to accept the need for regional co-operation and to recognise the benefits for all parties.

There are also many negative experiences with government investment in backhaul networks. Generally this involves the reinforcement of market power rather than opening up of public funded infrastructures for all service providers to access in a way that enhances competition. Kenya, for example, awarded a contract for their National Optical Fibre Backbone Infrastructure to connect 31 previously unconnected locations. It was given to the 49% government owned, Orange Kenya, without a competitive tender procedure. The network is currently only used commercially by Orange Kenya, with Safaricom testing the network, but no other networks making use of it.[31] While there will be specific circumstances in each country, publicly funded infrastructure should be open to all other networks, public and private. The pricing should be transparent and adjustable over time to fit new situations. The end-goal should be optimal services for consumers and experience shows this is best accomplished in a competitive market.

Private investment in backhaul networks has delivered remarkable results in liberalised markets, even in some of the most challenging circumstances. Liquid Telecom, of Zimbabwe, provides an example. Before 2013, the company built a backhaul network from Kolwezi and Lubumbashi in the Democratic Republic of Congo, to Capetown in South Africa a distance of 3 800 km. In 2013, Liquid Telecom acquired networks in Kenya, Tanzania and Uganda, thereby allowing it to operate overland from Mombasa to Capetown. This assisted some ISPs in Africa during a recent cable break near Egypt. Traffic could be rerouted via Capetown and then the western side of Africa.

The position of landlocked countries has been challenging in some regions. A landlocked country has to connect through other countries to get access to international backhaul routes. Policy makers from some landlocked countries say that transit countries have been reluctant to co-operate or that the operators from transit countries have imposed restrictions on the development of backhaul into their country. They mention practices such as overcharging, not allowing access to a landing station or submarine fibre consortium.

A report undertaken by the World Bank states that landlocked countries are not just victim to their geography. They also suffer from policies that they establish. “Landlocked countries tend to restrict trade in key 'linking' services like transport and telecommunications more than other countries. The phenomenon is most starkly visible in sub-Saharan Africa. In telecommunication markets, the dramatic benefits of liberalisation can still obscure the persistence of protection. This can result when countries that have abandoned monopolies still maintain stringent restrictions on entry and ownership. Significantly, from a market-access point of view, 43% of all landlocked countries limit the number of licences granted in the fixed-line telecom market, in contrast to only 4% of all coastal countries maintaining such restrictions. Moreover, landlocked countries tend to be less transparent in making licensing criteria publicly available. Landlocked countries impose more stringent limits on foreign ownership in telecommunications firms, and are also less likely to have instituted a regulatory authority that is independent from the sector ministry.”[32]

Establishing IXPs to improve backhaul

A fundamental step for the Internet community in any country is to establish one or more IXPs. For the most part this can be left to the market and Internet stakeholders given that the benefits are self-evident for participants at these exchanges. Nevertheless there remain countries that do not have IXPs and sometimes policy makers have needed to remove the barriers to their creation or to examine why they are not in existence and bring stakeholders together.

An IXP enables the exchange of traffic between connected networks. By connecting to the central platform, networks can use one port to connect to all participants, instead of needing a one on one relationship with all others. Through the use of route servers, automatic peering can be set up with a number of networks. The exchange of traffic is often without charges in one or more directions, without a written contract and without requirements on the balance of traffic. Around the IXP there are generally a large number of backhaul and transit networks, which increases competition and lowers prices. Furthermore networks will utilize the location to establish direct interconnections between their networks. Building a successful exchange requires good governance.

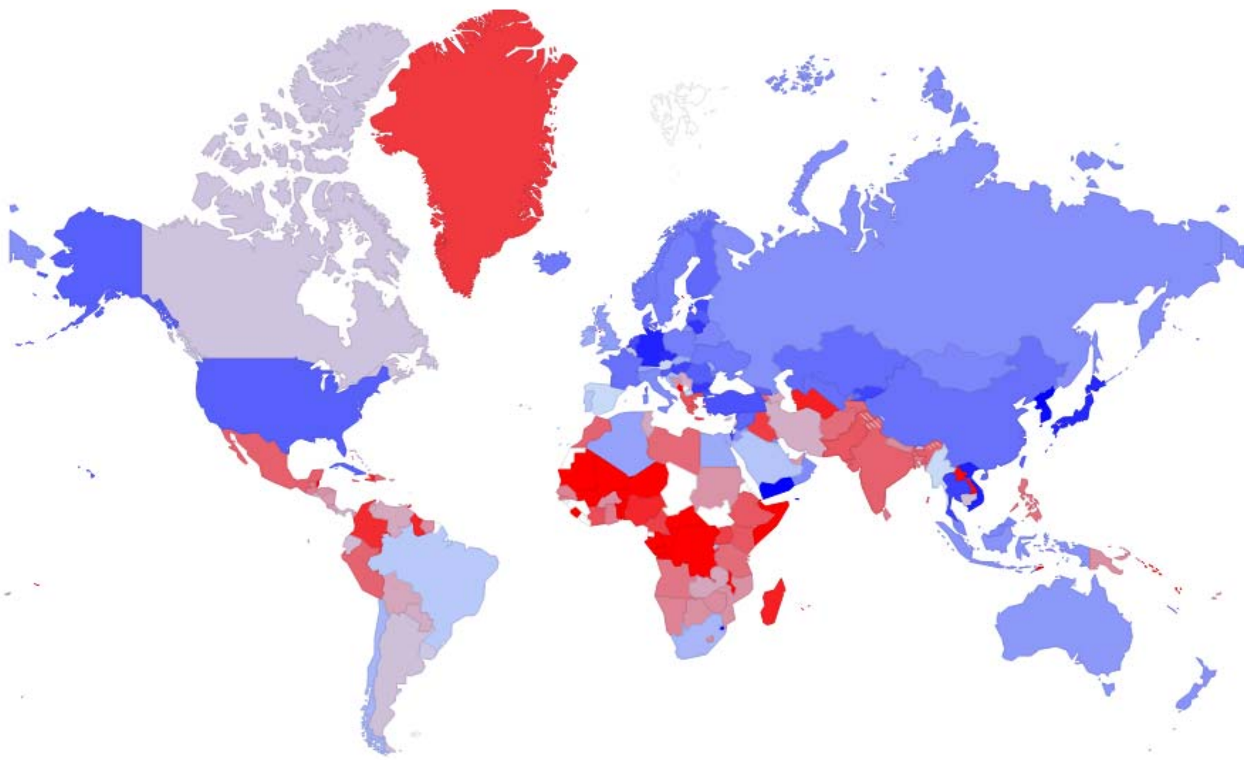
The Internet communities, in several developing countries, were among the first to recognise that establishing an IXP locally would save on international bandwidth. Early examples were the IXPs of Nepal and Kenya. Even when these countries saved only a few Mbit/s peak capacity per month, the benefits were significant, because at the time they were using satellite backhaul. Today, the Internet Exchange of Nepal carries peak traffic up to 1 Gbit/s, providing savings for its members up to USD 100 000 per month compared to buying transit.

Establishing an IXP does not have to be expensive. A second-hand switch is often more than capable of carrying the traffic of a new exchange. New switches can be bought for around USD 500 per port. Competent management is needed, but can be provided by the members, certainly initially when there are only a few members. The potential savings are, however, significant as demonstrated by the example of Nepal, which would more than cover the expenses of the IXP.

Brazil has opted to build out IXPs in all major cities throughout the country – the PTT Metro system. There are currently 19 active locations, with peak traffic levels varying between 40 Mbit/s and 140 Gbit/s. This project is managed through NIC.br, which also manages the ccTLD .br. This enables operators to exchange local traffic at the closest IXP with all the attendant benefits. This assists Brazil to avoid a challenge that still exists in many countries. In those countries, shifting traffic away from a city of one million people to another and then back again, for example, is not likely to be an efficient use of resources. Nevertheless, it is still the case in many countries, where the only IXP is located in the capital.

In order for an IXP to be able to function there has to be local traffic and the responsiveness is generally better if websites and content are hosted in close proximity (e.g. domestically). The Pingdom data indicates there are still a great number of nations, where content is not hosted locally (Figure 2). The complete list is available from the Pingdom website. Some notable examples are Brazil (54%), India (22%), Indonesia (66%), China (74%) and South Africa (58%) It should be noted, in some cases, the low number of sites registered in the ccTLD of the country distorts the accuracy of the data. For example the Comoros have 1 website in the Alexa 1 million and it is hosted nationally. In other cases the country's ccTLD is used for generic reasons, such as Tuvalu's .tv for television, Colombia's .co for company and, therefore, the sites registered under the ccTLD may not be hosted in the country.

Figure 2. **Local (blue) versus Foreign (Red) hosted content**[1]



Source: OECD, Pingdom, Alexa

Countries that do not have local hosting will also have difficulties establishing local IXPs and making these flourish. Generally, website owners move content location out of a country when it is the most cost-effective solution for them. Networks will, therefore, find fewer parties to exchange traffic with if policies are not favourable to encouraging local content hosting. The same point has been made for the need for a competitive market to ensure that ISPs enter into appropriate peering and transit relations so that traffic does not have to be exchanged outside a country.

In the most competitive markets peering and transit disputes can still occur but they tend to be more evident in countries where there is less developed competition. This is still the case even in some OECD countries. By not peering or buying transit locally, established networks force other ISPs and content providers to buy transit from them to reach customers in that country. If networks refuse to buy transit locally from these networks, but buy it from another transit provider, the traffic will be routed via an international link out of the country, to be exchanged elsewhere with the network. This puts a financial cost and an additional latency on traffic but regulatory intervention may not produce optimal outcomes.

[1] This map is for illustrative purposes and is without prejudice to the status of or sovereignty over any territory covered by this map.

In 1998, the Australian Competition and Consumer Commission (ACCC) tried to remedy a lack of peering between the largest operators, by requiring Telstra to peer with the three next largest operators, at that time, in the country. The effect was that these four networks only peered with each other and refused to peer with any other networks in Australia, thereby putting an even larger portion of traffic out of reach for local peering agreements. Some believe this impaired the development of the market and as a result the deployment of independent infrastructure, such as new national backbone and under-sea cables, for many years. When this independent infrastructure did emerge the very tight bandwidth caps evident in Australia, were dramatically expanded in more populated areas.

An alternative solution for a regulator might be to require networks to buy domestic transit from an operator who does not hold market power. In such a case the incumbent can refuse peering. The other ISP or content provider can, however, also refuse to buy transit from the incumbent and go to a third party, without an additional punishment on their traffic by it being routed outside the country and back again.

There are variations known on this refusal to peer. One is where networks (ISPs or content providers) that refuse to buy a paid peering and opt for transit instead, see their traffic routed via a saturated transit connection. This will deteriorate the performance of the services offered. Another is where the transit connection itself will not be saturated, but will appear saturated only for traffic to and from the specific network. These practices are difficult to detect and it is even harder to distinguish between intentional impairment and configuration errors.

ANNEX 1

WEBSITE HOSTING, HOME OR ABROAD?

The economic costs of website hosting are not uniform across economies. This results in websites being hosted outside of the economies they originate from and/or which they target. This is the case for several reasons. First, the application process for a domain name is longer and more costly in some economies than others. This results in some domain names being registered under a generic ccTLD instead of a national domain name. Second, webpage hosting might benefit from spillover effects from technologically advanced sectors; hence it can be more developed in more technologically advanced countries. Third, the degree to which the electricity supply can be guaranteed in an economy which determines the maintenance of a webpage could be a factor. This annex puts together a brief empirical check that looks at factors that might potentially be related to the webpage hosting decision process across economies.

Data

The **share of websites hosted domestically** is approximated by the share of economy-specific "country-code top-level domains" (ccTLDs) that is hosted in this specific economy. The ccTLDs are two-letter top-level domains especially designated for a particular economy, country or autonomous territory to use to service their community. For example, the ccTLD *.fr* refers to France, *.de* to Germany, and so forth.

These data are sourced from Pingdom in May 2013. Pingdom is a company that offers services to track the uptime, downtime, and performance of websites.[2] Pingdom is one of the main available sources for data on websites, their number, their performance and their hosting. Pingdom has used the Alexa top 1 million sites list and then determined for each ccTLD in the list where it was located. The Alexa top 1 million is determined by Alexa based on the use of a toolbar by consumers. Therefore, these data constitute a representative but not necessarily random sample from the whole population of websites. Data are collected by checking the IP-address at which the domain name is registered against a table listing the country the IP-address is located in.

There are two main potential biases related to the use of ccTLD as an input for proxy on the share of websites hosted in an economy. First, since there is no ccTLD that is widely used in the United States, and ".us" has too little coverage in order to be used as a good proxy, the United States is excluded from the dataset. Second, some economies have decided to allocate the rights to their ccTLD to third parties. For example, Tuvalu (*.tv*) and the Federated States of Micronesia (*.fm*) have taken advantage of the commercial interest in the abbreviations of their ccTLDs. Consequently, a number of such economies are considered to be "outliers" and will merit separate attention.

The benefit of combining the Alexa top one million with data on ccTLD's is that it filters out over 200 million domain names, which might be too small for the owners to make strong economic choices on where to host the site. For such sites other concerns may be more important. The top one million is likely to contain a large number of sites that do feel the economic benefit of hosting at home or abroad. And by using ccTLDs there is a self-identifying element that demonstrates that the site is associated with a particular country. Though many sites hosted under generic TLDs are also associated with a particular country, there is no reliable way at the moment to identify that association. This would require text analysis or visitor analysis.

2 www.pingdom.com

Concerning explanatory variables, the data have been collected at the country level. The main variables used for the analysis proxy were the following three phenomena: *i)* regulatory barriers to entry; *ii)* level of technological advancement of a given economy; and *iii)* reliability of electricity supply in the economy. With respect to the regulatory barriers to entry, they are measured by:

- **Ease of doing business** refers to conduciveness of regulatory environment to business operation. This measure ranks economies from one to 185, with first place being better. This means that a low numerical rank indicates conductive regulatory environment. (Source: World Bank, World Development Indicators)

The level of technological advancement of a given economy is proxied by:

- **Fixed broadband Internet subscribers** is the number of broadband subscribers with a digital subscriber line, cable modem, or other high-speed technology (Source: World Bank, World Development Indicators).

Concerning the reliability of the electricity supply in the economy, for the purpose of this exercise this is measured by:

- **Access to electricity** that proxies the reliability of the electricity network. It is measured by the percentage of population with access to electricity. Electrification data are collected from industry, national surveys and international sources (Source: IEA).

- **Electric power consumption per capita** measures the per capita production of power plants and combined heat and power plants less transmission, distribution, and transformation losses and own use by heat and power plants (Source: IEA).

The analysed cross-country dataset describes websites in 2013 in 209 economies. It should also be noted that some data are not available for some economies, so that some regressions use fewer number of observations.

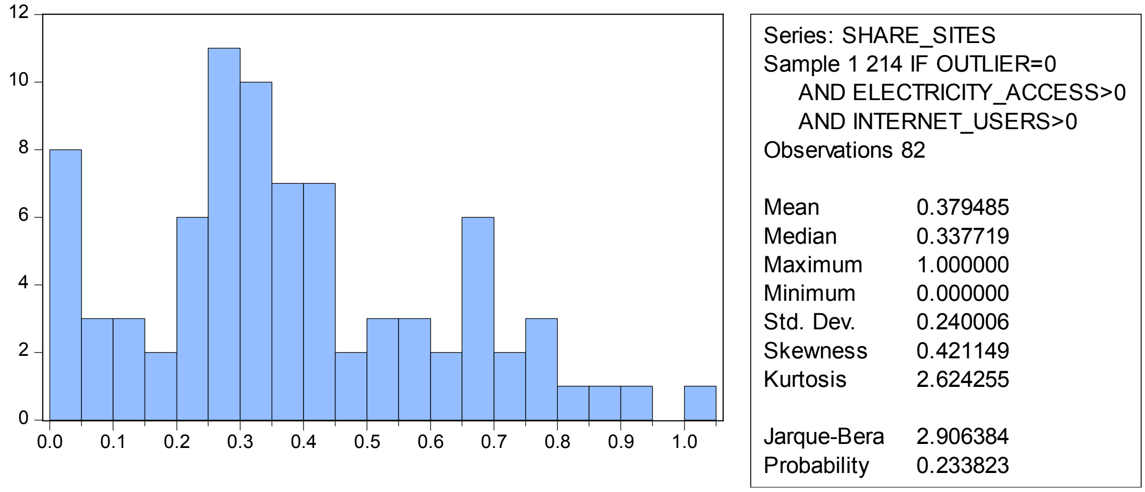
Econometric framework

The goal of this exercise is to shed some light on factors that could affect the decision process as to whether a website is hosted domestically or abroad, using the above-presented datasets. This poses two challenges in terms of the econometric model. Firstly, the dependent variable (data on websites hosted in an economy) is a percentage that ranges from zero to one. Secondly, these data lack a time dimension, hence the number of observations is limited to the number of economies for which data are available.

The first way to model this challenge is the basic ordinary linear regression. While this method is relatively simple, there are two main issues related to it. First, even though the model imposes a linear relationship, the actual relationship is not linear, but sigmoidal (s-shaped). Second, the model can predict values below zero or above one, which are simply not possible.

Given these limitations, the linear approach can be justified only if all data fall in the middle, linear section of the curve. Unfortunately this is not the case. Whereas only few observations fall within the (0.8, 1) interval, a significant number of observations is below 0.2 (see Figure 3).

Figure 3. Model observations



An alternative approach is to treat the proportion as a censored continuous variable (see Long 1997).[33] This implies that the regression follows a two-limit Tobit model. The main results can be seen in Tables A1.1 and A1.2).

The ease of doing business is also correlated with the share of webpages hosted domestically (the easier it is to do business the higher the shares of webpages hosted domestically). The share of webpages hosted domestically is also positively correlated with access to electricity and negatively correlated with the electric power consumption per capita, but the second one is not statistically significant. Access to electricity is not significant with the introduction of the number of Internet users into the regression, which points at (somehow obvious) the general significance of maturity of a given Internet market. This suggests that the impact of access to electricity on the decision whether to host a website domestically or not should be treated with caution.

Table A1.1. Factors related to the share of websites hosted domestically

All economies

GDP Per Capita (log)	0.03 (0.04)	0.05 (0.05)	-0.02 (0.04)	-0.04 (0.04)
Electricity Access	**0.002*** (0.001)	0.002 (0.001)	**0.002*** (0.001)	0.001 (0.001)
Energy Use		-5.08(E-06) (1.34(E-05))		
Ease of Doing Business			**-0.002**** (0.0007)	
Internet users				**0.005**** (0.002)
Constant	-0.08 (0.28)	-0.19 (0.38)	0.62 (0.35)	0.47 (0.16)
Number of observations	76	68	75	76

Notes: Robust standard errors in parentheses: ** p<0.05, * p<0.1

To refine the exercise presented above, it is illustrative to do a similar set of regression on a smaller sample of more mature markets, with a more developed infrastructure.[3] The results of a two-limit Tobit model on a sample of upper-middle income economies and high-income economies are summarised in Table A1.2.

The results generally confirm those previously presented (i.e. in Table A1.1). The ease of doing business and access to electricity are positively correlated with the share of webpages hosted domestically, and these correlations are statistically significant.

The share of webpages hosted domestically is also negatively correlated with the electric power consumption per capita, but the second one remains insignificant statistically. The access to electricity remains insignificant after the introduction of the number of Internet users into the regression; which means that the general development of the Internet infrastructure is only important at an early stage of economic development.

3 Economies with GDP per capita higher than USD 4 085. See http://data.worldbank.org/about/country-classifications

Table A1.2. Factors related to the share of websites hosted domestically

Upper-middle income economies and high-income economies

GDP Per Capita (log)	0.04 (0.04)	0.08 (0.06)	0.01 (0.04)	-0.006 (0.06)
Electricity Access	**0.003**** (0.01)	**0.002*** (0.001)	**0.003**** (0.001)	0.002 (0.001)
Energy Use		-1.18(E-05) (1.36(E-05))		
Ease of Doing Business			**-0.001*** (0.0007)	
Internet users				0.002 (0.002)
Constant	-0.32 (0.38)	-0.62 (0.57)	0.13 (0.48)	0.13 (0.57)
Number of observations	45	43	44	45

Notes: Robust standard errors in parentheses: ** p<0.05, * p<0.1

The results are robust to the inclusion of a range of indicators for which sufficient information is available for the analysed economies. These include: the share of the degree of urbanisation of an economy, indicators of competition, R&D expenditures and average years of tertiary education. It needs to be noted that as in other limited dependent variable models, the estimated coefficients do not have a direct interpretation.

Notes

1 www.oecd.org/internet/consumer/40839436.pdf .

2. For more information on 03B networks, see its website www.o3bnetworks.com/o3b-advantage/our-technology .

3 Networks Built on Milliseconds, Microwaves—Not Fiber Optics—Are Latest Thing for High-Frequency Traders, *Wall Street Journal*, 30 May 2012, http://online.wsj.com/article/SB10001424052702304065704577426500918047624.html

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5 Informa, "Understanding the Role of Managed Public Wi-Fi in Today's Smartphone User Experience: A global analysis of smartphone usage trends across cellular and private and public Wi-Fi networks", White Paper, 2013.

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8 Information obtained through private conversations with participants of an ISOC workshop on bandwidth. www.internetsociety.org/doc/bandwidth-management-internet-society-technology-roundtable-series

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18 Research on very High Bandwidth connectivity, CSMG for Ofcom, 2013, http://stakeholders.ofcom.org.uk/binaries/consultations/business-connectivity/statement/CSMG-report.pdf

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