INTERNATIONAL TELECOMMUNICATION UNION

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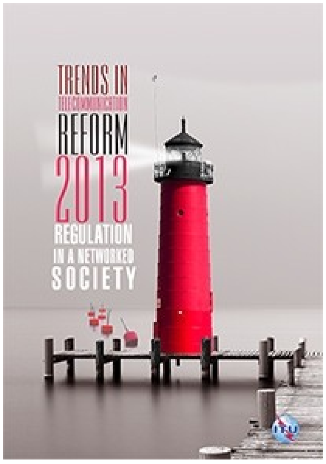
Blurring Boundaries:

Global and Regional IP Interconnection



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BLURRING BOUNDARIES: GLOBAL AND REGIONAL IP INTER-CONNECTION

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1. Introduction

The growth of the Internet since it was made commercially available in the early 1990s has been perhaps the most influential economic and social event of our time. The volume of IP traffic exchanged in 2010 was 1,200,000 times greater than in 1994.[1] This growth has been intensive: twenty households with average levels of Internet usage today generate more traffic than the entire Internet carried in 1994. Growth is also extensive, as broadband take-up has increased and the geographic reach of the Internet has expanded around the world. The Internet has created unprecedented opportunities for development, while at the same time challenging firms and governments by disrupting older business models and policy frameworks. Internet penetration, however, varies widely around the world, with much lower rates in developing countries (typically 10 times lower than mobile penetration rates).

The success of the Internet has been made possible by many factors, including the development of an efficient global market for connectivity through commercial agreements for the exchange of IP traffic. The basic model of peering and transit is now so well understood that the vast majority of peering agreements can be concluded on a handshake basis, without the need for a written document. The IP traffic exchange model has evolved over time to meet the needs of the Internet community. That process of adaptation is continuing today as new patterns of use drive structural change in the Internet ecosystem. This paper will review the current state of the market, and the forces that are likely to challenge it in the future.

As the Internet converges with, and displaces, older models of communication, the IP model of traffic exchange collides with the regulatory framework designed to promote policy goals in the traditional environment. This paper will examine the challenges faced by policy makers seeking to achieve those goals in the new environment, without interfering with the creativity, efficiency, and openness that has allowed Internet to deliver benefits to more than two billion users. Particular emphasis will be placed on the process of extending those benefits in greater measure to emerging economies through the development of the Internet ecosystem in-country and in-region.

2. Development of the IP market

2.1 Growth

From 1994 to 2010, the average annual growth in Internet traffic was about 140 per cent per year. Over the last five years of that period (1996-2010) traffic grew eightfold, or an average of about 50 per cent per year.[2] While the rate of growth has moderated, it is still remarkable for a system as big as the Internet has now become. For the period 2011-2016, Cisco forecasts that traffic will increase by a factor of four, to a total in 2016 of 1.3 zettabytes.[3]

As shown in Figure 1, Cisco predicts that that mobile data will be the fastest growing type of Internet traffic, at a compound annual growth rate (CAGR) of 78 per cent. By region, North America and Europe are expected to grow at 22 and 27 per cent, respectively. Traffic in the Asia-Pacific region, which is about equal to North America today, is forecast to grow at 31 per cent, and will thus be half again as great as that of North America by 2016. Other regions are forecast to make up ground through still faster growth.

Figure 1: Global IP Traffic, 2011-2016

IP Traffic, 2011–2016	2011	2012	2013	2014	2015	2016	CAGR 2011–2016
By Type (PB per Month)							
Fixed Internet	23,288	32,990	40,587	50,888	64,349	81,347	28%
Managed IP	6,849	9,199	11,846	13,925	16,085	18,131	21%
Mobile data	597	1,252	2,379	4,215	6,896	10,804	78%
By Segment (PB per Month)							
Consumer	25,792	37,244	47,198	59,652	76,103	97,152	30%
Business	4,942	7,613	9,375	11,227	13,130	7,613	22%
By Geography (PB per Month)							
North America	10,343	14,580	17,283	19,796	23,219	27,486	22%
Western Europe	7,287	10,257	13,026	16,410	20,176	24,400	27%
Asia Pacific	10,513	14,792	18,976	24,713	31,990	41,105	31%
Latin America	1,045	1,570	2,333	3,495	5,208	7,591	49%
Central and Eastern Europe	1,162	1,673	2,290	3,196	4,419	5,987	39%
Middle East and Africa	384	601	903	1,417	2,320	3,714	57%
Total (PB per Month)							
Total IP traffic	30,734	43,441	54,812	69,028	87,331	110,282	29%

Source: Cisco VNI,2012

2.2 Performance

The global market for IP connectivity has performed very well over time. It has produced lower prices, directed resources efficiently, called forth the investments necessary to keep up with the dramatic growth in traffic, and enabled the extension of the Internet to users around the world. The growth of peering, reductions in transit prices, proliferation of exchange points, and the development of content delivery networks (CDNs) have combined to reduce the cost and increase the quality of internet connectivity. If the connectivity necessary to carry the volume of traffic the Internet handled in 2010 were priced at the wholesale interconnection rates in effect in 1994, the global bill would be USD 16 Trillion, or slightly more than the GDP of the United States.

Prices for transit service have declined every year. Transit can now be purchased in larger markets for about two USD per megabit per month, depending on volume and other terms of the agreement, with some prices as low as USD 0.50. To put this into perspective, and to permit a crude comparison with price levels familiar in the traditional telecom space, these prices can be stated in the form of a per minute wholesale rate for the global transport and termination of voice traffic to any customer in the world. Even at the higher figure of USD 2, the voice equivalent would be about USD 0.0000008, at least five orders of magnitude lower than wholesale rates common in traditional telecom markets. This reflects in part the efficiency of IP networks, but also the fact that IP markets for the exchange of traffic have performed far better than those for traditional circuit-switched (TDM) traffic.[4] But transit prices also vary substantially by location and volume, reflecting differences in the weighted average distance the traffic must travel, scale economies, and market conditions in-region. These factors will be discussed in a later section of this paper, the experience of different countries will be reviewed, and best practices to address these challenges will be considered.

For a time after the telecom bubble burst in 1999-2000, some observers feared that the decline in transit prices was a temporary phenomenon driven by the excess capacity built up during the previous boom. It's now clear that these low prices are a long-term, sustainable trend that has been maintained for many years. As will be discussed below, investment has been forthcoming in recent years to build new Internet assets, including long-haul undersea cables.

2.3 Structure

The market for IP connectivity has evolved continuously over time, driven by changes in patterns of use (discussed below) and by the need to minimize costs and improve quality.

Peering. Through the continued expansion of peering, Internet Service Providers (ISPs) have disintermediated transit providers, reduced their transit expense, and increased their ability to deliver traffic directly to other networks.[5] The vast majority of Internet traffic now completes without touching any of the major backbone networks.

A recent survey of ISP networks gathered information about Internet peering agreements.[6] Responses were received from 4,331 different ISP networks, or approximately 86 per cent of the world's Internet carriers, incorporated in 96 countries, including all 34 members of the OECD and seven of the UN Least Developed Countries. Information was collected on 142,210 peering agreements.

The survey results indicate a highly developed market in which the terms of basic peering agreements are well known, and transaction costs are kept to a minimum. Only 698 of the agreements in the sample (0.49 per cent) were formalized in written documents. The other 141,512 (99.51 per cent) were "handshake" agreements in which parties agreed to commonly understood terms without creating a written document. Almost all of the agreements (99.73 per cent) had symmetric terms and were settlement-free. Only 374 agreements (0.27 per cent) included asymmetric terms such a compensation (or "paid peering") or minimum peering requirements imposed by one party on the other.

A surprising result of the survey was the prevalence of multilateral agreements, in which many ISPs meeting at an interexchange point (IXP) join a single agreement, rather than establish bilateral agreements with each of the other parties. The majority of the Autonomous System pairs observed in the sample were connected through multilateral agreements. The use of multilateral agreements can further reduce transaction costs. In some IXPs, a network is required to join the multilateral agreement as a condition of joining the exchange.

Figure 2: Probability of selection of a country of governing law; ten most likely and ten least-likely countries

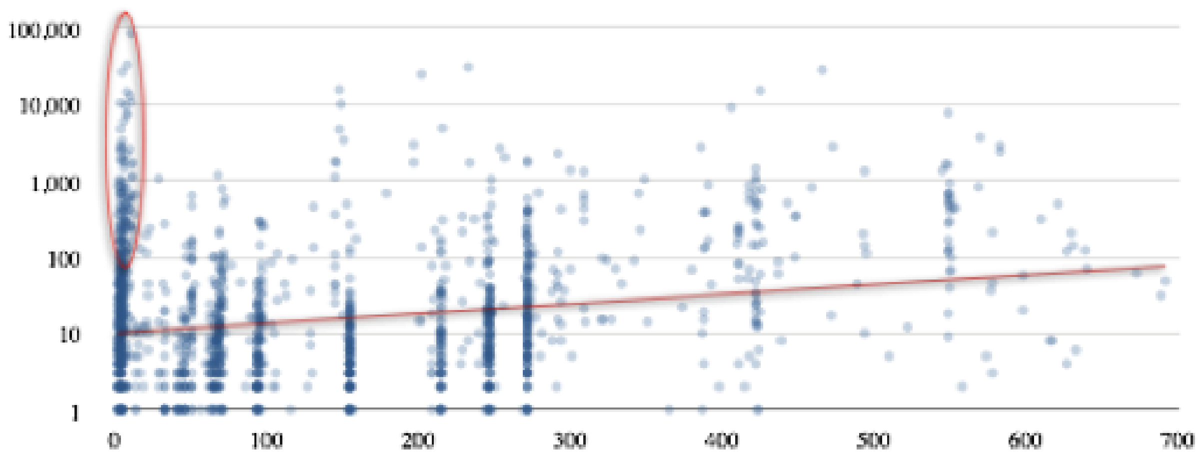
Source: Woodcock and Adhikari

Peering agreements generally specify a country whose laws will govern in the event of a dispute between the parties. Within the sample, the country of governing law in every case was also the country in which at least one of the parties was based. In other words, unlike some other markets (such as ocean shipping, for example) there does not appear to be any "third party" country that attracts firms not incorporated there to employ its legal framework for this purpose. However, the data do show clear preferences, with some countries being more likely to be chosen if one of the parties is incorporated there, and others less likely. Figure 2 shows the ten countries with the highest probability of being chosen, and the ten least likely. In nearly every agreement in which one of the parties is incorporated in the US or Canada, that country is selected as the country of governing law. On the other hand, there are some countries in which no agreements in the data set were selected for an agreement where one of the parties was incorporated outside this group, due to the the unattractiveness of their legal frameworks..

Networks may pursue different interconnection strategies. Figure 3 shows a distribution of the networks included in the survey, by the number of prefixes each network advertises (on the Y-axis) and the number of interconnection partners each network has reported (on the X-axis). The vertical cluster to the left of the Figure (circled in red) includes most of the large incumbent and global backbone networks. These large networks reach a wide universe of prefixes, but do so using a very limited set of interconnection partners. Outside this group, the red trend line on the Figure shows the number of interconnection agreements increasing as a network advertises more prefixes. These networks make increased use of peering to obtain the connectivity they need, and to reduce their reliance on transit. There is an interesting contrast between the older, "tier 1" networks, and large content-distribution networks (CDNs). CDNs that are comparable in size to the large tier 1 carriers have very broad interconnection arrangements, in terms of both the number and the geographic diversity of their interconnection partners. In this they follow the trend line on the Figure much more closely than do the Tier 1 carriers. This represents a clear difference in strategy, as well as the success that large CDNs have had in negotiating peering agreements with local access ("eyeball") networks. Finally, the other vertical clusters in Figure 3 represent multilateral peering agreements at large IXPs. The Hong Kong Internet Exchange, for example, has 144 participants.

Since peering and transit are substitutes for one another, as networks grow, as the price of transit falls, and as the costs of implementing peering arrangements change, these networks may adjust the amount of transit they buy, and "groom" their peering agreements, to roughly equate the cost at the margin of peering and transit in order to minimize their overall cost of connectivity. Both peering and transit are subject to scale economies. The cost of peering will generally fall as increasing volume allows the physical arrangements for peering to be utilized more efficiently. The cost of transit will generally fall with contract commitments for larger volume and a longer term.

Figure 3: Number of advertised prefixes (Y-axis) over number of interconnection partners (X-axis) per carrier



Source: Woodcock and Adhikari

Internet Exchange Points (IXPs). Two IP networks can meet and exchange traffic at any point they choose. However, by establishing a common point where multiple networks can meet it is usually possible to achieve greater scale and scope economies and reduce transaction costs. This is done through the use of IXPs.

When the Internet was first made commercially available it was very US-centric, and much of the traffic generated by European networks had to travel to the US to be exchanged, even if the traffic was addressed to a terminating point in Europe. This round-trip process, called "tromboning" adds cost and reduces quality by adding to the delay in transmission, or latency. As the Internet grew in Europe, and IXPs were established there, the need for tromboning diminished, and European IXPs became magnets for investment in Internet assets. Today, Europe has 137 IXPs, including seven of the ten largest in the world. Similarly, as Internet activity has grown in Eastern Europe, the center of gravity has moved eastward, with large IXPs in cities like Prague and Sofia. At the same time, a similar process was taking place in the more developed countries of Asia-Pacific.

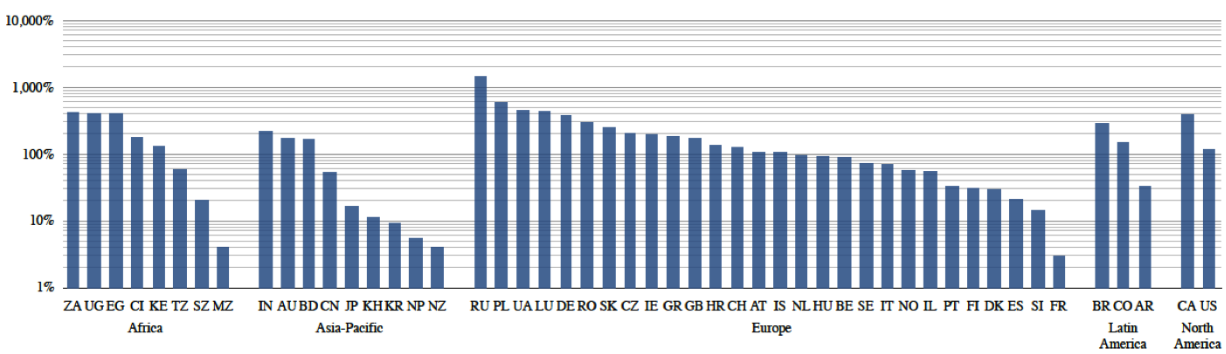
As the Internet has grown extensively in different regions around the world, this process of developing Internet resources and scale in-region has been repeated, with IXPs playing a key role. If there is not a convenient exchange point where traffic can be exchanged in-country or in-region, then traffic between two local subscribers may be tromboned to a distant exchange. For example, traffic within a Latin American country may be exchanged in Miami, or traffic local to a country in sub-Saharan Africa may be exchanged in Amsterdam.

The establishment of an IXP in-country or in-region can become part of a virtuous circle of investment and development of Internet assets. To the extent that local traffic can be exchanged at a convenient IXP, transit expenses can be reduced, and capacity on undersea cables can be used for long-haul traffic that needs it. Quality is improved when the route-miles the traffic must traverse, and the number of "hops," are reduced, thereby reducing latency. Research has shown that uptake of broadband and the usage of latency-sensitive applications, such as VoIP and video, increases when latency is reduced.[7] In this way, improvements in quality made possible by more direct routing can translate into increased domestic demand and revenues for ISPs and content providers.

The availability of a convenient domestic hub with access to domestic networks can also create incentives for global networks, CDNs, and content providers to establish a presence at the in-country ISP. Google, for example, has invested in caches to localize content in emerging economies. Similarly, domestic websites who have previously paid web hosting fees and transit to have their sites hosted abroad can save those costs, and increase quality, buy having them hosted locally. Having a convenient point nearby to drop off traffic may give domestic networks greater flexibility to optimize their routing and balance responsibility for transport costs when peering with international networks. By aggregating traffic at an IXP, participants may be able to negotiate better terms on larger purchases of transport services, and attract additional investment in domestic transport. Localizing the exchange of domestic or regional traffic at an IXP also protects those communications from the possibility of any interruption of service on undersea cables. Having a convenient point nearby to drop off traffic may give domestic networks greater flexibility to optimize their routing and balance responsibility for transport costs when peering with international networks. The development of Internet assets in-country can also encourage investment in complementary business development and investment in domestic access networks, IT-related businesses, and domestically-produced content. The availability of an IXP may also facilitate efforts by government to deliver services online.

An IXP cannot produce miracles by itself. For example, if participation in a domestic IXP is very costly, and domestic transport to reach that IXP is limited and expensive, then it may still be cheaper to trombone the traffic for exchange at a distant point. But an IXP can play an important role in a larger process of liberalization and market development.

Figure 4: Annualized percentage growth in domestic Internet Bandwidth production, grouped by region, 2005-2010



Source:Weller and Woodcock (2012), based on data from Packet Clearing House

At the other extreme, it is possible for a region to be oversupplied with IXPs, and some observers believe that this might be the case in Europe today. While having convenient points to aggregate and exchange traffic may reduce costs, as IXPs proliferate within a region it becomes more difficult for each of them to reach an efficient scale, resources are spent on transport links among them and ports for those links, and for any given network the cost of maintaining a presence at multiple IXPs may become burdensome. For similar reasons, in emerging economies where traffic volumes are initially low, it may be more useful to think in terms of regional IXPs where traffic from neighboring countries can be aggregated and exchanged, and the development of regional, cross-border transport arrangements may be important to allow such an IXP to succeed.

IXPs, more than 350 in all, have now been created in many countries around the world.[8] Yet more than half the countries in the world still have no IXP within their borders.[9] Figure 4 shows the growth of IXPs in different countries, grouped by region. Domestic Internet bandwidth production is a measure of the aggregate cross-section capacity of the switching fabrics of the IXPs within each country. The annualized growth rates in that measure over the five years 2005-2010 range from less than 20 per cent to 1,470 per cent (in Russia). Several african countries, including South Africa, Uganda, and Egypt, grew at more than 400 per cent.

Content Delivery Networks. Over the last decade, a new category of service provider has developed on the Internet -- the content delivery network, or CDN. A CDN provides resources to enhance the quality of delivery for Internet content. The two main quality-enhancing elements are more direct routing, to reduce distance and the number of hops, and the caching of content close to the recipient of the content. Caching reduces latency by allowing frequently-accessed content to be stored nearby, and reduces transport costs by limiting the need to retrieve the content repeatedly from a remote source.

Stand-alone CDNs like Akamai and Limelight were early, and very successful, providers of these services. A 2009 study by Atlas Internet Observatory estimated that the top five "pure-play" CDNs -- Limelight, Akamai, Panther, BitGravity, and Highwinds -- represented 10 per cent of Internet traffic.[10] Total CDN traffic has increased from 20-30 per cent of the traffic on Internet backbones in 2010 to 35-45 per cent in 2012. Today it is more helpful to think of CDN functionality as a business in which many providers participate, including stand-alone CDNs, content aggregators like Google, backbone companies like Level 3, and local access providers including incumbent telcos and cable companies. Google self-provides CDN services on a very large scale, becoming in the process the second-largest network on the Internet. Netflix is one of the largest providers of online movies in the US, and is rapidly expanding into other countries. It has been a customer of CDNs like Akamai and Level 3 to deliver the billion hours of video it streams every month. In June of 2012 it announced its own CDN, called Open Connect, which already carries 5 per cent of its traffic.[11] YouTube, another large online video provider now owned by Google, has had a similar arrangement for some time. Recent acquisitions by backbone companies appear to have been motivated, at least in part, by the CDN businesses of the acquisition targets. This would include Level 3's purchase of Global Crossing, and Tata's purchase of BitGravity.

The rise of CDNs has been driven by, and has also supported, the change in the services provided over the Internet described in the next section. As the mix of services has shifted, and as those services as well as CDN functions have been supplied by different entities, the distinctions between backbone networks, access networks, and media companies have blurred. For example, Comcast's role in this universe has changed substantially in a short time. In 2007 it was primarily a local cable operator, lacking its own backbone facilities, mainly focused on residential video and broadband services and highly dependent on upstream transit suppliers. By 2009 it had become a major provider of voice services, a net exporter of traffic, the sixth largest network by traffic volume, and the largest user of IPv6 addresses on the Internet.

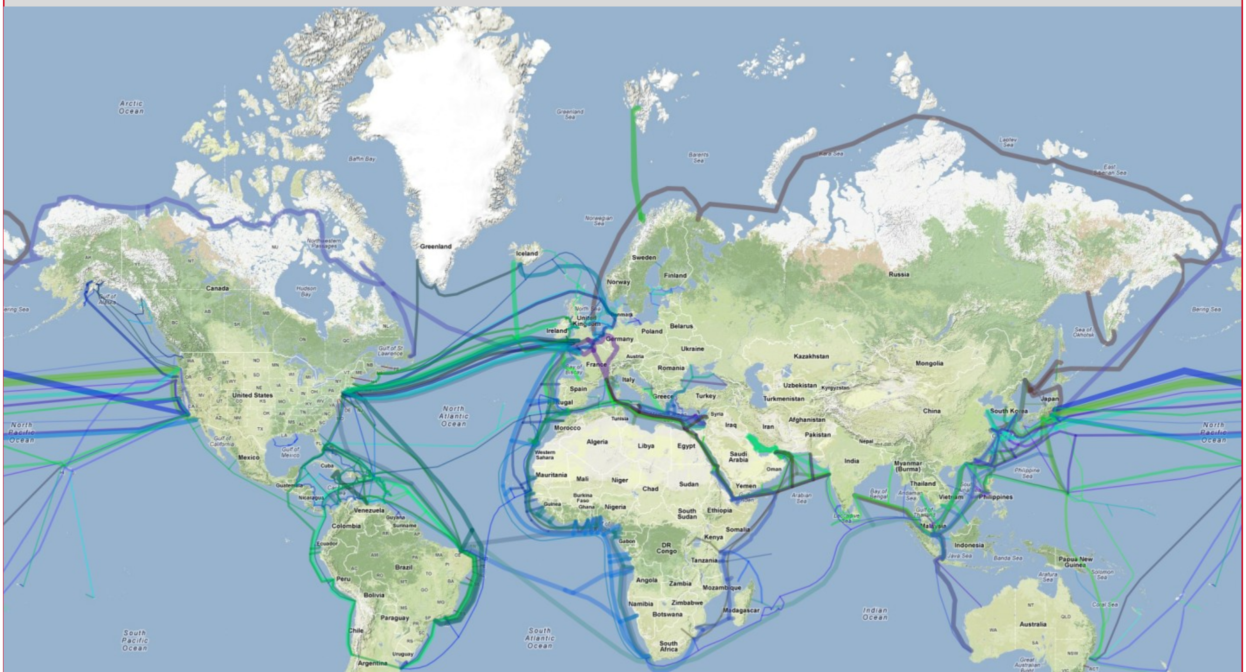
CDNs have, like the growth in peering, changed the topology of the Internet, flattening its structure, providing more direct delivery of traffic, and further disintermediating the providers of transit. While the market for Internet connectivity is often described as a hierarchical world with a rigid structure of Tier 1 and Tier 2 carriers, that picture is no longer accurate. As will be discussed below, the development of CDNs has set up an interesting process of negotiation to reset the terms of trade for the various parties along the value chain between content creators and local access networks. Through that process, the market for IP traffic exchange is beginning to generate answers to many of the questions raised in the debate surrounding net neutrality.[12]

For emerging economies seeking to create a virtuous circle of investment and growth, CDNs present some new opportunities for partnership. The purpose of a CDN is to deliver content directly to the terminating access network. They therefore provide the transport to a point in or near the terminating network, thus covering what has been a significant cost for networks in developing countries. They provide alternatives to the transit providers, yet they are not in the transit business. Google, for example, does not seek, or accept, traffic from other networks. Its model is to peer with the terminating network, rather than to charge it for transit. The percentage of Google traffic delivered via direct peering increased from 30 per cent in 2008 to over 60 per cent in 2011.[13] The willingness of large CDNs to peer with smaller networks, and to invest in caches in IXPs within developing countries, makes them potentially significant players in building a critical mass of Internet resources. At the same time, they represent a source of countervailing bargaining strength to offset the positions of incumbents in both developed and developing regions.

Investment in Internet facilities. In order to accommodate the rapid growth in Internet traffic, large investments in network facilities have been necessary. These include investments in routers, transport facilities, and switching fabrics in IXPs, and other things, in all regions. What is most interesting from a structural point of view has been the ongoing investment in long-haul facilities, particularly in undersea cables, around the world.

While the trans-Atlantic market had been well-served by cables for some time, the development of cable capacity across the pacific had lagged behind the growth of Asian markets, leaving them limited in capacity and route diversity. For many regions, such as Africa and Latin America, the limited availability of undersea cable capacity led to high rates, both for leased lines and for transit, a problem exacerbated in many cases by the tromboning of local traffic, which placed additional demand on the scarce resource.

Figure 5: Undersea cable routes, 2012

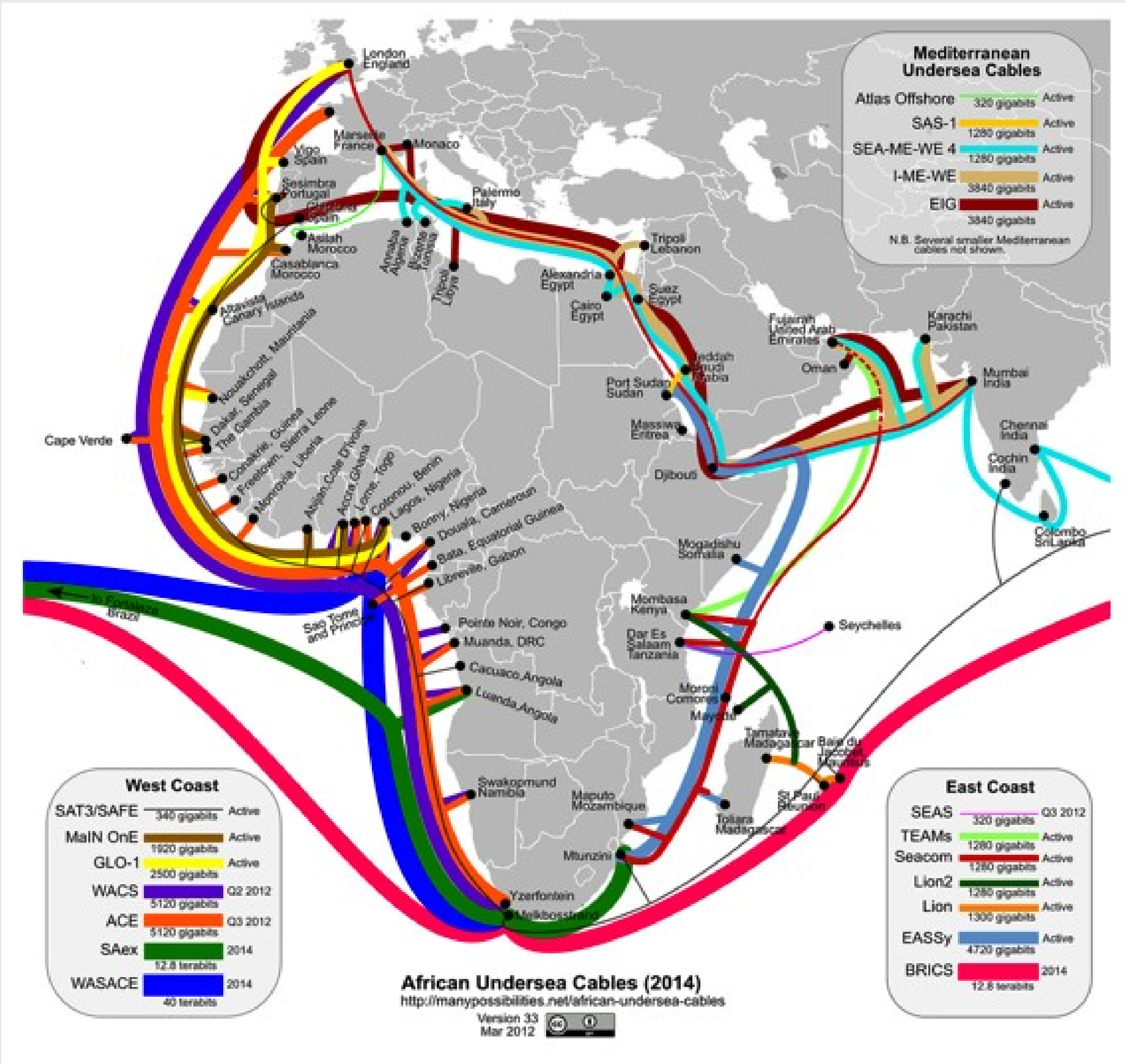


Source: Greg's Cable Map, http://www.cablemap.info

However, ongoing investment in new undersea cable projects, which has continued to a considerable degree even through the recent financial crisis, has begun to create additional capacity, route diversity, and competition in many regions. A global view of undersea cable routes is shown in Figure 5.[14] While much remains to be done, significant progress has been made which, together with other developments such as the creation of IXPs, has led to better performance in many markets. In 2010 and 2011, 19 new undersea cable systems representing an estimated investment of USD 3.7 Billion were deployed. Plans have been announced for 33 additional systems to be placed in 2012 and 2013, estimated to cost USD 5.5 Billion. Estimated construction costs for 2010-2013 by region are shown in Figure 7; note that the largest aggregate investment over the period will be around Africa.[15]

For example, the Trans-Pacific Express, the first new cable between the US and China in seven years, increased the available capacity between those two countries by a factor of sixty when it was completed in 2008. It now also reaches the Republic of Korea, Taiwan, and Japan. Several new cables have recently been, or will soon be, added to the existing capacity on both the east and west coasts of Africa, as shown in Figure 6.[16] As a result, the relative shares of the long-haul transport market in Africa are expected to shift from 45.6 per cent satellite, 54.4 per cent fiber in 2008 to 11.9 per cent satellite, 88.1 per cent fiber by 2014.[17] A new cable linking the US with Colombia and Brazil is scheduled to be deployed in the fourth quarter of 2012. Two additional cables scheduled in 2014 will also connect Brazil, Colombia, Panama, and the US.

Figure 6: African undersea cables (2014)

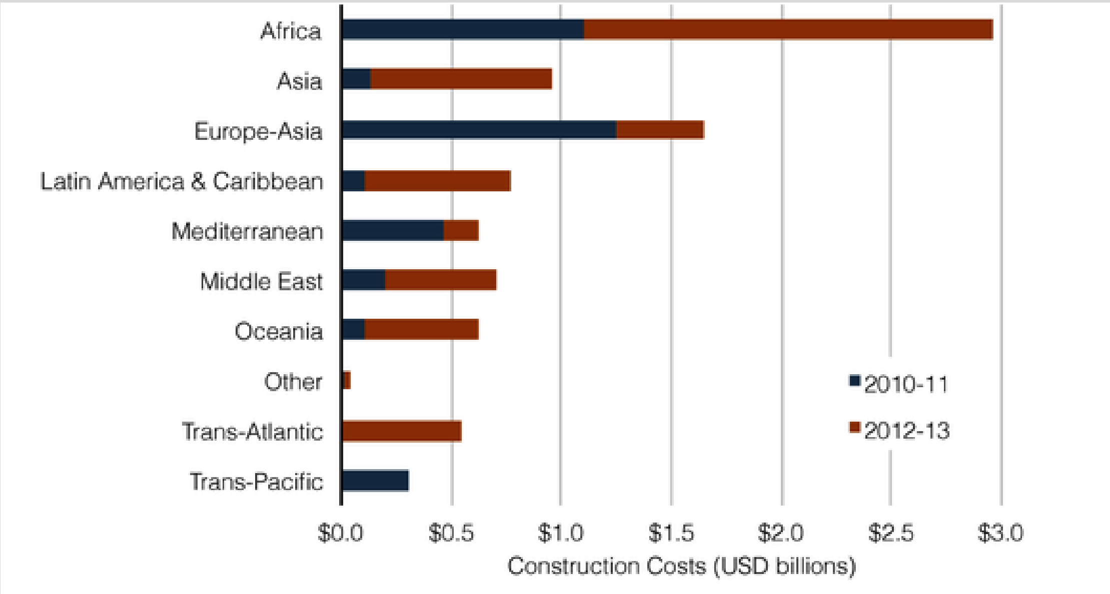


Source: http://manypossibilities.net/african-undersea-cables/

Although the Atlantic is already served by many cables, several new ones are scheduled to be laid over the next two years. One addresses an existing market, between New York and London. Owned by Hibernia Atlantic, when completed in 2013 it will reduce the route-miles between the two cities by 310 miles by following the shallow continental shelf, thus reducing latency by 5.2 milliseconds, a difference for which some business customers may be willing to pay a premium. Another new cable will link Brazil with Angola for the first time. In 2014 two additional Atlantic cables will be laid, one connecting Virginia Beach in the US with San Sebastian, Spain, the other between Brazil and Nigeria.[18]

This wave of new investment might have been difficult to predict a few years ago, given that existing cables still have spare capacity, or the potential to upgrade existing capacity, on many routes. One analyst has suggested that capacity constraints are not driving these projects. Rather, operators are interested in providing reduced latency and route diversity, and are attracted to enter those markets where margins have been relatively high in the past.[19] As this new competition enters those markets, they are driving down rates. The growth of the cable market has also brought much more diverse ownership, with participation from investors, telcos, and governments in developing countries as well as international carriers. This means that not only are there more cables and more capacity, but less monolithic control and more competition, not only among cables, but among different owners of capacity on a given cable.[20]

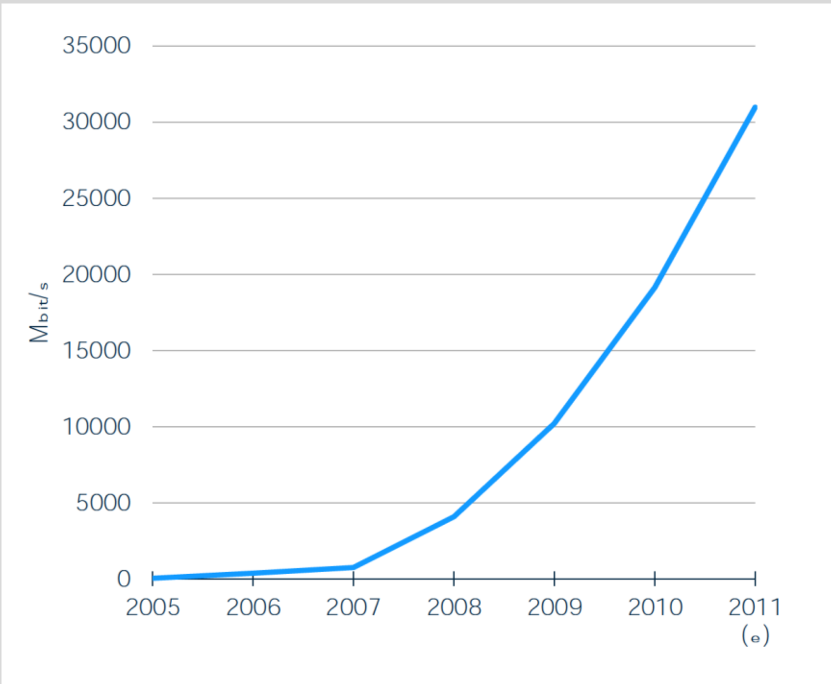
Figure 7: Submarine Cable Construction Costs by Region, 2010-2013



Source:Telegeography

Investment in long-haul capacity on terrestrial cross-border routes has been less spectacular than that in undersea cables, and in some areas has been limited by a lack of liberalization of cross-border arrangements. Nonetheless significant development has taken place. For example, the expenditure on cross-border terrestrial fiber in Africa in 2010 was USD 12 Billion. As Figure 8 shows, the total capacity of terrestrial cross-border routes in sub-Saharan Africa grew from 33 Mb/sec in 2005 to 30,960 Mbit/sec in 2011. These facilities are important to allow land-locked countries to reach the landing points for undersea cables, to handle regional traffic without tromboning, and to allow the development of IXPs as regional hubs.

Figure 8: International Internet bandwidth in sub-Saharan Africa supplied by terrestrial cross-border networks



Source: Africa Bandwidth Maps, 2012

3. *Changing patterns of use*

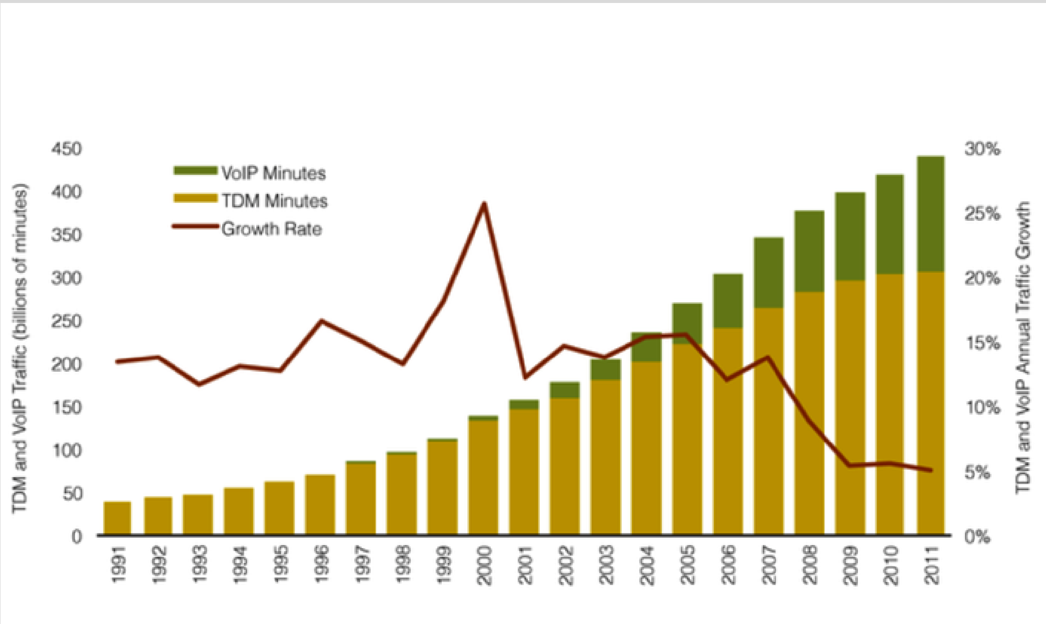
New trends in the way consumers, businesses, and institutions make use of the Internet have driven the structural changes discussed in the previous section. At the same time, the structural adaptations of the Internet ecosystem, such as the increased use of peering, the development of CDNs, and investment in new facilities, have made it possible for the system to support the new patterns of demand.

3.1 Decline and transformation of voice

For most of the history of communications, voice has been the primary offering, accounting for most of the revenue of the world's operators. Today, voice accounts for a small portion of the traffic carried on global networks. However, it still represents a significant share of carrier revenues. This share is likely to decline, for three reasons. Voice usage is declining, the price of voice service is being pushed downward, and the use of newer services is growing.

In developed markets, voice usage has peaked, and is in decline. A recent Nielsen survey in the US showed voice minutes of use declining across all age groups, especially among teenagers, falling 14 per cent in one year (2Q 2009-2Q 2010.) At the same time, the average teenager between the ages of 13 and 17 sent or received 3,339 texts per month -- more than six per waking hour (for teenage girls, the average is 4,050.)[21] Mobile voice usage had grown rapidly in the US and is still the highest in the world, but declined for the first time in 2010. In developing markets where mobile penetration is still increasing, total mobile voice usage may continue to grow for some time. The aggregate global volume of international calls is still increasing, but at a sharply declining rate. This is illustrated in Figure 9.

Figure 9: International call volumes and growth rates, 1991-2011



Source: Telegeography

The price of voice services is being driven downward by the shift to VoIP. Figure 9 shows the rapid increase in the percentage of International voice calling provided over VoIP. While most voice calling over mobile still uses circuit-switched technology, smartphone applications that facilitate VoIP calling are becoming more widely available. The rollout of 4G service using the Long Term Evolution (LTE) standard in many countries may spur a more rapid shift to mobile VoIP, since the greatly reduced latency of 4G systems allows them to support VoIP much more successfully than 3G systems could. The fact that many LTE systems will not support voice and data transmission simultaneously may also give consumers an additional incentive to avoid that constraint by turning voice into data.[22]

3.2 Video streaming and download supplants peer-to-peer

For years, carriers have been concerned that the growth of peer-to-peer (P2P) applications would overwhelm their networks. However between 2007 and 2009 the growth of P2P traffic slowed, and its share declined. Consumers have shifted their viewing habits to streaming and direct downloads of video. As a result, consumer usage on the Internet is now growing faster than business use. During peak viewing times in North America in 2012, Netflix alone accounts for 25 per cent of all traffic (upload and download), YouTube another 16 per cent, other CDN traffic 18 per cent, and all P2P traffic 12 per cent. However P2P still is the largest driver of upstream traffic on fixed networks in North America, accounting for 53 per cent of that traffic according to Sandvine. Cisco predicts that by 2016 video traffic equivalent to all the movies ever made will traverse the world's IP networks every three minutes.

Several other major trends in usage are driving growth in traffic. One is is the development of cloud services that are moving applications from desktops into data centers. Another is the growth of mobile data. Cisco predicts that by 2016 there will be three mobile devices for every man, woman, and child in the world, and that mobile data traffic will grow by a factor of eighteen between 2011 and 2016, a CAGR of 78 per cent, or three times faster than the growth in fixed network traffic.

CDN functionality may also find an expanded role in research and education. Broad-based collaborative research projects involving large data sets and distributed computing would benefit from the same methods used by CDNs to efficiently distribute consumer video. Educational television and online instruction programs could also benefit.[23]

3.3 Increased importance of quality

While the old mix of services on the Internet was somewhat sensitive to latency, the new mix is increasingly so.[24] Voice service has migrated from traditional TDM networks to the Internet, in the form of VoIP. Two-way video services have become more prevalent. Interactive games have increased in complexity, and streaming of games is displacing game consoles. And while large buffers can help one-way video steaming to tolerate some latency, consumers are becoming less willing to wait for buffers to fill. The migration of functions to the cloud means that operations that used to be handled locally on the desktop are now subject to latency between desktop and data center.

For business, two-way video conferencing is becoming more important as firms become more dispersed geographically and travel becomes more costly. Cisco predicts that video conferencing will grow eightfold between 2011 and 2016, significantly faster than other business traffic. And with global financial transactions growing in volume and speed, the tolerance for delay has become dramatically lower -- so much so that one operator is willing to spend $300 million to reduce the delay between London and New York by 5.2 milliseconds.[25]

4. Market response to changing demand

The combination of shifting demand for services by consumers and businesses, as well as dramatic changes in the structure of the Internet itself, have created both opportunities and challenges for market participants.

4.1 Improvements to quality

Many of the structural changes discussed above -- exchange of traffic locally at IXPs, increased use of peering, reduced reliance on transit, direct delivery of content and local caching through CDNs -- all combine to flatten the architecture of the Internet, producing shorter routes, fewer hops, and lower latency. CDN functionality is already used to deliver a very large proportion of Internet traffic. A new study estimates that local caching could be used for as much as 98 percent of all Internet traffic, so there is almost no limit to the potential scope for the shift of traffic to CDNs.

4.2 Continued investment

Despite earlier fears that low prices for Internet connectivity could undermine investment, in fact the necessary investment in the fabric of the Internet has continued. If anything, the market for undersea cables appears to be experiencing a boom. And that investment has not been confined to the more developed economies, but has extended to regions which are now starting from a lower level of infrastructure, and markets that have struggled to overcome a variety of challenges.

4.3 New challenges for operators

While investment has moved forward for the core of the Internet, incumbent operators of access networks, both fixed and mobile, have faced a series of new challenges. The traditional core services on which these carriers have relied for their cash flow are being disrupted. Voice calling plans with the greatest margins are fading as customers drop land lines, exchange post-paid mobile plans for prepaid phones, and switch to VoIP. Linear television services which have been the core revenue source for cable operators are threatened as customers drop those plans and rely instead on online video. A recent Deloitte survey of US households finds that nine per cent have already dropped their linear cable TV subscriptions, and another eleven per cent are considering doing so.[26] The global economic downturn has also caused both consumers and businesses to limit their spending.

All of this comes as increased volumes of traffic driven by the new services, especially video, call for increased investment to augment capacity. Rapid growth in mobile data have strained mobile networks, and increasing capacity through adding spectrum or subdividing cells is expensive, and in some cases infeasible. Cable networks designed to broadcast linear TV are often ill equipped to handle greatly increased video traffic from the Internet. While existing last-mile facilities may be able to handle the load, middle mile facilities and regional nets between the IXP and the last mile will generally have to be augmented to deal with the shift from broadcast to online video delivery.

While these challenges are real, they may also have been overstated by operators in some markets. While, as discussed in the next section, these market challenges are driving the evolution of business arrangements, they may call for intervention by policy makers.[27]

4.4 New business models and relationships

In the face of the changes in patterns of use and market structure, participants up and down the value chain are re-evaluating their business models and seeking to adapt.

Content creators and media companies are exploring ways to gain from the new avenues of distribution the Internet offers, while maintaining defensive strategies to preserve the revenues they get today from established delivery channels, such as linear television.

Internet content aggregators, such as Google, iTunes, Netflix, and Amazon, are negotiating on the one hand with content creators for the right to distribute their content online. On the other hand, they are negotiating, either directly or through the CDNs they hire, with local access or "eyeball" networks the terms under which they will be able to deliver their content to end users. Issues for these discussions might include whether they would peer with the access network or accept some form of paid peering, and the division of labor in the provision of real resources necessary to ensure the desired quality and handle the increased traffic. Some CDNs, for example, may be willing to transport traffic deep into the terminating network, and place caches close to the end user. By doing so, the CDN improves the quality of its service, while also contributing in kind to the middle-mile investment the access network must make to in order to handle the traffic.

At the end of 2010, disputes arose on both sides of the Atlantic, arising from these kinds of negotiation, that caught the attention of national regulatory authorities (NRAs), and raised concerns about net neutrality.

In the US, the dispute was between Level 3, acting as a CDN on behalf of Netflix, and Comcast, in its role as provider of cable modem service. In France, the dispute was between the US-based transit provider Cogent, acting on behalf of a video site based in Hong Kong, China named MegaUpload, and the French access network Orange. In both cases complaints were filed with the NRAs, the Federal Communications Commission in the US and ARCEP in France; after considering the cases, neither NRA chose to intervene.[28] Cogent then filed a complaint to the competition law authority in France, which so far has not chosen to intervene either.[29]

Despite the attention garnered by these high-profile cases, it appears that the more usual outcome of such negotiations is that the CDN has been able to peer with the local access network on a settlement-free basis.[30] In this way the market appears to be addressing many of the concerns raised in the net neutrality debate, such as the terms on which a content provider could deliver traffic to an access network, whether there would be a charge on the "other side" of the market, and how the physical costs of the interconnection arrangements would be divided between the parties.

However, a report earlier this year from the Body of European Regulators for Electronic Communications (BEREC), the association of European regulators, found a number of practices that gave cause for concern, including the widespread blocking of over-the-top VoIP applications by a few fixed incumbents and a larger number of mobile operators.[31]

Another response to market changes by incumbent operators is taking the form of what might be termed a "rotation" of their retail rates structures. Until now each operator has tended to view its traditional service as the core of its rate structure -- voice service for fixed and mobile operators, linear TV for cable operators -- and the new service segments they have entered (broadband and video for fixed and mobile, broadband and voice for cable) as "add-on" services providing incremental revenue. Now, with voice and video applications riding over broadband connections, these operators are realizing that the core service they provide is connectivity. This has led to restructuring of their offerings to make broadband connectivity the core offer, around which voice and video become add-ons. For example, both Verizon and AT&T, the two largest mobile providers in the US, have recently announced new data plans under which the subscriber buys a bucket of data, rather than a bucket of minutes, which is then shared among family members. Voice calls are unlimited, but data use is not.

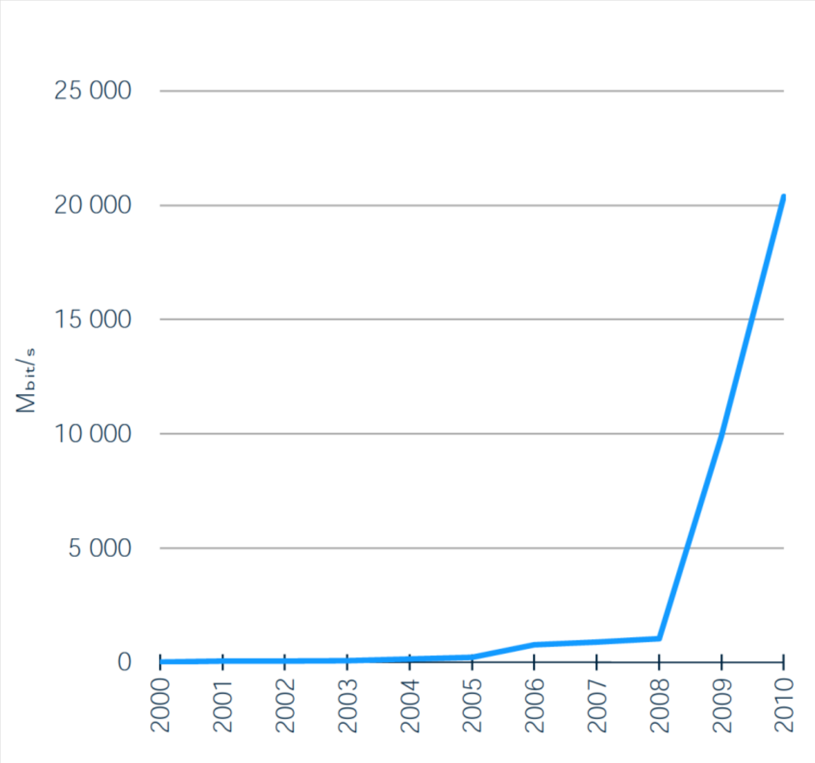
4.5 Virtuous circles in developing markets

The development of broadband services and use of the Internet have faced difficult challenges in many developing economies, given a combination of limited demand and high costs. In recent years, however, a combination of sound enabling policies and private investment have also produce many examples of significant growth and progress.

In **Kenya**, the Internet exchange KIXP was established at Nairobi in 2001, under a license from the Communications Commission of Kenya (CCK).[32] The exchange is operated by TESPOK, an association of ISPs.[33] Bandwidth capacity at KIXP grew gradually until 2009, when it began a period of dramatic growth made possible by the confluence of other factors, as shown in Figure 10.

As discussed above, several new undersea cables have recently been deployed around the African continent. Four new cables have been landed in Kenya in the last three years: The SEACOM and TEAMS cables in 2009, EASSy in 2010, and LION2 in 2012. By mid-2010 (i.e., not counting LION2) Kenya had 20 Gb/sec of international Internet bandwidth (see Figure 9). This was 20 times the amount available before the cables listed here landed, and 2000 times more than a decade earlier. An undersea capacity of 200 Gb/sec is available to be drawn upon if necessary. Recently a second IXP was opened in Mombasa, where all of the undersea cables land.[34] This has made it easier for Kenyan ISPs to shop competitively and to load-balance among the different cables, as well as saving on transport costs to Nairobi.

Figure 10: Kenya's international Internet Bandwidth Capacity (Mb/sec)



Source: CCK

This new international capacity has been complemented by the development of domestic and regional transport. Domestic backbones include the government-sponsored National Optical Fibre Backbone Infrastructure (NOFBI), a network built by the Kenya Power & Lighting Company (KPLC), and private networks owned by Orange and Kenya Data Networks. In November 2011 Safaricom announced plans to build its own 4000 km fiber-optic. These developments have reduced prices for domestic transport, reinforcing the cost advantages of exchanging traffic domestically, rather than at some foreign IXP.

Regional transport resources have also been put in place, including two links to Uganda, a point of presence in Kenya of the Tanzanian national fiber network, and planned links to Ethiopia and South Sudan. These links have allowed KIXP to become a regional hub, as KIXP members have won customers from neighboring countries, and have provided access to the undersea cables for landlocked neighbors. In the second half of 2011, 56 per cent of the Autonomous System numbers routed through KIXP were from 16 foreign countries, some as far away as the United States.[35]

The creation of KIXP, even before many of the transport investments discussed here, significantly reduced costs and improved quality. Latency was reduced from a range of 200-900 milliseconds to a range of 30 to 60 milliseconds.[36]

In 2011, Google placed a cache at KIXP. This combined with the factors discussed above, led to a dramatic increase in the amount of traffic exchanged at KIXP, with peak traffic now above one Gb/sec.[37] KENIC, the administrator of the .top level domain, has connected its root server to KIXP, which has helped it to become the most widely used TLD in Kenya, ahead of .com. KRA, the tax authority in Kenya, has benefited from the more robust exchange of local traffic to implement successful online systems to support clearing of customs for importers and filing income tax returns.[38]

Other countries in Africa have also realized substantial benefits from the establishment of domestic IXPs. In **Ghana**, for example, two IXPs were established in 2005.[39] Both were operated by non-profit organizations. GIX today has 15 members; the second IXP, AIX, is no longer active. As in Kenya, new undersea cable investment has created additional international bandwidth. Five different cables now land in Ghana; the most recent, WACs, connects fifteen landing stations along the west African coast with London. The WACs connection to Ghana was turned up early this year. As in Kenya, this international bandwidth has been complemented by some investment in domestic fiber transport.

Some of the same benefits have also been realized in Ghana. Costs have been reduced by eliminating the tromboning of traffic. Latency has been reduced from about 500 ms to about 25 ms. Google has established a cache at GIX. The peak traffic exchanged at GIX is about 540 Mb/sec, or about half the volume at KIXP.

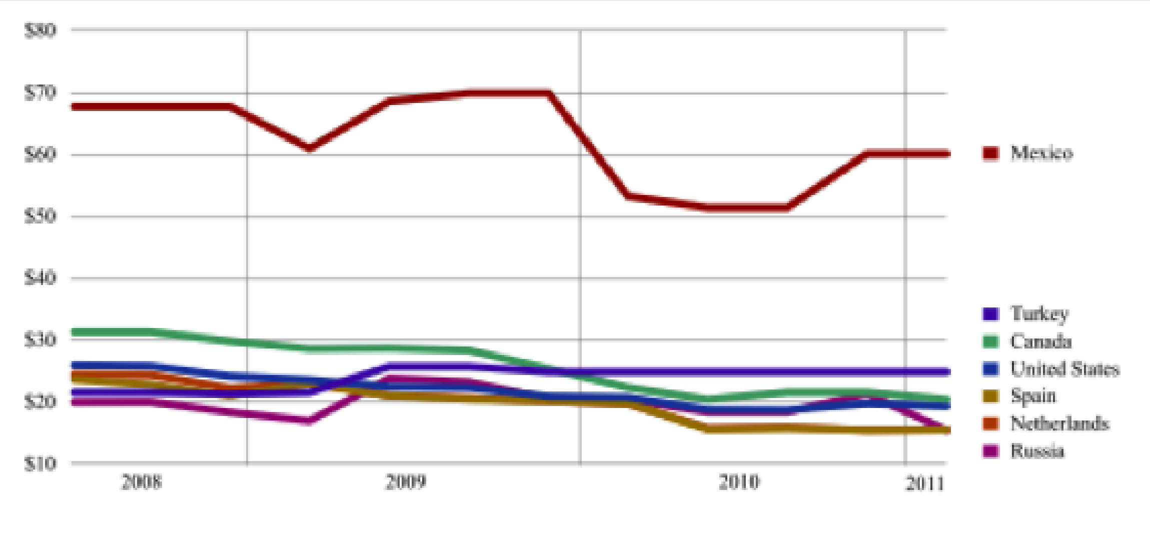
In Nigeria, IXPN was established in Lagos in 2006. It currently has 38 members, though not all of those are connected to the exchange.[40] Many of the benefits realized in other settings are already materializing in Nigeria. The peak volume of local traffic exchanged at IXPN is about 300 Mb/sec.[41] Tromboning of local traffic has been largely eliminated. Latency has been reduced from 200-400 ms to 10 ms or less. Google extended its network to Lagos in March 2010, and established a cache at IXPN. As in the other exchanges, some have noted Google's presence has led to a rapid increase in traffic, with Google now representing more than 50 per cent of all the traffic exchanged.[42]

IXPN is planning to become a distributed exchange by establishing six points of presence (POPs) in different regions of the country. This deployment could play a constructive role in reducing the cost of domestic transport. The first two points were established in Abuja and in Port Harcourt in 2012.[43] When IXPN was created, a decision was taken to limit its members to the exchange of local traffic. If that restriction were relaxed, IXPN could also become a hub for the aggregation of long-haul international traffic and for the exchange of traffic with neighboring countries.
The presence of the IXP has also created other opportunities for business development. For example, Interswitch, the leading platform for electronic transactions and payments in Nigeria, is connected to IXPN. Established by seven Nigerian banks, Interswitch links 10,000 ATMs and 11,000 point-of-sale terminals.[44] This framework has begun to attract financial platforms that were formerly hosted abroad have begun to return to Nigeria. Nigeria has opportunities to utilize IXPN to promote the distribution of domestic content both in-country and internationally, since Nigeria already has a film industry that produces more films each year than any other country except India.[45]

The African examples discussed here illustrate the potential for IXPs to generate significant benefits when combined with other elements of liberalized policy and private investment. However, the converse is also true: the lack of an IXP can limit opportunities. Figure 12 compares retail prices for transit provided to enterprise customers in different countries. The difference in transit costs shown here for Mexico and Turkey is partly explained by the lack of an IXP in Mexico.

Much remains to be done to promote the development of the Internet in Africa. Only about 1 percent of Internet traffic generated in Africa is exchanged locally, and 99 per cent of that exchange is concentrated in four countries: Egypt, Kenya, Nigeria and South Africa.[46] However, progress is being made through the deployment of undersea cables discussed above, which in turn have contributed to the growth of traffic at IXPs. Between June 2009 and July 2012, Africa's total inventory of terrestrial transmission networks increased from 465,659 kilometers to 732,662 km, bringing 40 per cent of the population within reach of an operational fiber node.[47] A number of projects are under way to increase the reach of regional transport and make regional traffic exchange more economic. For example UbuntuNet, an alliance of 13 national research and education networks (NRENs) plans to establish, over the next three years, backbones extending up both east and west coasts from South Africa, with extensions to exchanges in Europe. UbuntuNet members already peer at KINX in Nairobi, TINX in Dar es Salaam, CINX in Cape town, and JINX in Johannesburg, as well as in Amsterdam and London. At the European exchanges it is then able to buy transit cheaply.[48]

Figure 12: Retail price of enterprise Internet transit, mbps/month, in USD



Source:Telegeography

5. *Policy challenges for the future*

The available evidence shows that the global market for IP connectivity has performed very well. It has produced low prices, directed resources efficiently, and enabled the extension of the Internet to users around the world.

5.1 Variation in Outcomes

The development of Internet resources and opportunities has varied significantly by region and by country.[49] These differences are based in part on geography, distance, and scale, but are also highly sensitive to competitive conditions within country and to related choices by governments with respect to liberalization. These factors, rather than any market failure in global markets for IP connectivity, have played the major roles in determining the success of Internet development in emerging markets.

Costs of the inputs necessary to provide broadband have declined as demand has grown and markets have developed. In particular, the prices paid in many developing countries for international Internet connectivity have declined, in part as a result of the new investments in long-haul cable capacity discussed above. [50] Reductions in rates for international Internet connectivity, while both likely and welcome, will have a diminishing effect on the price at which domestic networks can offer broadband, as they will operate on a diminishing share of those networks' total cost.

5.2 Policy in developed markets

In developed countries, the legal and regulatory frameworks for telecommunications, and liberalization of those frameworks to promote competition, were in place before the development of the Internet. The Internet benefitted from the general framework of liberalization that provided freedom of market entry, access to rights of way, availability of leased lines, and so on. However, the market for the exchange of IP traffic has grown up outside the existing regulatory framework that has applied to the interconnection and the exchange of traditional circuit-switched voice, or TDM, traffic. As described above, the IP market has performed better than TDM markets have done.

Over time the TDM voice market has declined, and the IP market has grown. Legacy telco networks have adopted IP for most internal functions, and traditional services such as voice and video have been replaced by IP-enabled applications. This process has led to the possibility of a collision between the old, regulatory framework and the new, unregulated universe of IP connectivity. In some cases, policy makers might regret the loss of enforceable rules or of data reporting on the traffic exchanged outside the regulatory framework.

In others, interested parties might feel the loss of some right they enjoyed under the regulatory scheme, such as the ability to demand interconnection or to assess termination charges. This in turn has led to calls for NRAs to consider regulation of IP interconnection and traffic exchange.

In a few developed countries, regulatory authorities have considered this issue. In 2006 the Polish regulator, UKE, adopted some requirements to provide transit on the Polish incumbent, Telekomunikacja Polska (TP). This action was effectively vetoed in 2010 by the European Commission, which found that the UKE had not met the criteria for identifying new markets for regulation.[51] In the announcement of the Commission's decision, Digital Agenda Commissioner Neelie Kroes said: "The Commission fully shares the objectives of the Polish regulator in seeking competitive markets, but our assessment is that regulation of these particular markets for Internet traffic exchange services is not necessary to protect consumers or competition. If the market itself is able to provide for fair competition, don't disturb it with unnecessary regulations."[52]

Some concerns have been raised about arrangements for the exchange of voice traffic where the calls are being routed using a telephone number, since in most numbering systems the assignment of the number to the carrier serving the recipient gives that carrier some control over termination that it would not have for other IP traffic.[53] For this reason what little regulatory activity there has been among developed country regulators has dealt with voice traffic.

In the United States, the Federal Communications Commission (FCC) has generally refrained from regulation of IP traffic exchange, although a few limited provisions have been agreed as conditions for the approval of mergers. The FCC has recently taken comments from parties on whether regulation should be applied to the exchange of voice traffic over IP interfaces, but has yet to take any action.[54]

In Canada, the Canadian Radio-television and Telecommunications Commission (CRTC), has recently adopted a number of new regulatory provisions with respect to network interconnection for voice services.[55] The CRTC found that IP interconnection for voice traffic should continue to be carried out under bilateral commercial arrangements. It also found it unnecessary to mandate a default tariff for IP voice network interconnection. However, if a carrier is providing IP voice network interconnection to an affiliate, a division of its operations, or an unrelated service provider, then it must provide similar arrangements with other carriers. The carriers are to complete the negotiation process within six months of a request for interconnection. Either party may request mediation by the CRTC staff, or apply to the CRTC for intervention if an arrangement is not concluded within the six-month period.

The record in this area among developed countries is therefore quite limited. While the possibility of failure in IP markets cannot be ignored, and some intervention may be necessary in the future, as a general matter this temptation should be resisted, and a "bright line" should be drawn to avoid the application of traditional remedies to this new market. The reasons for this are many. Perhaps most obvious is the simple fact that prices in the regulated markets for TDM traffic exchange are many orders of magnitude higher than equivalent prices for IP traffic. This is the case even though many of the same firms participate in both markets. Clearly IP markets operate differently from the traditional ones.

Traditional frameworks for TDM interconnection and traffic exchange have sought to impose a particular order, such as "calling party pays," and in so doing have created a cascading flow of funds among customers and networks. While this may have been useful as a way of making the trains run on time, and funding certain social policy objectives, it wasn't based on sound economic principles.[56] The IP market has succeeded in part because it has never had to follow any such rule, or to serve as a conduit of funds. Rather, it serves only as a means for networks to exchange connectivity, nothing more or less, and is able to set a separate value for each such exchange.

Traditional frameworks for TDM markets have sought to guard against anticompetitive refusals to deal (i.e., refusal to interconnect) by imposing an obligation to interconnect. In a number of TDM markets, this has been necessary. However, in the absence of such obligations, participants in any market discipline unreasonable behavior, such as high prices or unreasonable terms, by refusing to deal with parties who behave that way.

The results of the survey of peering agreements discussed above suggest that the Internet has been able to achieve universal global connectivity with less than one per cent of a full mesh; that is to say that fewer than one per cent of all the bilateral arrangements that could exist actually do exist. One of the important functions of the market for IP connectivity is to determine which of the possible arrangements should be created and to direct resources efficiently where they are needed. It would be difficult for the IP market to perform this important role if parties had a general obligation to enter into such arrangements.

The irony of regulation in markets for interconnection is that the very tools that are available to policy makers to address perceived market failures also create and perpetuate market failures. This does not mean that such tools should never be used, but it does strongly suggest that the threshold for imposing them should be very high. The speed at which the Internet ecosystem continues to evolve is another cause for concern, as any regulation is likely to be obsolete before it can be adopted.

For similar reasons, the most sound approach for regulators to adopt where disputes arise over the termination of CDN traffic may be to observe the development of those markets, and intervene only when necessary (ex post) if possible. This appears to be the course already adopted in most countries, including the previously cited examples in France and in the United States. The negotiations up and down the value chain – between content creators and Internet aggregators of content, between those aggregators and CDNs, and between CDNs and terminating access networks – are establishing the terms of trade for new forms of content delivery. In particular the agreements being struck between CDNs and local networks are providing market-based answers to many of the questions that have been raised in the debate over net neutrality. They are determining how content will be delivered to broadband users, on what terms, and what resources will be brought to bear to ensure quality, and by whom. So far, the terms of these agreements appear to fall within a reasonable range, most often on a settlement-free basis, with a few examples of paid peering. Further, quality is being enhanced, not by subtractive means (traffic management software) but by adding resources in the form of direct transport and caches close to the end user.

In the context of these negotiations, it may be the case that the agreement between a CDN an incumbent operator may involve some payment (i.e., paid peering) although in practice most agreements so far have been settlement-free. As long as these agreements do not indicate a pattern of unreasonable exercise of market power by incumbents (and so far they have not) then NRAs do not need to intervene. On the other hand, NRAs also should not intervene to impose any mandatory termination payment on CDNs, or on any other network that delivers traffic to local access network. Providing adequate investment for local access networks is a worthwhile objective, but those networks should have to earn their revenue by providing value businesses, consumers, or interconnecting networks are willing to pay for through voluntary commercial agreements. Governments should not support this approach, and they should prevent any collusive action to impose such a system.[57]

5.4 Policy choices in emerging markets

Liberalization attracts investment, builds Internet assets and scale, and promotes growth by reducing costs. The only process that can shift the terms of trade in a country's favor in the international market for internet connectivity is increasing competition and investment, both in that country's domestic market and in the market for long-haul transport. Fortunately substantial progress has been made in these areas in recent years.

In emerging markets authorities have faced policy choices between defending the existing business models of national incumbents and liberalization to promote competition and the adoption of new services. These choices can be challenging as government is naturally concerned about the incumbent's ability to support future investment, to contribute revenues in the form of license fees, and to perform other desired social functions such as the provision of universal service.

Each country must find its own policy balance among potentially conflicting objectives. However, the conflict may not be as clear as it appears. The experience in many emerging markets has been that liberalization, by attracting investment and opening new opportunities, has been able to stimulate economic growth while also promoting increases in Internet resources, teledensity, and broadband deployment. These developments, in turn, have allowed countries to achieve better terms of trade in the international market for Internet connectivity.

The policy frameworks to promote development of Internet assets are in many ways the same ones that have been used to liberalize markets for traditional services. While the long-term case for regulation of IP interconnection is no better in emerging markets than in developed ones, there may be a case for short-term intervention where defensive actions by the incumbent have prevented the development of a domestic market. Best policy practices for promoting Internet market development will be discussed below.

5.5 The process for international treaty revision

The ITU's World Conference on International Telecommunications 2012 (WCIT-12), which meets in December 2012, will review the International Telecommunication Regulations (ITRs)[58] where the international treaty that is the basis of today's connected world will be reviewed. The ITRs were agreed in 1988 at the World Administrative Telegraph and Telephone Conference in Melbourne, Australia, and came into force in 1990. The ITRs set out principles for ensuring that networks can connect with each other smoothly, and that international services will be offered in a fair and efficient manner.[59] Within this context, proposals have been made to add provisions to the ITRs to foster cooperation in the development of international IP interconnections by promoting best effort delivery and end to end quality of service delivery.[60]

5.6 Best practices for the promotion of a virtuous circle of development

Governments in emerging economies can contribute to the development of a virtuous circle of investment and growth by adopting policies that open markets, promote competition, reduce barriers to investment, and facilitate the expansion of demand.

The most basic element of best practice is liberalization that opens the telecommunication market to competition. This would include the establishment of an independent regulator, privatization of the incumbent, opening the market to competitive entry without entry barriers or high license fees, access to rights of way, and availability of leased lines at reasonable rates.

Since mobile networks are likely to be important providers of broadband in most developing countries, policies that enable them to expand efficiently will promote rollout and take-up. These would include assignment of adequate spectrum resources, and policies that facilitate tower sharing, approval, and construction.

The development of international Internet connectivity will depend on the ability of investors in long-haul transport facilities arrange entry points at reasonable cost. Policies that simplify licensing for landing rights for undersea cables and cross-border arrangements for terrestrial routes, that minimize licensing fees, and that limit the ability of the incumbent to control such points, will facilitate such investments. Public investment may be helpful, but should be organized with care to avoid undoing the beneficial effects of privatization. The establishment of national backbones has in some countries crowded out private ISPs.

The development of domestic and regional transport networks is crucial both for IP backbones and for backhaul to deploy mobile networks. Market entry without excessive license fees and access to rights of way are important enablers.

As discussed above, establishing an Internet exchange point in-country or in-region can reduce reliance on transit, improve service quality, and provide a hub to attract investment. However, there is no guarantee that an IXP will succeed; the Packet Clearing House directory of global IXPs includes many that are now inactive.

- IXPs that are operated by independent entities without ties to any carrier are most likely to be successful. All of the examples cited above in Kenya, Ghana, and Nigeria are run by independent, non-profit entities. Development of IXPs in Brazil has been led by the Brazilian Internet Steering Committee (CGI), a public-private partnership funded in part by domain name registrations within the .BR country-code top-level domain.[61] Between 2006 and 2011, the number of IXPs in Brazil has grown from four to nineteen.[62] The CGI has made a policy of studying the factors contributing to the success or failure of other IXPs around the world. A cooperative membership model in which member ISPs participate in decision making helps to establish trust.

- Government can minimize barriers to the establishment of IXPs, such as high licensing fees. NRAs can have a role of neutral arbiter; the Uganda Communications Commission and the Malaysia Communications and Multimedia Commission have both played this role.[63] The regulator may also intervene in resolving objections raised by the incumbent, as in the case of Kenya.[64] However, direct management of IXPs can have unanticipated negative effects. For example, requirements that all members of an IXP must join a multilateral peering agreement may discourage some parties from joining the IXP.

- Attracting complementary assets, such as CDN caches and DNS root-servers, can add to the attractiveness of joining an IXP.

- A multilateral peering agreement at the IXP can reduce transaction costs and minimize communication or trust issues that might inhibit bilateral agreements.

- An ideal location for an IXP would have access to an international facility (undersea cable or terrestrial), be convenient to several potential member networks, and have a reliable source of electric power.

- Aggregation of traffic at an IXP can help its members of the exchange obtain better terms of trade from transit providers. Good practices to obtain better terms also include multi-homing to avoid being tied to one provider; regular monitoring and re-negotiation of contracts to take advantage of improvements both in the volume of traffic at the IXP and in competition; and arrangements with content providers to improve quality and reduce costs.[65]

Effective measures to limit anticompetitive behavior by the incumbent, such as monopolization of international gateways, denial of access to rights of way or leased lines, or control of IXPs. Regulation, or, in some cases, "jawboning" may be necessary to encourage agreements for IP traffic exchange with competing carriers.

Promotion of demand for broadband services. This could include e-government initiatives to deliver government services online, investment in networks for research and education, and promotion of development of local content. This objective can also be promoted through public-private partnerships. For example, Google has participated in a Google Apps Supporting Program (GASP) which has already established connections between the Lagos IXP and four participating universities. The program included the donation of a Juniper router to IXPN and training by Google on management of the network.[66]

Limits on foreign direct investment make it difficult to attract the investment necessary to expand broadband and Internet infrastructures, and limit participation by international carriers, content providers, and CDNs.

High domestic prices for network equipment can be a significant barrier to investment in Internet resources. High domestic prices for customer equipment, such as laptops and smartphones, as well as, high import duty taxes, luxury goods and service taxes, or certification policies that raise domestic prices for these items can inhibit broadband demand and Internet usage.

Defensive policies limiting the availability of attractive applications such as VoIP will limit the usefulness of broadband, discouraging take-up, while artificially raising costs to domestic consumers and businesses. Promotion of arrangements to allow the exchange of VoIP on an IP basis ("VoIP peering"[67]) would also facilitate development of this market.

6. Conclusion

The global market for Internet connectivity continues to grow rapidly and to perform well, producing low prices, directing resources efficiently, and calling forth the investment needed to sustain its growth. However, the results have varied significantly by region and country, driven by differences in distance and scale, as well as by government policies. Developing countries face challenges in promoting growth of Internet assets that will support the widespread availability and adoption of broadband.

In the last few years, significant new investments have been made in both international and domestic Internet connectivity in many developing economies. These have allowed growth in those countries to proceed at annual rates much higher than those observed in developed regions, albeit from a lower starting point. Countries with effective, liberalized policy frameworks have been best positioned to promote a virtuous circle of investment and growth. This paper has explored policy best practices to encourage a process in which investment, demand growth, and improving terms of trade can reinforce one another in support of rapid Internet and broadband development.

[1] This subject of this paper is the universe of IP traffic exchanged globally. This includes exchanges which are not part of the public Internet. For example, in its estimate of 30.7 exabytes per month of global IP traffic in 2011, Cisco includes 6.8 exabytes of what it defines as "managed IP" traffic, such as corporate IP WAN traffic and IP transport of TV and video. For the purposes of this paper, IP traffic and Internet traffic will be used interchangeably, unless there is a specific reason to draw a distinction. See Cisco Visual Networking Index: forecast and Methodology, 2011-2016, (Cisco VNI2012) at Table 1. http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-481360.pdf

[2] Weller, Dennis and Bill Woodcock. IP Traffic Exchange - Market Developments and Policy Challenges, OECD DSTI/ICCP/CISP(2011)2/Final forthcoming October 2012 at page 5. See also the Annex to this paper DSTI/ICCP/CISP (2011)2/ANN/FINAL.

[3] See Cisco VNI 2012 at Table 3. A zettabyte is one thousand exabytes.

[4] Some of the reasons for the difference in performance are discussed in the Annex to Weller and Woodcock (2012).

[5] The term ISP is used generically here to denote a network that participates on the Internet, including both backbone and local access networks.

[6] See Weller and Woodcock (2012), Annex 1. The same results can be found in Woodcock, Bill, and Vijay Adhikari, from Packet Clearing House (http://pch.net/resources/papers/peering-survey.)

[7] For instance, latency experiments conducted on Bing and Google search sites showed that a 2 second slowdown changed the number of queries per user by -1.8% and the revenue per user by -4.3% for Bing, while a 400 millisecond delay resulted in a -0.59% change in the number of queries per user for Google.
See http://perspectives.mvdirona.com/2009/10/31/TheCostOfLatency.aspx

[8] For a directory of IXPs, see http://pch.net/ixpdir.

[9] For a list of countries without an IXP, see Weller and Woodcock (2012), Appendix 4

[10] Labovitz, et al, Atlas Internet Observatory, 2009 Annual Report (Atlas 2009), at Page 15. http://www.nanog.org/meetings/nanog47/presentations/Monday/Labovitz_ObserveReport_N47_Mon.pdf. The study was a joint project of Arbor Networks, The University of Michigan, and Merit Network

[11] http://blog.netflix.com/2012/06/announcing-netflix-open-connect-network.html

[12] For a discussion of this process, see Weller, Dennis, "The Internet Market for Quality," Communications & Strategies, 4Q 2011. (Weller 2011)

[13] Labovitz, Craig. "CDN and Over-the-Top Traffic Data," Content Delivery Summit, May 2012. http://www.contentdeliverysummit.com/2012/Agenda.aspx

[14] Appendix 1 lists the undersea cables in operation globally in 2000, 2006, and 2012.

[15] http://www.telegeography.com/press/press-releases/2012/04/18/submarine-cable-construction-continues-despite-untapped-potential-capacity/index.html

[16] For a layered version of Figure 6 that shows the stages in which capacity around Africa has been and will be added over time, see http://www.slideshare.net/ssong/african-undersea-cables-a-history

[17] http://blogs.broughturner.com/2010/04/africa-moves-from-satellite-to-fiber-links.html

[18] Andrew Blum, "A Dive into the Digital Deep", Wall Street Journal, May 25, 2012. http://online.wsj.com/article/SB10001424052702304840904577422370903409342.html?mod=business_newsreel

[19] http://www.telegeography.com/press/press-releases/2012/04/18/submarine-cable-construction-continues-despite-untapped-potential-capacity/index.html

[20] See Akue-Kpakpo, Abosse, Study on International Internet Connectivity in Sub-Saharan Africa, March 2012 at page 20. For a list of cables and their ownership, see http://www.cablemap.info and http://manypossibilities.net/african-undersea-cables/

[21] http://blog.nielsen.com/nielsenwire/online_mobile/u-s-teen-mobile-report-calling-yesterday-texting-today-using-apps-tomorrow/.

[22] LTE smartphones configured for CDMA networks generally will not allow the user to download data and use the carrier's voice service at the same time. This creates an incentive for users to switch to over-the top VoIP applications that use the phone's data capability, and for the carriers to adopt VoIP for their own voice services.

[23] See http://billstarnaud.blogspot.ca/2012/06/why-cdns-are-critical-to-future-of-r.html

[24] Many services are also sensitive to jitter, which is caused when different packets take very different routes. This is another issue addressed by more direct routing provided by CDNs.

[25] See fn 18.

[26] http://gigaom.com/video/deloitte-cord-cutters/

[27] See, for example, Marcus, J. Scott, and Allessandro Monti, "Network operators and content providers: Who bears the cost?" WIK Consult 2011. http://ssrn.com/abstract=1926768

[28] In February 2011, in response to a question at a congressional hearing, the chairman of the FCC, Mr. Genachowski, expressed the view that the FCC's recent order on network neutrality was focused on protecting broadband consumers, not on peering disputes. The network neutrality rules "don't change anything with existing peering agreements," he said. See WSJ, "FCC Chairman: Net Neutrality Rules Don't Cover Comcast-Level 3 dispute." February 16, 2011. http://online.wsj.com/article/BT-CO-20110216-718576.html

[29] For a discussion of these cases and their implications, see Weller (2011). For a more recent report, see http://www.olswang.com/articles/2012/07/the-net-neutrality-debate-recent-developments-in-europe/

[30] Labovitz (2012) for example reports that CDNs are "now (nearly) completely peered."

[31] http://berec.europa.eu/eng/document_register/subject_matter/berec/press_releases/24-berec-publishes-net-neutrality-findings-and-new-guidance-for-consultation

[32] KIXP was initially launched in 2000, but was forced to close after a complaint from the incumbent Telkom Kenya that the IXP violated its exclusive right to carry international traffic. KIXP reopened in 2001, with a license from the CCL, the first IXP in the world to be required to have a license. See Kende, Michael, "Overview of recent changes in the International IP interconnection ecosystem," ITU Workshop on Apportionment of Revenues and International Internet Connectivity, Geneva, January 2012.
[33]
[34] See Akue-Kpakpo (2012) at 18.
[35] Mwangi, Michuki, "The African Peering & Interconnection Scene: Developing the Critical Mass," European Peering Forum, September 2012. http://www.peering-forum.eu/assets/presentations2012/AfricanPeering.pdf
[36] Russell Southwood, "Via Africa: Creating Local and Regional IXPs to Save Money and Bandwidth," International Telecommunication Union and International Development Research Center, 2005, http://goo.gl/D1rkK, at page 12.
[37] Kende 2012 at Slide 16.
[38] Mawangi (2012)
[39] See Bulley, Ayitey, "The Peering Scene in Ghana," Africa Peering and Interconnect Forum, Accra, August 2011
[40] http://www.nixp.net/index.php?option=com_content&view=article&id=13&Itemid=13
[41] Mwangi (2012)
[42] Choi, Yen, "Building Critical Mass at an IXP: The IXPN case study," Africa Peering and Interconnect Forum, Accra, August 2011
[43] Nigeria: NITDA Establishes IXPss to Crash Internet Cost, http://allafrica.com/stories/201205220342.html
[44] http://www.interswitchng.com/#PAYMENT%20INFRASTRUCTURE. See also Mwangi (2012)
[45] "Nollywood: Lights, camera, Africa," The Economist, September 27 2012, http://www.economist.com/node/17723124?story_id=17723124&CFID=153287426&CFTOKEN=59754693
[46] Mwangi (2012)
[47] Hamilton Research, Africa Bandwidth maps http://www.africabandwidthmaps.com
[48] Martin, Duncan, "UbunduNet's connectivity, peering, transit, and all that," AfPIF, August 2012. http://www.internetsociety.org/sites/default/files/images/Duncan%20Martin_UbuntuNet%20Update%20for%20AfPIF_2012.pdf
[49] A review of market developments by region and country is provided in Weller and Woodcock (2012)
50 Southwood (2005) at page 8.
[51] For a more complete discussion, see Weller and Woodcock. See http://europa.eu/rapid/pressReleasesAction.do?reference=IP/10/240&format=HTML&aged=0&language=EN&guiLanguage=en. Commission letter at http://circa.europa.eu/Public/irc/infso/ecctf/library?l=/commissionsdecisions&vm=detailed&sb=Title.
[52] http://europa.eu/rapid/pressReleasesAction.do?reference=IP/10/240&format=HTML&aged=0&language=EN&guiLanguage=en.
[53] For discussion of this point see Weller and Woodcock, and Marcus, et al, The Future of IP interconnection: Technical, Economic, and Public Policy Aspects. WIK-Consult, 2008, prepared for the European Commission (WIK 2008), at Pages 114–120.
[54] See Report and Order and Further Notice of Proposed Rulemaking, FCC 11-161, Adopted October 27, 2011. Released November 18, 2011. (FCC Universal Service and Access Reform Order) See also Comments filed February 24, 2012, and Reply Comments filed March 30, 2012.
[55] See "Network interconnection for voice services," File number 8643-C12-201105297, 19 January 2012. (CRTC 2012)
[56] In a general model of traffic exchange, Katz and Hermalin found that the commonly used frameworks, such as calling party pays, are optimal only in extreme cases, or corner solutions, where extreme values of the relevant parameters, such as demand elasticities and incremental costs, are assumed. Hermalin, Benjamin E., and Michael L. Katz, Sender or receiver: who should pay to exchange an electronic message? Rand Journal of Economics, Volume 35, No. 3, Autumn 2004 http://faculty.haas.berkeley.edu/hermalin/Hermalin_Katz_RAND.pdf
[57] For further discussion, see Weller and Woodcock (2012).
[58] http://www.itu.int/en/wcit-12/Documents/WCIT-background-brief4.pdf
[59] Article 1.3 of the ITRs says: "These Regulations are established with a view to facilitating global interconnection and interoperability of telecommunication facilities and to promoting the harmonious development and efficient operation of technical facilities, as well as the efficiency, usefulness and availability to the public of international telecommunication services."
[60] http://www.itu.int/en/wcit-12/Documents/draft-future-itrs-public.pdf"
[61] Weller and Woodcock (2012)
[62] https://prefix.pch.net/applications/ixpdir/ See also Oliveira, Salerme, "International Internet Connectivity - The Brazilian Experience," ITU Workshop on Apportionment of Revenues and International Internet Connectivity, Geneva, January 2012
[63] Southwood (2005) at page 23.
[64] Akue-Kpakpo (2012) at 21.
[65] Galliano, Roque, "Transit Service Practices," ITU Workshop on Apportionment of Revenues and International Internet Connectivity, Geneva, January 2012
[66] http://www.google.com/africa/universityprograms/inst/gasp.htm
[67] For more detailed analysis on the topic, see the GSR09 Discussion paper on the Future of VoIP interconnection, at: http://www.itu.int/ITU-D/treg/Events/Seminars/GSR/GSR09/doc/GSR09_VoIP-interconnect_VanderBerg.pdf