BROADBAND STRATEGIES TOOLKIT: MODULE FIVE

TECHNOLOGIES TO SUPPORT DEPLOYMENT OF BROADBAND INFRASTRUCTURE

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5.1 Introduction--Broadband and Its Impact

Broadband networks provide a medium capable of quickly delivering information, communications and entertainment ("ICE"). High speed wired and wireless networks can transmit digital bits making it even possible for instantaneous delivery of capacity intensive applications such as full motion video like that seen on broadcast, cable and satellite television channels. Prior generations of narrowband networks could not deliver such content, because they had available limited amount of channel capacity, also known as bandwidth. Such narrowband channels only could handle slow speed services, such as electronic mail, because of limited available radio spectrum, or closed circuit capacity, typically measured in cycles per second, or Hertz ("Hz"). Attempts to use narrowband networks for services requiring high bandwidth resulted in user frustration as the desired content could not arrive fast enough to deliver a clear and constantly changing video image, or even a high fidelity signal for reliable voice and music delivery. Narrowband lines created a backup of traffic commonly termed a bottleneck. The inability to provide timely delivery of traffic resulted in congestion.

Broadband technologies, like those used to support the Internet [1] offer the promise of faster, better, smarter, more versatile, personalized, cheaper and more convenient access to a wealth of ICE services. Few users of available broadband networks would give up these benefits for the slower, but cheaper option of using older technologies, such as conventional, dial up telephone networks. With retrofitting existing wired and wireless telephone networks can combine analog, voice services, with digital, data services. Likewise cable television networks can add data and telephone services to existing video offerings. Subscribers of these broadband services enjoy reliable and user friendly access to a broad array of services.

Most subscribers of broadband networks readily can learn how to use them, but few acquire much insights of how the networks operate. In most instances failing to acquire such "digital literacy" imposes no significant burden. However, having even a basic understanding of how broadband networks work can provide a foundation for achieving more effective and possibly cheaper use of broadband technology. Understanding how these networks operate can provide policy makers, regulators and users with a better sense of the strengths, vulnerabilities, opportunities and threats generated by the evolving migration from several different analog networks into a single, consolidated medium commonly referred to as the Internet, or World Wide Web. [2]

The promise of a single Internet medium for access to most content confirms that technological innovations have promoted a convergence of ICE markets. Previously separate, stand alone media provided a specific subset of the services represented by this now convergent ICE marketplace. Broadcasters delivered radio and television content to specific receivers, i.e., radio and television sets. Telecommunications companies provided voice connections between subscribers using wired and wireless telephones. Publishers of printed content, such as newspapers and magazines, delivered their "hard copy" products through physical distribution channels having nothing to do with electronic media.

Converging telecommunications and information technologies now make it possible for the Internet to provide a single medium for delivery of content to several devices in both fixed and mobile locations. While television broadcasters transmitted content for reception by one type of screen, Internet-mediated video content also can reach television sets, but also computer monitors, tablets and smartphone screens. Delivery to multiple devices and screens can occur, because content carried via broadband networks have been converted from their native analog state, to digital bitstreams.

Broadband Type Comparison

	Wired Broadband		Wireless Broadband	
	FTTH	DSL	Terrestrial (Wi-Fi, FWA, WiMAX)	Satellite
Speed (Best Effort)	100Mbps - 1Gbps	1Mbps - 50Mbps	10Mbps - 50Mbps	1Mbps - 10Mbps
Installation Cost	High	Very Low (Telephone copper cable can be used)	Moderate (Lower than FTTH)	High
Installation Unit	Area	Area	Area	Pin-point
Characteristics	➢ **Very fast and stable connection** ➢ Last-one-mile wiring is needed ➢ Trunk line is needed	➢ Speed depends on the **distance from the telephone company's building** ➢ No need for last-one-mile wiring ➢ No need for a trunk line	➢ **No need for last-one-mile wiring** ➢ Trunk line is needed	➢ **The only practical broadband for certain areas** ➢ No need for last-one-mile wiring ➢ No need for a trunk line
Target Areas	Populated areas, such as urban areas and central areas of suburbs	Areas within a certain distance from the telephone company's building	Broad areas where users are scattered	Areas under severe geographic conditions, such as island and mountains

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source: Government of Japan, Ministry of Internal Affairs and Communications, available at: http://www.itu.int/ITU-D/asp/CMS/Events/2010/ITU-MIC/S5-06_Mr_Atsushi_Ozu.pdf.

Once digitized all forms of content appear as a sequence of data capable of carriage via the broadband networks that make up the Internet. The standards that organize the Internet provide common formats for identifying, addressing, labeling, switching, routing and managing traffic. In particular, the Transmission Control Protocol and Internet Protocol, [3] provide standards for managing content broken up into small units of capacity known as packets for transmission via any available network interconnected with other networks that collectively comprise the Internet. The Internet Protocol provides an addressing system much like the numbering system used by telephone companies.

Telecommunications and Information Processing via the Same Network

The technologies that support innovation in telecommunications also provide new ways to deliver, process, manipulate and add value to information. Policy makers and regulators working in the telecommunications sector increasingly face issues involving the combination of legacy services, such as broadcasting and video program delivery, with new services that use telecommunications as the transport medium for information processing. The expanding use of the Internet as a primary medium for delivering most information, communications and entertainment ("ICE") services shows how convergence in markets and technologies will impact assumptions about how the ICE ecosystem operates. For example, increasing reliance on the Internet to deliver content to retail users means that previously stand alone technologies will converge so that one cannot segregate—and apply separate regulatory and market impact assumptions—about the print, radio, television, cable television, wired and wireless telecommunications and Internet media.

One way to appreciate the impact of converging technologies is to combine them in a vertical array ranging from the physical transmission media at the base and rising to the most sophisticated software, applications and content deliverable to consumers. The Open System Interconnection ("OSI") model provides a vertical view of the elements that combine to offer ICE services via new media such as the Internet. This model layers the Internet's architecture into seven increasingly sophisticated and specialized components: physical, data link, network, transport, session, presentation and application. The model calls for the independent operation of the layers, but also supports the interaction of various applications and equipment designed to use the features represented by each layer.

At the physical layer various media provide a wired or wireless conduit for the transmission of ICE content. It provides the hardware used to send and receive data on a carrier, including defining aspects of the physical medium used. At the data link layer traffic is encoded and decoded into bits that are collected in units called packets. This layer includes the traffic management rules used in the Internet's Transmission Control Protocol to control the flow of traffic and its synchronization as occurs in the routing of content via Ethernet, Asynchronous Transfer Mode and Frame Relay networks. The Network layer provides switching and routing technologies that create temporary pathways for traffic to move toward the desired final destination. This layer, in conjunction with the Transport and Session layers above it, handles the use of the Internet Protocol addressing system for identifying the source and destination of traffic, plus error handling, congestion control, packet sequencing and the setup and break down of the temporary pathways. The Presentation layer defines the format of the data exchanged (*e.g.*, text, graphic), followed by the Application layer that defines how applications communicate with each other over the network (*e.g.*, e-mail) using various protocols. [4]

OSI (Open Source Interconnection) 7 Layer Model

Layer	Application/Example		Central Device/ Protocols			DOD4 Model
Application (7) Serves as the window for users and application processes to access the network services.	**End User layer** Program that opens what was sent or creates what is to be sent Resource sharing • Remote file access • Remote printer access • Directory services • Network management		**User Applications** SMTP		GATEWAY Can be used on all layers	Process
Presentation (6) Formats the data to be presented to the Application layer. It can be viewed as the "Translator" for the network.	**Syntax layer** encrypt & decrypt (if needed) Character code translation • Data conversion • Data compression • Data encryption • **Character Set Translation**		JPEG/ASCII EBDIC/TIFF/GIF PICT			
Session (5) Allows session establishment between processes running on different stations.	**Synch & send to ports** (logical ports) Session establishment, maintenance and termination • Session support - perform security, name recognition, logging, etc.		**Logical Ports** RPC/SQL/NFS NetBIOS names			
Transport (4) Ensures that messages are delivered error-free, in sequence, and with no losses or duplications.	**TCP** Host to Host, Flow Control Message segmentation • Message acknowledgement • Message traffic control • Session multiplexing	PACKET FILTERING	TCP/SPX/UDP			Host to Host
Network (3) Controls the operations of the subnet, deciding which physical path the data takes.	**Packets** ("letter", contains IP address) Routing • Subnet traffic control • Frame fragmentation • Logical-physical address mapping • Subnet usage accounting		**Routers** IP/IPX/ICMP			Internet
Data Link (2) Provides error-free transfer of data frames from one node to another over the Physical layer.	**Frames** ("envelopes", contains MAC address) [NIC card — Switch — NIC card] (end to end) Establishes & terminates the logical link between nodes • Frame traffic control • Frame sequencing • Frame acknowledgment • Frame delimiting • Frame error checking • Media access control		**Switch Bridge WAP** PPP/SLIP	Land Based Layers		Network
Physical (1) Concerned with the transmission and reception of the unstructured raw bit stream over the physical medium.	**Physical structure** Cables, hubs, etc. Data Encoding • Physical medium attachment • Transmission technique - Baseband or Broadband • Physical medium transmission Bits & Volts		**Hub**			

Source: Escotol.com, available at: http://www.escotal.com/osilayer.html.

Looking at the OSI Layered model, one might consider telecommunications infrastructure concerns as limited to the lower layers that more directly focus on the physical connections contained in information and communications technology ("ICT") networks. However the integrated and convergent nature of all seven levels requires an appreciation by all stakeholders. For example, when retail subscribers experience congested or inoperative service, they may not know which of several ventures should bear the blame. They simply want service to return to normal without regard to which layer of service became dysfunctional and which, if any, regulator has jurisdiction.

Analog Humans and Digital Networks

Broadband networks provide the medium for digital bitstreams, having converted analog traffic. This conversion takes content created by and for humans and makes it possible for carriage by computers and digital networks. Humans have several analog body parts used to see, hear, feel and communicate. Air held in our lungs provides a carrier for signals created (modulated) by our larynx, also known as the voice box. We receive sound via our ears where the modulated signals are replicated by ear drums and converted into weak electrical signals useable by our brains. Our eyes concentrate light and color at the optic nerve which also converts the signals into electrical impulses.

While the human body retains its analog characteristics, ICTs mostly have migrated to digital transmission and processing formats. The digitization of networks promotes more efficient use of spectrum such as the ability to compress a signal so that it uses less bandwidth. Digitization also makes it possible to for a single network to handle different types of traffic generated from many sources, by subdividing the content into small units, called packets, and switching these packets via available transmission capacity offered by possibly many network operators. When coupled with improvements in content storage and the speed of broadband network transmission, digitization supports fast transmission, switching, processing and delivery of content. Consumers can more readily access, transmit, share, copy and store digitized content.

Digitization operates as a key driver for making broadband networks capable of providing faster, better, smarter, more versatile, cheaper and more convenient services. Digital networks can transmit content faster than narrowband networks thanks to the availability of wider transmission channels (more bandwidth) and larger allocations of radio spectrum to create more channels having larger capacity. Transmitting signals within larger channels can increase the bit transmission speed which in turn reduces the time it takes for content to arrive at the desired destination. The term bitrate refers to the speed by which a carrier can transmit and deliver content. Broadband networks can transmit digital bitstreams at a rate of between less than one million bits per second, i.e., 1 Megabit per second (1 "Mbps") and more than one billion bits per second, i.e., 1 Gigabit per second (1 "Gbps"). Narrow strands of glass fibers provide a much faster transmission medium than available via copper networks.

Another measurement of broadband networks' comparative advantages to analog predecessors lies in their ability to transmit bandwidth intensive content without triggering congestion that would cause a backup in the delivery of bits. Broadband networks can deliver content so quickly that users can download, process and view full motion video content in the same manner as reception via conventional broadcast, cable and satellite media. The term throughput refers to the amount of content, measured in bytes, represented by a file, or other source of content. Narrowband networks could only make timely delivery of small files containing a few kilobytes of content.

Larger files, such as those containing full motion video content, including images in high definition, constitute many megabytes of content. This type of content requires that networks operate at fast transmission speeds having the ability to deliver large megabyte files on a timely basis. For so called streaming content, the network must transmit bits that immediately will be processed and converted into pictures and sound, as occurs when the Internet serves a medium for "simulcasting" live television content, or for the immediate decoding and display of video files as occurs when consumers download and simultaneously view content like a movie or television program received via the Internet.

In addition to operating at vastly higher transmission speed, digital networks also promote the likelihood that content will arrive without significant degradation in quality. Digital networks offer high data integrity, because they convert content into a coded sequence that travels easily through digital transmission links. Should any portion of the data sequence get lost, dropped or delivered too late for timely conversion back into usable content, digital network can resend it. Consumers welcome the ability to send and receive perfect copies of content, but National Regulatory Authorities, policy makers and courts should appreciate that fast network transmission of perfect copies makes it much easier for piracy of copyrighted content. Previously analog networks could not transmit high capacity files corresponding to video content. While these networks could handle smaller music files, the delivery process took significant time with the potential for noise and other factors to degrade the quality of illegal copies.

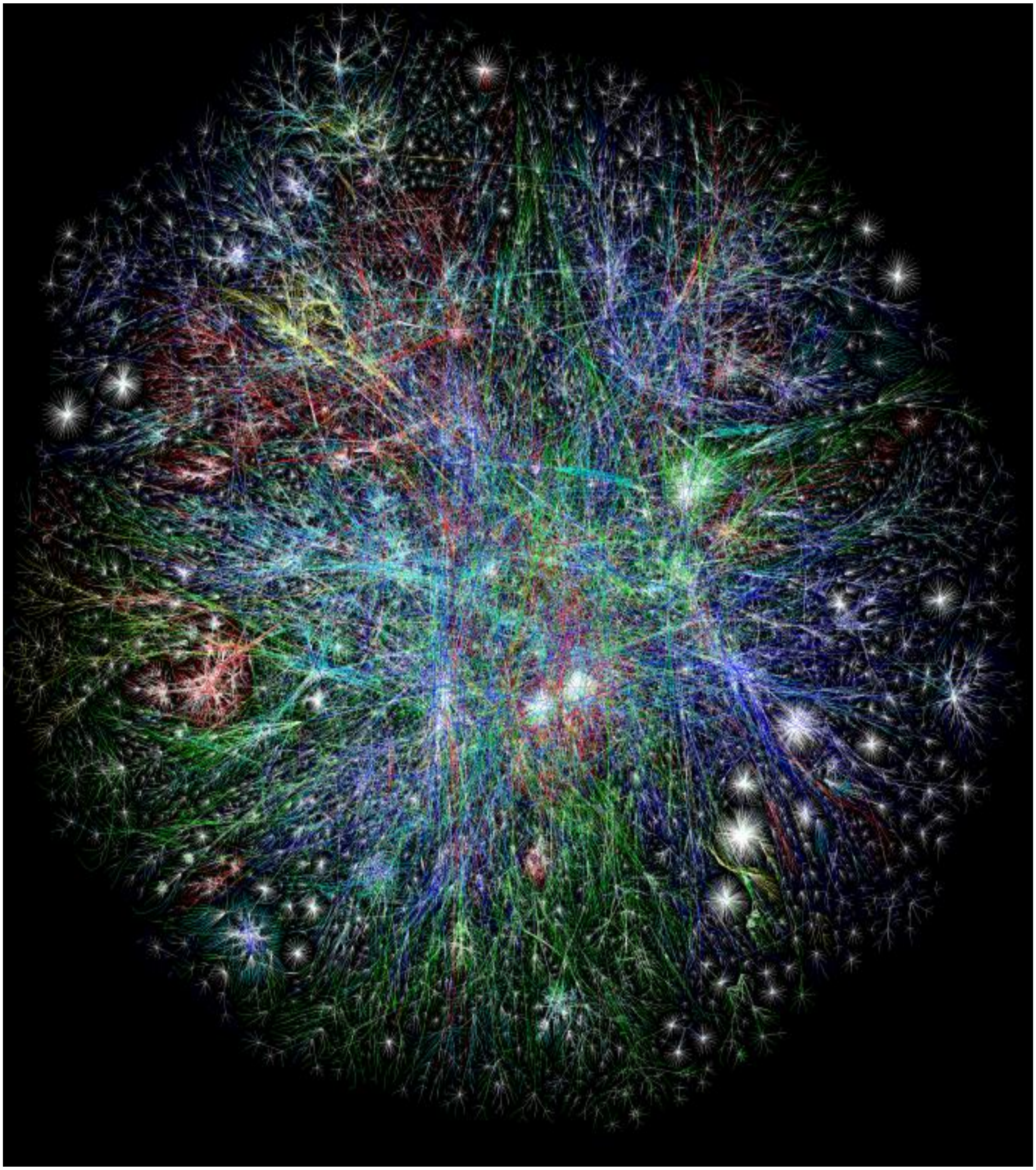
Digital transmission through broadband networks also promotes the proliferation of new services that requires two-way interactivity between users. Even with a narrower and possibly slower uploading capability, broadband network users now can create and share content as they interact with others. For example, many social networking sites allow subscribers to upload content, such as photographs, and for selected "friends" to comment on the shared material.

Broadband is the Common Thread in a Network of Networks

Reliable and high quality access to the complete range of services available via broadband networks requires that every participating carrier operate with generally the same speed and efficiency. Consumers of broadband services typically rely on several carriers, commonly referred to as Internet Service Providers ("ISPs") to provide a portion of the complete, two-way ("duplex") link from and to sources of content. The Internet has been characterized as a "network of networks" [5] and a cloud [6] to emphasize how many different carriers must cooperate with each other by interconnecting their networks using common operating standards so that subscribers have easy, reliable and uninterrupted access to services and content located anywhere. Because many services require broadband connections for each leg that combine to form the complete link, any gap or reduction in service quality will degrade the total performance of the network as perceived by end users, i.e., final recipients of content and services.

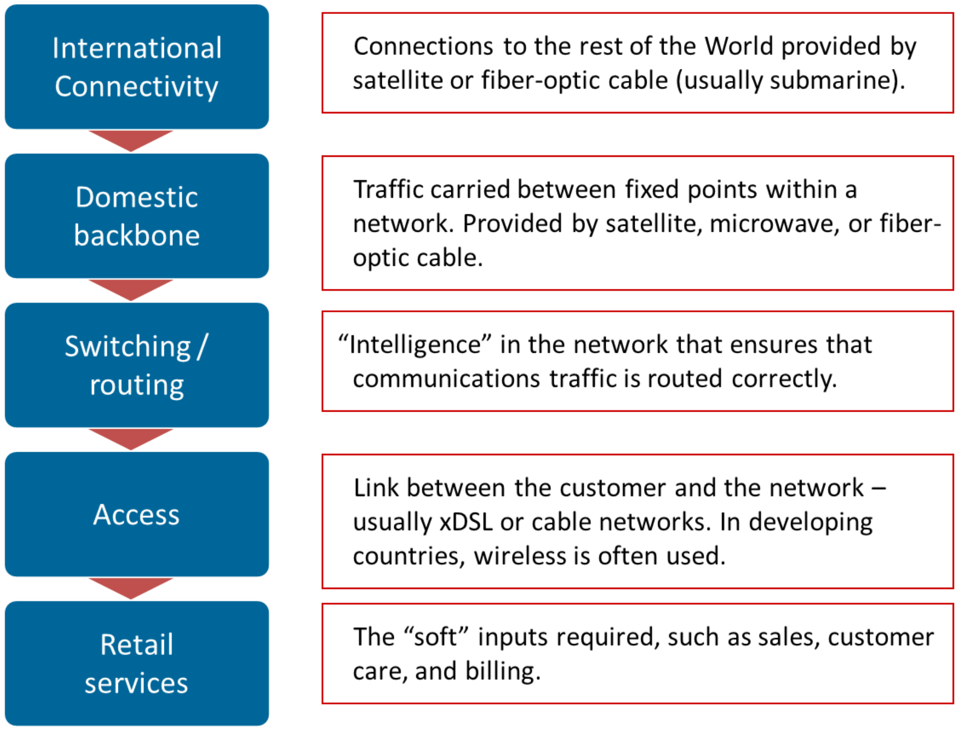
The concept of cloud computing emphasizes the integrated and interconnected nature of broadband networks, but inside the cloud are specific networks containing the telecommunications lines, and data traffic routers that link consumers with the content they desire. The information and communications technology ("ICT") ecosystem seamlessly combines the basic building blocks of telecommunications transmission capacity with software and other forms of information processing. Much of the content and network enhancements are located at the edges of networks where content is originally transmitted and eventually received. However the networks transmitting such content must have sufficient intelligence to identify the location of source material as well as its destination. Data networks use intelligent switches and routers to make decisions how to route traffic in the fastest and most efficient way at the time of the decision.

Visualizing the Internet as a Cloud and Network of Networks



source: The Opte Project, available at: http://www.opte.org/maps/tests/

The Broadband Communications Supply Chain



source: The World Bank, Mark D.J. Williams, Broadband for Africa Developing Backbone Communications Networks, p. 4 (2010); available at: http://elibrary.worldbank.org/content/book/9780821381724.

When broadband subscribers experience inferior service they may not readily know the cause, because they lack the diagnostic tools to identify the worst performing device or transmission link in the group of participating ISPs. Additionally packet switching of content constantly changes which carriers participate as cloud computing and data networking typically use any available network transmission capacity offered by many different carriers.

You can get a sense of how multiple carriers participate in broadband networking by launching a simple tracking tool known as traceroute. This software program transmits and tracks a small amount of data sent from your location, or an origination point you designate, to a destination you also specify. You receive a line-by-line report on which carrier networks participated in the carriage of your traffic to the final designation. The traceroute report identifies the networks used to route your traffic. Using multiple tracereoutes over time, you can see how the routing can change as the then current availability of networks changes. Traceroute tools also provide a report on the length of time it took to traverse a network from one geographical point to another.

Example of a Traceroute from Denver, Colorado United States to Sydney, Australia

1 veserv1 (66.17.141.110) 0.172 ms 0.096 ms 0.062 ms

2 66.54.149.69 (66.54.149.69) 1.902 ms 6.314 ms 1.311 ms

3 ge-6-24-515.car1.Denver1.Level3.net (63.211.250.17) 1.305 ms 1.556 ms 1.842 ms

4 ae-31-51.ebr1.Denver1.Level3.net (4.68.107.30) 6.402 ms 2.217 ms 13.363 ms

5 ae-2-2.ebr2.Dallas1.Level3.net (4.69.132.106) 23.835 ms 17.447 ms 17.972 ms

6 ae-1-60.edge2.Dallas3.Level3.net (4.69.145.12) 17.510 ms 20.658 ms 18.097 ms

7 ex-3-1-0.er1.dfw2.us.above.net (64.125.12.73) 17.328 ms 17.148 ms abovenet-levle3-xe.dallas3.level3.net (4.68.63.38) 57.938 ms

8 ge-2-1-0.mpr1.dfw2.us.above.net (64.125.27.73) 17.128 ms 19.487 ms 18.245 ms
MPLS Label=448742 CoS=6 TTL=1 S=0

9 xe-1-2-0.cr1.iah1.us.above.net (64.125.26.130) 23.410 ms 22.282 ms 21.876 ms
MPLS Label=633529 CoS=6 TTL=1 S=0

10 xe-1-3-0.er1.lax9.us.above.net (64.125.26.122) 66.848 ms 47.634 ms 47.212 ms
MPLS Label=391497 CoS=6 TTL=1 S=0

11 ge-2-0-0.mpr3.lax9.us.above.net (64.125.31.90) 47.524 ms 46.298 ms 45.649 ms
MPLS Label=774617 CoS=6 TTL=1 S=0

12 so-0-0-0.mpr4.lax9.us.above.net (64.125.26.146) 100.005 ms 45.132 ms 49.471 ms

13 64.124.200.234.allocated.above.net (64.124.200.234) 46.608 ms 50.029 ms 45.204 ms

14 so-4-0-0.bb1.b.syd.aarnet.net.au (202.158.194.157) 197.119 ms 196.145 ms 195.272 ms

15 ge-1-1-8.bb1.a.syd.aarnet.net.au (202.158.202.41) 191.984 ms 192.289 ms 193.792 ms

16 gigabitethernet0.er1.usyd.cpe.aarnet.net.au (202.158.202.194) 232.429 ms 194.210 ms 191.807 ms

17 gw1.er1.usyd.cpe.aarnet.net.au (202.158.202.202) 192.326 ms 200.158 ms 195.941 ms

18 vlan3166.brc-h69-1.gw.usyd.edu.au (129.78.253.77) 193.937 ms 214.900 ms 195.490 ms

19 vlan3072.nx7-s01-2.gw.usyd.edu.au (129.78.254.206) 199.189 ms 193.544 ms 193.193 ms

20 solo-rproxy.ucc.usyd.edu.au (129.78.155.111) 201.936 ms 193.163 ms 195.268 ms

Higher Stakes for Developing Countries

Consumer demand for broadband network delivered services raises the stakes for timely and effective deployment of ICT. Nations that do not have widespread access to affordable broadband service risk losing comparative advantages in global markets, particularly for information intensive applications. Lesser developed countries (“LDCs”) which may not have achieved ubiquitous access to narrowband, voice services, now face the task of adding broadband access to a universal service mission. The added broadband burden may raise the total cost of network development, but technological innovations can help LDCs possibly avoid having to retrofit legacy networks and instead concentrate on installing next generation networks (“NGNs”) that can “leapfrog” prior generations and vintages of technologies. These cutting edge technologies exploit technological convergence making it possible to provide both voice and data services via a single Internet link.

Broadband technologies can expedite a nation’s access to digital networks configured to transmit data bitstreams combining voice, text, data, video, graphics and other content. In many LDCs the opportunity to install and operate best in class technologies may lie in wireless networks that already may provide widespread geographical coverage for narrowband voice telephone service. Third and fourth generation wireless networks provide faster data services, possibly reaching parity with some current generation wired broadband options. However, the use of radio spectrum may constrain the ability to scale services to a large subscriber population if National Regulatory Authorities do not authorize access to more bandwidth. Likewise developing countries may not have achieved the same pace in migrating from second generation wireless technologies to third and fourth generations that offer more bandwidth and data transmission capabilities.

Additionally consumers in developing countries may not have the opportunity to select from two or more broadband distribution technologies as occurs in many developed countries where both cable television, telephone and possibly electric companies offer broadband services. The lack of so-called intermodal competition from two facilities-based carriers using two different broadband technologies, may limit the degree of competition and consumer choice. Similarly the lack of more than one carrier using the same technology may limit intramodal competition as occurs when a nation has more than one wireless telephone company.

Because broadband networks can achieve significant improvements in many types of personal and commercial transactions, nations increasingly recognize the importance of making broadband access widely available and affordable. The Finish legislature enacted a law that recognizes the right of all residents to access affordable broadband, while many other nations have integrated broadband access into existing universal service programs that subsidize access and provide other financial incentives to operating carriers. [7] Other nations, have added access to affordable and widely available broadband service as a policy goal worthy of government funding and subsidies previously used only to promote access to voice telephone service.

5.1.1 Managing the Transition from Narrowband to Broadband

Despite the allure of broadband technologies and the obvious market demand for it, incumbent carriers cannot simply execute a strategy of quickly replacing all existing plant that use "legacy" technologies such as narrowband copper wire used to provide conventional public switched telecommunications services ("PSTN"). Both carriers and National Regulatory Authorities ("NRAs") have to manage the transition with caution to ensure that subscribers do not face substantial and immediate hikes in service rates resulting when carriers seek to "write off" substantial plant investments, i.e., to recoup all PSTN investment in a short period of time. Additionally complex regulatory issues will arise including the valuation of the rights of way used for replacement broadband services, the potential for a reduction in the geographical scope of access to broadband services and the need for subscribers to acquire additional equipment such as computers and terminal adapters to make it possible to use existing telephones over a Voice over the Internet Protocol ("VoIP") network. NRAs will need to reform universal service policies to achieve progress in access to both voice and data services.

Broadband technologies require carriers to invest substantially in new plant at the very same time as these ventures have high capital expenditures in expanding the range and upgrading the services of both wired and wireless networks. While the Internet can provide a single medium for virtually all types of services, now provided via separate networks, the carriers must manage an incremental conversion that squeezes out as much value as possible from embedded plant for as long as possible.

For example, carriers providing wired voice telephone service can retrofit the PSTN to provide some types of broadband services at a relatively low additional investment per line. This Digital Subscriber Line ("DSL") service cannot match the versatility and transmission speed of fiber optic glass networks, or even the latest generation of wireless service, commonly referred to as 4G. But as a transition technology, DSL can provide a more quickly installed broadband service without the need for carriers to replace the copper wire network with a completely new wired or wireless distribution network.

Both developing and developed nations will have consumers keen on accessing the most recent services and technologies available. Both broadband carriers and NRAs may struggle to satisfy such demand. Carriers will need to upgrade even recently installed networks, so that they can offer even higher bit transmission speeds. NRAs may need to find additional radio spectrum to accommodate demand for wireless broadband service.

Video will serve as a key driver for faster broadband networks with ever improving content delivery capabilities. Initially improvements in image resolution could occur using the same amount of radio spectrum and wired capacity through the use of compression techniques that help conserve bandwidth. In many areas of the world, broadcast, satellite and cable television operators have successfully migrated from delivering standard definition television to high definition television. However engineers have devised even higher resolution video images that will double or even quadruple the number of columns and lines that must be reproduced thirty times a second. So-called ultra high definition television, delivered via wired and wireless broadband networks, will require more bandwidth and the implementation of more effective conservation techniques.

5.1.2 Reference Documents and Case Notes

Traceroute and the Network of Networks

You can receive a line by line report on the networks used to send a small amount of data. Traceroute software provides a graphical summary of how the Internet operates as a Network of Networks providing users with seamless connectivity via the networks of many interconnected carriers. Here are some Traceroute World Wide Web sites:

http://www.traceroute.org/;

http://network-tools.com/;

http://www.geektools.com/traceroute.php;

http://tracert.com/trace_exe.html.

Visualizing the Internet Cloud

The traceroute and other network diagnostic tools provide a visualization of how the Internet functions through the physical interconnection of networks at various locations around the world. Many telecommunications lines, routers, servers and other equipment provide service in a such user friendly, seamless way that the Internet can be analogized to a cloud. The following sites provide a visual depiction of the networks that form this cloud:

http://mappa.mundi.net/maps/maps_020/walrus.html;

http://www.infovark.com/blog/wp-content/uploads/2008/03/internet_map2.jpg;

See also Visualizing Global Internet Performance with Akamai, World Wide Web site; available at: http://www.akamai.com/html/technology/visualizing_akamai.html;

Bredan's Blog, *Visualizing the Cloud*; available at: http://dtrace.org/blogs/brendan/2011/10/04/visualizing-the-cloud/;

The Internet Map; available at: http://internet-map.net/.

Packet Switching

Most Internet traffic is subdivided into small units of capacity called packets. The Transmission Control Protocol ("TCP") used by ISPs offers traffic management procedures for the transmission and delivery of these packets to the intended recipient using the network capacity of two or more participating carriers. Each separate packet traverses the network facilities of any participating ISP with available transmission and switching capacity. TCP usually provides for "best efforts" routing of packets meaning that first arriving packets at a router are the first to be delivered to recipients, or carried onward toward the final destination.

The following sites offer a tutorial on how packet switching works:

Oregon Public Broadcasting, Packet Switching Demo
http://www.pbs.org/opb/nerds2.0.1/geek_glossary/packet_switching_flash.html;

Virginia Tech, Online Course; available at:
http://courses.iddl.vt.edu/CS1604/15-Lesson_14/03-Packet_Switching.php.

Internet Addressing

One can access a desired Internet site by keying in an easily remembered name into a World Wide Web browser such as Internet Explorer and Mozilla Firefox. The Internet Protocol establishes a series of rules for the creation of an address and a governance system operates for the registration of the names and the resolution of disputes. The addressing system combines a name with a top level domain designation such as .com, .edu and .gov representing commercial ventures, educational institutions and government organizations respectively.

For background on the Internet addressing system see:

Modular Software Corp., *An IP Primer*; available at: http://coyote.easyco.com/ip-prim.htm;

Bagwell Marketing, Domain Name Primer: *Everything You Need to Know about Domain Names*; available at: http://www.bagwellinternet.com/report-domain-names.html;

Microsoft Corp., *Understanding TCP/IP addressing and subnetting basics*, available at: http://support.microsoft.com/kb/164015.

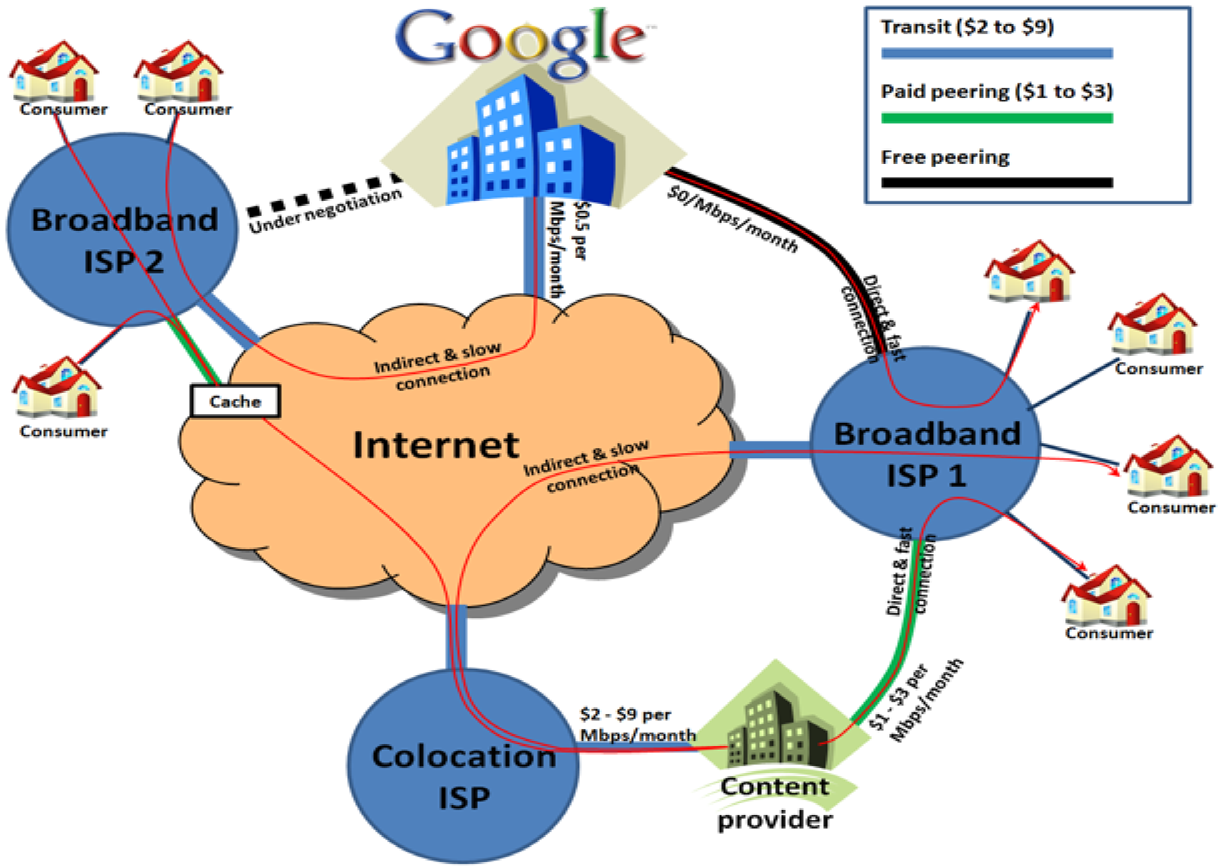
5.2 Overview of Broadband Networks

Characterizing the Internet as a cloud and a network of networks emphasizes how users benefit from the seamless integration of many different carrier facilities located throughout the world. The Internet design emphasizes convenience and simplicity even as complex network interconnections take place between equipment of different vintage and manufacturer. By agreeing to use a common set of operating standards, all ISPs have the ability to interconnect the equipment needed to transmit, switch, identify, label and deliver traffic. This means that users can access content located anywhere within the Internet cloud by using a universally agreed upon addressing system that uses easily remembered words, e.g., www.worldbank.org. These domain names translate into a sequences of numbers used by devices called routers to identify the origin and destination of traffic as well as the next network that will deliver traffic closer to its intended destination, or to the final destination. The Internet addresses of senders and recipients of traffic are located in the header portion of packets. Content is located in a separate portion of each packet commonly referred to as the payload.

Broadband networks combine high capacity transmission lines with devices such as routers that coordinate the delivery of traffic. By analogy think of the telecommunications lines as high capacity highways, or pipelines and routers as the traffic lights that manage the intersection of lines, i.e., their interconnection, and the routing of traffic that typically involves a switch from one transmission line to another, i.e., a handoff from one carrier's network onto the network of another carrier.

The Internet offers fast and reliable management of high capacity traffic bitstreams thanks to the reciprocal agreements among ISPs to share transmission, switching and routing duties. Peering refers to an agreement between two ISPs to exchange Internet traffic typically with no payment if the traffic handed off to the other ISP roughly equals the volume received from the other ISP. [8] For instances where ISPs exchange unequal traffic volumes, the carrier generating more traffic volume typically has to pay the other carrier for its comparatively greater traffic carriage, a financial transaction commonly referred to as transiting.

Peering and Transit Agreements



source: George Ou, The Internet Society (Nov. 10, 2009); available at: http://www.digitalsociety.org/2009/11/fcc-nprm-ban-on-paid-peering-harms-new-innovators/.

Internet traffic can quickly and seamlessly maneuver through the cloud using the networks of many ISPs. ISPs agree to interconnect their networks and have both technological means and financial incentives to secure a complete link from an end user upstream via his or her retail ISP and many other interconnected ISPs all the way to the source of desired content and back. The specific networks use at any time during the connection can change, because carriers subdivide Internet traffic into packets and the decision on which carrier network to use for each packet is made "on the fly," i.e., as the packets are presented to a router. Routers typically use operating standards that switch individual packets on a "best efforts" basis that identifies which of possibly several networks are available and which individual network is most likely to deliver traffic quickly onward to another ISP, or to the retail ISP serving the end user requesting the content.

Hierarchical Structure of the Internet

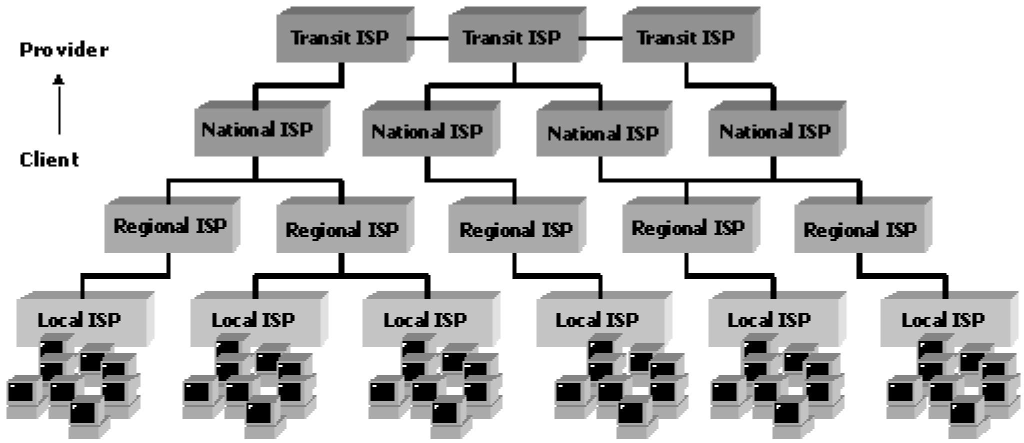
The Internet ecosystem divides into a number of separate network elements that combine to provide users with a complete link to and from sources of content. A retail ISP serving end users provides the first connection that originates an upstream traffic flow used by subscribers to initiate a request for content, e.g., a query submitted to a search such as Google, or to upload their own content, e.g., uplinking a photograph to a social networking site such as Facebook. More than one retail ISP may offer broadband links to individual subscribers, but generally end users opt to subscribe to only one carrier for all uplinking and downlinking services.

In many locales consumers have a choice of technological options that include broadband provided by a telephone company that has retrofitted its voice network to provide data services, a cable television company that has reassigned a portion of its video content delivery capacity for data services, one or more terrestrial and satellite wireless carriers and possibly the electric power company. These carriers have limited opportunities to aggregate traffic and achieve operational efficiencies for the first and last kilometer link, [9] because eventually they must identify and deliver or receive traffic from each and every subscriber on an individualized basis. However, retail ISPs can aggregate traffic for upstream delivery to other carriers and receive such aggregated traffic from these carriers.

The ability or inability to aggregate traffic has great significance on how much operational efficiency and cost savings an ISP can generate. As traffic moves upstream from a retail ISP the carriers providing intercontinental and transoceanic transmission have the greatest ability to combine traffic onto the fastest and highest capacity transmission links available. This traffic aggregation function makes it possible for such carriers to accrue best possible scale efficiency and to become a part of the largest class of operators known as Tier-1 ISPs. [10] These ISPs provide long haul traffic delivery and typically only interconnect directly with other similarly-sized Tier-1 ISPs, on zero cost, peering terms. Smaller ISPs may also enter into peering agreements, but typically have to pay transit fees to Tier-1 ISPs for access to their long haul services.

The Internet ecosystem can be visualized as a hierarchical pyramid with many comparatively small ISPs serving individual localities and regions, with fewer ISPs operating upstream as Tier-2 and Tier 1 carriers.

Hierarchy of ISPs



source: Geoff Huston; available at: http://www.potaroo.net/ispcol/2000-11/2000-11-peering.html

Internet traffic also has characteristics that affect how ISPs configure their networks. Because most subscribers download more content than they upload Internet networks have to handle more downstream traffic. This asymmetrical traffic volume requires some ISPs, particular retail carriers, to allocate more capacity for downstream transmissions than for upstream flows. Similarly ISPs have to configure networks that can handle and quickly respond to significant variation in the total volume of traffic demand made by individual subscribers. Most Internet subscribers have "bursty" traffic requirements as they will require fast, high capacity downloading capability for a period of time after which they may impose no significant demands whatsoever. ISPs need to have the ability to accommodate high throughput demand, e.g., downloading a very large file containing video content, but also to reassign network resources when one subscriber completes a bursty demand for transmission capacity and starts to watch the downloaded content.

The Internet ecosystem will constantly change as new types of content and uses emerge. Current developing trends include increasing reliance on wireless broadband networks, the proliferation of applications designed for use of these networks and the rapid inclusion of Internet connected sensors to monitor the health and performance of both people and devices. These trends will have a substantial impact on how planners design and configure future networks. With increasing reliance on wireless networks ISPs will need to convince government regulators to reallocate and assign more radio spectrum for Internet access. A growing "Internet of Things" [11] means that our understanding of what the Internet can do will expand into an even larger ecosystem of people, devices and monitors.

Another developing Internet trend reduces the hierarchical nature of interconnections and increases the number of financial compensation arrangements available. When the Internet started only a few carriers participated and they generally had roughly equal volumes of traffic to exchange. Additionally these carriers did not have to pay close attention to traffic volumes, because governments typically subsidized their operations. Most governments have stopped or reduced subsidizing Internet development thereby prompting ISPs to pay closer attention to capital and operating costs, including whether an interconnecting carriers generates more traffic than it receives. ISPs generating more traffic for carriage by another carrier now have to pay for such access. Faced with significantly higher interconnection costs, these carriers have explored new ways to interconnect networks.

For example many smaller Tier-2 ISPs have agreed to interconnect directly rather than rely solely on higher capacity Tier-1 carrier networks. Additionally ISPs of all sizes increasingly opt to interconnect and to store content at a centralized location commonly referred to as an Internet Exchange. Such co-location makes it possible for many ISPs to interconnect in the same building. This promotes operational efficiency and reduce interconnection costs.

Very large suppliers or repositories of content also consider alternatives to relying on one or more ISPs to manage delivery. These ventures, such as Google, Facebook, and Youtube can secure and manage their own network routings closer to end users. Some content providers have registered to secure an Autonomous System identifier that specifies routing options as though the content source operated as an ISP. In the alternative Netflix has under consideration the installation of high capacity storage units on subscriber premises that will contain hundreds of the most popular content thereby reducing the aggregate subscriber demand for immediately downloaded content.

5.2.1 The Broadband Supply Chain

While many components parts make up the broadband supply chain, they split into two basic categories: conduit and content. Conduit refers to the technological means by which geographically separated users of the Internet can connect with equally dispersed sources of content. The Internet seamlessly combines the conduit function with content so that end users can readily access desired content simply by keying in easily remembered names, or Web addresses, or clicking on an icon, a small image that launches an application and accesses content.

While willing to pay directly for specific content, applications and software, consumers generally consider their broadband subscription as entitling them to expect their retail ISP to make all necessary arrangements to provide consistently reliable broadband links to all content sources. Accordingly while a complete understanding of broadband supply chain necessitates examination of each component part, consumers generally consider Internet access a single transaction regardless of how many ISPs and diverse telecommunications network facilities participate in the complete routing and management of the links between end users and sources of content.

A variety of ISPs participate in the transmission, switching, routing, storage and data base interrogation that are necessary for making complete links between end users and content sources. The transmission element refers to broadband transmission technologies that use closed circuit media, such as copper wire and fiber optic cables, as well as radio spectrum to provide a wideband conduit for content to travel to and from end users. These telecommunications links constitute the core carrier functions for which National Regulatory Authorities have direct jurisdiction to ensure that consumers have widespread access on reasonable terms and conditions. In subsequent sections, this Module will explain how each broadband transmission technology operates.

To achieve global connectivity, broadband networks need robust and flexible telecommunications line switching and routing functions. Routers manage the selection of which telecommunications network will deliver traffic for each of possibly many legs in a complete link up. As identified in a traceroute report, the networks participating in the provision of service are accessed by routers that switch between available networks on the basis of available capacity and the destination of the traffic. Routers inject intelligence into the switching and routing process, because they make network selection decisions based on an analysis of network capabilities immediately available as well as interrogation of data bases to identify the source of content and its intended final destination.

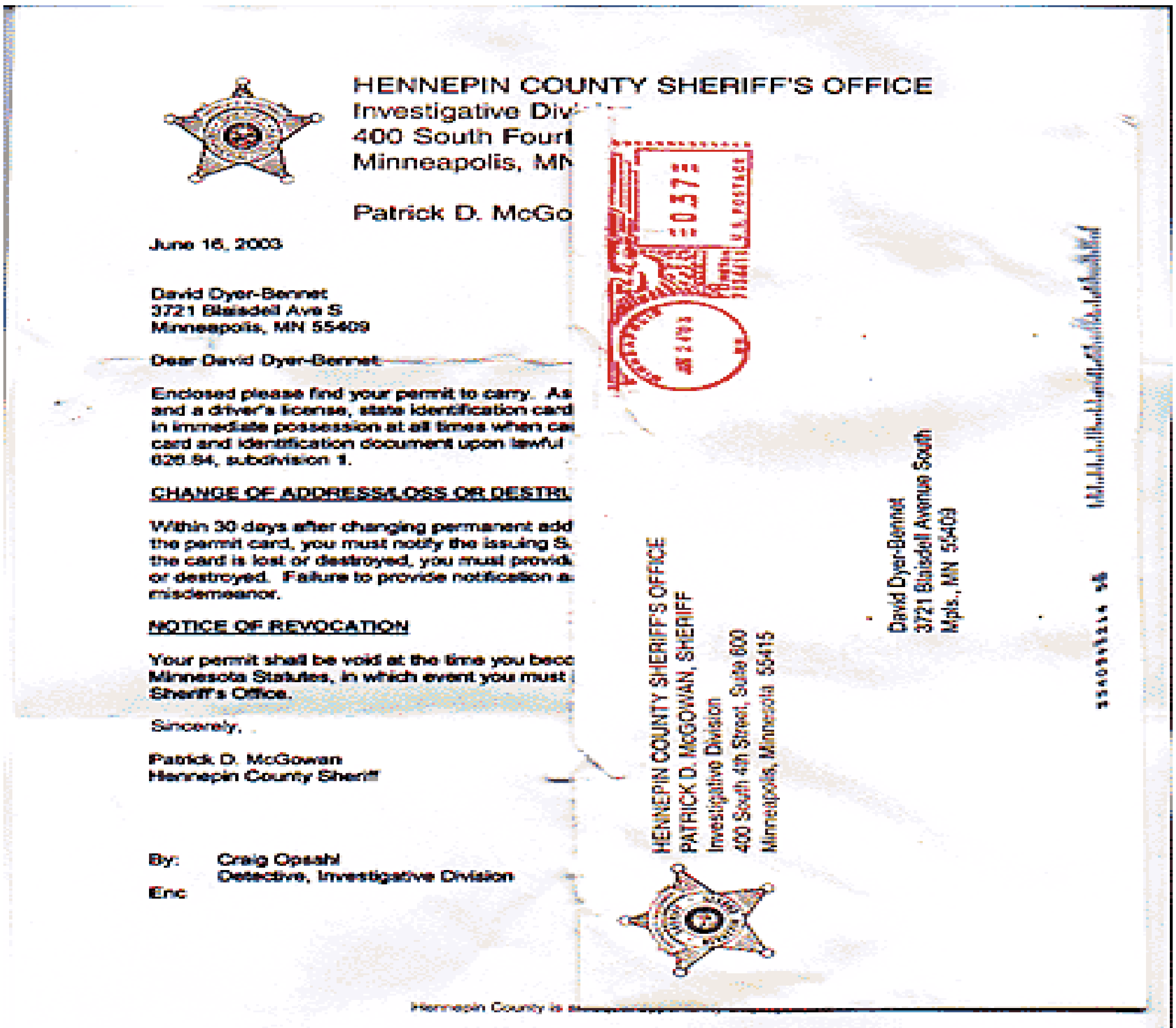
Because routers need to look up the identity of traffic sources and recipients, network operators create data bases, located in computers with high storage capacity known as servers. Just as routers have to select the next telecommunications link to transmit traffic onward toward its final destination, these devices also have to interrogate servers containing information about the identity of network users. Servers responding to this "look up" function may be located at a distance from the router, but a very fast lookup of Internet Protocol addresses must occur before the router can decide onto which network to switch the traffic. Based on traffic conditions and the location of the destination for a particular bitstream routers then coordinate the hand off from one network, the initial source of traffic, onto another network possibly operated by a different ISP.

5.2.2 The Transition to All-IP Networks

Technological and marketplace convergence favor increasing reliance on a single Internet-based network to provide most information, communications and entertainment ("ICE") services. Current and next generation networks [12] use uniform Internet standards, formats and protocols making it possible for them to deliver globally just about any type of content, including that previously available only from one specific type of medium, e.g., broadcast radio and television, via wireless point-to-multipoint technology. With increasing reliance on the Internet as a single source of content, previous medium-specific media may become less important.

The Internet is becoming a single conduit for all types of content, because it can switch, route, sort and store digital bitstreams. All types of content can be converted into digital bits and subsequently organized into packets. Packet switching technology can send bitreams representing many different types of content, e.g., voice, music video, text, photographs, etc. generated by different sources via shared networks that combine to form the Internet.

One can analogize packet switching with the older legacy delivery of mail by postal carriers. Much of the traffic handled comes to a post office in two parts: 1) an exterior envelope containing information about the source and destination of the communication; and 2) an interior space for content, such as a letter. Packet switching uses the same two part structure: packet headers contain routing information including the IP addresses of sender and intended recipient and the payload containing content.



One can anticipate the transition to an ICE marketplace served primarily by the Internet as a "one stop shop" for most content thanks to digitization and standard operating protocols. Consolidation by the Internet can trigger a migration by consumers from several standalone and mutually exclusive networks. Instead of using a separate network for telephone calls, watching video programming and web browsing consumers increasingly can rely on a single, versatile

Internet available via several wired and wireless transmission technologies, each using the same Internet formats.

The term all-IP network refers to the ability of networks using the same standard formats to offer many different types of services that previously were available only via separate, single purpose networks. By consolidating the number of networks needed to deliver all forms of ICE, all IP-networks can reduce or eliminate the need to have separate networks for radio, television, cable television, telephone service, data and even other physical delivery systems used to reach consumers of print media such as newspapers and magazines.

Migration to an all IP-network will enhance the value of broadband Internet access for both network providers and consumers. Having digitized their networks and replaced many different operating standards for the single, now preferred Transmission Control Protocol/Internet Protocol combination, network operators can market Internet access as a single, preferred medium for any and all ICE services. Consumers can benefit when previously separate demand for content can be aggregated and delivered via a single, more versatile and convenient conduit.

5.2.3 Cloud Computing and Enterprise Networking

Even as carriers in developed and developing nations strive to extend broadband services to residential and small business users, the more sophisticated requirements of large business users also require accommodation. High volume users increasingly want telecommunications and Internet carriers to combine telecommunications and information technologies to offer customized services. Carriers now have the ability to provide managed networks using software to configure a temporary, "virtual" network designed to meet the specific requirements of one large volume broadband user.

A technique known as Multiprotocol Labeling Switching ("MPLS") enables carriers to insert routing instructions as labels that preclude the need to inspect packet headers and to look up the location of the source and destination of traffic. MPLS and other techniques work to make it possible for an entire corporate network, spanning many countries and continents, to operate much like a local area network which provides campus-wide Ethernet connections to many computers.

The integration of information and telecommunications technologies may have started at the multinational corporate level, but increasingly sophisticated individual users also have diversifying network requirements. With a broadband connection employees and sole proprietors have the means to maintain a Web presence 24 hours a day, 7 days a week. The line between work and leisure can become fuzzy when one can respond to work demand at home and at other off site, remote locations at any time. Additionally employees have a preference to use personal handsets and privately owned home computers to handle work-related requirements. It appears quite possible that high level ICT applications designed for corporate users may extend to employees as they work from home and other remote locales.

5.2.3.1 Reference Documents and Case Notes

An IP-Centric Ecosystem

The Internet's versatility and ease of use makes it plausible to suggest that it will operate as the primary medium for delivering most of the information, communications and entertainment service consumers want. Viewing the Internet as a single source for all forms of content promotes efficiency and scale, but risks the formation of very powerful ventures having significant control over the Internet marketplace. Competition need not be threatened, or eliminated simply because all network operators choose to use the same transmission, routing and switching protocols. However, reliance on a single medium for all types of content means that previously separate and stand alone networks may consolidate and converge into one massively large and powerful medium.

For background on an IP-centric network environment see:

Brian S. Mitchell, Drexel University, *The TCP/IP Data Communications Protocol*; available at: https://www.cs.drexel.edu/~bmitchel/course/mcs721/tcpip.pdf;

Nokia Siemens Networks, *Smart Connectivity A Vision of Tomorrow's Connected World* available at: http://www.nokiasiemensnetworks.com/sites/default/files/document/WPSmartConnectivityV1.pdf.

5.3 Basic Technologies for Broadband Connectivity

This section will provide a tutorial on the many different transmission technologies used to provide broadband services. Because wireless broadband technologies likely will become an increasingly significant option, this section will also provide an introduction to basic radio spectrum management. Additional background on spectrum management is available in the ICT Regulation Toolkit, Module 5, Section 2.2; available at: http://www.ictregulationtoolkit.org/en/Section.3513.html.

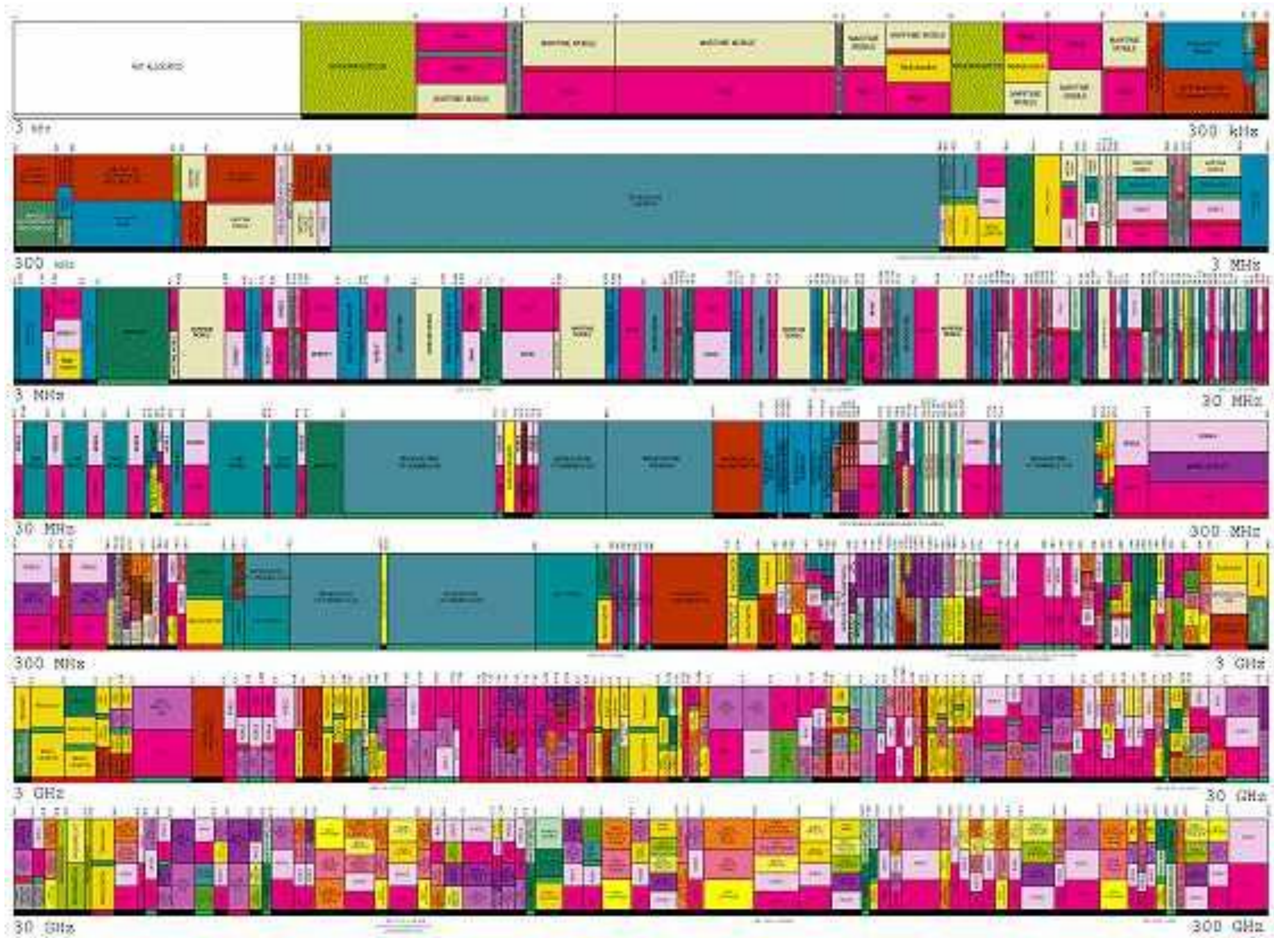
5.3.1 Spectrum Management

While key wire-based technologies operate using closed circuit copper or glass conduits, wireless broadband transmission technologies use radio spectrum, a shared resource with physical characteristics that require attention to the potential for excess demand and interfering uses. Typically governments manage the allocation and assignment of spectrum with an eye toward reducing the likelihood of both interfering use of the same frequency and insufficient capacity to meet current and future demand for specific services, such as wireless broadband.

Governments manage this shared public resource by acting as a "traffic cop of the airwaves" who determines what uses can be made for specific blocs of spectrum and who can use specifically assigned frequencies through licensing. These potentially intrusive management strategies originated when spectrum users had limited technological means to avoid causing interference to other users of the same frequency. Rather than risk the potential for harmful interference, governments typically identify a specific use for a range of frequencies and assign specific frequencies solely to one user. When multiple users receive authorization to use the same frequency from a National Regulatory Authority, the potential for interference is deemed minimal primarily based on the geographical separation of the licensed users.

This allocation of spectrum blocs by service and assignment by specific user has occurred in both intergovernmental forums such as the International Telecommunication Union ("ITU"), and unilaterally in specific national spectrum policies. For example, the ITU, a specialized agency of the United Nations, decided long ago which frequencies nations should use for commercial radio and television broadcasting. Individual governments have a sovereign right to determine whether to accept the global consensus on such spectrum allocations and how to assign usage rights. Generally nations implement the consensus spectrum allocations decisions made at the ITU, but they can vary the terms and conditions under which operators secure spectrum usage rights. Even as many nations support commercial use of broadcast spectrum by private operators some nations, including developed nations such as the United Kingdom, continue to have government entities as the sole national broadcaster, or as a subsidized alternative to commercial broadcasting.

Spectrum Allocations in Blocs



source: United States National Telecommunications and Information Administration, United States Frequency Allocation Chart (2011); available at: http://www.ntia.doc.gov/files/ntia/publications/spectrum_wall_chart_aug2011.pdf.

Wireless Broadband Spectrum Management

Wireless broadband operators need large amounts of spectrum so that they can provide very fast transmission of feature rich content, such as full motion video, to ever increasing numbers of subscribers with growing demand for service. Because all useable spectrum already has a specified use, governments can accommodate growing demand for wireless broadband spectrum only by reallocating blocks of spectrum with already specified uses. This means that existing or prospective users of spectrum authorized to use specific frequency bands, may lose that right, or face the need to share access, a process that requires coordination based on location of the spectrum use, or the implementation of techniques designed to support multiple, non-interfering use by two or more nearby operators.

High bandwidth requirements and rising demand for wireless broadband combine to support the use of radio spectrum at very high frequencies. These frequencies, measured in the billions of cycles per second, termed GigaHertz ("GHz"), only recently have become available as scientists invent ways use spectrum that increasingly has characteristics of visible light energy. Useable radio spectrum lies on a continuum with sound energy at the low end and infrared and light waves at the high end. Low radio frequencies have some characteristics like sound such as the ability to penetrate walls and other obstructions. Very high frequencies have some of the characteristics of light such as the ability to bounce off obstructions. Having only recently made allocations of the highest usable frequencies, governments can more easily accommodate the vast demand for wireless spectrum at these high frequencies in light of the possibility that at least some frequency bands have few current government and commercial users.

Very high spectrum also has transmission characteristics, known as propagation, which supports many broadband uses. For example, these frequencies, like light, lose power quickly and on a predictable and measureable basis. Wireless broadband operators can use the same frequencies at nearby locations without interference thereby making it possible to accommodate lots of simultaneous uses in the same region. This efficient frequency reuse can occur, because very high frequencies do not travel long distances, a characteristic much more likely to occur at lower frequencies. At lower frequencies signals with the same transmission power travel farther and thereby have the potential to interfere with more users operating on the same frequency over a larger expanse of terrain.

The likely growing demand for wireless broadband service can generate a shortage, unless governments respond by reallocating additional spectrum. Candidates for such reallocation generally represent underused spectrum that results from an initial overly generous allocation, or because usage patterns have changed. Spectrum reallocation decisions typically generate conflicts, because no incumbent user group will welcome the need to operate more efficiently, possibly having to satisfy all requirements with a net reduction in available spectrum capacity. Governmental spectrum users will invoke national security and cost concerns over any loss of available spectrum, while incumbent private users also will complain about incurring higher costs and inconvenience.

All spectrum has value, but that triggering the greatest demand logically also has the greatest value. Governments may try to extract some of this value by auctioning off the most desirable spectrum designated for the most attractive services that include wireless broadband. While some spectrum auctions have accrued limited returns, ones allocating mobile radiotelephone service and next generation broadband networks have generated up to several billions of dollars for national governments.

Spectrum Conservation

Because spectrum scarcity is all but inevitable for broadband applications, governments likely will try to reallocate additional spectrum by forcing some users to make do with less. This freeing up of spectrum can occur when new digital technologies make it possible for operators to:

send signals using less total bandwidth;

carry multiple calls and data sessions over the same channel;

compress signals so that content can travel using narrower channels;

increase the speed by which traffic reaches an end user; and

use new techniques that avoid causing interference even by users in close proximity using the same frequency.

The so-called Digital Dividend [13] provides an example of how digital transmission techniques make it possible to accommodate incumbent operators' bandwidth requirements using less total spectrum. When broadcast television operators convert from analog to digital transmission, governments typically can "refarm" portions of the frequency band allocated by reassigning all incumbent users into a smaller range of usable channels thereby freeing up spectrum for new uses. [14] Digital transmissions reduce the potential for harmful interference between the signals of two or more television broadcasters, because the signal weakens (attenuates) quickly after serving a predictable geographical area. Analog signals on the other hand degrade more slowly making it possible for signal reception and interference to occur over farther distances from the transmitter. By relocating all broadcasters onto more closely aligned channels governments can free up spectrum and reallocate it for wireless broadband use.

Spectrum conservation also can take place through the use of transmission formats that facilitate shared use by several simultaneous users of the same frequency channel. By using smart transmitters and receivers, equipped with digital signal processing technology, many nearby operators can identify unused spectrum and operate at very low power. Before transmitting, smart radios can identify actual existing users nearby, or consult a data base of known users.

Additionally governments can permit use of allocated, but sparsely used spectrum thereby permitting unlicensed uses in these geographically dispersed "white spaces." [15] NRAs typically allow white space use only if it does not cause interference with licensed operators, and other users having a higher access priority. Governments also can identify spectrum for shared use by unlicensed, low powered devices such as Wi-Fi routers that provide wireless access to broadband services. However excessive use of unlicensed spectrum leads to what economists call "the tragedy of the commons" [16] when no one can productively use a shared resource due to overuse that becomes apparent when users encounter congestion and interference.

Because governments cannot typically remedy all types of existing or anticipated spectrum scarcity, carriers have to employ many types of spectrum conservation techniques. Section 5.7.2 will identify many strategies used by wireless broadband carriers.

5.3.1.1 Reference Documents and Case Notes

Spectrum Management

Radio spectrum has different value based on the specific amount of bandwidth available, propagation characteristics, allocated uses and demand. For example, spectrum allocated for wireless mobile services such as cellular radio and broadband, can generate billions of dollars in a competitive auction. On the other hand some spectrum has little value, because of limited demand, or because a legislature or National Regulatory Authority has decided that the public should have access on a free and unlicensed basis as is the case for Wi-Fi spectrum. Spectrum scarcity occurs when demand exceeds supply and a government cannot quickly add to the inventory of available spectrum allocated for a specific use.

For background on the value of spectrum and its management see:

International Telecommunication Union, Telecommunications Development Sector, *Exploring the Value and Economic Valuation of Spectrum* (April, 2012); available at: http://www.itu.int/ITU-D/treg/broadband/ITU-BB-Reports_SpectrumValue.pdf;

United States Department of Commerce, National Telecommunications and Information Administration, *Some Basic Elements of Spectrum Management*; available at: http://www.ntia.doc.gov/book-page/basic-elements-spectrum-management;

The World Bank, InfoDev, ICT Regulation Toolkit, 1.1 Introduction to Spectrum Management Overview; available at: http://www.ictregulationtoolkit.org/en/Section.2656.html;

New America Foundation, *The Citizen's Guide to the Airwaves* (2003); available at: http://www.newamerica.net/files/airwaves.pdf;

New America Foundation, J.H. Snider, *The Cartoon Guide to Federal Spectrum Policy* (2005); available at: http://www.newamerica.net/files/archive/Pub_File_1555_1.pdf.

5.3.2 Fiber Optic

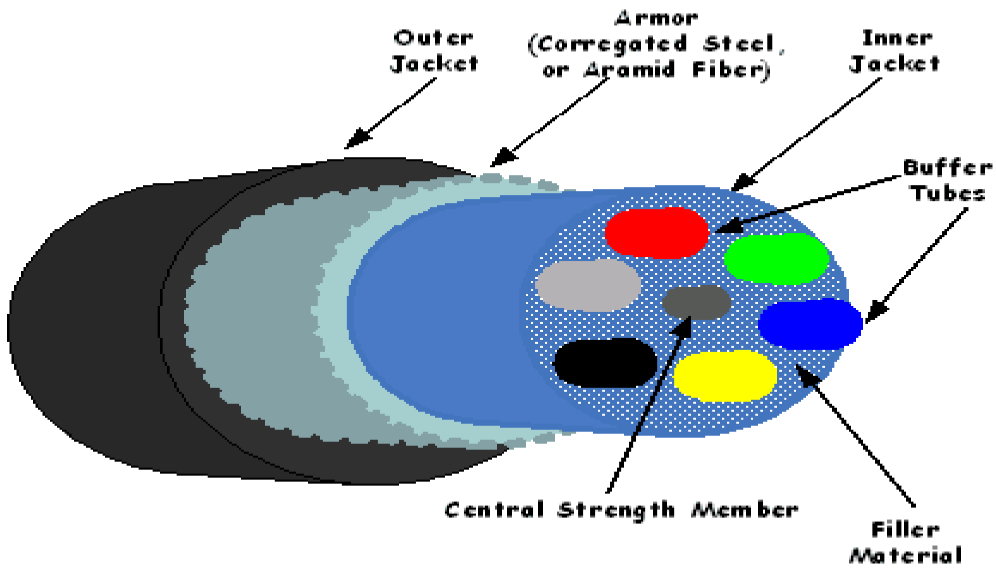
Increasingly widespread installation of flexible, fiber optic cables as thin as one strand of hair constitutes one of the major telecommunications transmission media for broadband networking. Glass strands coated ("doped") with trace amounts of rare earth elements such as erbium provide a medium that can guide extremely fast pulses of laser light beams across significant distances without the need for reamplification ("regeneration") of the signal. Very narrow, high frequency light energy can travel great distances, because this type signal can "refract" or bounce from one edge of a glass cable to the other without quickly degrading or weakening as happens when electrons travel through copper wires. While a copper medium generates friction and resistance to the conduction and transmission of electrons, the glass medium offers far less obstruction to the transmission of laser signals.

Carriers using fiber optic cables can transmit vast amounts of broadband traffic, not only because single strands have wideband capacity and fast transmission speeds, but also because many pairs of cable (for two-way, simultaneous upstream and downstream "duplex" traffic) can be bundled together and then encapsulated with plastic and metal cladding for structural support. Dense Wave Division Multiplexing makes it possible for multiple laser beam ("optical carrier") transmissions to take place via a single cable strand using different, non-interfering lightwave frequencies.

While the technology of fiber optic cable refraction and transmission involves complex science, the use of lasers in compact disk ("CD") and digital video disk ("DVD") players can provide insights on how the cables operate. If you were to examine the operation of CD and DVD players, you would see an apparently constant illuminating red or blue light, which you should examine only from a distance and at an angle. The light source actually turns on and off in very quick succession matching the on and off sequence of data transmissions which can be reduced to a series of ones and zeros. CD and DVD players use the laser beams to "read" the digital signal streams imbedded in the disk. The concept of different operating frequencies are represented by the red laser beam used by lower frequency and lower capacity CD and first generation DVD players, as well as the higher frequency and higher capacity "blue ray" laser frequency used by current generation DVD players.

The substantial capital expenditures required to install fiber optic cables support their use primarily for high capacity transmission projects often covering long distances. Operators seek to spread the cost to acquire rights of way and install wires within ductwork over a large pool of users. While the services provided via fiber optic cables may be priced on an average cost basis, the installation costs of such facilities are distance sensitive, i.e., the total cost increases incrementally as the length of the cable installment grows. However, once installed fiber optic cables provide great opportunities to scale up and increase overall transmission capacity simply by activating additional cable pairs, or by using multiple frequencies of light in each cable. Except for instances where operators cannot economically justify the cost of installing cables most long haul carriage of broadband traffic takes place via fiber optic facilities.

Fiber Optic Cable Elements



source: United States Dept. of Transportation, Highway Administration. Fundamentals of Telecommunications; available at: http://ops.fhwa.dot.gov/publications/telecomm_handbook/chapter2_01.htm.

5.3.2.1 Reference Documents and Case Notes

For a primer on how fiber optic cable operate see:

Matt Burns, Techcrunch.com, *A Clever Video Primer On Fiber Optic Cables*; available at: http://techcrunch.com/2011/06/22/a-clever-video-primer-on-fiber-optic-cables/;

Youtube videos; available at:
http://www.youtube.com/watch?v=llI8Mf_faVo; and
Tutor Vista, Optical Fibres; available at:http://www.youtube.com/watch?v=aqazAcE19vw;

Australian Broadcasting Corp., How Optical Fibre Works; available at: http://www.abc.net.au/news/2011-05-31/how-optical-fibre-works/2737088;

Fiber-to-the-Home Council, *Advantages of Optical Access*; available at: http://www.broadbandproperties.com/2007issues/feb07issues/ftthprimer_feb.pdf;

OECD , Fibre Access: Network Developments in the OECD Area", OECD Digital Economy Papers, No. 182, OECD Publishing (2011); available at: http://dx.doi.org/10.1787/5kg9sqzz9mlx-en.

For background on how Dense Wave Division Multiplexing works see:

Columbia University, High Performance Communication Networks (EC/TC), *Dense Wave Division Multiplexing*; available at: http://www.ee.columbia.edu/~bbathula/courses/HPCN/chap04_part-3.pdf;

Gerald P. Ryan, The Applied Technologies Group, *Dense Wavelength Division Multiplexing*; available at: https://aresu.dsi.cnrs.fr/IMG/pdf/dwdm_ciena.pdf;

Fiberoptic.com, DWDM - Dense Wavelength Division Multiplexing, *DWDM systems* available at: http://www.fiberoptic.com/adt_dwdm.htm.

Kansas City Gigabit Test and Demonstration Project

After inviting localities throughout the United States to submit proposals Google selected Kansas City, in the states of Missouri and Kansas to serve as the first site for the construction of a metropolitan wide broadband network operating at speeds in excess of 1 Gigabit per second ("Gbs"). Goggle hopes that this test and demonstration project will show how the private and public sector can partner to expedite widespread access to next generation networks capable of delivering service at bitrates well in excess of what the fastest networks currently can provide.

For background on the Google Fiber—Kansas City Gigabit Test and Demonstration Project see:

http://fiber.google.com/about/;

http://www.youtube.com/watch?v=6uZVqPuq81c;

Geek.com, How Google Fiber Will Work; available at: http://www.geek.com/articles/chips/how-google-fiber-will-work-20120726/

The Australian National Broadband Network

Determining that it should expedite the availability of affordable and ubiquitous broadband service, the Government of Australia has underwritten the development of a wholesale broadband network with the goal of serving every resident in the country. The venture will provide direct fiber connections to 93 percent of the population at speeds of up to 100 megabits per second ("Mbps") with the most remote residents served by terrestrial wireless and satellite technology providing bit transmission rates of up to 12 Mbps. The network will provide business with up to 1 Gbps downstream and 400 Mbps upstream service.

For background on Australia's National Broadband Network see:

NBN Co. World Wide Web site; available at: http://www.nbnco.com.au/;

Government of Australia, Department of Broadband, Digital Communications and the Digital Economy, National Broadband Network World Wide Web site; available at: http://www.dbcde.gov.au/broadband/national_broadband_network;

The Coalition's Plan for Fast Broadband and an Affordable NBN (April, 2013) (proposing modifications that will reduce the cost of the NBN); available at: http://www.malcolmturnbull.com.au/wp-content/uploads/2013/04/Broadband.pdf; Background Papers, available at: http://www.malcolmturnbull.com.au/wp-content/uploads/2013/04/Background.pdf;

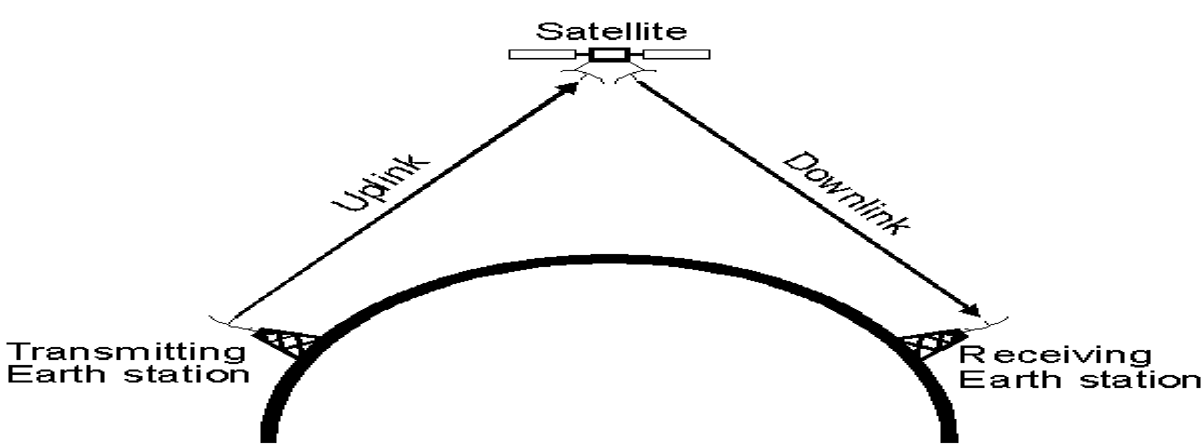
International Telecommunication Union, Case Study, *Toward Universal Broadband Access in Australia;* available at: http://www.itu.int/ITU-D/asp/CMS/Docs/Australia_broadband_case.pdf;

Carnegie Mellon Heinz College, Max Booker, ed., *An Analysis of the national Broadband Network* (April, 2012); available at: http://www.heinz.cmu.edu/download.aspx?id=3164.

5.3.3 Satellite

Satellites perform a vital role in the broadband ecosystem, particularly for nations located far from coastal connections to transoceanic fiber optic cables and major population centers served by them. From a vantage point located 22,300 miles above earth communications satellites can provide a signal relay service covering as much as one third of the earth's surface. By operating as a "bent pipe" satellites can receive "uplinked" signals from earth and relay ("downlink") them back down to locations within a large "footprint," or signal contour. Satellite technology has made a reality to something envisioned by science fiction author Sir Arthur C. Clarke. He predicted the use of an artificial satellite located at a specific orbital location where the speed of the satellite relative to the earth's orbital speed made the satellite appear motionless.

Communications Satellites Operate as "Bent Pipe"



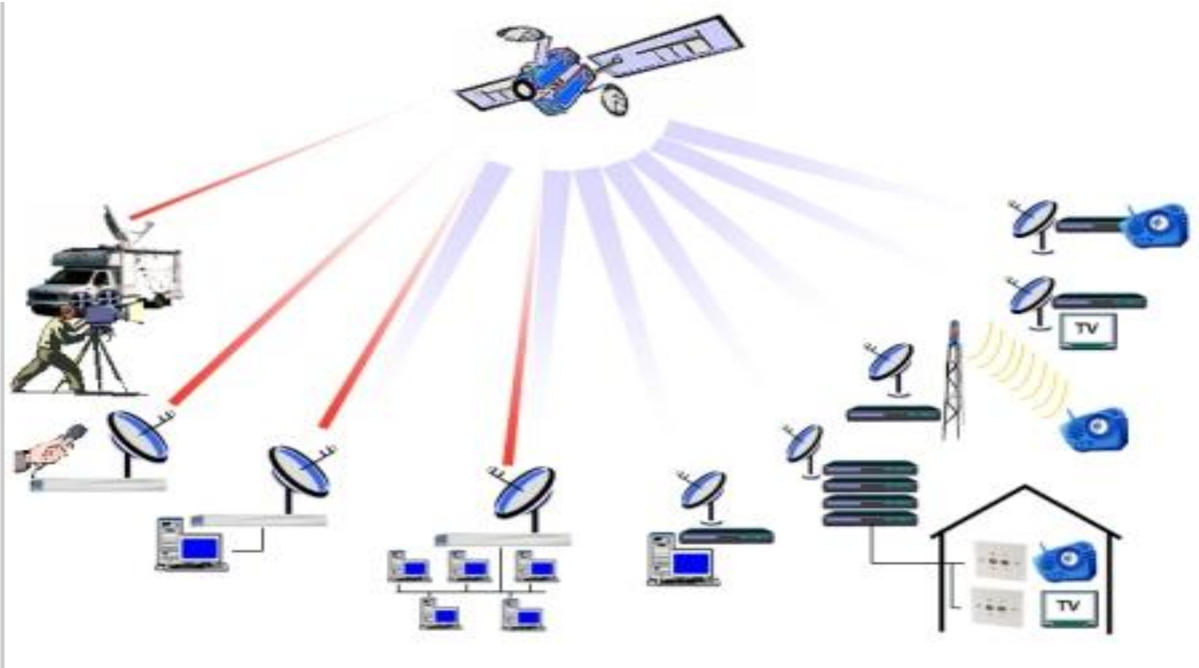
source: Viterbi Voices Blog site (July 18, 2012); available at: http://viterbivoices.usc.edu/emily/summer-at-boeing/.

These geostationary satellites are located in a narrow orbital arc where the earth's gravitation pull is offset by the centrifugal force created when the satellite was launched. Because communications satellites primarily are subject to the earth's gravitation pull, they are termed geosynchronous. Communications satellites also operate in a geostationary mode when their orbital speed matches that of the earth and the satellites operate above the equator. At this location satellites appear to hover, motionless thereby eliminating the need for receiving dish antennas on earth to track a moving target. Such earth station equipment costs less when they can "lock in" on a satellite operating in a single location.

Signal transmissions from satellites travel long distances and generate a large footprint on the surface of the earth. An unconcentrated satellite signal can cover as much as one-third of the earth's surface making it possible for a single source of content to reach many receivers located within the footprint. This point-to-multipoint capability makes satellites well suited for content delivery targeted for access by many simultaneous users, e.g., video and television relay, but the distance from earth results in some negative factors when used for Internet access by individuals and for point-to-point communications between two people as occurs in telephone calls. The time it takes to send and receive traffic from distant satellites results in comparatively more delay than what occurs using terrestrial options. Such latency can present problems for traffic that frequently switches between sender and receiver, videogames. Also without increasing signal strength by narrowing the size of the footprint, or using higher powered transmitters satellites require large earth station dish antennas and other equipment having significant bulk and expense[1].

Satellite Point-to-Multipoint Service

[1]There are technologies to address latency. See http://www.vsat-systems.com/Education/Satellite-Internet-Explained/Performance/Protocols-and-applications/

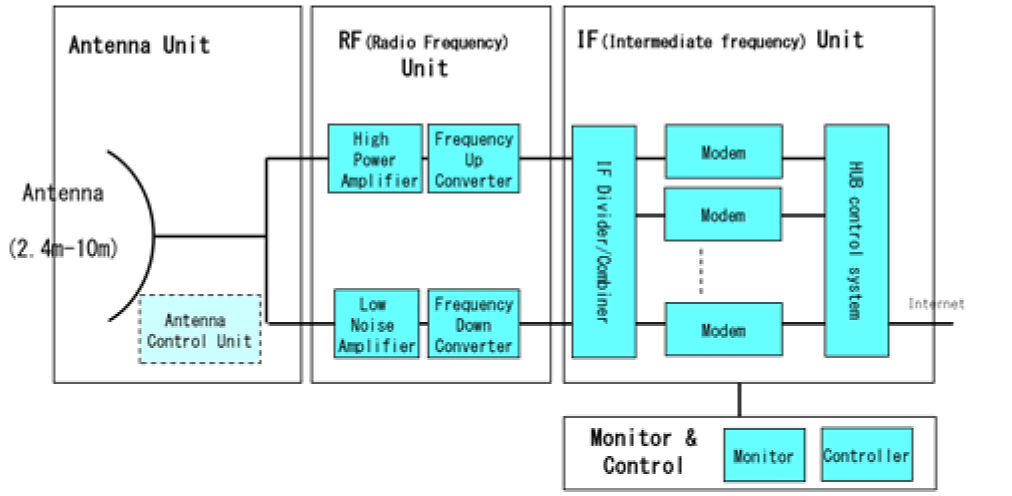


source: Deha Telekom, available at: http://www.deha.net.tr/satellite_vpn.html.

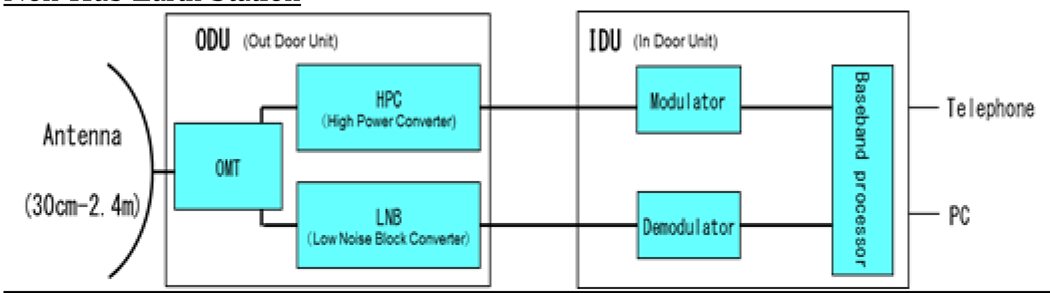
Despite their limitations, satellites perform a vital role in extending the geographical scope and reach of broadband access to areas where a business case does not support private venture investment in very high capacity fiber optic cable, or terrestrial wireless services. Satellites may provide the only viable, "gap-filling" broadband distribution technology to the most remote and least populated locations in the world. Additionally networks using many small, low cost satellite earth stations can serve users located in remote areas as well as places where the terrain makes terrestrial services comparatively more expensive, or infeasible, e.g., a chain of islands, and communities situated in remote desserts, mountaintops and valleys. Users in these remote areas can access broadband satellites using Very Small Aperture Antenna ("VSAT") earth stations operating as a geographically dispersed network. A star topology VSAT network combines a central hub earth station with many smaller terminals. A mesh network eliminates the need for a central hub. Another broadband network access option in remote areas combines the use of VSATs with a terrestrial network such as wi-fi or Wi-MAX.

Block Diagram of VSAT Hub and Other Earth Stations

HUB



Non-Hub Earth Station



Source: SKY Perfect JSAT Corporation

In light of ever-increasing consumer demand for high speed, high capacity broadband service, satellite operators have begun to launch satellites with much more available bandwidth optimized for data services. These High Throughput Satellites ("HTS") have greater size and overall transmission power than previous satellite generations. They also use many small and steerable, "spot beam" transmitting antennas that can concentrate signals to cover a smaller portion of earth thereby making it possible to use receiving dishes with a diameter of 1-3 meters.

Satellites have significant disadvantages compared to fiber optic cables rendering them a more expensive option for point-to-point broadband transmission services. Satellites only can offer a fixed amount of bandwidth while a few fiber optic cable pairs can transmit the total capacity of all available communications satellites. Satellites have a usable life of about fifteen years and cannot easily be repaired should a malfunction occur. On average one out of every ten communications satellite launches fails and a single satellite typically costs $300 million or more to construct, insure, launch and track. Additionally the large distance between satellites and users results in longer transmission time (latency) than what it takes to send and receive via a terrestrial network. For two way traffic, such as voice and some kinds of Internet traffic that involve frequent changes in who transmits and who receives, such latency can present a problem.

Despite these cost disadvantages, satellites offer comparatively greater cost savings for point-to-multipoint applications, such a video content distribution, because activating an additional receiving point within the satellite footprint has low costs, primarily the installation of a relatively inexpensive receiving antenna and associated electronics.

Basic Technical Elements of Satellites

Satellites provide a broadband signal relay function requiring them to have onboard all the electronics needed to receive content and resend it back to earth. The receiver/transmitter ("transceiver") function requires radios, tuned to satellite frequencies—typically at the very high GigaHertz ("GHz") range—and capable of both receiving and transmitting content. To power these radios, satellites need a constant source of electrical power. The primary source comes from solar energy collected by panels that cover much of the satellite's exterior. However, because the moon occasionally blocks access to solar energy in an eclipse, satellites also must have rechargeable batteries onboard.

Satellites operate in a number of extremely high frequency bands for two primary reasons. Because of the distance between earth-based users and satellites (ranging from a few hundred to 22,300 miles) transmissions must use very narrow signals to achieve a direct line of sight link to a tiny, distant target. For downlinking from the satellite even a very narrow beam expands as the signal travels down toward earth. Extremely high frequencies transmit with very narrow amplitude and therefore have the desired propagational characteristics. Also satellites require substantial blocs of radio spectrum. National Regulatory Authorities could identify new previously unused extremely high frequency bands for which satellites could make the first practical use.

Multinational and national spectrum managers use alphabetical letters to identify the frequency bands allocated for satellite use. The C-band and Ku-band represent the major frequency band used by most communications satellites, with the later used Ka-band offering more spectrum for data and broadband service. Satellite frequency bands typically have different allocations for spectrum used to "up-link" to a satellite and for spectrum used to "down-link" from the satellite. Generally the uplinking bands operate at higher frequencies than the downlinking bands. For example the C-band uplinking frequencies range from 5.925 GHz to 6.425 GHz with the downlinking frequencies at 3.7 to 4.2 GHz.

The lettered satellite spectrum also identifies frequency bands that support different types of service, in part based on signal propagation characteristics. The L-band offers spectrum at the lowest frequencies now used by satellites. These lower frequencies make it possible to for consumers to use very small, lightweight handsets to communicate with satellites. Satellites operating in low earth orbit ("LEO"), only a few hundred miles above earth, can receive comparatively weaker signals than ones operating in geostationary orbit 22, 300 miles above earth. Mobile satellite service ventures, such as Iridium and Globalstar operate in the L-band. Other L-band services include satellites used primarily for maritime, aeronautical and mobile applications like that offered by Inmarsat. Additionally global positioning satellite ("GPS") services operate in the L-band. These satellites operate in Middle Earth Orbit ("MEO"), about

12,500 miles above earth, and transmit with at high power making it possible for mobile handset manufacturers to install a very small module capable of receiving GPS signals.

The S-band and X-band generally provide spectrum for government satellites including frequencies used for defense, intelligence and some remote sensing applications. S-Band is also used for satellite phone and TV broadcasting in some countries.

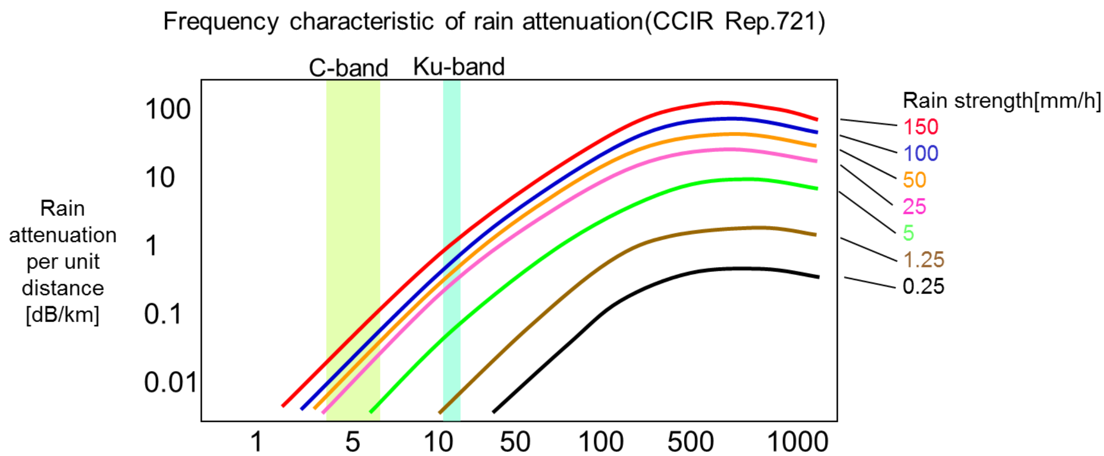
The Ka-band provides and increasingly used frequency band for the latest generation of communications satellites, particularly ones providing broadband access such as High Throughput Satellites. At Ka-band frequencies (17.3-30 GHz) satellite operates need to consider the potential for rain, fog and smog to weaken and interfere with signals. Ka-band satellite operators can increase the transmission signal strength. Alternatively some Ka-band operators, e.g., o3B, use MEO orbiting satellites that can combine high transmission power with shorter distances to earth to ensure reliable service.

Satellite Frequencies

Band	Frequency	Wave length	Available Bandwidth	Rain Attenu ation	Example satellite	Size of Earth station	Information Rate	Application
L	1.215GHz - 1.71GHz	Long	Narrow	Small	GPS,INMARSAT	Small	Small	GPS, Inmarsat telephone
S	1.71GHz - 2.7GHz				MTSAT, MBSAT, JCSAT	Small	Small	Mobile satellite phone
C	3.4GHz - 7.075GHz				INTELSAT, JCSAT	Large	Large	Broadcasting VSAT Mobile backhaul
X	7.075GHz - 8.5GHz					Large	Large	Military
Ku	10.6GHz - 15.7GHz				INTELSAT, JCSAT	Middle	Large	Broadcasting VSAT Mobile backhaul
Ka	17.3GHz - 30.0GHz	Short	Wide	Large	Superbird, WINDS	Small	Large	VSAT

Source: SKY Perfect JSAT Corporation

Potential for Signal Attenuation From Rain



Source: SKY Perfect JSAT Corporation

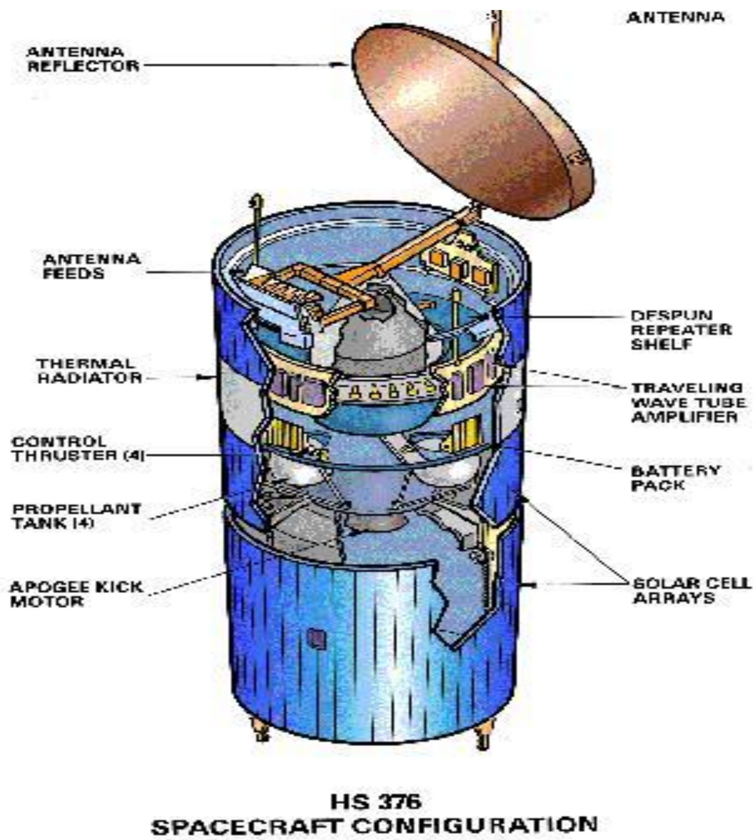
The frequency range of transceivers is limited by the amount of total weight the satellite can support. Typically satellites have several hundred MegaHertz ("MHz") of bandwidth which is measured in terms of transponders each having about 36 MHz of capacity. Satellites double their transponder capacity through the process of polarizing signals, in the same manner as coated sunglasses block certain solar frequencies while allowing other frequencies through. Satellite receivers and transmitters are able to use signals polarized horizontally and vertically using the same frequency without significant interference.

Operating at such a great distance from earth, satellites need to amplify both received and transmitted signals. A two step process provides the necessary amplification ("gain"). First satellites use parabolic antennas that collect received signals from all angles of the curved circular surface. Similarly they aggregate transmitted signals across the same surface when transmitted back to earth. The collection and aggregation of signal strength provides a natural, non-electronic amplification in much the same way as ears and eyes collect and concentrate sound and light respectively. Satellites collect both received and transmitted signals at a single focal point known as the feed horn. Additional signal amplification takes place electronically in both receivers and transmitters.

Satellites also need systems to manage the steep variation in temperature caused by direct exposure to the sun and the absence of such exposure. Heat sinks are used to draw away heat and reduce the temperature of sensitive electronic components. Satellites also need onboard ways to keep the satellite in its proper orbit ("on station") and properly pointed down toward earth (proper "azimuth setting)." To achieve ongoing stability, including the elimination of vibration to antennas and other sensitive components, satellites use internal motors or gyroscopes that spin internally, or at external locations lacking proximity to sensitive components. So called spin-stabilized satellites combine internal gyroscopes and exterior spinning to achieve stabilization. One way to visualize this process is to examine washing machines that have an interior basin that spins at high speeds to draw away water from cleaned clothing in what is commonly called the spin cycle. As the interior basin spins the exterior vibrates less. For spin stabilized satellites the external spinning and interior gyroscope spinning makes it possible for other parts of the satellite to operate without vibration and instability.

source: Samsung; available at: http://www.samsung.com/latin_en/consumer/home-appliances/washers-dryers/washing-machine/WA11V5WDP/XAP.

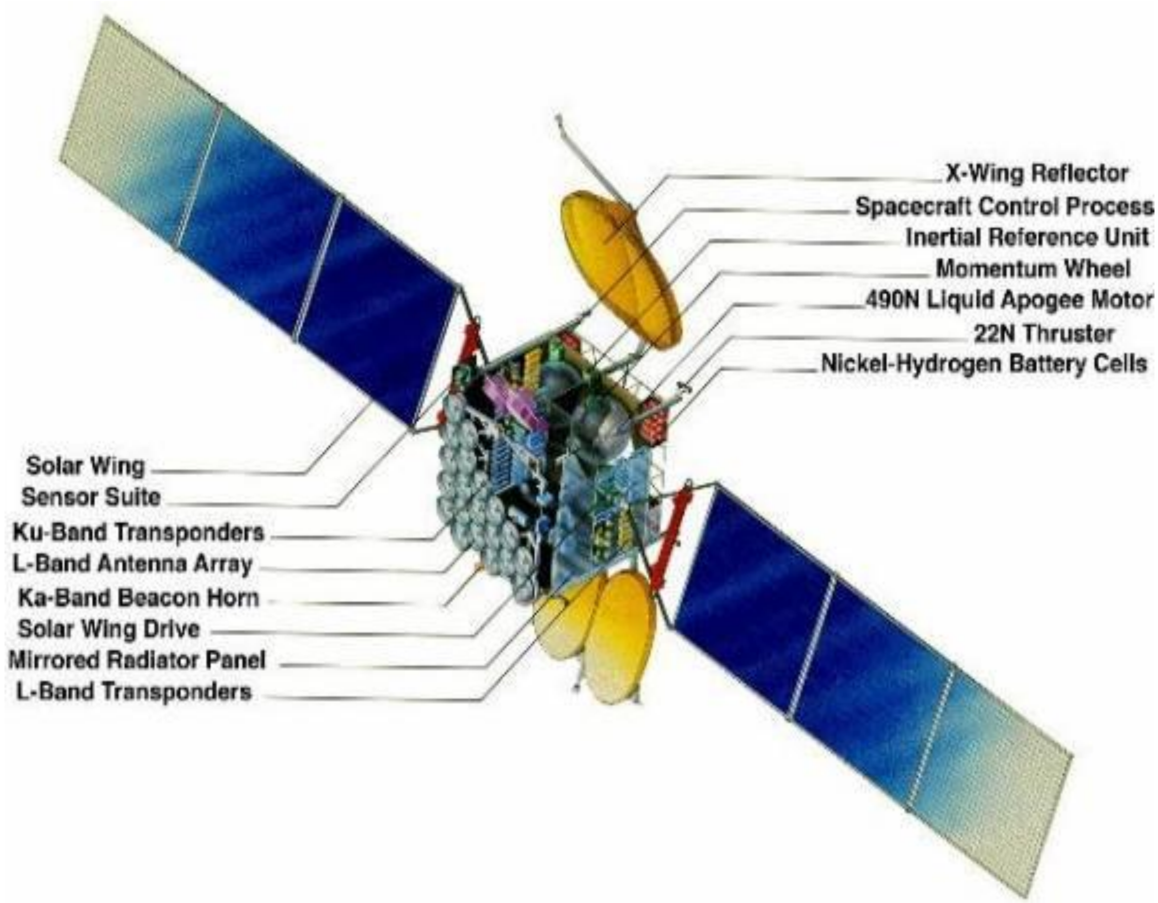
Spin-stabilized Satellite



source: Astronautix.com; available at: http://www.astronautix.com/craft/hs376.htm

The now dominant satellite design uses long wings and an interior spinning motor to control the three major axis of flight: yawl, pitch and roll. Satellites of this type are termed three-axis stabilized. Satellite carriers prefer this design, because it can provide more bandwidth using a much larger payload than spin stabilized spacecraft.

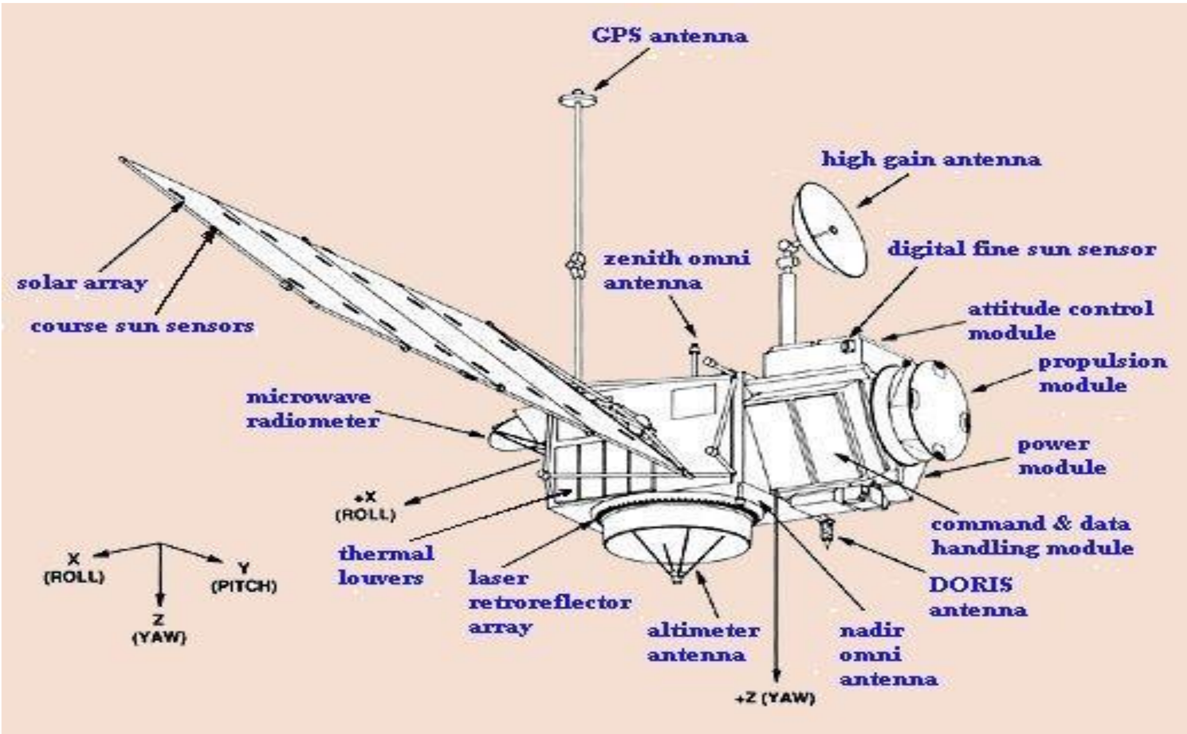
Three-axis Stabilized Satellite



source: Astronautix.com; available at: http://www.astronautix.com/craft/hs376.htm
available at: http://www.astronautix.com/craft/hs601.htm

Satellites also need the ability to rise to geostationary orbit from a lower, temporary position reached by using large capacity thrusters attached to the rocket launcher. Satellites also may have to change orbital parking places ("slots") and to make minor adjustments in their location and earth pointing orientation or attitude. Small thrusters located on the satellite provide short bursts of propulsion to place and return a satellite to its proper location and orientation relative to earth. Most satellites use a gas fuel known as hydrazine to control their position or attitude. Because satellites have only a fixed amount of fuel on board, often station keeping is the first operational element of a satellite to fail. Such satellites tend to wobble in orbit and can continue to provide service, albeit less reliable. New generations of satellites will use electric propulsion instead of gas power thereby reducing their weight and extending useable life. Satellites also have on board processors to receive and respond to instructions issued from earth and to send down information about their current health and operating conditions ("telemetry").

Satellite Components



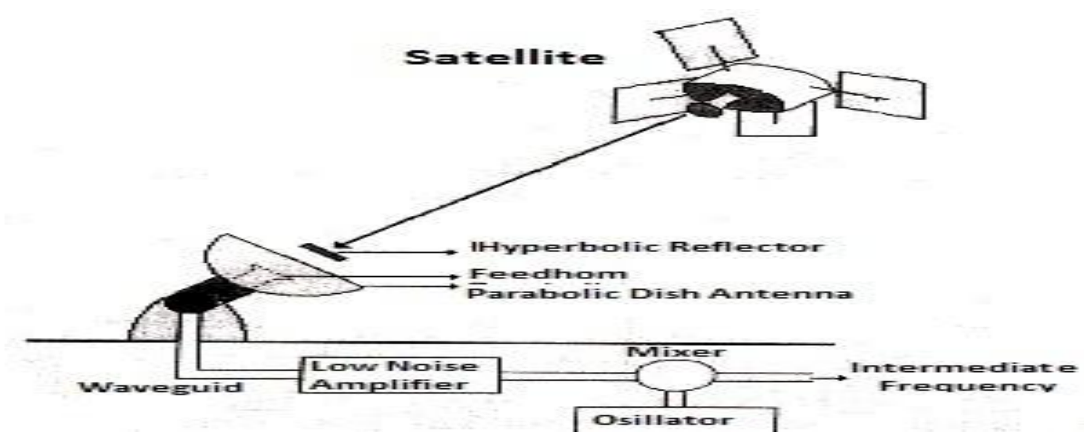
source: University of Texas, TOPEX/Poseidon; available at: http://www.tsgc.utexas.edu/spacecraft/topex/compo.html.

Basic Technical Elements of Satellite Receivers

Satellite receivers ("earth stations") combine many of the same elements contained in satellites to process and convert signals into useable content. Outdoors a parabolic antenna ("dish") must have an unobstructed "line of sight" to the desired satellite downlink transmission. Most communications satellites hover 22,300 miles above the equator so earth stations located north must point south and earth stations south of the equator must point north. Dish antennas located close to the equator have a more advantageous "look angle" toward the satellite, because the signal from the satellite will traverse less of the earth's atmosphere, as it points upward at a more direct angle. Likewise the dish can avoid more obstructions, because it can be pointed well above the horizon pointing upward instead of across the horizon. A satellite antenna located on the equator would point straight upward while dishes near the north and south pole have to point only a few degrees above the horizon.

In the immediate vicinity of the antenna satellite earth stations have electronic components that process and amplify the weak signal that has traversed 22,300 miles and been concentrated at the feed horn located above the center of the parabola. The GigaHertz frequencies used to transmit content are converted to lower frequencies so that cheaper and more effective amplification can take place. A device known as a block converter/low noise amplifier performs the frequency conversion and amplification process. The signal subsequently travels via a closed circuit low loss wire and is attached to the antenna terminal of a receiver. Inside the receiver the signal may undergo additional frequency conversions and filtering. Additionally the desired content is detached from the radio frequency carrier, a process known as demodulation. The now stripped off content is delivered to a proper device for consumption, e.g., a computer terminal, radio receiver, or television set.

Satellite Receiver Components



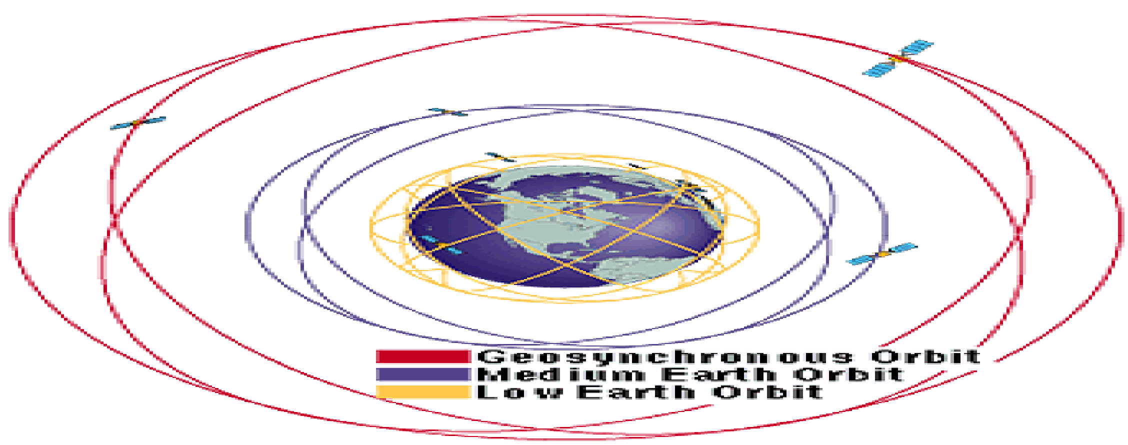
source: DAE Notes; available at: http://www.daenotes.com/electronics/communication-system/satellite-communication#axzz2Gdng89bH.

Satellite Orbits and Footprints

Satellites operate in several orbital locations, based on their function and target audience. as does the size of the transmission contour ("footprint") received on earth. For maximum coverage and connectivity communications satellites operate in the geostationary orbital arc and use unconcentrated "global beams." By concentrating the downlink beam size, satellite operators can increase the strength of the received signal available in a smaller geographical area. Satellites operating in geostationary orbit typically have global beams for maximum coverage, plus concentrated beams, having a smaller footprint, but making it possible for users within the smaller coverage area to install smaller receiving antennas. As a satellite footprint decreases in size the strength of the received signal increases making it possible to use smaller antennas. Concentrated footprints of geostationary satellites can cover an entire hemisphere, with about half the coverage as a global beam, a zone within one hemisphere, with about one quarter the coverage of a global beam, or as small a coverage area as a single metropolitan area (a "spot beam"). Geostationary orbiting satellites can more readily provide broadband services using spot beams, because the higher signal strength supports the needed wideband link and users can transmit and receive content using the smallest possible earth stations.

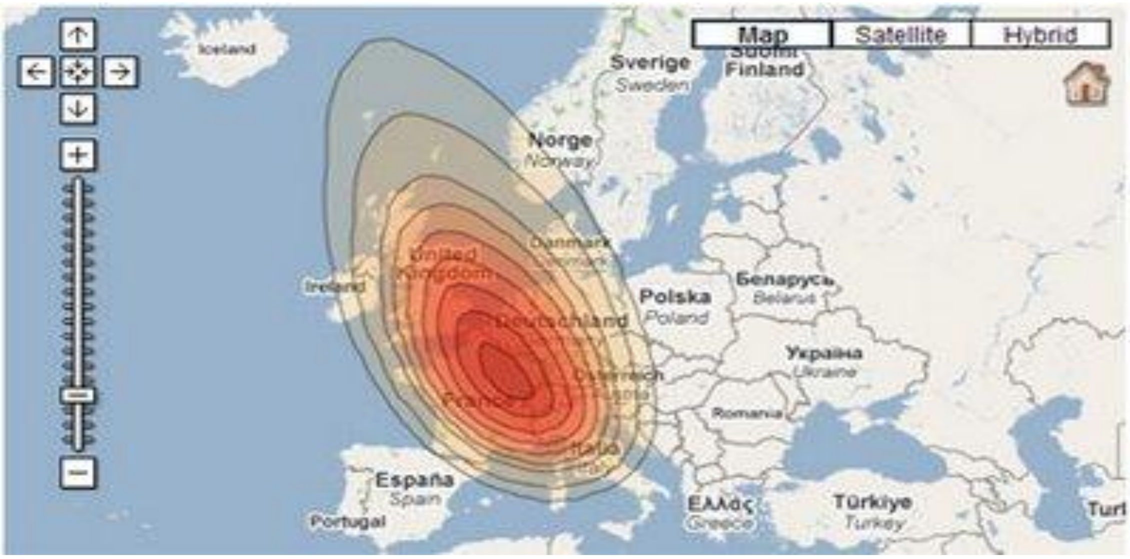
Satellites operating in orbits closer to earth are better equipped to provide broadband services, because of the lower signal delay and the ability to generate adequate signals for use by small, even handheld devices. Satellites located closer to earth than 22,300 miles lose their geostationary orbital status. This means that they become moving targets orbiting in known locations that must be tracked and monitored from earth. Several existing and planned broadband satellite venture have designed a network using satellites in middle earth orbit ("MEO"), a location where satellites can still operate without the risk of being pulled back to earth by gravity. MEO broadband networks require more operating satellites, because the closer proximity to earth reduces the footprint size. However this closer location makes it possible for subscribers to communicate with these satellites using small, lightweight devices.

Three Major Types of Satellite Earth Orbits



source: U.S. Army Information Systems Engineering Command, Automated Information Systems (AIS) Design Guidance Long-Haul Transmission Systems; available at: http://www.fas.org/spp/military/docops/army/lhaul/Lhfinweb.htm

Satellite Footprint Map

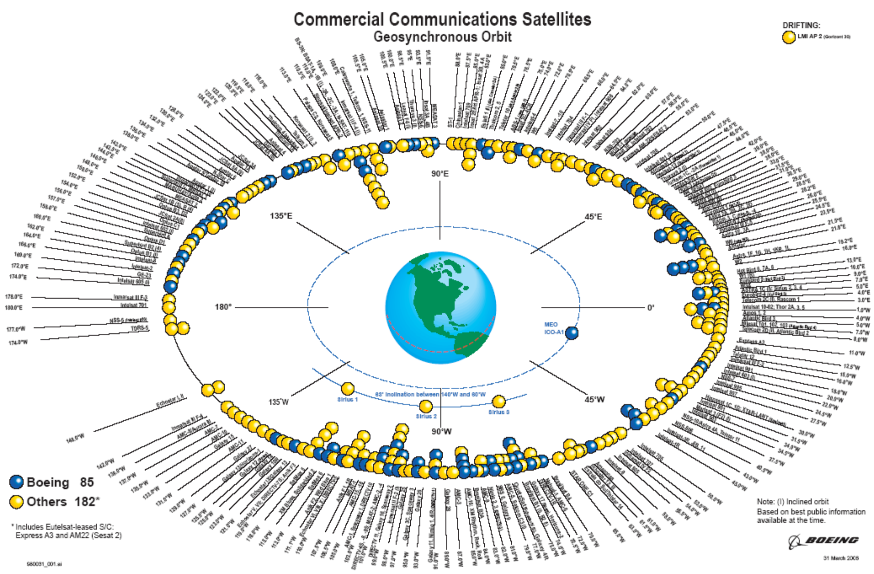


source: Google Maps Mania, Satellite Coverage Map; available at: http://googlemapsmania.blogspot.com/2008/07/satellite-coverage-map.html.

Coordinating Satellite Use

Because of the potential for interference and the duty to share scarce resources, nations using satellites must coordinate their use of both satellite orbital locations and frequencies. The International Telecommunications Union ("ITU") provides a multinational forum for conflict avoidance through the process of registering future uses and conflict resolution by providing a forum for parties to negotiate ways to avoid actual or anticipated interference. Invariably conflicts will occur, because only a relatively small number of satellites can share the geostationary orbital arc and demand for satellite services continues to grow.

Nations generally coordinate the use of satellite orbital slots through an ITU notification process that favors the first filed registration. This process may create incentives for prospective satellite operators to register uses prematurely and to increase the anticipated number of orbital slots required. The ITU has sought to reduce such "paper satellite" registrations and to impose deadlines for operators to launch and operate a satellite.



http://www.boeing.com/defense-space/space/bss/launch/980031_001.pdf

5.3.3.1 Reference Documents and Case Notes

For a primer on how satellites work see:

- Boeing, Corp. *What Is A Satellite?* available at: http://www.boeing.com/defense-space/space/bss/about/What_is_a_Satellite_2006.pdf;
- Bruce A. Henoch, *Satellite Technology Basics*; available at: http://www.sia.org/Stratos-Henoch-SatelliteBasicsIWCE2007.pdf;
- INTELSAT, *A Practical Introductory Guide on Using Satellite Technology for Communications* (2010); available at: http://www.intelsat.com/wp-content/uploads/2013/01/5941-SatellitePrimer-2010.pdf.

For background on the satellite industry and its market segments see:

- *State of the Satellite Industry*; available at: http://www.sia.org/wp-content/uploads/2012/05/FINAL-2012-State-of-Satellite-Industry-Report-20120522.pdf.

Geostationary Orbiting Satellites

International Telecommunications Satellite Organization

INTELSAT was established by national governments in 1965 to operate the world's first global communications system. The organization first operated as a cooperative, but later privatized into a commercial venture. INTELSAT operates geostationary orbiting satellites, including ones 22,300 miles above the equator in slots located between continents to maximize geographical coverage and connectivity. For background on INTELSAT see: http://www.intelsat.com/.

International Maritime Organization

Inmarsat was organized in 1979 to provide service to maritime users. This organization operated as a cooperative using spectrum allocated specifically for maritime applications. Nations participating in Inmarsat subsequently amended the treaty level management document to authorize the organization to serve aviation ("aeronautical") and land-based users. Inmarsat subsequently privatized and now provides broadband services via geostationary satellites. For background on Inmarsat see: http://www.inmarsat.com/index.htm.

Middle Earth Orbiting Satellites

O3b

O3b proposes to use Medium Earth Orbit ("MEO") satellites, located approximately 8,000km away from Earth to provide voice and data service primarily to users in lesser developed nations situated near the Equator. The network will use Ka frequencies (20-30 GHz) in an orbital constellation that emphasizes service to users located 45 degrees north and south of the Equator. The venture's name refers to the other three billion people on earth who lack access to advanced telecommunications services due to geography, political instability and economics.

For background on the o3b network see:

- http://www.o3bnetworks.com/; and
- http://www.sspi.com.br/portal/images/stories/pdfs/spectrumday2010/spectrum-day-2010-o3b.pdf.

Low Earth Orbiting Satellites

Iridium

The Iridium satellite networks uses 66 low earth orbiting satellites to provide voice and data service primarily to users in locations where reliable terrestrial service does not exist. Because the Iridium satellites operate close to earth their footprints are small thereby requiring a larger number in the constellation of satellites to provide global coverage. Iridium satellites are interconnected and cross-linked so they can communicate with nearby satellites in adjacent orbits. For background on the Iridium network see: http://www.iridium.com/About/IridiumGlobalNetwork/SatelliteConstellation.aspx.

Using Satellites for Broadband Service

While satellites lack the capacity of terrestrial networks such as fiber optic cables, their large geographical coverage makes it possible to provide broadband service to users in many widely dispersed locations that may never qualify for terrestrial broadband network service. Recently launched satellites in the Ka-band (20-30 GHz) offer high power and large bandwidth making it possible for offer broadband service at speeds exceeding 10 megabits per second.

For background on satellite broadband services see: International Telecommunications Union, Telecommunications Development Sector, *Regulation of Global broadband Satellite Communications* (April 2012); available at:http://www.itu.int/ITU-D/treg/broadband/ITU-BB-Reports_RegulationBroadbandSatellite.pdf.

For background on High Throughput Satellite ("HTS") see:

- Steve Schuster, *High Throughput Satellites Benefit Military and Medicine*, Via Satellite magazine web site (May 24, 2013); available at: http://www.satellitetoday.com/publications/st/feature/2013/05/24/high-throughput-satellites-benefit-military-and-medicine/;
- Intelsat General Corp., *Defining High Throughput Satellites (HTS)* (March 26, 2013); available at: http://www.intelsatgeneral.com/blog/defining-high-throughput-satellites-hts;
- Harris Caprock: http://www.kafactcheck.com/hts.php;
- Via-Sat web site: http://www.viasat.com/;
- iDirect site: http://www.idirect.net/; and http://www.digital-brochure.org/idirectX7/
- HNS site HN and HX system description: http://www.hughes.com/technologies/satellite-systems
- Gilat SkyEdge system description: http://www.gilat.com/SkyEdge-II

Satellite Industry Reports and Forecasts

For a comprehensive report and forecast on the commercial satellite industry, see United States Federal Aviation Administration, 2012 COMMERCIAL SPACE TRANSPORTATION FORECASTS (May, 2012); available at: http://www.faa.gov/about/office_org/headquarters_offices/ast/media/2012_Forecasts.pdf.

For a complete list of satellites and their transmission footprint, see http://www.satbeams.com/footprints

5.3.4 Microwave

Microwave technology offers low cost solutions to broadband requirements mostly for non-residential applications. For many decades it provides point-to-point analog services using very high frequencies [17] that can provide first and last kilometer services for local and long distance telephone companies, as well as business users. Microwave radio offers long haul transmission using a chain of repeater transmitters, each transmitting over a distance of up to 50 kilometers.

Microwave transmissions have proved quite reliable and cost effective service, largely because ample spectrum makes it possible to transmit a large volume of traffic over such networks. Operators can achieve efficient scale which makes it possible to spread the costs of constructing towers and installing the necessary electronics over a large user base.

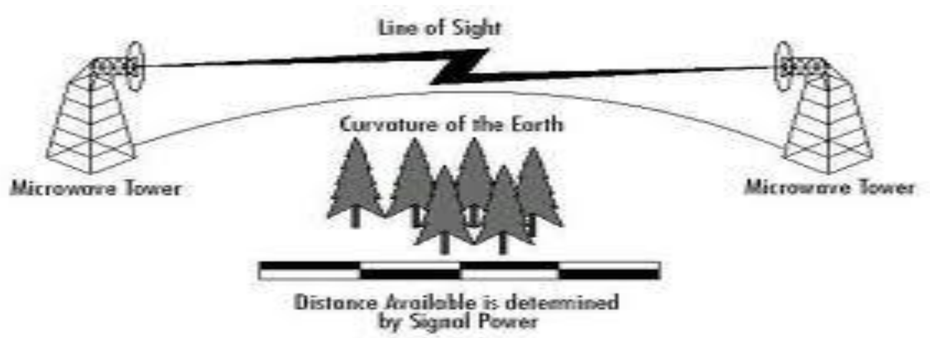
While microwave frequencies operate in bands that favor line of sight, directional transmissions, they also can provide point-to-multipoint services spanning an entire contour of 360 degrees. Recent examples of such "omni-directional" service include wireless fidelity ("Wi-Fi") that provides short range broadband access to multiple portable devices and Worldwide Interoperability for Microwave Access ("WiMAX") service offering broadband access with signal contours extending out for up to 15-20 kilometers.

Microwave radio networks use parabolic antennas, much like that installed for satellite communications. However the antennas are pointed across the horizon in the direction of a transmitting antenna located on a tower or rooftop installation some distance away. Like satellite communications microwave radio transmitters need an unobstructed "line of sight" link to the next transmitting antenna in a network chain. Microwave networks contain a relatively simple combination of receivers and transmitters typically located at high vantage points to avoid obstruction by buildings and terrain. Transmitters contain a number of subsystems that include multiplexing, the combining of many different channels of traffic, encoding and modulating signals, alignment of traffic onto the proper transmitting frequency, signal amplification and filtering for spectrum control. Receiver functions include filtering, down-conversion of frequencies for easier processing and amplification, demodulation, decoding, and demultiplexing.

Microwave radio can provide a cost-effective, land-based solution particularly for terrain not favoring inexpensive underground ductwork installations, e.g., swampy, rocky and sandy locations. Similarly microwave radio can operate in urban locales, including the central business district, where tall buildings provide an ideal vantage point for line of sight transmission and reception above all obstructions. Because microwave networks do not require the installation of below ground ducts, or closely spaced above ground poles, installation can occur on a relatively short timetable. Placing transmitting and receiving antennas at high vantage points also prevents most service disruptions, like that caused by cuts in wires.

On the other hand microwave network operators need to coordinate their use with other operators to avoid congestion and interference, especially in urban locales. Additionally some equipment, located in remote and hard to reach places, will need maintenance and a source of electric power that may not be generally available in the area. Operators also need to consider propagation factors including the potential for rain and snow to cause signal fading and weakening.

Microwave Point-to-Point Communications



source: TEMS Investigation, Wireless Networking, Part Five; available at: http://pathloss40.blogspot.com/2010/11/wireless-networking-part-5.html

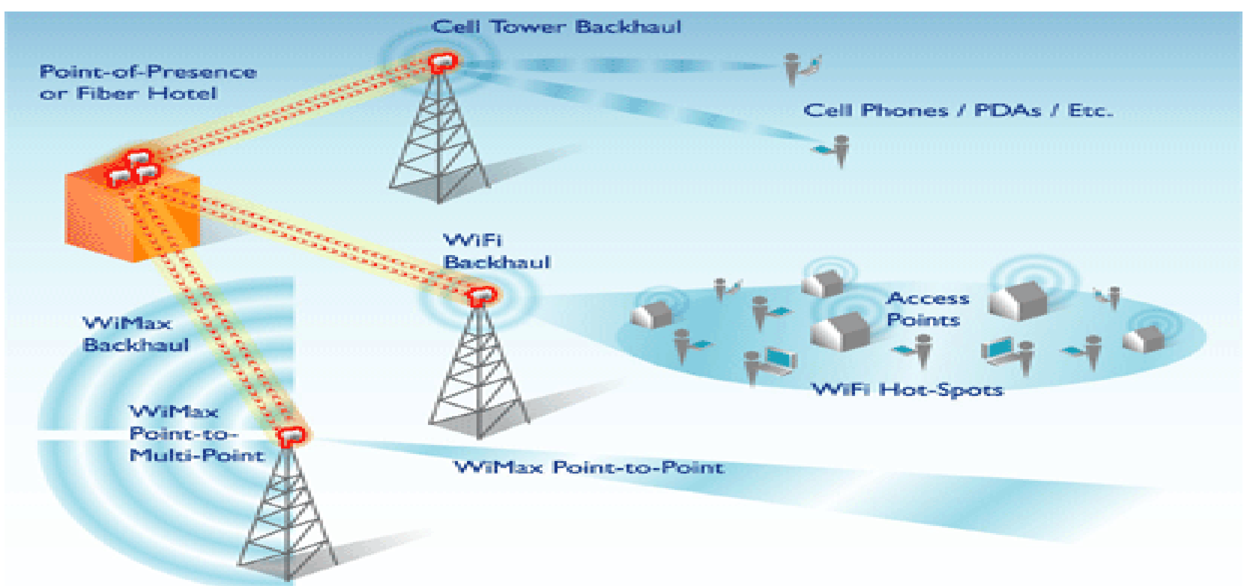
Microwave Backhaul and Middle Mile Services

Microwave radio networks can provide long, medium and short haul carriage of broadband traffic. Long haul applications typically substitute for fiber optic and copper based networks, because hostile terrain conditions necessitate wireless tower-based operation instead of transmissions underground, or via closely spaced poles. Short haul carriage includes the first and last kilometer access to private networks, such as a dedicated network for retailers, banks and other financial service providers, manufacturers, etc. Recently some stock market traders have installed dedicated, private microwave networks, because they can provide slightly faster opportunities (lower "latency") to receive the latest share price information and to execute trades.

For medium distances microwave radio networks provide essential links between facilities of users and network operators. So-called middle mile services provide a link between the geographically separate factories and other installations of users within a region. A single business venture may have the need to link many different factories, office building, warehouses, and campuses within a region. Each facility can communicate with all others via the short haul first and last kilometer microwave radio facilities interconnected with other microwave facilities designed to transmit at farther distances.

Microwave radio also provides essential "backhaul" functions for networks including satellite and terrestrial wireless networks. Many traffic receiving facilities are situated in remote locales that must be interconnected with network management facilities typically located at a central point, often in a city or suburb. Microwave backhaul networks receive and deliver traffic originating at remote tower sites like those providing cellular radio telephone service. The towers that provide service to cellphones and smartphone also contain parabolic antennas to send voice and broadband data traffic to a central facility, commonly referred to as the Mobile Telephone Switching Office ("MTSO") for onward delivery to other networks, including the Internet "cloud."

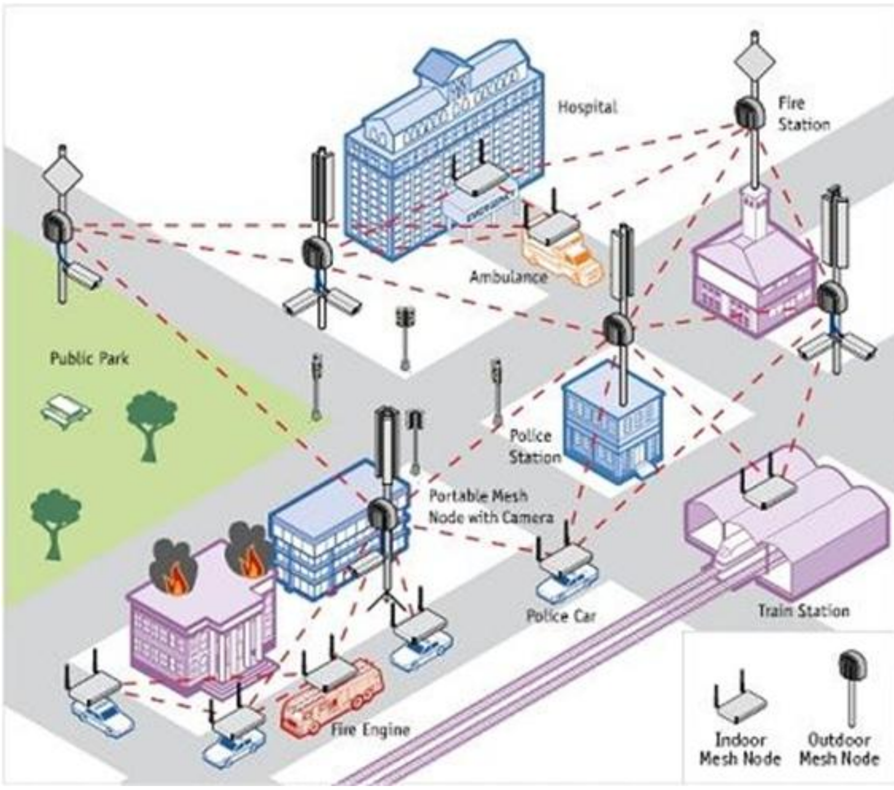
Wireless Backhaul



source: New Tech Observer, Wireless Backhaul Technology Improves by Ten Fold (April 9, 2012); available

at: http://www.newtechobserver.com/2012/04/wireless-backhaul-technology-improves.html.

Middle Mile Routing



source: Mobile Backhaul Blog site, Wireless backhaul technologies (April 9, 2012); available at: http://mobilebackhaul.blog.com/2012/09/04/new-generation-of-mobile-backhaul-technology-rising/

5.3.4.1 Reference Documents and Case Notes

For background on microwave backhaul see:

http://digital.olivesoftware.com/Olive/ODE/MissionCritical/Default.aspx?href=MCR%2F2012%2F11%2F01&pageno=30&view=document.

For a comparison of microwave and. fiber optic cable backhaul see: http://www.ceragon.com/files/Mobile%20Backhaul%20Fiber%20Microwave%20-%20White%20Paper.pdf.

For an analysis of fixed and mobile network technology options see:

OECD, *Fixed and Mobile Networks Substitution, Complementarity and Convergence*, available at: http://dx.doi.org/10.1787/5k91d4jwzg7b-en.

For background on the design of wireless networks see:

Book chapter from *Wireless Networking in the Developing World*, a free book about designing, implementing, and maintaining low-cost wireless networks http://wndw.net/pdf/wndw2-en/ch11-casestudies.pdf.

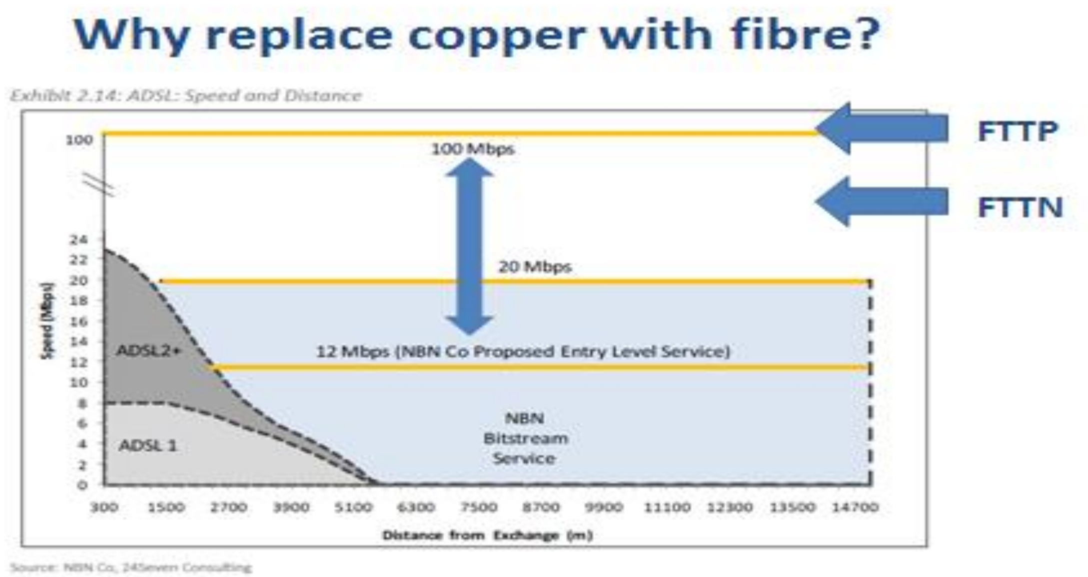
5.3.5 Copper

Copper metal has provided a closed circuit medium for telecommunications since the onset of telegraph and telephone service in the late 1800s. Wireline communications exploit the electron conductivity of copper and its historically moderate price. While far from ubiquitous wireline copper networks typically serve all areas with high and moderate population density and many more remote areas have qualified for universal service subsidies that extend the geographical reach of service. Copper has provided a cost-effective way to route voice, data, and video traffic via above-ground wires attached to poles and through underground ductwork. Wireline service costs increase with the distance served by a network, but carriers may average costs.

For many years copper wireline networks have provided both first and last kilometer service as well has long haul transmission. The conventional wireline Public Switched Telephone Network ("PSTN") uses narrow gauge copper wire pairs to form a "local loop" connection between individual subscribers and a nearby telephone company switching facility. Telephone companies provide highly reliable service using direct current to power the local loop at short distances not requiring electronic amplification. For onward delivery from the initial switching facility, commonly referred to as the End Office or Central Office, telephone companies aggregate traffic by multiplexing so that larger capacity trunk line and inter-office channels handle many simultaneous calls. Telephone networks have evolved over time to incorporate digital transmission technologies and increasingly efficient routing and multiplexing of traffic.

Copper wires of higher thickness ("gauge") and more insulation and support ("cladding") can provide a closed circuit medium for the delivery of video content. Cable television networks use coaxial cables to offer many channels of video content through a locality or metropolitan area. Cable television operators provided the first truly broadband, two-way networking capability to residences. They started offering one way retransmission of a few broadcast stations, so called Master or Community Antenna Television. Cable operators later expanded the bandwidth available from the coaxial cable to provide many additional channels, installed an upstream channel and provided each subscriber with an address so that individual subscribers could request and receive specialized content, e.g., pay per view, video on demand, premium programming.

Both the PSTN and cable television networks have been retrofitted so that they can provide broadband, Internet access. While next generation networks primarily will use wireless and fiber optic connections, currently most residential broadband access comes from two copper-based networks: 1) Digital Subscriber Line ("DSL") service provided by telephone companies and 2) cable modem service provided via cable television networks discussed in Section 5.7.1.



5.4 International Connectivity

Broadband access to the Internet requires the seamless interconnection and coordination of many networks operated by different carriers. People refer to the Internet as a "network of networks," because users simply "call up" web sites by keying in easily remembered domain names such as www.worldbank.org. Behind the scenes, a series of universally agreed to operating standards support the integration of the several links needed to connect consumers of content with sources. Carriers interconnect their telecommunications lines using common protocols that make it possible to identify and link users and sources of content. Many users also refer to Internet access as "cloud computing," because the various interconnected networks appear invisible as though they operated in a cloud.

We can penetrate the obscurities of the Internet cloud to identify each and every network used for any particular link. Traceroute software and Internet web sites offer an easy way to generate a report on the specific networks used to reach a user-identified destination. To achieve global accessibility and connectivity, several different types of carriers participate. These carriers have transmission and routing equipment in identifiable locations, even though users generally do not think of the Internet in terms of the locations of specific devices and equipment. Internet access starts with a query or request generated by an individual, machine or sensor located in a specific location. A "retail" Internet Service Provider ("ISP"), which has installed wired or wireless facilities, provides the first leg of this Internet routing. The first link is often described as the first kilometer or mile, but the actual length may span vast distances via a satellite earth station instead of other local options such as DSL, cable modem, microwave and cellular radio.

The retail ISP connects upstream with one or more ISPs that may not provide service to residential users, or other “end users” including small and medium sized businesses. Many of these ISPs provide “wholesale” service in the sense that they concentrate on providing service to large volume users, such as multinational corporations and governments. Most of these ISPs own and operate lines with extremely large transmission capacity that provides long haul service across vast distances including transcontinental and transoceanic coverage. The ISPs may connect directly with content providers, or with a retail ISP that provides the so-called first and last kilometer service to and from the content source.

International connectivity among ISPs operates in a hierarchical fashion with comparatively many retail ISPs, and fewer ISPs that offer long haul services to subscribers in a diverse geographical area. Among long haul ISPs the hierarchy continues and becomes more exclusive with very few operating as so-called Tier-1 ISPs and more operating as Tier-2 ISPs.

Tier-1 ISPs represent the largest carriers having the most extensive and highest capacity networks. These carriers also carry the most traffic and typically qualify for interconnection with other carriers on a zero cost, “sender keep all” basis, i.e., no funds are transferred between two ISPs largely because a roughly equal amount of traffic originates from one carrier for onward delivery by the other carrier. The term peering [18] refers to the zero cost interconnection arrangements Tier-1 ISPs negotiate. Smaller ISPs typically secure access to Tier-1 carrier networks on a paid basis commonly termed transit, or paid peering.

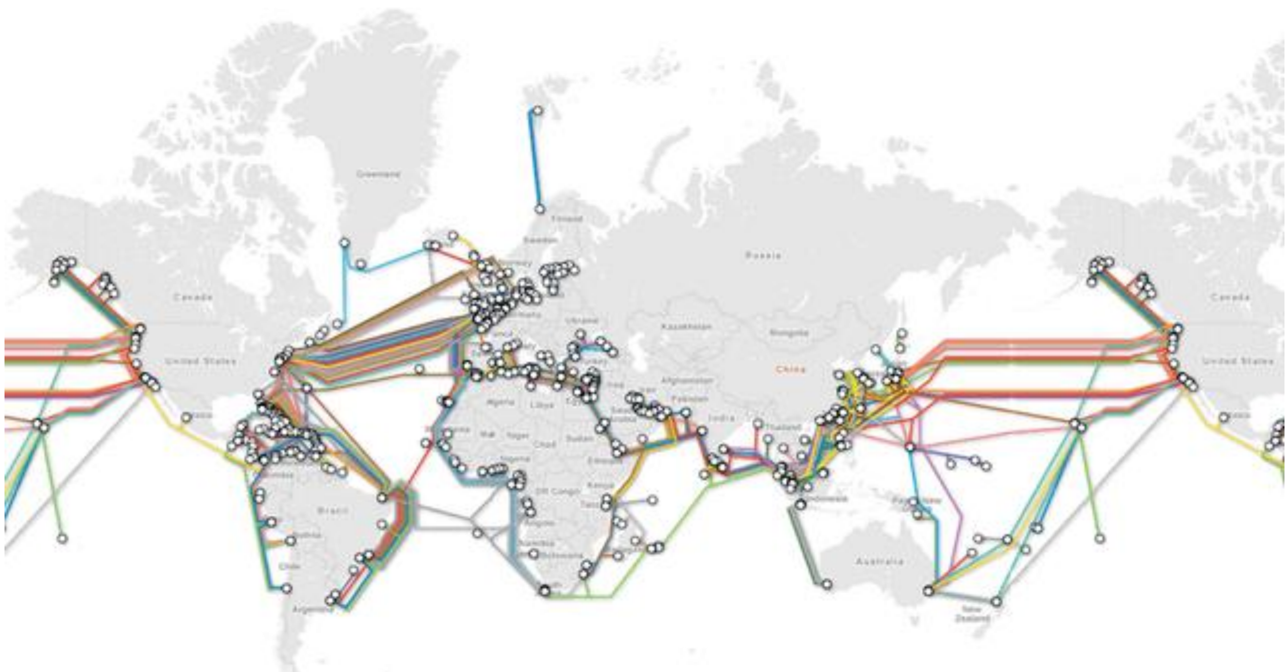
As the Internet matures and more ISPs enter the marketplace, new hybrid arrangements have evolved that deviate from the peering/transiting dichotomy. For example, some Tier-1 ISPs have opted for “private peering” where they interconnect directly with another ISP, outside of Internet Exchanges. [19] Some ISPs now agree to “multilateral peering” where more than two carriers interconnect on common terms and conditions at an Internet Exchange.

5.4.1 International Links

Fiber optic submarine cables and communications satellites provide the vast majority of broadband international links. For nations bordering on a coast submarine fiber optic cables provide the most cost-effective option as a cable installation can combine several cable strands, each capable of transmitting at a rate of several Gigabits per second (“Gbps”). For example the recently installed TAT-14 cable linking the United States with several points in Europe has a baseline capacity of 10 Gigabits per second that carriers subdivide into three service offerings: Synchronous Transport Module 1 (“STM-1”), approximately 155.520 Mbps; STM-4 , approximately 622.080 Mbps and STM-16, approximately 2.5 Gbps. The cable system has four fiber pairs configured for 47 channels each with about 10 Gbps in capacity, making the total design capacity of the cable system 3.2 Terabits per second.

Satellites cannot match fiber optic cables in the terms of overall capacity and bit transmission speed. However satellites can provide a cost-effective way to distribute broadband Internet traffic to many locations within a footprint as compared to the single point-to-point design for submarine cables. Satellites have the ability to transmit broadband Internet traffic at rates exceeding 15 Mbps, but more affordable retail offerings typically offer somewhat slower service, particularly for uploading content to the satellite. [20]

Transoceanic Fiber Optic Cables



source: Telegeography, Submarine Cable Map; available at: http://www.submarinecablemap.com/

5.4.2 Internet Links

Having made the near complete conversion from analog to digital networks carriers have great flexibility in the manner in which they load traffic onto available transmission capacity. Technological convergence makes it possible for both domestic and international transmission facilities to combine voice and data traffic rather than use specific links for Internet traffic separate from conventional voice traffic lines. Instead, Internet links use transmission, switching and routing protocols optimized for data traffic, but also capable of handling voice traffic configured for transmission via Internet links. Put another way carriers no longer configure networks with an eye toward allocating transmission capacity for specific types of service. With traffic converted into packets of digital bits, both international and domestic links can handle bitstreams that subsequently will be converted into voice, data, video, text and other types of traffic.

Technological convergence means that a reference to Internet links has less to do with the nature of the traffic carried and more to do with the operating standards used by the carrier as well as the terms and conditions established for the complete delivery of the traffic. [21] This means that carriers are less likely to identify the nature of the traffic, e.g., telephone call versus video link, or to use legacy measures of the traffic, e.g., minutes of use. Instead the traffic will be identified in terms of the capacity and speed of the transmission link as well as the interconnection arrangements established for that link.

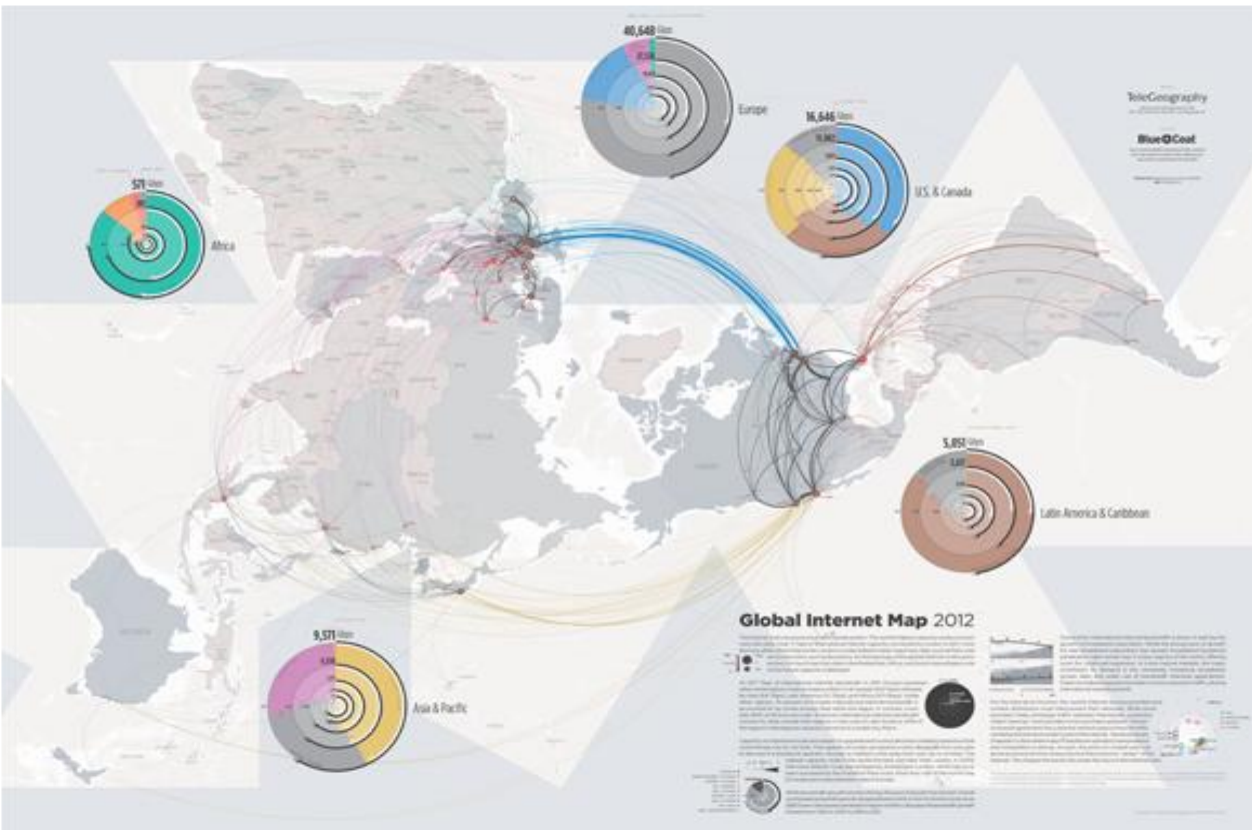
When carriers establish interconnection terms and conditions for Internet links, they increasingly refrain from applying the longstanding financial terms and conditions used in telecommunications and telephone service in particular. These legacy arrangements characterized interconnection as a “settlement” based on usage, such as voice minutes. Carriers handing off more traffic than they received from a specific carrier had to transfer funds to the “terminating” carrier. Carriers providing long distance telephone service negotiated a compensation arrangement, commonly referred to as an accounting rate, applicable to every minute of usage. For Internet links carriers are less apt to meter traffic in terms of time. Instead they will interconnect based on the capacity of the network links used and an estimate of overall traffic volume handled. For Internet links carriers substitute a measurement of minutes used with a determination of the bandwidth and bit transmission speed made available for the carriage of traffic originated by another carrier and routed onward to the final destination, or to the network of another carrier located closer to the final destination.

ISPs use different vocabulary and transmission measures when they interconnect Internet links. Also they generally use commercial negotiations to establish agreements, rather than rely on government forums, or regulated terms and conditions contained in a public contract known as a tariff. The largest Tier-1 ISPs, providing the longest links with the highest capacity, typically choose to interconnect directly with other similarly large and important carriers. Based on the assumption that Tier-1 ISPs typically have the same amount of transmission capacity available in different geographical regions, these carriers initiate interconnection negotiations with the expectation that they probably will not need to transfer funds. If two ISPs generate the same amount of traffic for each other to handle, then no money transfer should occur, because ISP A hands off to ISP B roughly the same volume of traffic that ISP B handed off to ISP A to handle. Such equivalency allows the carriers to “bill and keep” all funds generated from service. ISPs use the term peering to refer to interconnection arrangements based on traffic equivalency.

When two ISPs do not have roughly equivalent traffic volumes, the carrier generating more traffic that it receives incurs an obligation to compensate the other ISP. The term transit refers to negotiated terms and conditions when interconnected traffic volumes are unequal and a transfer of funds has to take place. The Internet links available to consumers combine peering and transiting capacity seamlessly so that in the vast majority of instances Internet access is available to any site, typically via more than one carrier and route.

Only in rare instances have ISPs refused to maintain an existing arrangement, or come up with acceptable replacement terms and conditions. When a dispute cannot get resolved two ISPs no longer will interconnect their Internet links. However, consumers usually do not experience service outages, because carriers typically negotiate several interconnection arrangements, covering two or more alternative routing arrangements, commonly referred as multi-homing. Except in instances where only one carrier provides "single homing" access to and from a content source and destination, one carrier's decision to "de-peer" and not interconnect usually does not result in the inability to have Internet traffic routed to and from any source or recipient of content.

Global Internet Map



Source: Telegeography, Global Internet Map 2012; available at: http://www.telegeography.com/telecom-resources/map-gallery/global-internet-map-2012/index.html.

5.4.3 Implementation Issues for International Connectivity

Thanks to a common set of operating protocols carriers can interconnect their broadband networking with ease. For Internet traffic the Transmission Control Protocol ("TCP") provides a widely used standard for traffic switching, routing and transmission. TCP helps support economic efficiency in the production of equipment, such as routers, by establishing a common standard useable by all manufacturers. While many devices are available and later vintages incorporate newly available features, the TCP supports high volume production of routers and other equipment produced based on the ability to sell them to all carriers and other users throughout the world. Put more simply the TCP establishes a standard "traffic cop" management function that most Internet equipment uses.

Additional enhancement of international connectivity results from the use of a common Internet addressing system, the Internet Protocol ("IP") by both consumers and carriers. Having a common addressing system means that consumers need only remember the names attributed to desired Internet sites, e.g., InfoDev.org. Carriers install devices, such as routers, that can read IP addresses and convert them to a larger sequence of numbers that corresponds to a specific installed device, e.g., the computer and the network used to originate a request for service as well as the name of the designated source of the requested service, or content.

The IP provides the basis for a universally supported addressing system that can establish order and promote ease in use by subscribers. While behind the scenes, ISP use routers to look up identities and locations of service requesters and providers from special servers containing such registrations, requesters only need to key in a single IP address. End users do not even have to know the procedures for assigning IP addresses and the method for organizing them. So called Top Level Domains refer to the type of organization housing the computer that originates a service request and the server that delivers requested content. For example .edu identifies an educational institution and follows its name or acronym. The complete address for the Pennsylvania State University in the United States combines www, to identify the part of the Internet providing Internet World Wide Web sites, the acronym psu followed by edu. Other top level domains include .com, .org, .mil., .co. and net representing in sequence commercial ventures, inter-governmental, multilateral and nongovernmental organizations, militaries, companies and networks. Additionally an IP address can specify the country location attributed to the IP address, e.g., www.bbc.co.uk for the United Kingdom based British Broadcasting Corporation.

While operating protocols promote international connectivity other factors have the potential to hamper progress and impose higher costs, particularly for users and operators least able to afford them. Maximum international connectivity requires the existence of networks for each and every link in the pathway between content server and recipient. Ideally each network should be in place and readily accessible either because one venture owns and operates each link, or because multiple ventures use common operating protocols and have agreed to mutually beneficial interconnection terms and conditions. In the multiple carrier scenario consumers can benefit by having access to more than one routing option as well as the potential that carriers will compete for both the long haul links and the first and last kilometer links.

On the other hand consumers may incur higher costs and inferior service if multiple carriers cannot easily interconnect their networks, or when few if any carriers are available to provide service. The weakest link—in terms of competitiveness and ease of interconnection—can have the most significant impact on the quality, convenience and affordability of service. For example, if the lack of network options forces a carrier to resort to indirect and circuitous traffic routing, both the carrier and its subscribers will suffer in terms of higher costs and inferior quality of service, including higher latency. The Internet's operating protocols are designed to secure a complete link from the network capacity that is both immediately available to a specific ISP and represents one of the possibly many options for which the ISP has secured interconnection rights. If no such link exists, the ISP and the TCP/IP will search for alternative, indirect options.

ISPs and their subscribers in developing countries face the greatest possibility that they may not have access to the most direct and efficient routing, at the least cost. Direct network interconnection may not exist. The lack of competition might make a direct link prohibitively expensive. ISPs that might want to interconnect networks may lack an efficient and low cost way to do so. When direct interconnection cannot take place, indirect options have to suffice even though they add time, distance and cost to a link. For example, until nations in Africa had local or regional interconnection facilities, ISPs had to secure interconnection at distant facilities, some located many thousands of kilometers away. The term tromboning refers to the need to use circuitous routing to achieve interconnection that optimally could have occurred at a more convenient, nearby location.

Even for ISPs in relatively close proximity to each other, if direct interconnection cannot take place, a short link between countries would have to be replaced with two longer links to a third nation having ample interconnection facilities, e.g., nations in Europe. For example consider a still plausible scenario where African ISP-1, receiving a request to contact nearby African ISP-2 might not have a direct interconnection option. Instead African ISP-1 must route the traffic to a European ISP with which it has a transit agreement. African ISP-1 and its European transit service provider might interconnect at an Internet Exchange located in Europe. The African carrier would incur the costs to carry the traffic to Europe as well as the transit costs incurred when the transit providing European ISP routes the traffic to African ISP-2. The European ISP might provide the return path from Europe to Africa by itself, or via interconnection with one or more other ISPs with which it peers or transits, for onward carriage to African ISP-2's network.

Years ago African ISPs might have identified ways to secure routing of their traffic via other generous carriers who might agree to provide transit services at low prices. The term hot potato routing refers to a strategy of handing off traffic as quickly as possible so that other carriers incur more of the total cost to secure a complete link. Because all ISPs now pay close attention to traffic volumes and the flow of traffic, ISPs cannot easily find inexpensive hot potato routing opportunities. ISPs bear the obligation to build or lease the facilities necessary to handle traffic without premature handoffs. However even if an ISP in a developing country did not want to handoff traffic to avoid network costs, having to do so now triggers higher routing costs.

ISPs not keen on exploiting hot potato routing opportunities need to have networks available to route local and regional traffic as well as the ability to interconnect with all needed networks. Because even the largest Tier-1 ISP does not own or least all the network capacity needed to reach any and all sites throughout the world, all ISPs need to have access to a facility that operates as a hub and interconnection point for many ISPs. These Internet Exchanges (examined in Section 5.5.2) provide the physical means for achieving local, regional and international connectivity by serving as the agreed to "meeting point" for all ISPs operating in the vicinity as well as those ISPs equipped to provide long haul transmission to other continents.

Internet Exchanges provide seamless interconnection between local operators providing first and last kilometer service with other ISPs operating international links.

5.5 Domestic Backbone

When broadband service is characterized as an "information superhighway" the domestic and international links used for medium and long haul carriage aggregate traffic from many individual users. First and last kilometer links may serve only one subscriber, or a small group in close proximity, but so called backbone networks use very high capacity transmission facilities that carry the traffic of many subscribers. Carriers can maximize network efficiency by collecting traffic and injecting it onto high capacity transmission lines for carriage over long distances. Multiplexing provides the traffic loading process whereby the traffic of many individual subscribers is combined for carriage by high capacity cables and wireless links onward toward the final destination. Demultiplexing unloads and disaggregates inbound traffic so that the ISP can route content to the appropriate end user.

Domestic backbone networks use the same transmission technologies as international backbones with the same goal of providing full connectivity. However there exists a likelihood that domestic backbones may not reach remote and hinterland locations, particularly in developing countries. Even if two distant cities share access to a domestic backbone, localities situated between these two hubs typically do not have the traffic and financial resources to persuade network operators to install branches off the backbone trunk.

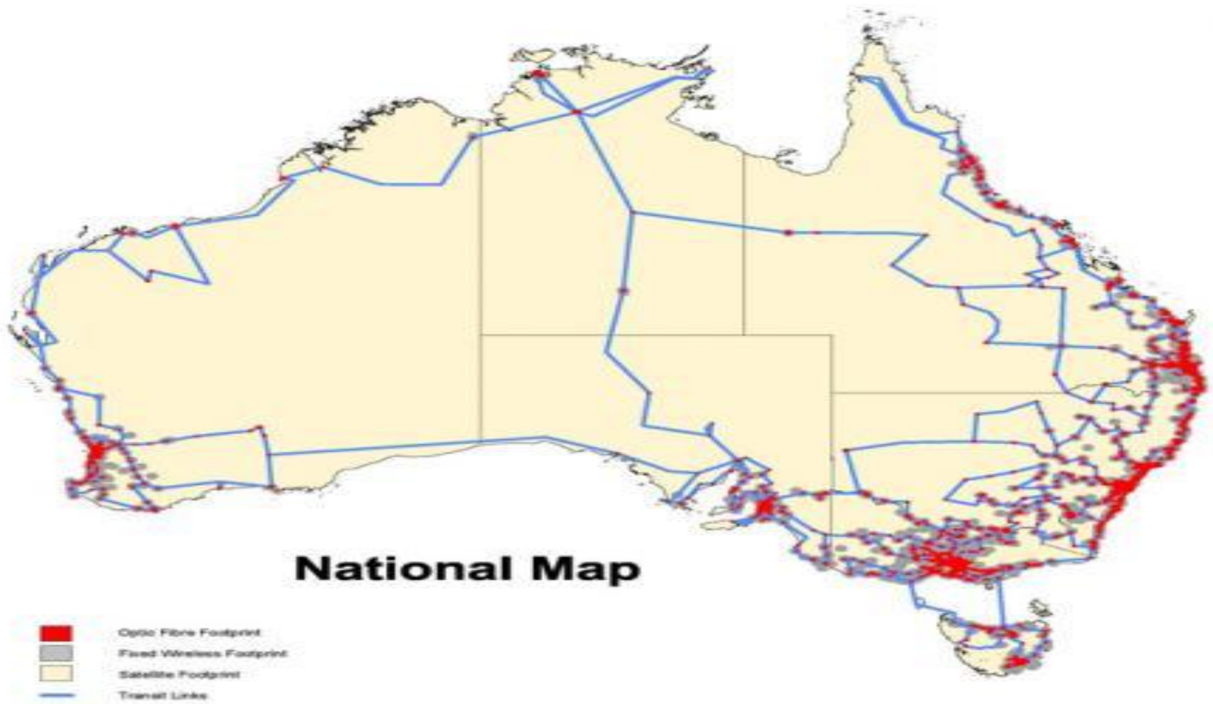
International connectivity has become certain thanks to sufficient demand and the competitive necessity of having to offer widespread network access throughout the world. Such certainty does not exist for domestic connectivity even in developed nations, because both private and public carriers may have determined that they cannot generate sufficient revenues and profits when serving remote locales. Accordingly domestic backbone networks may link different urban centers, including ones separated from more closely situated cities. For example, Perth, in Western Australia has reliable, high speed broadband connections to all of the other Australian cities located a significant distance to the east. However, some localities far closer to Perth than Perth is to the other major Australian cities currently lack access to similar domestic connectivity.

Domestic backbone networks can be analogized to the multi-lane long haul national highways that traverse great distances. For subscribers close to these networks access is a relatively easy and inexpensive undertaking, far cheaper than the cost of installing a new highway interchange. Both copper and fiber optic networks can be spliced to add short haul branches. But for subscribers located farther away, a carrier may not consider the necessary branch link an affordable investment based on the distance sensitivity of the investment, i.e., the cost rises in direct relationship to distance from the backbone. As the branch line increases in length the population of prospective and actual subscribers may not increase sufficiently to offset the higher costs. Put another way, the cost of backbone construction, operation and maintenance requires a degree of population density sufficient to generate adequate subscribership and revenues for the carrier to recoup costs and accrue a reasonable profit.

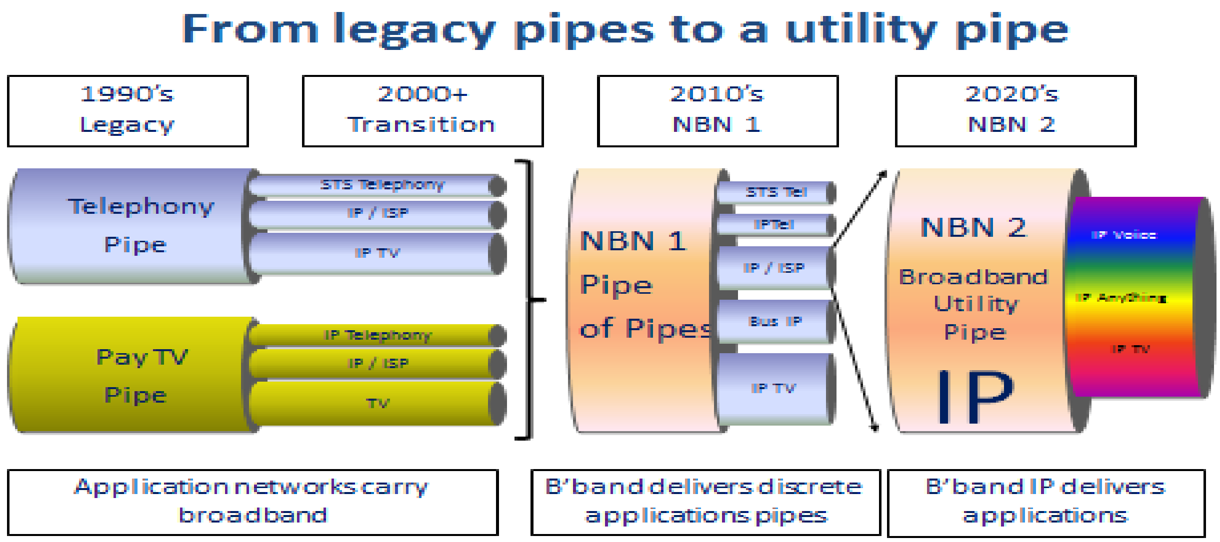
Many ISPs seek to offset the high cost of serving remotely located subscribers by averaging the total cost of network operation. Cost averaging makes it possible for ISPs to offer a single monthly subscription rate not based on an individual subscriber's actual distance from a backbone and ISP switching facility, or the distance between the subscriber and sources of content. Cost averaging creates the impression that Internet access is "distance insensitive," i.e., that the cost of providing service does not vary with the distance between subscribers and ISP facilities and between subscribers and the source of content they seek. Internet carriage of traffic does cost more as distance increases, but ISPs willingly have averaged costs to offset and mask the difference. Subscribers pay the same monthly rate regardless whether they seek content from far away sources, or from nearby ones. ISPs may offer tiered service at different prices, based on the total volume of content downloaded and uploaded, but without reference to the overall distance traveled by the content.

ISPs operating domestic backbone networks also incur the cost of having diverse and redundant routing options for each link. To provide high quality of service, ISPs need to design, install, operate and maintain two or more links, so that all routes have an alternative routing option in the event the main link becomes congested or inoperative, e.g., from a cut in the cable. Routing diversity refers to having two or more physically separate, but interconnected networks, typically operating in a ring, so that an indirect and more circuitous option exists during an outage and congestion in the more direct route. Redundancy refers to the ability of a network operator to offer subscribers more reliable service, perhaps backed up by a quality of service guarantee. The TCP traffic management standard supports near instantaneous traffic re-routing from the main line to alternatives in the event of an outage or congestion.

Australia's National Broadband Backbone

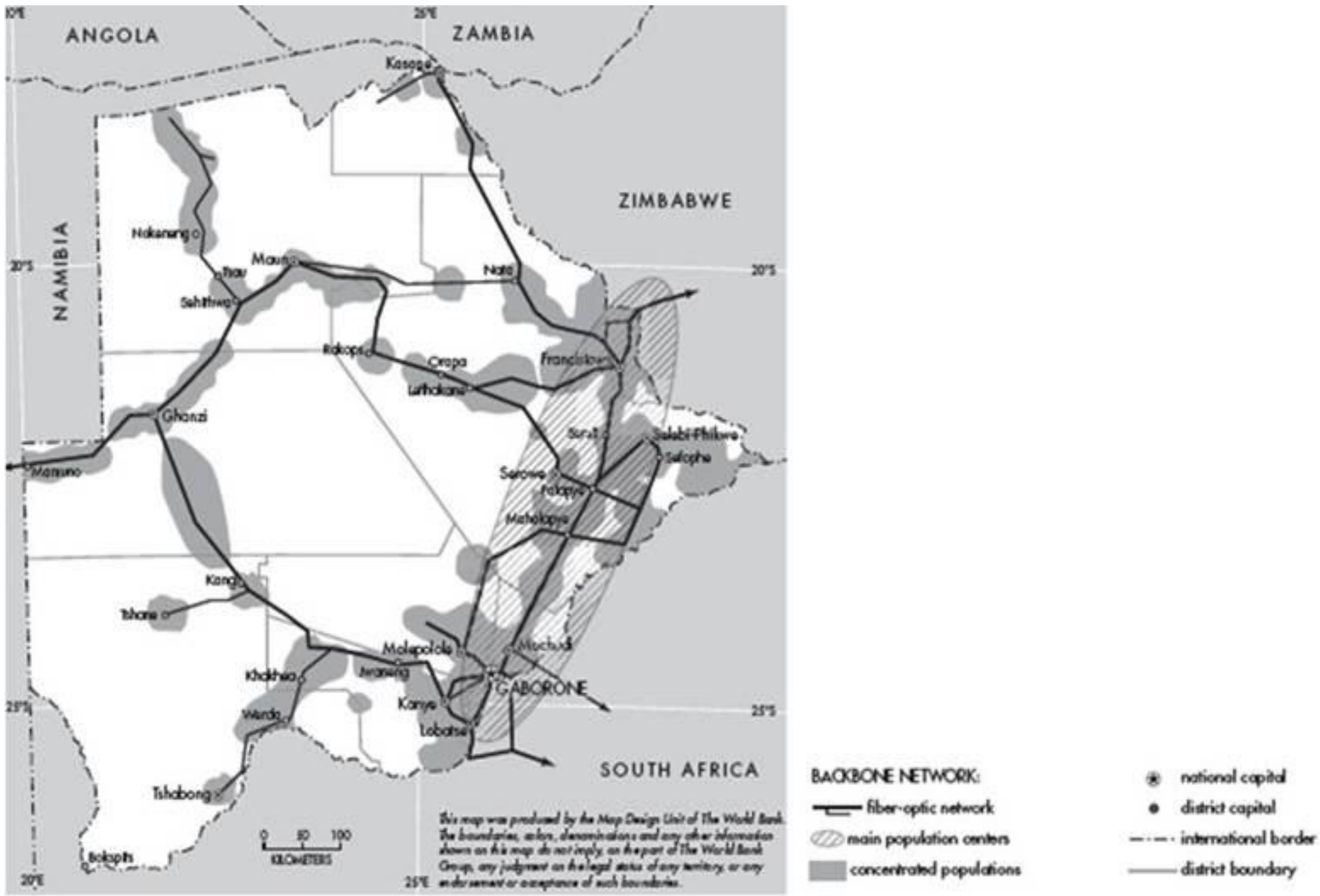


source: ARN, *NBN adds 300,000 premises to fibre footprint, releases details of full coverage*(July 30, 2010); available at: http://www.arnnet.com.au/article/355196/nbn_adds_300_000_premises_fibre_footprint_releases_details_full_coverage/.



Source: Robert James and John de Ridder, "Fixed broadband – Australia's next utility", Communications Policy Research Forum (Sep. 2008); available at: http://deridder.com.au/files/Fixed%20Broadband%20is%20the%20Next%20Utility%20Final.pdf

Backbone Networks in Botswana



Source: The World Bank

5.5.1 National Links

National links refer to domestic backbone networks as well as other facilities that provide high capacity and fast bit rate connections to backbone networks. Such non-backbone networks include branch lines or “backhaul” facilities that link specific localities, users and widely dispersed facilities, such as wireless radio tower sites, to a backbone network. Additionally national links provide so-called middle mile services that provide transmission services between first and last kilometer facilities, which originate and terminate Internet traffic, and long haul networks, including domestic and international backbone networks.

Carriers may price national links on a distance and usage sensitive basis, resulting in far higher total and per unit of capacity rates than what backbone carriers charge. Comparisons to first and last kilometer costs are difficult, because at the retail level, such subscriptions cover Internet access which factors in both the cost of conduit access and arguably includes a contribution to defray the cost of the content made available. An end user Internet access subscription also includes the local ISPs’ peering and transiting costs for securing access upstream to other ISPs that participate in the set up of multiple network links to achieve a complete connection from end user to content source, regardless of location.

Middle mile and backhaul markets tend to have less competition resulting in fewer redundant and diverse routing options. ISPs typically first concentrate on installing domestic and international backbone facilities so that the largest volume users, typically located in urban locales, have access to the rest of the world as well as at least one high quality, reliable link between domestic urban centers. ISPs extend the geographical reach of facilities that access backbone networks, perhaps with more emphasis on geographical coverage as opposed to accommodation of the middle mile and backhaul needs of specific users.

In many instances, for different reasons, broadband users in both developed and developing nations, may incur steep charges for access to national links. National broadband plans typically address how to stimulate private investment in facilities that extend broadband networks into remote, hinterland locations. Many nations emphasize private-public partnerships that combine government and private sector resources. Governments can create financial incentives, but also contribute to projects by offering rights of way for the installation of ducts and towers used by transmission facilities. Governments also can facilitate sharing in the cost and use of networking infrastructure by rewarding carriers that work conscientiously to pool resources without conspiring not to compete, or to fix prices. Given the high costs in broadband infrastructure construction, competing carriers should not always have to build separate telecommunications lines and switching facilities. Where existing conduits and rights of way are available, governments can promote shared use. Many of the competing long haul telecommunications networks in developing countries started by using existing rights of ways secured long ago by railroads, electric utilities and gas pipelines. [22]

5.5.2 Internet Exchanges

Internet exchanges provide a much needed interconnection point for ISPs providing local, regional, national and international service. Because no single ISP typically owns or leases all the networks needed to achieve a complete every link between end user and content source, ISPs agree to interconnect their networks, often at a single facility where multiple interconnections can take place between and among many ISPs. Internet exchanges centralize and economize the network facility interconnection process, by making it possible for several ISPs to share in the cost of installing, operating and maintaining the site. Many Internet Exchanges are jointly owned by the carriers that interconnect networks. Other commercial sites are owned by real estate developers, or ventures unaffiliated with the carriers. A hybrid model combines public and private partners, much like arrangements made for airports, seaports, exhibition halls and sports facilities. A non commercial alternative uses a cooperative, or not for profit model to stimulate use of a facility and the benefits accruing to nearby service subscribers.

The lack of Internet exchanges in lesser developed regions has exacerbated the so called

Digital Divide. [23] The lack of international and domestic backbones, branch lines, middle mile options, backhaul routes and direct links with end users surely contribute. However, once various networks get built by different ISPs, collectively all carriers need convenient and nearby access to Internet Exchanges to facilitate the interconnection and exchange of traffic. Without these facilities interconnection cannot take place within the region where traffic originated, or eventually will terminate. Instead ISPs must resort to lengthy and circuitous routing of traffic at distant Internet Exchanges. Such "tromboning" of traffic, representative of the long tubing in the musical instrument, increases the time it takes for traffic to reach its final destination as well as the cost.

The operator of Ghana's Internet Exchange summarizes the benefits of having an in-country facility:

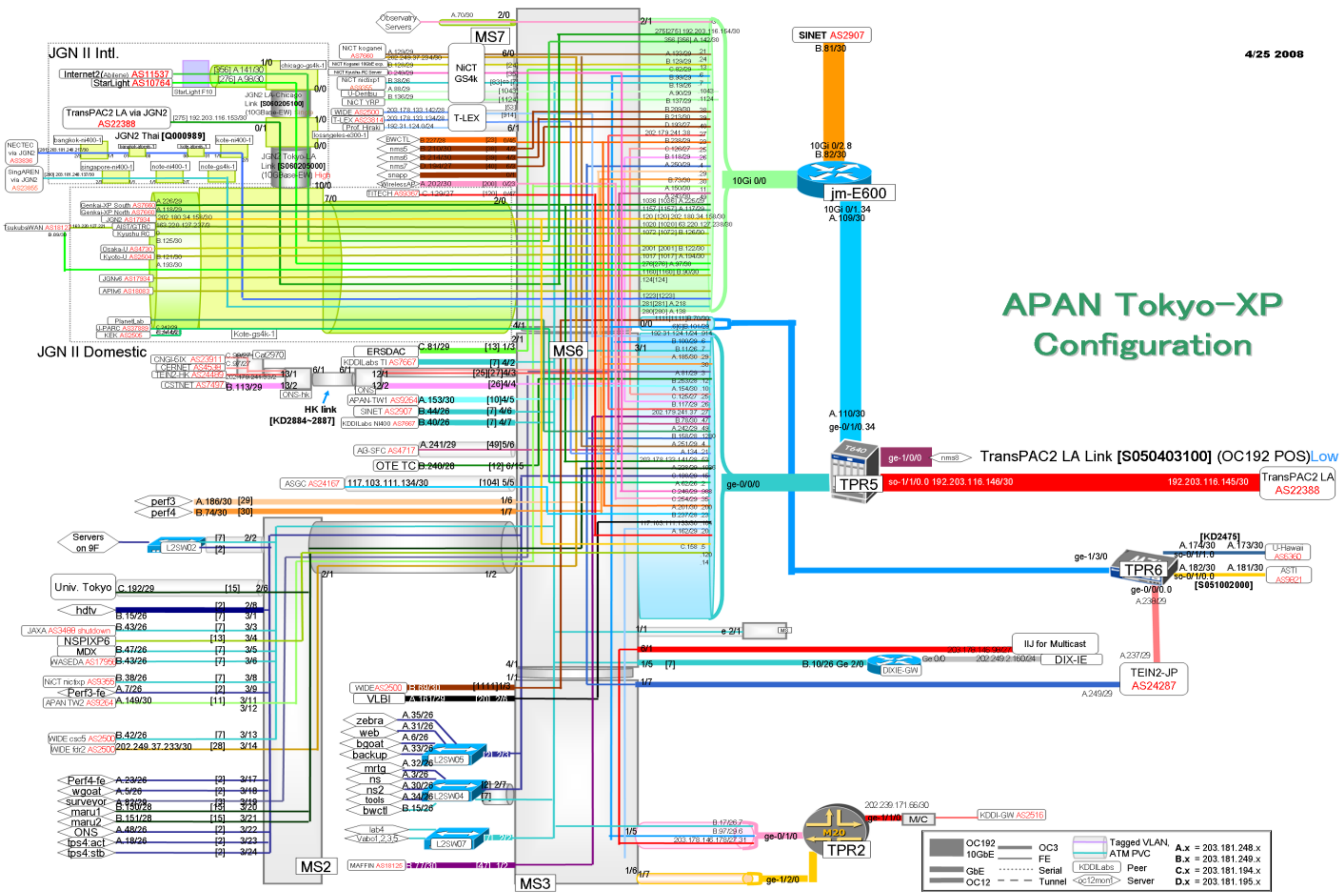
"The value of an IXP is clear to governments, regulators, industry experts, and industry members for good reason: it usually heralds significant development and opportunities for new revenue in the local ICT industry. It is because of this eventual national pay-off that IXPs are usually financed by donations from individuals, organizations, corporations, governments, etc. One point of failure for Exchanges is attempting to finance them by means other than donations or sponsorship.

"The cost of the Exchange is minimal compared with the benefits. Exchange points have two benefits (short and long term) that directly address two obstacles to ICT growth (international bandwidth costs and network latency). The short-term benefit happens overnight. Once ISPs are connected to the Exchange, they will no longer pay international bandwidth costs for local, Ghanaian traffic. This cost savings, however, is not the only value of an IXP.

"The long-term benefits far outweigh the short-term. Once the ISPs are connected to the GIX, latency or transit time of traffic becomes a fraction of what it was since it stays within the same network. As a result of this increased speed and reliability, additional 'value-added' services become possible on the national network. Exchange Points make web content hosting, audio and video streaming, E-commerce, E-governance, etc. possible. Right now ISPs and local businesses often go outside of Ghana for advanced Internet solutions such as the above, taking revenue elsewhere. With the GIX, all of that business and the revenue that comes with it can come to Ghana creating more entrepreneurial opportunities, jobs, and options for investment.

"In Ghana the cost of Internet bandwidth and connectivity is highest compared to the rest of the competitive world. In one sense the cost of sending a local destined email is equal to the cost of sending an internationally destined email. To overcome this anomaly, connecting to a local or National exchange in this case GIX ensures that the cost of sending a locally destined email is at a lower cost. With the offsetting of the local traffic to the exchange point, the upgrading of International links of operators can be postponed for an additional period. Therefore translating to saving on the International link capacity. These savings can further be extended to the operators customers." [24]

Internet Exchange Interconnections



Source: Internet Society, available at: https://nsrc.org/workshops/2008/sanog12/day1/netmanage/tokyo-xpconf.png.

Internet Exchange Governance

By design Internet Exchanges require the joint investment and participation of multiple carriers. The more carriers that agree to fund an Exchange, the lower their shared costs and the more routing and interconnection opportunities become available to both carriers and consumers. Because Internet Exchanges involve multiple carriers, the management and governance of these facilities may require scrutiny by governments to ensure that no single carrier, or group of carriers can dominate in ways that reduce the benefits to other carriers and Internet users. National Regulatory Authorities may require transparency in the terms and conditions for affiliation with an Internet Exchange to ensure that carriers do not collude to raise prices to consumers, or to handicap other carriers, including ones that do not have an ownership interest in the facility.

Internet Exchanges typically contribute to the integration and interconnection of local, national, regional and international routing options and carrier choices. However without adequate safeguards they can help bolster the market power of a dominant carrier, or a small group of carriers. Internet Exchange governance documents should provide clear and fair terms for financial, technical and operational terms for membership by new carriers as well as their interconnection rights. Carriers should cooperate in the operation of Internet Exchanges without such collaboration leading to a reduction in competition for traffic and subscriptions.

Best practices in the operation of Internet Exchanges include assurances that whoever manages the facility (government agency, university, non-profit association, carrier consortium, etc.) the Exchange operates in the spirit of neutrality and openness. Internet Exchanges should secure competitive bids for the construction of the facility with benchmarks in the contract for timely and cost-effective performance. The parties should agree to locate the facility in close proximity to where existing and prospective network facilities are located. The facility should have the ability to increase in size ("scalability") on an incremental basis. Governance of the facility should ensure fiscally sound stewardship.

5.5.2.1 Reference Documents and Case Notes

60 Hudson Street, Lower Manhattan

One of the largest and most important Internet Exchange is located in New York City. An instructive video about this facility, Ben Mendelsohn, *Bundled, Buried & Behind Closed Doors* is available at: http://vimeo.com/30642376.

African Internet Exchanges

The very large continent of Africa remains underserved both in terms of Internet access and the number of essential interconnect and traffic exchange points. However several nations have achieved progress with the recent installation of an Internet Exchange.

List of Internet Exchanges in Africa

Name	Established	URL		Location
AIXP	2006	http://www.angola-ixp.ao/	Luanda	Angola
BINX	2006	http://www.binx.org.bw/ http://www.info.bw/bispa/binx.html	Gaborone	Botswana
KINIX	2002	http://www.ispa-drc.cd/kinix.htm	Kinshasa	Democratic Republic of the Congo
CR-IX	2002	http://www.nsrc.org/db/lookup/operation=lookup-report/ID=1100200161570:488991867/fromPage=EG	Cairo	Egypt
CAIX	2004	http://www.caix.net.eg/	Cairo	Egypt
GIXP	2005	http://www.nsrc.org/db/lookup/report.php?id=8&fromISO=GH http://www.gixa.org.gh/	Accra	Ghana
CI-IXP	Jun 2007	http://nsrc.org/AFRICA/CI/R	Abidjan	Ivory Coast

Name	Established	URL		Location
		eport-IXP-CI-2007.pdf		
MSIXP / KIXP-MSA	2010	http://www.tespok.co.ke/index.php/msixp.html	Mombasa	Kenya
KIXP	Nov 2000	http://www.kixp.or.ke/	Nairobi	Kenya
LIXP	Aug 26, 2011		Maseru	Lesotho
MIX	Dec 2008	http://www.mispa.org.mw/mix.html	Blantyre	Malawi
MIXP	Jun 2006	http://www.gov.mu/portal/sites/mixp/index.htm	Quatre Bornes	Mauritius
Moz-IX	May 2002	http://www.mozix.org.mz/	Maputo	Mozambique
IXPN	Jul 2011	http://www.nixp.net/	Abuja	Nigeria
IXPN	2006	http://www.nixp.net/	Lagos	Nigeria
IXPN-PH	July 2012	http://www.nixp.net/	Port Harcourt	Nigeria
RINEX	Jul 2004	http://www.rinex.org.rw/	Kigali	Rwanda
SLIX	2009	http://www.slix.sl/	Freetown	Sierra Leone
CINX	2009 ?	http://ispa.org.za/inx/cinx-information/ http://stats.cinx.net.za/	Cape Town	South Africa
NeutrINX	Sep 2011	http://www.ne	Centurion	South Africa

Name	Established	URL		Location
		utrinx.org.za/		
DINX	Sep 2012	http://stats.dinx.net.za/	Durban	South Africa
GINX	Mar 2005	http://ginx.org.za/	Grahamstown	South Africa
JINX	Dec.1996	http://www.jinx.net.za/	Johannesburg	South Africa
SIXP	2011	http://sixp.sd/	Khartoum	Sudan
SZIXP	Jun 2004	http://www.nsrc.org/db/lookup/operation=lookup-report/ID=1090612703142:488719200/fromPage=SZ	Mbabane	Swaziland
AIXP	2007	http://www.aixp.or.tz/	Arusha	Tanzania
TIX	Jan 2004	http://www.tix.or.tz/	Dar es Salaam	Tanzania
UIXP	May 2003	http://www.uixp.co.ug/	Kampala	Uganda
ZAIXP	Jun 2006	http://ispa.org.zm/	Lusaka	Zambia

Name	Established	URL		Location
ZINX	July 2001	http://www.zispa.org.zw/zinx.html	Harare	Zimbabwe

Source: Network Startup Resource Center, Internet eXxchange Points in Africa; available at: https://nsrc.org/AFRICA/ixp/.

A global map of Internet Exchanges is available at: Data Center Map, Internet Exchange Points, http://www.datacentermap.com/ixps.html and

The Packet Clearing House, Internet Exchange Directory, available at: https://prefix.pch.net/applications/ixpdir/.

A video explaining the role of Internet Exchanges is available at: http://www.internetsociety.org/what-we-do/issues/internet-exchange-points-ixps.

Several best practices handbooks and case studies now offer guidance on the planning, installation, operation and management of these facilities:

Internet Society, *Promoting the Use of Internet Exchange Points: A Guide to Policy, Management, and Technical Issues; Internet Exchange Points: Collaborating for the Greater Good*, available at: http://www.internetsociety.org/ixpimpact; see also, African Peering and Interconnection Forum (AfPIF); available at: http://www.internetsociety.org/events/afpif;

African Union, Division on Information Society, African Internet Exchange System, available at: http://pages.au.int/infosoc/pages/african-internet-exchange-system?q=infosoc/pages/african-internet-exchange-system;

Michael Kende, Analysys Mason, *Terrestrial Capacity: From Cape Town to Cairo – Reality or Illusion* (Aug. 23, 2012); available at: http://www.internetsociety.org/sites/default/files/images/Analysys%20Mason%20Cross-Border%20data.pdf.

5.5.3 Implementation Issues for Domestic Backbone Networks

Domestic backbone networks provide the essential connection between urban networks as well as the necessary extension of broadband access beyond central business districts to suburban, exurban and rural localities. These networks bridge the Digital Divide by providing broadband access to users located in regions having less than ideal demographic and demand characteristics. The first Internet access opportunities typically become available to business users in close proximity to each other in a nation's central business district and to switching facilities, commonly referred to as Internet Exchanges, where Internet Service Providers ("ISPs") interconnect with each other and access cross-border links.

Domestic backbone construction can provide a cost-effective way to expand the geographical reach of broadband access as well as the total population served. However the capital intensive nature of broadband network construction presents numerous financial challenges, coupled with many managerial and logistical issues in implementing a business plan to build or extend a domestic backbone network. Backbone planning requires consideration of ways to maximize geographical reach and market penetration as well as strategies for economizing through the pooling of investment and sharing of costs among multiple network operators.

Backbone networks generate substantial upfront costs well before carriers can deliver service to paying customers. As a threshold matter a single carrier or consortium of carriers must agree on the technology to be used as well as the routing of the network. Backbone networks typically use high capacity, point-to-point microwave links, or fiber optic cable. While the former may have less initial costs, because carriers can install towers at intervals of up to 50 kilometers, it offers less initial broadband capacity and does not have the capability of increasing bandwidth ("scalability") as available from multi-strand, fiber optic cable installations.

Most domestic backbone networks use fiber optic networking technologies, because of their initial and scalable capacity. However such terrestrial networks require a dedicated pathway for the installation of the cables, known as a right of way, and ductwork used to house and protect the cables. Backbone operators have incentives to install high capacity networks whose bandwidth capacity can increase in response to growing demand by activating additional "dark," "unlit" capacity. Because significant funds and effort typically are needed to secure all necessary rights of way and operational authority, operators install ample capacity with an eye toward spreading the costs over the largest possible amount of bandwidth use. Many nations have licensing and permitting authority shared between a National Regulatory Authority and other administrative entities having jurisdiction over a state, province, country, or even a smaller region.

Domestic backbone operators in both developed and developing nations need to identify opportunities for cost sharing without making it possible for competing carriers to fix prices and otherwise pursue collusive and market disrupting arrangements. Just as competing carriers can cooperate in the construction, operation and management of a single Internet Exchange, they also can share the costs of a single domestic backbone, particularly the infrastructure that can be shared efficiently. There are several components in broadband networking that are passive in the sense that individual carriers do not have to design, install and manage the technology.

For example, competing wireless carriers can share in the cost of installing and maintaining a tower onto which they install their own electronic devices such as transmitters, receivers and antennas. The carriers can divide up the cost of designing, constructing and operating the tower including the cost of supplying or bringing power to the site. For terrestrial networks carriers can share in the cost of acquiring rights of way to install ductwork and cables on private or public property.

5.6 Metropolitan Connectivity

Broadband network planning requires stakeholders to design optimal ways for accessing the Internet cloud and for engineering accessibility throughout a nation. Planners start by securing access to major regional and international telecommunications links and by installing a domestic Internet Exchange. Subsequently they extend the geographical scope of Internet access by constructing a domestic backbone network that provides a broadband connection between urban centers and eventually extends broadband access into the hinterland. As planners increase the penetration of broadband access into less densely populated areas, they also should pay attention to a less obvious requirement: ensuring connectivity between and among users within a metropolitan area. As urban regions spread out the tasks of ensuring metropolitan connectivity becomes increasingly challenging.

Metropolitan connectivity constitutes a possibly underappreciated goal, because users require both access to the Internet cloud and the rest of the world, but also access between and among various points within a sprawling metropolitan region. The “anchor tenants” of broadband networks typically have very large demand for bandwidth and access requirements in many different locations. For example, a multi-national corporation involved in the extraction, processing and export of natural resources typically would have broadband access requirements in remote areas, where the resources are situated, as well as other locations that process and refine the material plus regional headquarters and locations handling administrative functions. Additionally such an important user might have several facilities within a metropolitan area housing management staff who typically have broadband requirements both for interacting with other corporate personnel as well as the various organizations that support the business, e.g., bankers, attorneys, consultants, and engineering firms.

Metropolitan connectivity provides both the first and last kilometer access to the Internet cloud as well as the so-called middle mile access that links various outposts of both affiliated and unaffiliated ventures located at many dispersed locations within a country. Because not all of these users are physically near existing domestic backbone networks, carriers will need to devise ways to provide similar broadband functionality even though possibly far fewer users will require access. In light of the fact that demand may not be as robust as that for direct access to the domestic backbone, network operators cannot achieve the same scale economies and accordingly will have to charge higher rates on a per unit of capacity basis. Middle mile access typically costs more to provide thereby resulting in a commensurately higher cost to users.

Users of metropolitan broadband networks have the same “mission critical” traffic as customers located at or near a domestic backbone. As a threshold matter, they will need to assess whether to seek authority to construct and operate their own dedicated network, to rely on an existing operator to lease existing capacity, or to build new facilities to accommodate the user’s specific requirements. This “make/buy” decision depends on many factors including the price of available capacity, as well as dedicated new facilities and the ease or difficulty in securing regulatory authority to construct private facilities and to interconnect them with equipment and lines operated by incumbent carriers. If a National Regulatory Authority will not allow installation of private facilities, or imposes unreasonable terms and conditions, users with specific metropolitan broadband service requirements will have little bargaining power when resorting to negotiations with an incumbent carrier. While some users are functionally "captive" to the terms and conditions imposed by a single incumbent carrier, others can leverage the ability to relocate elsewhere to secure fair rates.

Metropolitan network negotiations may generate high rates for users particularly when carriers cannot anticipate that other nearby users would require similar services thereby helping the carrier offset the high, initial costs incurred to accommodate the needs of one user. Network operators have to provide the same sort of service quality and reliability as available from public networks even though doing so generates higher costs when as few as one user leases capacity. Backbone operators routinely install redundant, back up capacity as well as two or more different routing options so that they can continue to provide essential service even when congestion or an outage occurs. Middle mile users have the same requirements for redundant and diverse traffic routing options.

In addition to middle mile service, metropolitan connectivity includes "backhaul" options, particularly for wireless carriers. Backhaul service provides links from remote locations, e.g., a rural cellphone tower, back to an urban location where the wireless carrier would route calls to intended call recipients including ones using the city's wireline network. Not all wireless carriers install both the towers needed to provide service throughout a region and the backhaul capability needed to route rural traffic to urban switching facilities and call recipients. To conserve capital and to expedite the availability of service, wireless carriers may concentrate on the installation of tower sites without the fiber optic cable or microwave radio backhaul links needed to route traffic from and to remote tower sites. Incumbent domestic wireline carriers may be expected to accommodate the back haul requirements of cellphone companies. In many nations incumbent operators are classified as common carriers having the obligation to satisfy the reasonable service requirements of end users and even other carriers. This classification typically obligates incumbent carriers to provide service even if doing so would require the installation of facilities likely to be used only by few, if any customers other than the cellphone carrier that initiated the request for service.

5.6.1 Regional Metropolitan Links

Broadband network planners typically use a blend of wired and wireless technologies to meet the demand for middle mile and backhaul services by end users and carriers. Because the total demand for any specific link may not generate a substantial volume of traffic, network operators will need to use comparatively less expensive technologies than that used for high demand links. Wireless microwave services can provide a cost-effective solution to these lower volume "sparse route" requirements. These wireless technologies provide service to users in fixed locations, rather than the more familiar mobile services such as cellular radiotelephone service.

Regional metropolitan links provide an example of how two broadband technologies can combine to solve specific end user requirements. For broadband users in remote locations a single technology solution would prove too expensive. A network operator could not make a business case to extend the fiber optic domestic backbone to the remote customer, or even to install a dedicated branch unit off the backbone. Instead the carrier routes traffic via existing broadband facilities to the point closest to the remote user with sufficient population density and demand and then installs lower capacity broadband, wireless facilities to link "off network," remote users with the backbone. Because of the distance from the backbone such branches are not considered first and last kilometer services.

5.6.2 Implementation Issues for Metropolitan Connectivity

Metropolitan connectivity presents network planners with many challenges, because of the number of routes needed and the lack of readily available options. The importance of the domestic backbone and a possibly large rural footprint makes it more likely that carriers can quickly and economically secure the rights to install facilities. Incumbent carriers typically have a legal status that authorizes them as public utilities to demand property easement access based on "eminent domain" which favors the public interest claims of the carrier over the property rights of individual land owners. Additionally network operators may choose to locate backbone networks along existing rights or way such as that used or abandoned by railroads, electric utilities, pipeline operators and highways.

Middle mile and backhaul routing in more densely populated areas may trigger more difficult and time consuming rights of way acquisitions. Because much of the route may cover still densely populate terrain, the carrier cannot claim to be extending first time broadband access and the carrier may not qualify for the option of invoking eminent domain. Land owners located near a proposed tower site or conduit installation may not want the disruption and possible division of a single tract of property. In developed nations property owners have banded together to oppose network facility installations. The phrase Not in my Back Yard ("NIMBY") refers to the typical displeasure property owners have toward rights of way requests of public utilities and telecommunications carriers.

5.7 Local Connectivity

Local connectivity refers to the first and last link used by broadband users to receive ("download") and transmit ("upload") the various forms of content, software and applications available via the Internet cloud. Local connectivity constitutes only one part of the multiple links to and from the Internet cloud, but broadband subscribers may consider it "Internet access," because they pay a monthly subscription to the retail ISP providing the first and last link. This subscription also defrays the costs incurred by the retail ISP for accessing links farther upstream needed to complete a connection between an end user and a source of content.

The emphasis on local connectivity is justified for a number of reasons. First, a nation may have ample broadband backbone capacity, but satisfying individual subscribers' needs requires broadband connections to and from a backbone. For the first and last kilometer of this route the carrier typically has to install a line dedicated for the sole use of one subscriber. Measures of broadband market penetration and subscriptions typically identify the total number of actual subscribers, the upload and download transmission rates available to them and the cost of service. Second, local connectivity completes the interconnected and integrated links needed to provide what consumers consider Internet access. Put another way the Internet as a "network of networks" cannot provide seamless access to the content unless and until consumers have broadband options available at their homes, small businesses and other sites. Third, concerns about the viability, affordability and competitiveness of local connectivity dominate public policy and regulatory discussions. In many developing countries—and even some developed ones—local connectivity options may be limited both in terms of the number of technological options available ("intermodal competition") and the number of competitors using the same technology ("intramodal competition"). Fourth, local connectivity, marketed as Internet access, constitutes one of the core services that carriers combine to offer a desirable and discounted "bundle" of services. Consumers accrue savings and carriers generate higher revenues with a "Triple Play" bundle of access to the Internet, video programming and voice telephone service.

The Internet cloud and network of networks concepts exemplify the hierarchical nature of Internet access. One can consider the transmission, switching and routing technologies that make up the Internet as numerous and geographically dispersed at the base of the pyramid. Moving up the number of ISPs and the geographical coverage concentrates. Retail ISPs provide dedicated broadband links to users: a one to one ratio of service. At the actual first and last few feet or meters of service a wireline ISP has to install a physical medium that serves just one subscriber. Wireless ISPs use a single carrier to serve the traffic origination and termination needs of retail subscribers. Upstream from the retail last kilometer link, ISPs aggregate traffic onto higher capacity cables and wireless links so that a single conduit carries the traffic of very many subscribers simultaneously. Upstream ISPs offer very high capacity limited to specific routes, typically between cities and across great distances.

5.7.1 Wireline Access Technologies

Currently the primary local broadband technologies use upgraded and modified copper wire conduits already installed by telephone and cable television companies. Incumbent carriers have determined that they first should "retrofit" existing wire-based technologies, because doing so conserves capital and extends the useable life of plant already installed. While replacing copper conduit with fiber optic cable offers consumers much faster bit transmission speed, incumbent carriers have determined that few localities currently have the population density and willingness to pay for a fiber optic broadband delivery networks to specific end users. In the interim, incumbent carriers have identified ways to reconfigure existing networks so that they can provide a combination of voice, data and video services.

Telephone companies offer a transitional, copper-based technology that upgrades the available bandwidth sufficient to provide a carrier just barely wide enough to provide broadband, telephone and on-demand access to a single video channel. Cable television companies have more available bandwidth making it possible to reassign one or more television channels for broadband access. For many locations, broadband carriers eventually will replace the copper conduit with fiber optic cables, perhaps initially with a hybrid network that combines the two media. For example, the term Hybrid Fiber/Coax refers to the installation of new fiber optic cables from traffic management headquarters to a point closer to end users, whose access to that midway point continues to rely on existing copper lines.

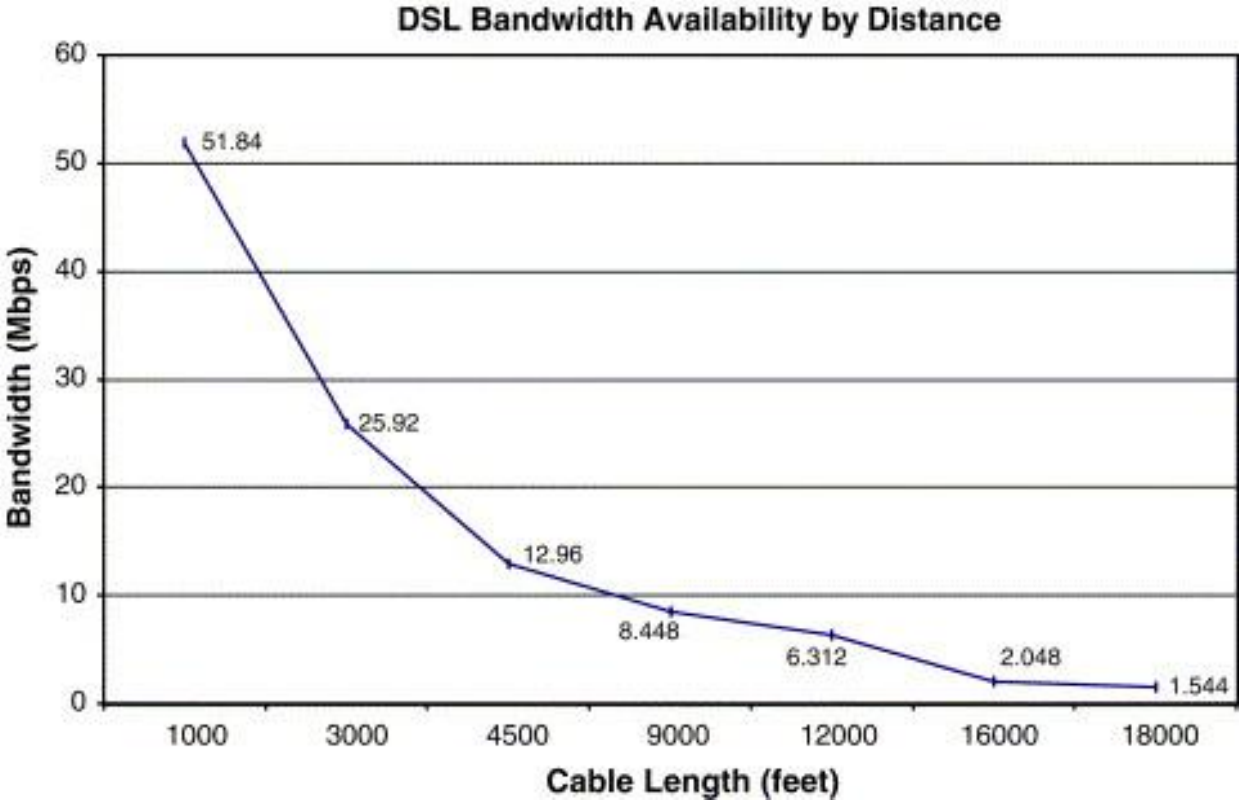
Digital Subscriber Line Service

Telephone companies can provide broadband Digital Subscriber Line ("DSL") service by expanding the bandwidth available from the narrow gauge copper wires used to provide the first and last kilometer of telephone service. In essence DSL constitutes a transitional technology upgrade or retrofit using already installed copper wire. This wire uses a narrowband carrier to deliver voice telephone calls. The bandwidth generated by the narrowband voice carrier is only 3000-4000 cycles per second, also known as Hertz. A 3-4 kiloHertz ("kHz") channel can provide only a low fidelity signal, but that is sufficient for the transmission of voice conversations.

Broadband signal transmission requires more bandwidth so that the signal can carry the higher volume of information contained in the Internet cloud. Instead of narrowband delivery of a telephone call, broadband channels must offer both the capability of carrying lots more information, e.g., full motion video content, and to do so on a timely basis so that the content does not freeze, blur, or become unavailable. Put another way broadband networks need to have the bandwidth capacity capable of delivering high throughput, i.e., lots of information typically measured in bytes. Bandwidth intensive applications, like video, require fast, broadband networks having the capability of delivering content on an immediate, "real time" basis.

Telephone companies can expand the bandwidth available from the narrow gauge, pair of twisted copper wire from 3-4 kHz to as much as 1500 kHz that also can be stated as 1.5 MegaHertz ("MHz"). With this expanded carrier, telephone companies can offer broadband service typically at transmission speeds averaging 1.5 million bits per second (1.5 "Mbps") with high transmission speeds available to subscribers located near the telephony company switching facility. The highest transmission speed available, termed Very High DSL ("VDSL") can offer speeds reaching 55 Mbps over a distance of 1000 feet from a telephone company switching office, or an Optical Network Unit installed to serve a specific neighborhood or real estate subdivision.

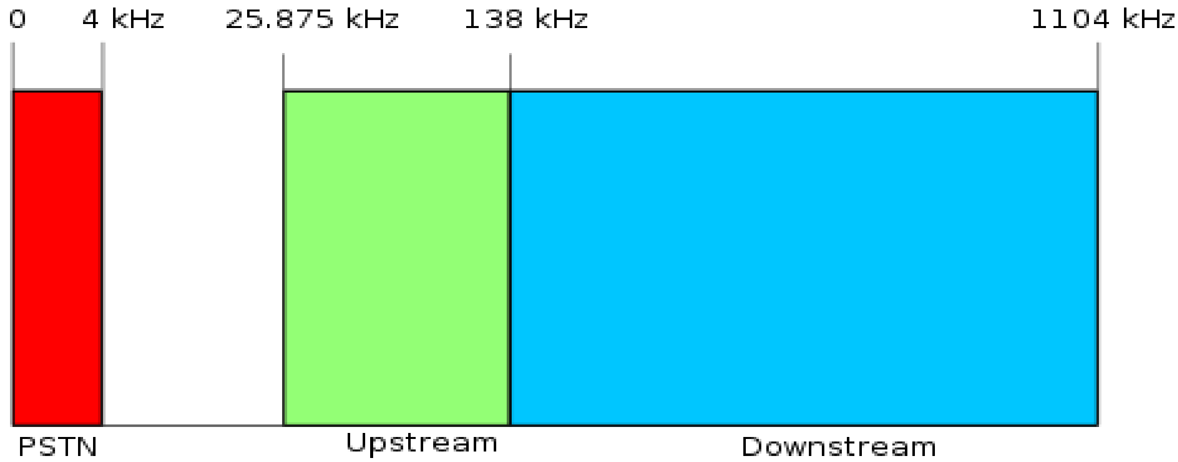
DSL subscribers located relatively close to a telephone company switching facility can receive higher bit transmission speeds, but subscribers located more than 5 kilometers typically cannot receive any DSL service at all. Because telephone companies use unamplified copper wire as the medium for service, signals weaken ("attenuate") as the distance increases between subscriber and telephone company switching office.



source: Tony H. Grubesica and Alan T. Murray, *Geographies of imperfection in telecommunication analysis*, 29(1) Telecommunications Policy, 69-94 (Feb. 2005).

DSL technology offers relatively slow bit transmission rates, compared to that available from cable television and fiber optic networks. To maximize the effectiveness of DSL networks, carriers configure the service to make more transmission capacity available for downloading than for uploading of content. This lack of symmetry between uploading and downloading responds to the fact that most broadband subscribers download more capacity than they upload. The term Asymmetric Digital Subscriber Line ("ADSL") refers to a DSL service configured with more downloading capacity. DSL service that has equal downloading and uploading capacity is called Symmetric DSL.

Asymmetric Digital Subscriber Line Bandwidth Allocation



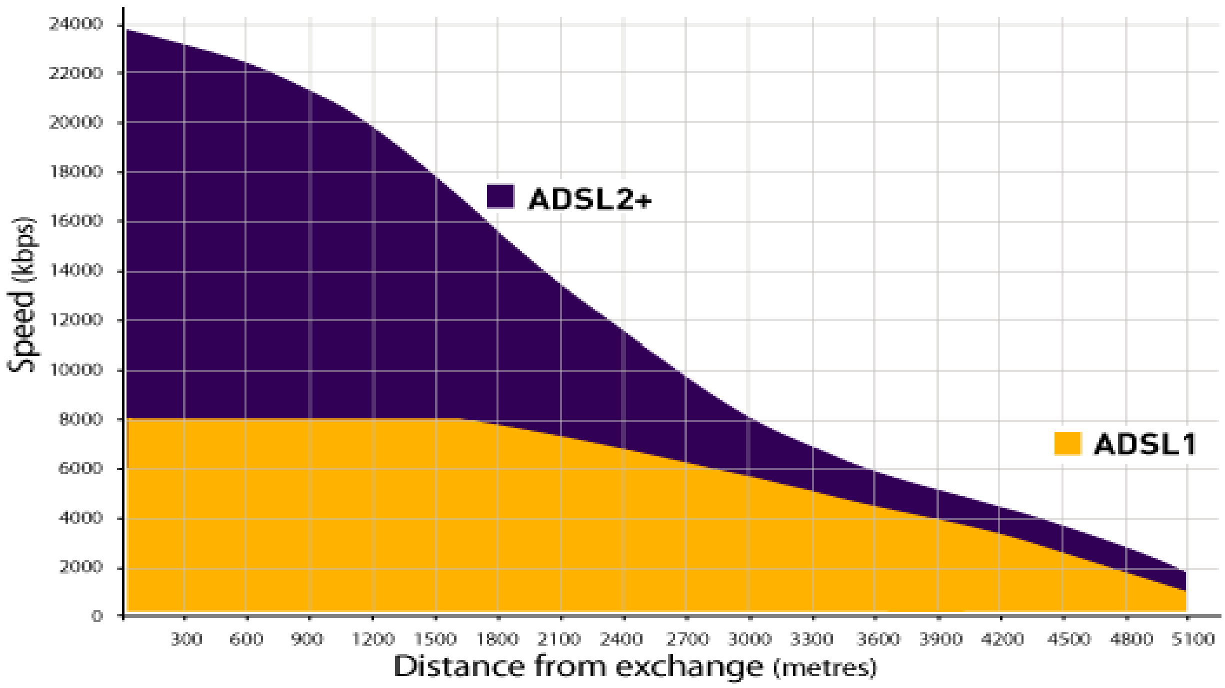
Red area is the frequency range used by normal voice telephony (PSTN), the green (upstream) and blue (downstream) areas are used for ADSL.

Source: Wikipedia

Many Types of DSL Service

DSL Type	Description	Data Rate Downstream; Upstream	Distance Limit	Application
IDSL	ISDN Digital Subscriber Line	128 Kbps	18,000 feet on 24 gauge wire	Similar to the ISDN BRI service but data only (no voice on the same line)
DSL Lite (same as G.Lite)	"Splitterless" DSL without the "truck roll"	From 1.544 Mbps to 6 Mbps downstream, depending on the subscribed service	18,000 feet on 24 gauge wire	The standard ADSL; sacrifices speed for not having to install a splitter at the user's home or business
HDSL	High bit-rate Digital Subscriber Line	1.544 Mbps duplex on two twisted-pair lines; 2.048 Mbps duplex on three twisted-pair lines	12,000 feet on 24 gauge wire	T1/E1 service between server and phone company or within a company; WAN, LAN, server access
SDSL	Symmetric DSL	1.544 Mbps duplex (U.S. and Canada); 2.048 Mbps (Europe) on a single duplex line downstream and upstream	12,000 feet on 24 gauge wire	Same as for HDSL but requiring only one line of twisted-pair
ADSL	Asymmetric Digital Subscriber Line	1.544 to 6.1 Mbps downstream; 16 to 640 Kbps upstream	1.544 Mbps at 18,000 feet; 2.048 Mbps at 16,000 feet; 6.312 Mbps at 12,000 feet; 8.448 Mbps at 9,000 feet	Used for Internet and Web access, motion video, video on demand, remote LAN access
VDSL	Very high Digital Subscriber Line	12.9 to 52.8 Mbps downstream; 1.5 to 2.3 Mbps upstream; 1.6 Mbps to 2.3 Mbps downstream	4,500 feet at 12.96 Mbps; 3,000 feet at 25.82 Mbps; 1,000 feet at 51.84 Mbps	ATM networks; Fiber to the Neighborhood

DSL Bitrate Varies with the Distance from the Telephone Company Switch



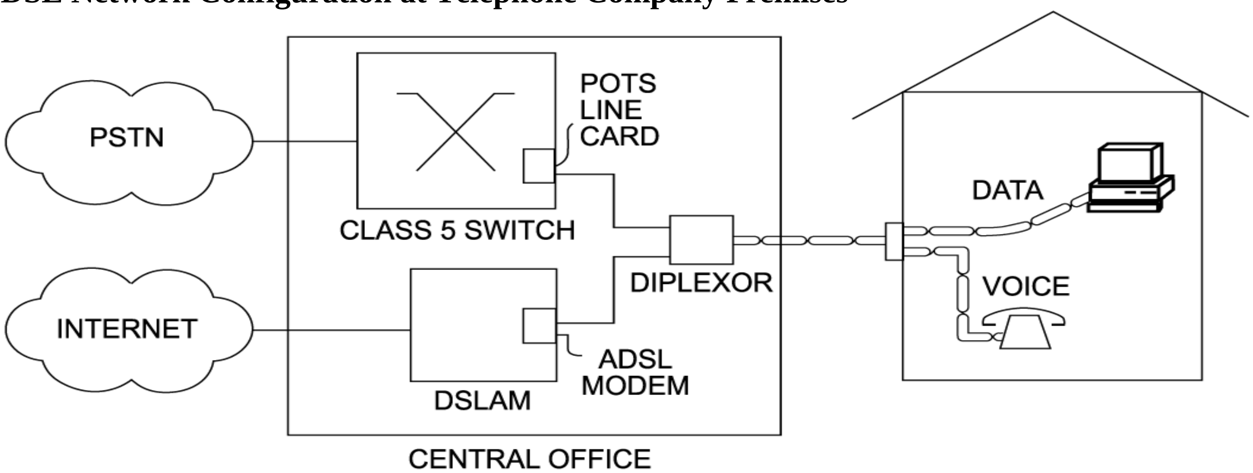
source: Mark Jackson, ISP Review (Sep. 20, 2010); available at: http://www.ispreview.co.uk/articles/10_UK_Rural_Broadband_Solutions/.

Telephone companies also have an operational reason to provide ADSL instead of symmetrical service that offers equal bandwidth for uploading and downloading. When subscribers upload content the most likely place where data traffic may interfere with voice traffic occurs at the telephone company switching facility handling both types of traffic in close proximity to each other. Uploaded data arrives at the telephone company switching facility with the weakest signal. Because data starting at the telephone company switching facility has the strongest signal the telephone company can spread the signal over wider bandwidth and thereby transmit content at a higher bit rate.

At the telephone company offices closest to subscribers, certain upgrades are needed to provide DSL service. Carriers need to separate "legacy" voice telephone traffic from the new data traffic. They achieve this separation by using a frequency splitter to divide the frequencies used for voice service from the newly available bandwidth made available for DSL service. The voice traffic continues to route to the Central Office for the customary switching and routing along a hierarchy of facilities that multiplex traffic onto very high capacity, long haul transmission lines. Separately Central Offices, equipped to provide DSL service, receive the data traffic and route it to a separate traffic aggregator, commonly known as the Digital Subscriber Line Access Multiplexer ("DSLAM"). This device aggregates Internet traffic for onward delivery via long haul Internet traffic transmission lines and disaggregates it for delivery to the intended recipient.

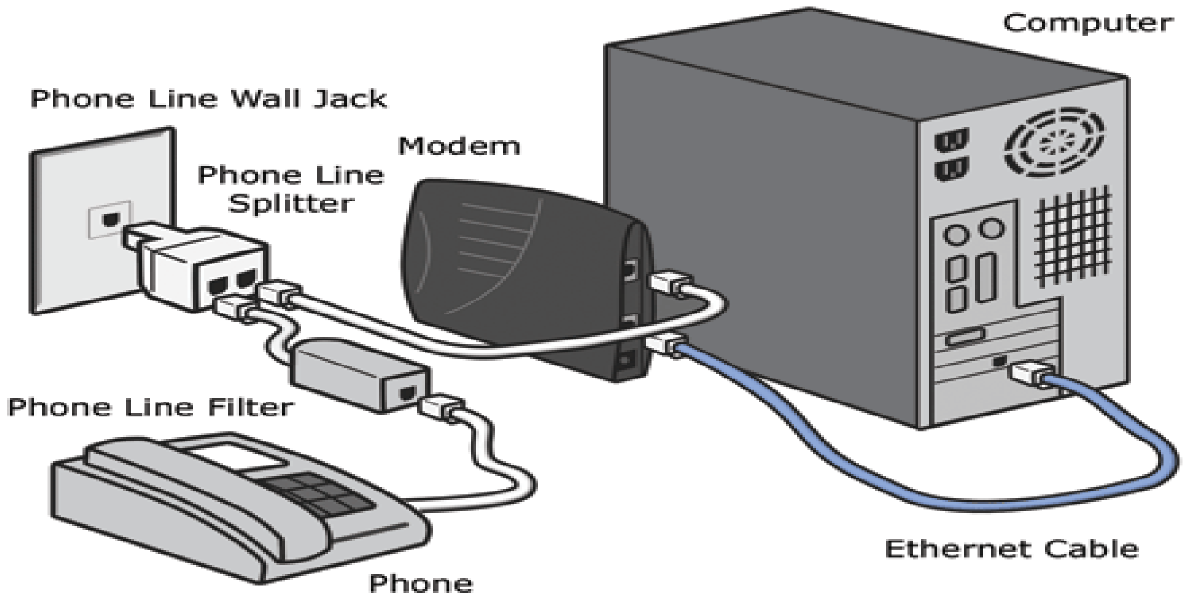
At residences DSL subscribers must use filters to block the data frequencies at jacks used for voice telephone service. DSL subscribers also need to install a device that modulates and demodulates Internet, data traffic thereby differentiating it from conventional voice traffic. This modem device connects to a conventional telephone service jack and also to a computer, or wireless router serving one or more portable devices.

DSL Network Configuration at Telephone Company Premises



source: The Progress and Freedom Foundation, available at: http://www.pff.org/issues-pubs/pops/pop6.13regulatoryoverkill.html

DSL Configuration on User Premises



source: Kingpin Internet Café Blog site, Home Networking; available at: http://wbrowser04.blogspot.com/2010_06_01_archive.html.

DSL service offers slow, but cheaper broadband service as compared to what cable television operators offer. Additionally the need for subscribers to be located no farther than 5 kilometers from a telephone company switching facility further reduces the market size of potential subscribers. Similarly telephone companies do not serve all locations within the 5 kilometer potential service area. Localities with the greatest population density and most favorable demographic characteristics, e.g, high income, typically attract the first company investment in the retrofitting needed to provide service.

Cable Modem Service

Cable television operators also can retrofit their existing networks to provide broadband service starting with the conversion of as little as one 6 MHz television channel into an Internet access link. By partitioning ("diplexing") this bandwidth, cable operators can designate the frequencies represented by this channel as available only for uploading and downloading Internet traffic. A modem similar to that used for DSL service can tune solely to the bandwidth now designated for Internet access and modulate and demodulate data traffic through that channel.

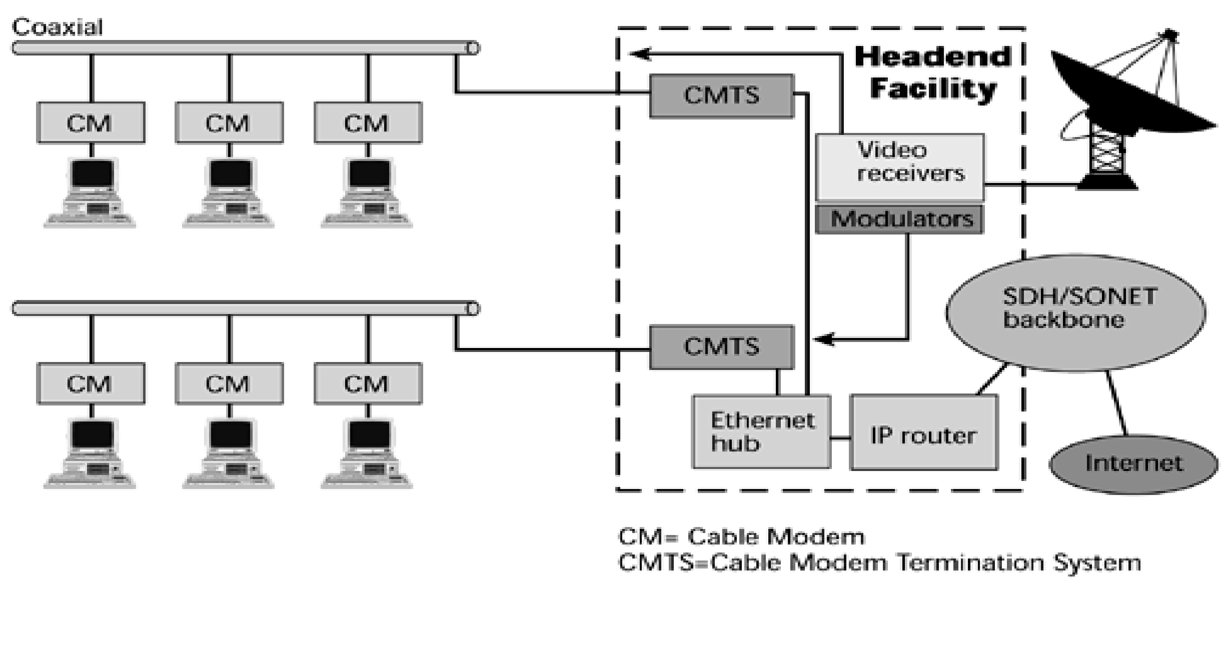
Because the cable television distribution grid operates with amplifiers located throughout, cable modem service can be offered everywhere the company previously offered video service. Additionally cable modem service can operate at bit delivery speeds well in excess of what DSL can provide. Cable operators can further increase delivery speeds by adding more bandwidth in 6 MHz increments, a process known as cable bonding.

Cable modem service costs subscribers significantly more than DSL service, but the cost may offer a better rate on a per Mbps basis. For example, DSL service typically costs between $18-$30 USD per month, while cable modem service typically costs between $20-$75 per month. A $30 rate for 1.5 Mbps would cost more on a per megabit delivery speed if a cable operator offered 6 Mbps service for anything less than $120 per month. Increasingly broadband subscribers require bit transmission speeds well in excess of 1.5 Mbps to receive such bandwidth intensive content as high definition television on an instantaneous, "streaming" basis.

Cable modem service represents a third major upgrade in service. In the first generation cable television operators simply imported broadcast television signals to places too far away to receive signals "off air" using the two small telescoping antennas supplied with the set ("rabbit ears") and possibly even if one installed a rooftop antenna. In the second generation, cable operators increased the inventory of content to include networks that did not broadcast their content. Instead of serving as a community antenna for broadcast content only, cable television operators used satellites and microwave networks to distribute additional content. In this second generation cable operators expanded the available bandwidth for television and also created a small upstream link from subscribers so that they could be identified by address for billing and content delivery purposes.

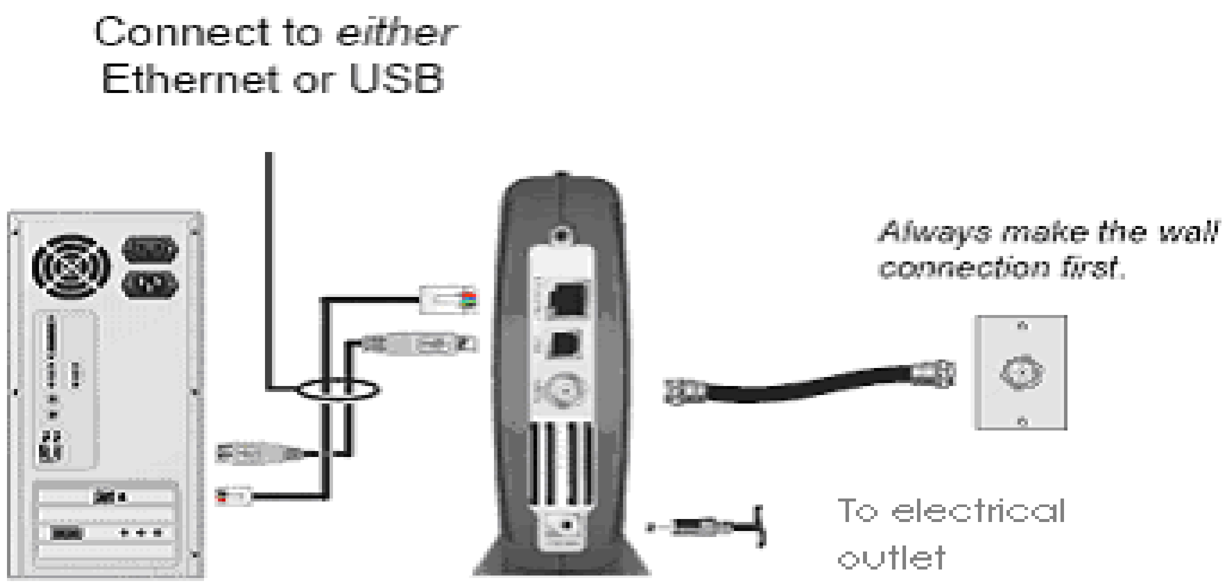
In the third generation cable operators expand the range of service available to include telephone and Internet access in addition to video content. The cable television distribution grid becomes the functional equivalent to a Local or Metropolitan Area Network ("LAN" or "MAN") capable of providing high speed data transmissions both downstream and upstream to all subscribers. LANs initially provided data networking within an office building or throughout a college, or corporate campus. Now cable operators offer the same functionality in the third generation of cable television network development.

Cable Modem Configuration on Operator Premises



source: Lillian Goleniewski, Telecommunications Essentials, p. 73; available at: http://flylib.com/books/en/2.566.1.73/1/.

Cable Modem Configuration on User Premises



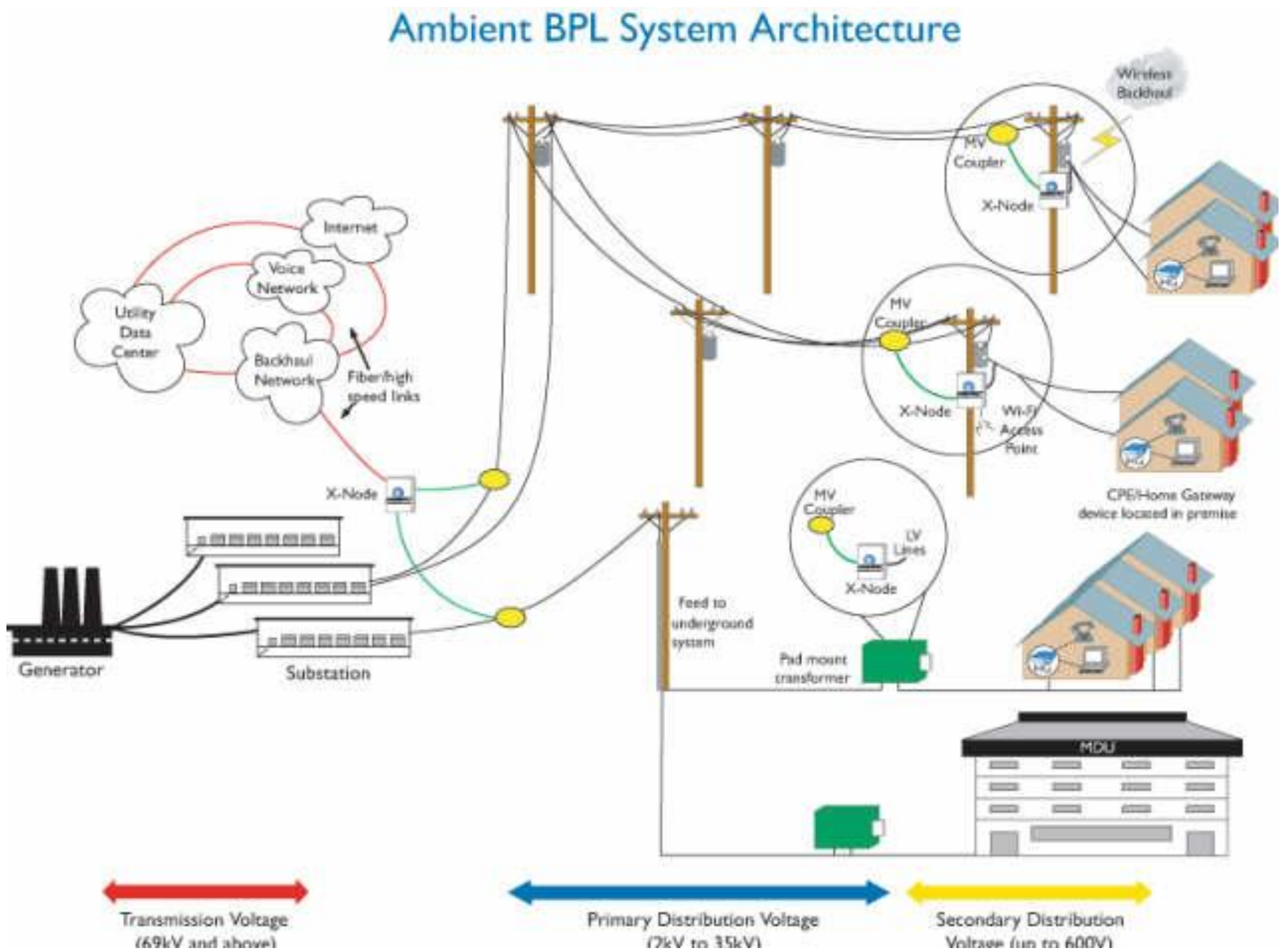
source: Knology of Kansas, Connecting Your Cable Modem; available at: http://kansas.knology.com/help/internet/setup.html

Broadband Over Powerline

The nearly ubiquitous electric power grid offers a potential third wire capable of providing broadband into residences and businesses. Broadband over powerline ("BPL") uses the transmission power of the electricity delivery to carry signals using much higher frequencies. While an electrical conduit generates a quite noisy and inhospitable environment for other types of transmissions, advances in digital signal processing makes it possible to differentiate a high frequency data signal from the predominant, lower frequency electrical current. BPL uses lines in the electrical grid operating at several thousand volts instead of the highest powered lines that operate with tens of thousands of volts.

The greatest challenge in making BPL commercially viable lies in solving two problems: 1) ensuring that the data signal can pass through transformers near retail subscribers that lower ("step down") the transmitted voltage to the 110-220 volt level used by consumers; and 2) convincing National Regulatory Authorities that the data signals, typically operating between 1.7 and 80 MHz, will not leak out of the grid and interfere with wireless radio users.

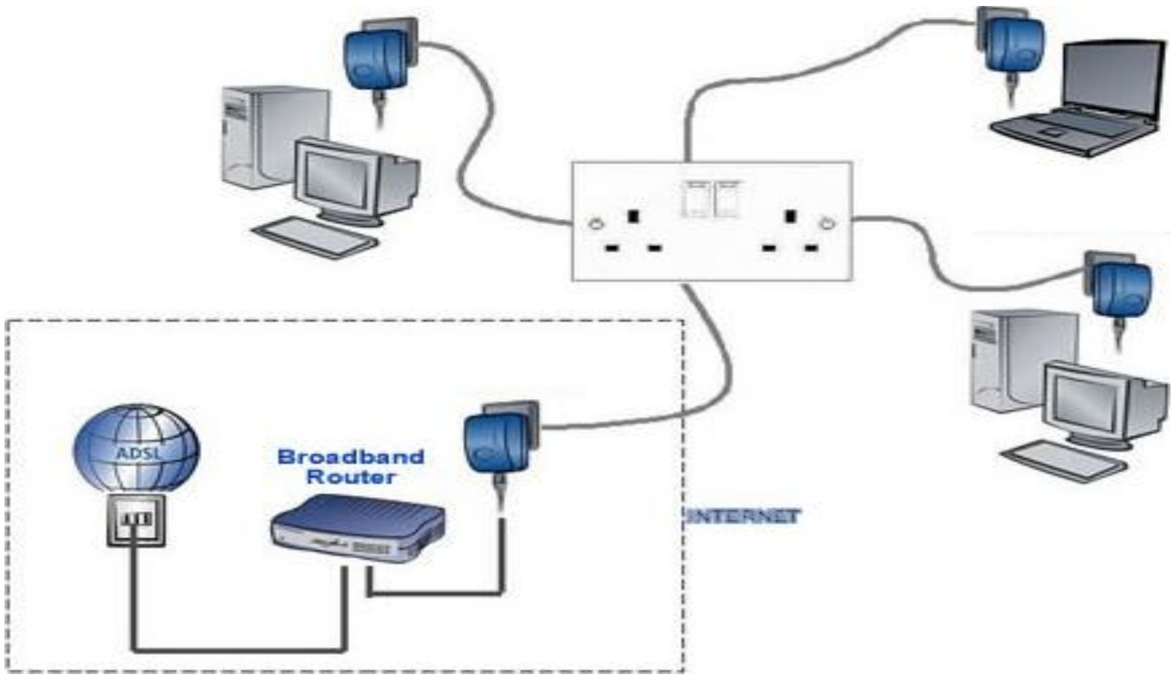
BPL injects and extracts broadband data signals onto the electrical grid. An inductive coupler transfers the data signal onto the power line by wrapping around the line, without directly connecting to the line. The extraction process decouples the data signal and sends it to a on premises modem for demodulating inbound traffic and modulating outbound traffic in the same manner as DSL and cable modems.



source: Migsmobile Blog site; available at: http://www.migsmobile.net/2009/03/13/the-state-of-broadband-over-power-lines/.

For nations where a transformer provides individual premises with the final voltage conversion to 110-220 volts, the extraction process can fail, because the signal has become unrecoverable. A solution to this problem relies on a wireless router, operating on a pole or above a conduit, to handle the first and last few meters outside of the transformer.

Home Configuration of BPL



source: Multiple-Wireless Solutions; available at:
http://www.multiplewireless.com/broadband.over.power.line.html.

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Andrew C. Schneider, Digital Subscriber Line Technology; available at:
http://www.telebyteusa.com/dslprimer/dslprimer.htm;

Cisco Documentation, Digital Subscriber Line; available at:
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Peter Macaulay, DSL Standards Update; available at:
http://www.dslreports.com/forum/remark,12089082.

For background on how cable modems operate see:

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www.todoprogramas.com/manuales/ficheros/2008/7.8200.6431.pdf;

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Hyun- Cheol Chung, *Developments in Cable Broadband Networks*", OECD Digital Economy Papers, No. 170, OECD Publishing, available at: http://dx.doi.org/10.1787/5kmh7b0s68g5-en.

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About.com Video, High-Speed Internet - Cable Versus DSL; available at: http://video.about.com/compnetworking/Cable-Versus-DSL.htm.

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BPL - Broadband over Powerline; available at: http://www.infocellar.com/networks/new-tech/BPL/BPL.htm;

State of New Jersey, Office of the Ratepayer Advocate, Broadband Over Power Lines A White Paper; available at: http://www.state.nj.us/rpa/BPLwhitepaper.pdf;

Chano Gómez, Convergence in Home Networking: Broadband over Powerline and Other Wireline Technologies, powerpoint presentation (Nov. 11, 2009); available at: http://www.ewh.ieee.org/r6/scv/comsoc/Talk_021109_Powerline.pdf;

Byung-Wook Kwon, *Broadband over Power Lines (BPL): Developments and Policy Issues* (2009); OECD Digital Economy, Papers, No. 157; available at: http://dx.doi.org/10.1787/222266878856.

5.7.2 Wireless Access Technologies

Because many nations lack ubiquitous access to new or transitional broadband wireline technologies, wireless options can provide telecommunications access into remote localities. Developing countries typically have the most areas unserved, or underserved by incumbent carriers. Ironically this lack of service can make it possible for the installation of cutting edge wireless broadband technologies that can help developing countries expedite broadband access even in remote areas. Just as wireless technologies made it possible for developing nations to accelerate the availability of voice telephone services into even the most remote and sparsely populated areas, they also can help these nations accelerate broadband deployment, an outcome referred to as "leap forging."

Wireless technologies have the potential to offer faster, cheaper and more widespread installation of broadband services. Using microwave frequencies and an antenna that transmits a 360 degree, "omnidirectional" signal, wireless carriers can cover a contour or circle of land area spanning over 100 kilometers. Wireless network operators do not have to install ducts, conduits and wires to serve each and every subscriber. Instead the omnidirectional signal from a single tower can deliver voice and data traffic to any user within the transmission contour and also any user can communicate with the tower using a small, lightweight handset. Wireless telecommunications technologies have significant initial costs, which are incurred before revenues accrue from service, but the incremental cost of adding a subscriber is low and ongoing operating expenses may be low as well. This means that even with substantial, startup costs, many types of telecommunications and information networks can succeed in the marketplace if additional subscribers do not trigger even higher capital investment and carriers incur relatively low costs in maintaining their network.

The economic term positive network externality refers to the ability of networks to increase in value as more subscribers join. With relatively low incremental costs, carriers and service providers can offer free or inexpensive subscriptions that become more valuable as subscribership grows. Positive network externalities create incentives for more and more users to "join the bandwagon" as evidenced by the success of social networking, auction and ecommerce sites.

Wireless technologies can provide both mobile and fixed services. Cellphone users appreciate the benefits of thetherless mobility, i.e., the enhanced productivity and efficiency made possible by having telephone access anytime and almost anywhere. But for many broadband applications, much of the benefits accrue from access to the Internet cloud regardless whether the user is moving, or at a fixed location. Wireless services use leapfrogging technology in the sense that remote localities lacking any Internet access can secure roughly the same quality of service, previously available only to urban users.

Cellular Radiotelephone Service

Before we examine wireless broadband technologies, some fundamental aspects of how wireless technologies work can offer helpful perspective. Wireless technology made a huge leap in the early 1980s with the introduction of cellular radiotelephone service. Before that time few users of wireless service existed, because the technology was quite expensive, capacity constrained and unable to provide uninterrupted service for more than a few minutes. Before carriers offered cellular service, they used single transmitters that did not connect with other towers to provide continuous service to users moving out of range from the first tower and into range of another one. This meant that a mobile user could only carry on a conversation for a few minutes before losing contact with the tower containing facilities for linking the user with the wireline telephone network. Carriers installed only a few towers operating with limited amount of bandwidth.

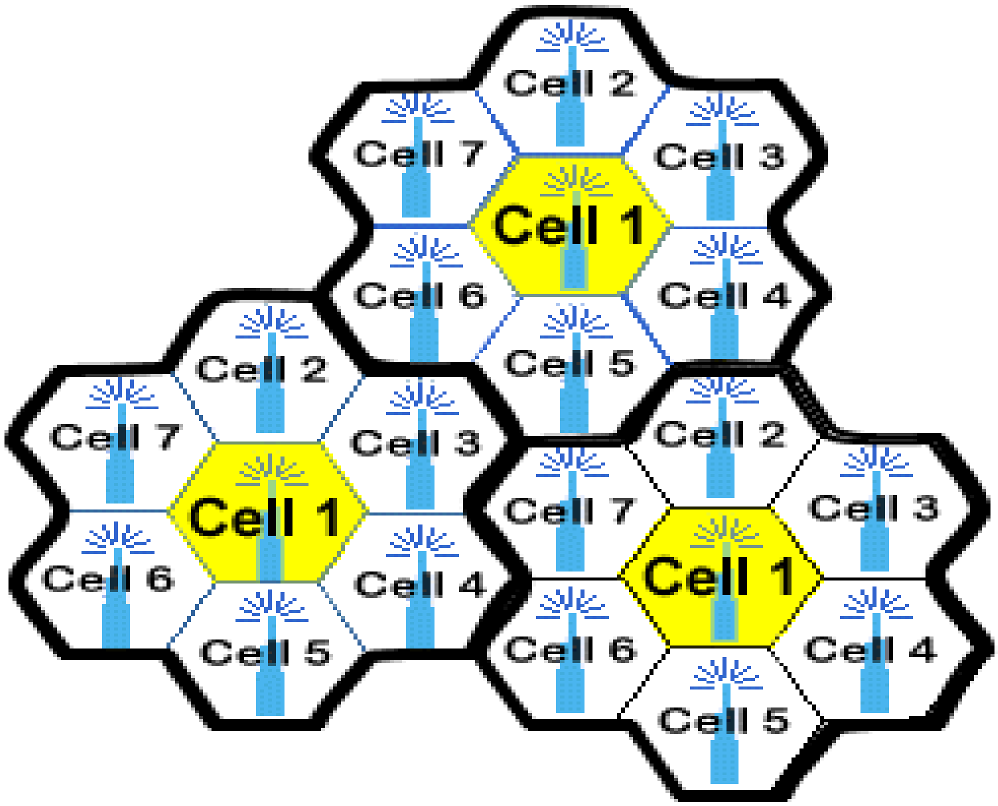
Cellular radio uses more bandwidth and has the capability of reusing high frequencies to support many more simultaneous telephone calls. It also has the ability to hand off calls from one tower to another making it possible for a mobile subscriber to maintain a conversation as the call can be forwarded from tower to tower as the user moves out of range from one and into range of another. Frequency reuse and the ability of manage the hand off of calls from tower to tower makes it possible for cellphone networks to serve many more users, to offer vastly lower rates, given large scale operations, and the ability to provide reliable service for calls running more than a few minutes.

The use of the term cellular refers to the ability of wireless carriers to transmit from overlapping signal contours generated by transmitters on adjacent towers. Cellphone service has been visualized as using the tightly connected hexagonal honeycombs of a beehive to emphasize continuous service achieved through frequency reuse of overlapping cells. In reality the cell contours are circular, but the concept of signal contour integration offering continuous service constitutes an essential component to reliable mobile wireless service.

Frequency reuse makes it possible for carriers to have nearby towers operating on the same frequency without generating harmful interference that would prevent callers and call recipients from hearing each other. Because cellphone networks use very high microwave frequencies, the signals weaken ("attenuate") very quickly and managers can track the geographical coverage of reliable service. At the point whether a single tower service contour starts to deteriorate rapidly a second tower is installed having a slightly overlapping signal contour. At a small distance from the first tower, the cellphone operator can install another tower using the very same frequencies as the first tower, but because of the sharp "rolloff" in signal the transmissions of the first tower do not interfere with a later built tower operating on the same frequencies.

Cellular networks can provide service continuity by using technologies that manage the conversion of frequencies when mobile users move from one tower signal contour to another. The Mobile Telephone Switching Office ("MTSO") constantly monitors the strength of signals from towers to handsets and vice versa. When the signals start to attenuate, due to a user moving away from a tower, the MTSO orders the user's handset to change to the transmitting and receiving frequencies of the adjacent tower. This handoff requires an immediate change in radio frequency and tower communication, sometimes resulting in a "dropped call" when the change does not take place on time.

Frequency Reuse

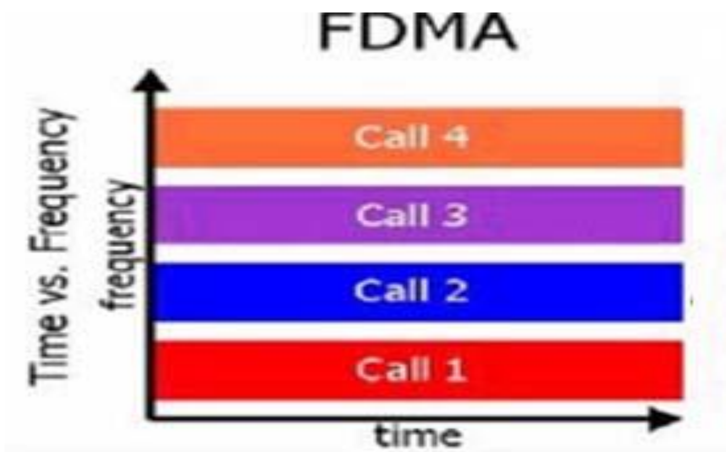


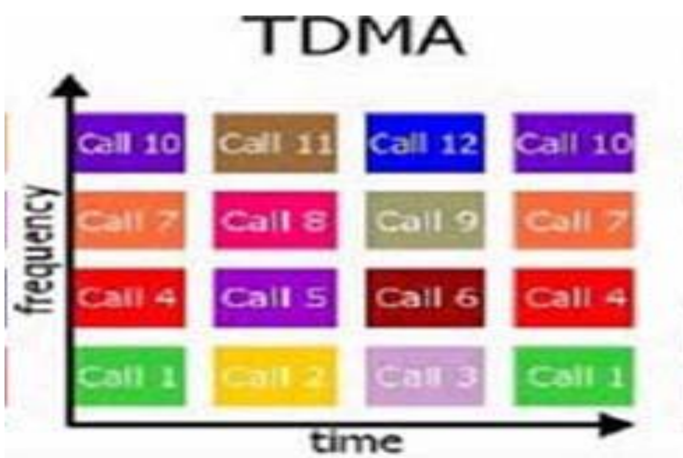
source: GSM Favorites.com, Introduction to Cellular Communications; available at: http://www.gsmfavorites.com/documents/introduction/gsm/

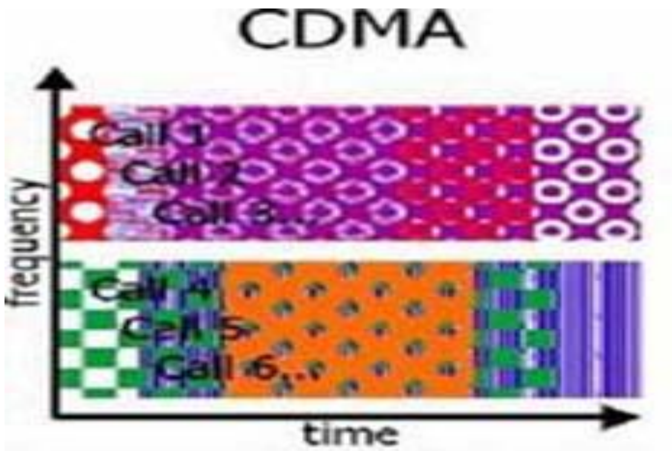
Cellular networks can provide service to vastly more subscribers than previous technologies thanks to more available spectrum allocated by National Regulatory Authorities, frequency reuse and several types of spectrum conservation technologies that make it possible for several users to share the same channel. Cellphone service initially used generously large channels of spectrum available for use by a single subscriber. Over several generations of service cellular networks have increased spectrum efficiency by using transmission technologies that make it possible for multiple subscribers to share the same frequency channel. Time Division Multiple Access ("TDMA") allocates a shared channel among multiple users by assigning very short slots of time. Code Division Multiple Access ("CDMA") allocates a shared channel by assigning users different code sequences. These advanced technologies require handsets that not only can quickly change the frequencies they use ("frequency agility"), but also operate using complex transmission formats that require well calibrated synchronization of use within an assigned time slot, or code sequence.

Handsets have evolved from serving as a radio transmitter and receiver ("transceiver") to the functional equivalent of a powerful, lightweight and radio equipped computer. Smartphones offer a wide versatility of services including the ability to display video content, play music, take pictures and operate as an Internet browser. These devices offer users the option to discontinue or not await wireline telephone service, as well as the opportunity to access most of the Internet cloud content previously available only to full sized computers.

Frequency, Time and Code Division Multiple Access







source: Kyle Bryson, Alison Chen, and Allen Wan, Rice University, ***FDMA vs TDMA vs CDMA: What's the difference?*****; available at: http://www.clear.rice.edu/elec301/Projects01/cdma/compare.html.**

Four Generations of Cellular Service

Sine the middle 1980s, wireless radiotelephone service has evolved in four distinct generations. In the first generation, spanning the middle and late 1980s, cellular radio used analog transmission formats to provide wireless telephony only. Urban subscribers benefitted from efficiency and productivity enhancements, while subscribers in rural and remote areas, many not having any existing telephone service option, enjoyed the benefits of access to the Public Switched Telephone Network.

First generation service used spectrum in the Ultra High Frequency band (400-900 MHz), including frequencies previously allocated for television service. Handsets were heavy and service was expensive. Early adopters of cellular service included users with high incomes, such as doctors, attorneys and bankers, but also service technicians, such as plumbers and electricians who benefitted from the ability to schedule appointments and receive directions without having to stop and look for a wireline payphone.

The second generation of cellphone service (early 1990s) introduced digital transmission technologies and the first spectrum conservation techniques. In the second generation, new spectrum allocations increased available bandwidth in the 1-2 GigaHertz range. At these higher frequencies operators had to install more towers, because of shorter signal range, but the greater frequency reuse opportunities promoted scale in light of the ability to handle many more simultaneous telephone calls.

In the second generation cellphone operators started to introduce new services, such as texting, which retrofitted the existing signal strength monitoring and handset polling function of the MTSO which tracks the location of every operational handset. Whenever a handset is on, it regularly sends a short sequence of numbers and letters to the nearest tower which forwards these identifying sequences to the MTSO so that it can route an inbound telephone call to the proper subscriber and also provide dial tone for one requesting service. Cellphone operators created an extremely low cost and vastly profitable texting service by providing subscribers with the opportunity to key in letters and numbers corresponding to a message instead of a cellphone identification sequence. Texting is limited to about 160 letters and numbers, because that corresponds to the amount of bandwidth and time allocated to each passing opportunity for a handset to send its identification code sequence.

In the third generation (early 2000s) cellular networks acquired the first ability to handle data traffic. Because all types of software, applications and content can get subdivided into small digital units of capacity, wireless networks became a slow speed option for accessing Internet –based content. In the third generation wireless operators retrofitted their networks to handle data traffic commingled with voice calls. Subscribers soon started to rely on so-called 3G networks for Internet access, but they often grew frustrated with the speed at which they could download and upload content that required high bandwidth, e.g., full motion video. 3G networks could readily handle the real time, "streaming" of music and the distribution of web pages, but not the streaming of full motion video and other more bandwidth intensive applications such as some forms of video gaming.

The fourth generation of wireless service has started to offer dedicated high speed data service at bit transmission speeds exceeding what terrestrial DSL offers and rivaling that from some cable modem services. 4G service makes it possible to consider wireless a competitive alternative to many terrestrial, wireline services. The proliferation of handsets, including tablets and lightweight computers, coupled with ever increasing content and software options has stimulated increasing demand for wireless spectrum. Experts disagree on whether and how 4G networks can handle all of the demand for service, particularly if wireline telephone companies opt to discontinue some or all terrestrial wireline services thereby migrating more and more subscribers to wireless options.

5.7.2.1 Traffic Offloading and Other Spectrum Conservation Techniques

In light of extraordinary growth in the demand for mobile services—especially broadband—National Regulatory Authorities cannot readily solve all existing or potential spectrum shortages simply by reallocating more bandwidth. Wireless operators have to come up with strategies for conserving spectrum including ways to offload traffic from their congested towers onto less heavily used frequencies, or higher capacity wireline options. Additionally carriers can treat voice and data traffic differently so that two parallel networks can be optimized to handle each type of traffic. An alternative view anticipates an Internet-driven network where all traffic functions as data, including voice traffic that can be digitized and subdivided into voice packets for processing like other forms of data traffic.

For first and last kilometer local connectivity, wireless carriers have offered retail subscribers the option of installing a device known as a femtocell that operates as a miniature cellphone tower. This device extends the in-building signal penetration of a wireless network, and also can change the frequencies used and even take traffic off the wireless network and place it onto a wired broadband connection. However these devices need to coordinate service with an adjacent tower and the potential exists for interference with other units, as well as dropped calls and lost data packets.

Ironically most wireless carriers initially refused to allow subscribers the option of using their handsets to access alternative networks such as Wi-Fi and competing Voice over the Internet Protocol services. The carriers considered these technologies as depriving them of traffic and network minutes of use. Now that some carriers have offered unmetered service and have experienced network congestion they gladly support the offloading of traffic onto other networks.

The use of femtocells provides an example of how a series of overlapping wireless signals, provided by multiple carriers and transmitters, will cover most locations. Satellites provide the largest service contours covering up to one-third of the earth's surface. Terrestrial wireless networks offer megacells and macrocells covering many kilometers in rural locations, but also microcells serving only a as little as one kilometer in the central business district of a city. Smaller picocell service will cover less than one kilometer with femtocells, Wi-Fi, Bluetooth and sensors covering a few meters, often within a building. Intelligent devices and networks integrate access to multiple networks in a seamless manner offering high quality and reliability. These integrated network are compatible for human interaction, computer to computer communications and an "Internet of Things" incorporating billions of sensors able to monitor the real time condition of people, places, and the environment.

Overlapping Cells With Different Service Contours

Cell Type	**Deployment Scenario**	**Coverage Area (sq. miles)**	**Estimated Capacity (bit per second per Hz per sq. mi.**	**Unit Cost**
Mega-cell	**On mountain top**	**2000-3000**	**.001-.0025**	**$300-500k**
Macro-cell	**On towers or rooftops; 50-200 ft.**	**10-30**	**.10-.25**	**$100-300k**
Micro-cell	**One street poles; 20-30 ft.**	.005-.01	100-200	$10-30k
Pico-cell	**In building with distributed antennas**	**.001-.005**	**1000-5000**	**$50-200k**
Femto-cell	**In building with single low power antenna**	**<.002**	**5000-20000**	**$50-200**

Source: Tolaga Research, *Fixing the Follies of Femtocells* (Aug. 2010); available at: http://www.tolaga.com/pdfReports/femtoReport0810.pdf.

Wi-Fi

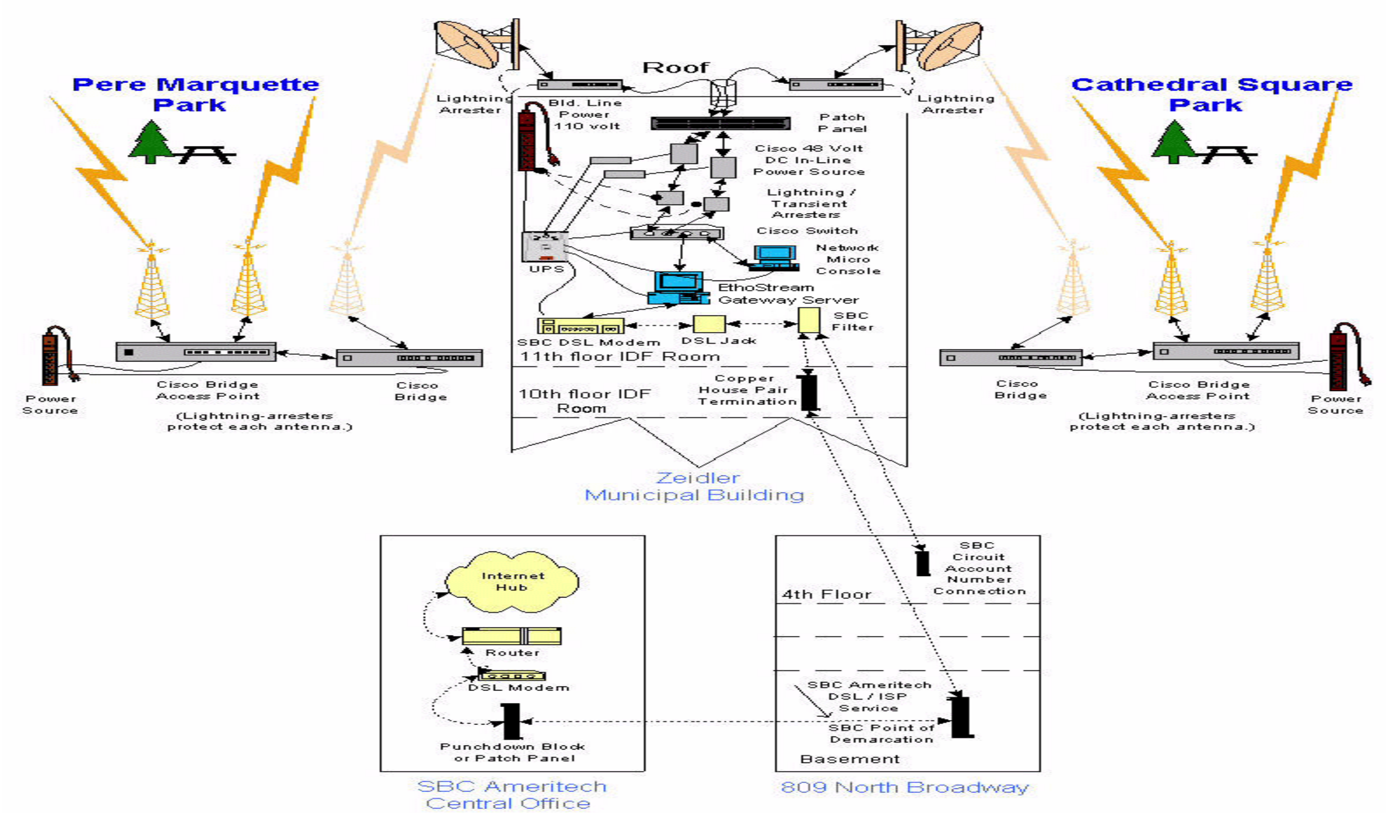
Wireless Fidelity ("Wi-Fi") extends access to a wired or wireless broadband service to multiple users within a small distance. This technology offers an extension of an existing broadband service, such as DSL and cable modem service. In essence Wi-Fi constitutes an "access to access" service, because it extends the accessibility of a usually fixed wireline broadband service to wireless and mobile users within a closed and limited area, e.g., a home or coffee shop. Wi-Fi service typically requires the installation of a wireless router operating on unlicensed microwave spectrum at low transmission power. Computers equipped to transmit and receive Wi-Fi frequencies can communicate with the Wi-Fi router serving as an interface for downloading traffic from the Internet cloud and receiving traffic for uploading to the cloud.

Few business or residential users of Wi-Fi know that they are using microwave radio transceivers, typically operating in the 2.4 and 5 GigaHertz ("GHz") frequency bands, to connect their mobile handsets, tablets and computers to a wired broadband service (Digital Subscriber Line and cable modem) or a wireless broadband service (cellular radio, or possible another microwave network such as Wi-MAX). Wi-Fi provides a very low power, omnidirectional broadband signal that can deliver and receive content originating in the Internet cloud, or playback devices such as a DVD and Compact Disk player.

Wi-Fi is a microwave radio technology that provides a wireless link to various devices that combine with another broadband link for receiving content and for issuing instructions to receive more content, or to upload content. A Wi-Fi receiver and transmitter is typically housed in a device called a router that consumers use to receive and send content. Routers take content previously received from the Internet and forward it onward to untethered devices. Routers also can receive instructions from these wireless devices and forward them to a broadband Internet connection for uplinking to an Internet-based server containing desired content.

Wi-Fi routers typically cost less than $100 USD in part because manufacturers and other stakeholders agreed to use a common set of transmission and operating standards, including the radio frequencies Wi-Fi uses and how signals are formatted. The Institute of Electrical and Electronics Engineers ("IEEE") has created a number of operating standards for wired and wireless Local Area Networks that include Wi-Fi. The Wi-Fi standards are numbered 802.11 and then have several different letters representing succeeding generations of standards typically representing an increase in transmission bitrate. The most recent standard or protocol 802.11n refers to Wi-Fi networks operating in the 2.4 and 5 GHz frequency bands having bit transmission speeds of up to 150 Mbps.

Wi-Fi Network, Milwaukee, Wisconsin



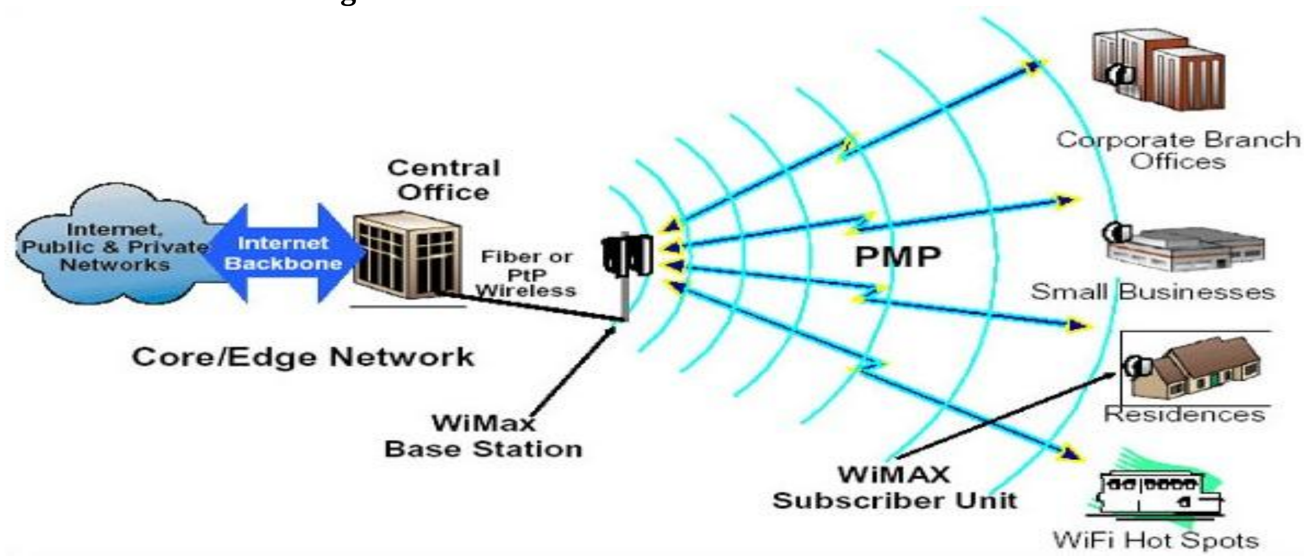
source: City of Milwaukee, Diagram of WiFi Network; available at:
http://city.milwaukee.gov/WiFiDiagram2827.htm

Wi-MAX Network Configuration

Wi-MAX stands for World Wide Interoperability for Microwave Access and it refers to another standards-based (IEEE 802.16) microwave technology, typically operating at 2.5-3.5 GHz frequencies. Wi-MAX can provide backhaul and first and last kilometer broadband service at speeds of up to 30-40 Mbps. The higher bit transmission speed combined with greater signal reach has prompted some observers to deem Wi-MAX "Wi-Fi on steroids." Wi-MAX promoters had expectations that it would provide a competitive alternative to cellular radio services including next generation network standards that also promise vast improvements in bitrate. However, it appears that so-called 4th Generation cellular radio standard Long Term Evolution ("LTE") has overtaken Wi-MAX as the preferred option for extremely high speed, cutting edge wireless broadband service.

Wi-MAX provides the ability to extend Wi-Fi type access over a larger transmission contour and in some instances on a commercial basis using licensed spectrum. However as is the case with Wi-Fi when Wi-MAX network demand grows and as users move farther from a transmitter, actual achieved bit rate speeds decline. In operation Wi-MAX networks typically deliver broadband services ranging from 1-15 Mbps.

Wi-MAX Network Configuration



source: Mechanical Engineering Blog site, What is WiMAX | Worldwide Interoperability for Microwave Access | Next Generation 4G Wireless Technology; available at: http://www.mechanicalengineeringblog.com/947-what-is-wimax-worldwide-interoperability-for-microwave-access-next-generation-4g-wireless-technology/.

5.7.2.2 Reference Documents and Case Notes

For background on how cellular radio telephone service works see:

Indian Institute of Technology, The cellular concept - System Design issues; available at: http://www.youtube.com/watch?v=whYljse4Abc&feature=related.

The concept of frequency reuse is explained at: http://www.youtube.com/watch?v=q2NcUQW4qEY.

Background on the 4th Generation wireless standard known as Long Term Evolution is available at:

http://www.youtube.com/watch?v=NjNf-6zxMPA;

http://www.youtube.com/watch?v=lNQcSgKVhSk; and

http://www.youtube.com/watch?v=XkBDTxn0D-U.

Background on Wi-Max technology is available at: IEEE 802.16 WMAN Resource Center, *What is Wi-MAX*: http://www.palowireless.com/i802_16/wimax.asp.

Background next generation Ultra Wideband networks is available at: Intel, *Ultra-Wideband (UWB Technology) Enabling high-speed wireless personal area networks*, http://www.intel.com/technology/comms/uwb/download/ultra-wideband.pdf;

Ben DuPont, Wireless Mesh Networks: An Introduction; InformationWeek Analytics; download from: http://reports.informationweek.com/abstract/20/7396/Network-Systems-Management/fundamentals-wireless-mesh-networks.html.

Case Studies of Rural Wireless Internet Service Via Wi-Fi and Wi-MAX

Keokuk, Iowa; http://www.youtube.com/watch?v=W3QoYURCvAo.

KwaZulu-Natal, South Africa: http://www.howwemadeitinafrica.com/case-study-connecting-rural-africa-to-the-internet/15624/.

Rural Alberta, Canada: http://www.itu.int/ITU-D/study_groups/SGP_2006-2010/events/Case_Library_old/americas/CANADA-WiMAX-presentation.pdf.

Rural United Kingdom: http://www.youtube.com/watch?v=Q2OgFMUPsRQ.

Malaysia: http://p1.com.my/.

Africa: http://www.columbia.edu/itc/sipa/nelson/newmediadev/WiMax%20And%20Africa.html.

Sri Lanka: http://www.broadband-toolkit.org/; and http://www.itu.int/ITU-D/treg/publications/BB_MDG_SriLanka_Final.pdf.

Background on the cost of installing and operating a Wi-MAX network is available at: http://www.wimaxforum.org/sites/wimaxforum.org/files/document_library/appnote_wimaxbusiness.pdf.

5.7.3 Implementation Issues for Local Connectivity

Most local connectivity projects present challenges in terms of coordination, logistics, access to capital and availability of necessary supporting components such as electricity. In developing nations the challenges may be more significant, because planners may seek to install broadband before other infrastructure projects such as electricity, sanitation and water. For wireless projects in remote locales, spectrum shortages may not present a problem, but the anticipated frequencies must be cleared with National Regulatory Authorities so that no potential interference will occur.

Local wired and wireless broadband project planners do not have to "reinvent the wheel." The World Bank and other organizations have identified best practices with an eye toward providing a template for new projects. For example, in the Dominican Republic the national regulatory authority INDOTEL undertook a multi-phased implementation of broadband connectivity projects requiring first that administrative and legal underpinnings for the project, the nature of the license to be awarded and the contract to be signed are well understood. [25] It also required a number of practical steps be undertaken to ensure successful completion of the project, including assessing demand, running an economic model to determine the maximum subsidy to be offered, implementing a transparent and thorough tender procedure, close supervision of projects, development of dedicated web pages and raising awareness among prospective users.

The Dominican Republic already had enacted laws governing the basis by which INDOTEL would establish regulatory authority, transparent rules on government-sponsored procurements and a universal service funding program. For each prospective project INDOTEL undertook economic analysis of broadband demand as well as a cash flow analysis to determine the net present value ("NPV") and the internal rate of return ("IRR") of the project.

INDOTEL's demand analysis had four categories of review:

1) Collect and analyze secondary data and information such as demographics, the economic situation of households and individuals, geography, traffic and tariffs;

2.) Collect, compile and analyze primary micro-economic data on individual customers, households, companies, institutions, and others by means of questionnaires, interviews and other information gathering tools;

3) Use econometric modeling techniques to determine the demand functions, establish the accuracy of the estimates, and calculate elasticity and other parameters needed to quantify demand. These techniques are used for each type of service, each geographic area, each period of time, for incoming and outgoing calls, payment types, and for different socioeconomic levels; and

4) Evaluate and present the results, including an assessment of their relevance for the aspirations and objectives of the companies and/or institutions that required the demand estimates

INDOTEL also estimated the revenue generating potential of proposed broadband projects with an eye toward identifying how much of a subsidy the government should contribute to make the project viable in light of a projected negative net present value. [26] This process requires estimates of capital investments, recurring operating expenses and maintenance costs. For each project INDOTEL calculated an output based aid ("OBA") subsidy, a direct payment, "to support investments, for example, in rural areas where the cost of construction and service provision combined with limited revenue potential makes the project commercially unfeasible. A key requirement for a one-time OBA-type subsidy is that it results in the establishment of an operation and service provision that should ultimately be self-sustaining and commercially viable." [27]

Governments can decide to provide subsidies based in part on an assessment whether a project only needs preliminary funding to become commercially viable, or whether recurring subsidies are needed. In the latter case, governments typically establish service milestones and conduct audits of operators to ensure that a project meets specified benchmarks and will provide adequate service.

5.8 Practice Notes

African Internet Exchange System

Following adoption of the African Regional Action Plan on the Knowledge Economy ("ARAPKE") framework, the Second Ordinary Session of the African Union Conference of Ministers in charge of Communication and Information Technologies ("CITMC") requested the African Union Commission and the United Nations Economic Commission for Africa to accelerate the implementation of the flagship projects including the development of Internet Exchange Points ("IXPs"). IXPs, also referred to as Internet Exchanges, provide the opportunity for many Internet Service Providers ("ISPs") to hand off and receive traffic at a convenient regional facility instead of having to establish several direct interconnections, or using costly interconnection and traffic management services of other carriers.

The African Internet Exchange System ("AXIS") project aims to create a robust Africa-wide internet system by installing IXPs in nations lacking any such facility, along with five regional internet hubs to serve as many African ISPs as possible. The African Union Commission has received funding from the Luxembourg Agency for Development Cooperation and the EU-Africa Infrastructure Fund. The Internet Society, a non-governmental organization with expertise in the Internet technology, logistics and coordination will assist the African Union to use the funds efficiently. Senegal, Burkina Faso, Burundi, Niger, Namibia and Guinea have been selected as the first countries to benefit from the project. The Internet Society's Africa Interconnection and Traffic Exchange program aims to have 80 percent of local Internet traffic exchanged within Africa by 2020.

Implementation of the AXIS project involves several phases. Before actual construction of facilities representatives of the Information Society visit candidate nations for an IXP with an eye toward explaining the benefits of the facility and how it would operate. These community mobilization and technology training workshops can help explain the cost savings, efficiency enhancing and consumer benefits accruing from having an in-country IXP. IXPs can reduce yearly operating expenses for ISPs, including transiting costs imposed by other carriers. Additionally multiple ISPs can share IXP infrastructure costs reduces . Broadband subscribers benefit by the possibility of lower rates as well as the likelihood of faster service and less latency (delay) in accessing content, particularly that available from regional carriers.

For background on African IXPs and best practices in developing IXPs see:

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EACO Task Force on EAIXP, Report of the Task Force Meeting on East Africa Internet Exchange Points (EAIXPS) Connectivity (May, 2012); available at: http://www.eaco.int/docs/Reports/Report_EAIXP_Connectivity_TaskForce.pdf.

Broadband Decision Tree

Both private and public network planners need to identify which of many broadband technological options best match specific requirements in a particular region or locality, taking into consideration such factors as the terrain, expanse of desired land coverage, population density, level of existing interest in broadband, ability to pay for service and distance from existing service options. Using these and other locality-specific factors, planners can begin to identify which broadband technologies constitute candidates for providing services. Having identified viable technological options, planners subsequently need to assess which one option provides the most cost-effective and efficient solution, taking into consideration whether grants and subsidies are available for projects identified as commercially unviable and unsustainable without one-time, or continuing subsidization.

Broadband network planners can begin to develop a decision tree based on experience gleaned from projects occurring in similarly situated areas. The decision tree below can provide a baseline template.

Preliminary Assessments

Map Existing and Planned Narrowband and Broadband Plant

Before assessing which of many broadband technologies can optimally serve a specific geographical area, planners should map existing and planned infrastructure. Such documentation can help identify specific areas lacking broadband service and also start the process of determining which technological options are feasible and efficient. Broadband mapping also should identify the location of Internet Exchanges, telephone company switching locations, cable television headends, wireless carrier tower sites and existing broadband network locations.

In addition to mapping existing and prospective broadband assets, mapping projects also can identify the population density of locations having some forms of broadband access as well as those areas currently lacking any option. In the unserved areas, population density and geographical terrain will have a substantial impact on what broadband option is both technologically feasible and affordable. For example, in mapping existing broadband backbone network lines, planners can assess whether adjacent areas have sufficient population density to support either extending the backbone, building lower capacity branches, or using wireless networks. Similarly maps that identify the locations of telephone company switching facilities and cable television headends can provide planners with locations possibly served by retrofits of existing plant, e.g., Digital Subscriber Line broadband service to areas having sufficient population density and close proximity to a telephone company switch.

Identify the terrain of the targeted locality or region.

If the terrain has swamps, deserts, mountains and other obstacles, technologies requiring the installation of ducts, poles and towers typically become cost prohibitive. Wireless options—particularly satellite earth stations—will offer the best option based on this criterion. If the terrain supports installation of comparatively low cost ducts, poles and towers wireline options may offer the best option, including construction of a branch, or back haul link to an existing broadband network facility.

Identify the desired terrain coverage area and conduct an analysis of population density demographics and interest in broadband.

Network planners should specify the locality and region targeted for broadband access. The size of the desired broadband footprint and its population density have a significant impact on which technologies can provide the most cost-effective solution. Most targeted locations will have sparsely populations, but some may have the population comparatively more concentrated in villages than others. Generally the more concentrated the population, the greater the likelihood that broadband options can include access from individual residences, or at least multiple facilities, instead of a single access point such as a telecentre or kiosk. Planners should use surveys to assess interest in broadband and willingness to pay for service.

Inventory the nearest wireline and wireless broadband options and estimate the cost to extend them to the targeted locality or region.

While network planners may have to construct "islands" of broadband access, typically using satellite option, they first should determine the distance from the targeted locality to the closest existing broadband access options. Planners should assess whether and how existing networks can extend to the targeted locations. Some technologies, such as DSL, are distance constrained meaning they cannot penetrate farther into the hinterland. Others have no technological limitations, but planners will need to calculate whether a business case can be made for an extension, on an unsubsidized basis, with a one-time infusion of capital, such as a grant, or only with ongoing subsidization.

Broadband Options in Relation to Terrain and Population Density

Broadband planners cannot readily erect a flow chart that specifies which technology to install based solely on population density levels and terrain. However, several basic "rules of thumb" can provide a baseline for analysis of particular circumstances.

Telephone and Cable Television Network Retrofits Typically Offer Timely and Lowest Cost per Prospective Subscriber Passed

Broadband planners wisely opt to retrofit existing telecommunications plant whenever possible. This strategy helps extend the useable life of existing, "sunk investment" and helps conserve capital by reducing the amount of capital expenditures needed to offer a broadband option. Areas already served by terrestrial, narrowband telephone service can include broadband Digital Subscriber Line service with an investment of as few as a few hundred dollars per home passed. Of course the cost of a network retrofit will vary as a function of population density. Also one should appreciate that many remote locations may have wireline telephone service thanks to universal service subsidies and not because the location and population density supported the network installation free of government mandated financial support.

Wireless Options May Offer Cost-effective Service to Locales Lacking Terrestrial Wireline Options

Areas currently lacking cable television or wireline telephone service can be prime candidates for terrestrial wireless network installations. The ongoing buildout of cellular radiotelephone service well into the hinterland corroborates this point. Once a wireless voice network has extended into a specific geographical region, carriers may voluntarily make the additional investment to support broadband options. Targeted government subsidies and other universal service financial incentives can expedite the timetable.

Satellites May Offer the Carrier of Last Resort Option

Even now many geographical areas lack terrestrial broadband access, because the population density, terrain and proximity to existing broadband network assets do not support buildout farther into the hinterland. For these least populated, most remote locations satellite broadband access may constitute the only feasible option. Typically satellite broadband costs more than terrestrial options and may offer comparatively slow bit transmission speeds. Subscribers to satellite service must acquire and install an antenna, receiver and possibly other devices such as a modem. This equipment has become less expensive and smaller over several generations of innovation, but they do add costs typically not incurred by wireline subscribers.

Because the satellite option may constitute the best and only solution for people in quite remote areas, ICT development specialists have devoted much effort at finding innovative ways to economize and to maximize access. For example, rather than install a very small antenna for each subscriber, some communities have installed a somewhat larger satellite antenna capable of serving many users at the same time. The term very small aperture terminal ("VSAT") refers to these satellite dishes that facilitate shared use. A single VSAT antenna linked with a terrestrial wireless delivery medium, such as Wi-Fi or WiMAX can serve an entire village.

Many residents, in remote communities also have limited discretionary income thereby necessitating the search for ICT development grants and subsidies. Typically "community champions" help identify and aggregate demand for broadband with an eye toward demonstrating the viability of a satellite project to private, public and non-governmental organizations with grant money available.

For background on broadband network planning see:

Ole Brun Madsen and Tahir M. Riaz, Aalborg University, Department of Control Engineering, Center for Network Planning *Planning Broadband Network Infrastructure*; available at: http://vbn.aau.dk/files/16623182/Planning_broadband_infrastructure_-_a_reference_model.pdf;

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For case studies on broadband projects see:

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Oxford Internet Inst., Development and Broadband Internet Access in East Africa (March 2010); available at: http://www.oii.ox.ac.uk/research/projects/?id=59;

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InfoDev, Municipal Broadband Networks, Local Open Access Networks For Communities and Municipalities; available at: http://infodev.caudillweb.com/en/Project.85.html;

Broadband Commission for International Development, Case studies on broadband and MDGs (2012); available at: http://www.broadbandcommission.org/work/documents/case-studies.aspx.

For broadband decision tree templates see:

Blandin Foundation, The Community Broadband Development Process; available at: http://www.blandinfoundation.org/_uls/resources/Community_Decision_Tree.pdf;

International Telecommunication Union, ITU News, Drawing up a broadband plan (Sep. 2011); available at: http://www.itu.int/net/itunews/issues/2011/07/22.aspx.

Broadband Mapping

Mapping existing geographical availability of broadband networks constitutes one of the first steps undertaken in formulating a strategic development plan. This inventorying process may seem straightforward, but one should not underestimate the cost and complexity involved in acquiring an accurate assessment of existing installed physical plant. For example the United States federal government allocated $240 million to develop a comprehensive national broadband map as well as maps of individual states. See National Telecommunications and Information Administration, National Broadband Mapping Program, available at: http://www.ntia.doc.gov/legacy/broadbandgrants/broadbandmapping.html.

Best practices include on site and road tests to confirm reported availability as well as the solicitation of reports from end users using in person interviews, online surveys and informal self-reporting, sometimes referred to as crowdsourcing. See Sam Knows, Join our broadband campaign…Sign up with us today to accurately measure your broadband performance, web site, available at: http://www.samknows.com/broadband/signup.

Additionally formal reporting requirements of facilities-based carriers can promote mapping accuracy. Map creators should make their findings readily available and provide consumers with both the opportunity to see what options exist and to provide corrections and updates to incorrect data.

Interactive maps can provide information about broadband access opportunities from businesses and residences as well as information about which community anchor institutions exist in a neighborhood, or locality. Maps also should provide contact information for broadband providers as well as informational about any programs designed to stimulate and subsidize access.

For background on broadband mapping see:

United States National Broadband Map, How connected is my community? available at: http://www.broadbandmap.gov/;

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New Zealand Broadband Map, available at: http://koordinates.com/maps/BroadbandMap/sets/;

Government of South Africa, Ministry of Communications, Broadband Presentation, Nov. 6, 2012; available at: http://www.doc.gov.za/index.php?option=com_docman&task=doc_download&gid=173&Itemid=104;

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Conversion from Analog to Digital Television and the Digital Dividend

The delivery of broadcast, satellite and cable television has migrated, or soon will migrate from analog to digital transmission. While this conversion will impose costs on both operators and viewers significant benefits will accrue including the ability to view a higher quality image and the opportunity for nations to reallocate a significant portion of broadcast television spectrum for other uses including wireless broadband. Because digital television offers a more efficient and higher quality transmission, containing as much as six times more content for display, broadcasters can offer more than one video signal still using a 6 MegaHertz channel. National Regulatory Authorities can group all broadcasters within a smaller range of frequencies thereby freeing up broadcast television spectrum for reallocation.

Digital television will require consumers to replace their existing television sets, or install a device that receives digital signals and converts them back to analog for viewing. New digital television sets can display a higher quality image that increases the number of columns and lines of pixels, the individual and tiny squares of color that combine to form an image. High Definition Television ("HDTV") is typically classified by the number of pixel lines and whether the video image is created in one line-by-line sequence, called progressive scanning, or by the sequencing of even lines in one scan followed by another scan of the odd lines, called interlacing. While standard definition, analog television generated about as few as 350 visible lines of resolution, HDTV offers 1080 lines. HDTV also presents video signals in a ratio of length to width like that occurring in movie theaters. This aspect ratio also makes it possible to reproduce entire movie images when broadcast on television. Previously movie images were cut from a 16 x 9 aspect ratio to 4x3.

The migration from analog to digital television will generate what some call a Digital Dividend, because freed up broadcast television spectrum can expand the amount bandwidth available for current and future broadband wireless networks. In many nations wireless carriers providing broadband services have expressed concerns about a scarcity of available spectrum, particularly for Next Generation Network ("NGN") services that require lots of bandwidth to transmit content, such as full motion video, at bit transmission speeds comparable to wired networks. The reallocated broadcast spectrum offers superior signal transmission characteristics, known as propagation, because of its frequencies are lower than that previously allocated in many nations for wireless mobile services.

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TV Without Borders, An Introduction To Digital TV Technology; available at: http://www.interactivetvweb.org/tutorials/dtv_intro/dtv_intro;

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Gérard Pogorel, Open Society Foundations, *Mapping Digital Media: The Digital Dividend* (April, 2011); available at: http://www.opensocietyfoundations.org/sites/default/files/mapping-digital-media-digital-dividend-20110823.pdf;

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Mohsen Ghommam Malek, Spectrum Arrangement and Digital Dividend (March, 2012); available at: http://www.itu.int/ITU-D/arb/COE/2012/DTV/documents/doc5.pdf;

International Telecommunication Union, Broadcasting: Events; available at: http://www.itu.int/ITU-D/tech/digital_broadcasting/DB_Events.html.

Deep Packet Inspection

As the Internet evolves subscribers will have diversifying network requirements that place different demands on broadband networks. For example, viewers of full motion video will need high bit transmission speeds with little tolerance for delays in delivering such "mission critical" content. On the other hand broadband networks can handle content with less time sensitivity in ways that conserve bandwidth and use network capacity during off peak times. Internet Service Providers ("ISPs") increasingly use technologies that can identify the nature of subscribers' service requirements by inspecting labeling information contained in packets as well as the actual content being transmitted.

Deep Packet Inspection ("DPI") provides ISPs with tools to identify subscribers' bandwidth requirements, to prioritize traffic and to prevent piracy by implementing restrictions on copying content . Some consider this technology controversial, because it equips ISPs with the means to offer different levels of service and to charge for higher quality of service. On one hand offering "better than best efforts" routing can enhance the user experience for subscribers requiring high quality service that conventional "best efforts" routing will not achieve. On the other hand DPI can provide ISPs will many ways to avoid operating as neutral conduits leading some to express concerns that the Internet will become less open and receptive to improvements and innovations.

DPI provides real time monitoring of packets as they travel through an ISP's network. The technology can inspect header information that typically provides information about the source and destination of the traffic. Additionally DPI can examine packet payloads and identify the nature and type of traffic being transmitted. This capability will make it possible to identify "mission critical" content can provide superior service, possibly at a premium rate. However ISPs can also use this technology to prioritize, degrade, or block traffic, not because of network conditions, such as congestion, or even at the request of a subscriber. Under a worst case scenario DPI can provide ISPs with ways to identify traffic so that it can be subject to inferior service with the goal of forcing subscribers or content sources to pay more to achieve a basic level of acceptable service. DPI also raises questions about privacy as ISP and even third parties can use the technology to track and profile online usage.

For more information on deep packet inspection see:
Office of the Privacy Commissioner of Canada, *What is Deep Packet Inspection*; available at: http://www.priv.gc.ca/information/research-recherche/dpi_intro_e.asp;

Syracuse University, <The Network is aware>, Social Science Research on Deep Packet Inspection; available at: http://dpi.ischool.syr.edu/Home.html;

Dr. Milton Mueller, *DPI Technology from the standpoint of Internet governance studies: An introduction* (Oct. 21, 2011); available at: http://dpi.ischool.syr.edu/Technology_files/WhatisDPI-2.pdf;

Duncan Geere, Wired.Co.Uk, *How deep packet inspection works* (April 27, 2012); available at: http://www.wired.co.uk/news/archive/2012-04/27/how-deep-packet-inspection-works;

Christian Fuchs, Centre for Science, Society & Citizenship and Uppsala University - Department of Informatics and Media, *Implications of Deep Packet Inspection (DPI) Internet Surveillance for Society* (July, 2012); available at: http://www.projectpact.eu/documents-1/%231_Privacy_and_Security_Research_Paper_Series.pdf.

Featurephones Smartphones and Tablets

As wireless networks become more sophisticated and able to handle data applications at high speeds, the nature, type and number of useable handsets also will expand. The handsets that transmit and receive wireless signals now range from simple devices designed primarily to provide telephone calls to ones that operate much like portable computers. Generally the cost of handsets increases as the number of functions and available services rises. For wireless subscribers interested primarily in voice communications, as well as the ability to send and receive text messages and photographs, a variety of "featurephones" are available at low cost. These handsets lack many of the news features and either lack the capability, or offer less than optimal access to Internet-based, data services. Some recent vintage feature phones also offer additional features such as personal digital assistant note taking and scheduling, a media player, a touchscreen, Global Positing Satellite GPS navigation and Wi-Fi access. Currently a majority of consumers use feature phones, but near term migration to smartphones will reduce market share, particularly in developed nations.

Smartphones offer far more use options, because manufacturers have installed an operating system with data access in mind. Most smartphones use a mobile operating system created by Google, Apple, Nokia, Research in Motion, and Microsoft. These devices use high performing computer chips and typically have larger screen capable of displaying high definition content, including full motion video. Some smartphone users rely on their wireless connection exclusively for broadband data services, while others continue to maintain subscriptions to both wireless and wireline broadband services. Other smartphone users may never have acquired a personal computer, or laptop before resorting to smartphone access to the Internet.

Tablets offer users an even larger screen and more computer processing power coupled with wireless access that may include both Wi-Fi and mobile radio frequencies. Tablets still offer voice and text communications options, but their size and power favor data communications. Many content providers now offer services optimized for access via tablets and smartphones. These so-called applications accommodate the smaller screen sizes of smartphones and tablets as compared to tablets. Applications also offer fast access to a specific service or function as compared to the possibly larger options available from a world wide web site containing many pages of content.

Feature Phones

source: Floridasportsfishing.com; available at: http://floridasportfishing.com/magazine/pros-tips/01-using-a-mobile-phone-aboard-your-boat.html.

Smartphones

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Hybrid Broadband Using a Combination of Copper and Fiber Optic Cables

Carriers providing terrestrial broadband services typically attempt to upgrade and retrofit existing networks facilities, rather than replace them entirely with costly new technologies such as fiber optic cables. A combination of newly installed glass fiber optic cables and already installed copper wire cables provides an opportunity to extend the usefulness of existing plant and also to reduce the amount of capital investment needed to provide next generation network services. The word hybrid is used to identify networks that combine older “legacy” facilities with newly installed plant. As some future date these hybrid combinations will get replaced with entirely new equipment that can offer even better transmission speeds and capacity. However in the interim time period carriers have found ways to expedite the introduction of networks offering improvements to an all copper wire medium.

Companies providing both basic wireline telephone service and cable television service have devised ways to combine fiber optic cable connections with existing copper wire. The replacement process typically starts between carrier facilities with the last wire replacement occurring for the wire providing the first and last link to individual subscribers.

The term Hybrid Fiber Coax (“FTC”) identifies a network that combines fiber optic and copper coaxial cables. The terms Fiber to the Pedestal (“FTTP”) and Fiber to the Curb (“FTTC”) identify the location where copper wires continue to provide the network delivery. The retained copper wire is located at the point where a network connects directly to an end user, on the curb near a street, or at a frame, called a pedestal, where the wire linking a residence is connected with another copper or fiber optic wire. For residential subscribers the “drop line” leading to and from a residence is located on the property of the subscriber, but typically along a right of way or easement at the edge of the property. The drop line may connect with another copper line, or to the first of many fiber optic links.

At the location where copper and fiber optic cables are connected, the carrier must also install equipment that can convert the transmitted signals from an optical carrier to a copper wire based carrier and vice versa. Telephone companies can extend the reach of their broadband services and increase the transmission speed and capacity by replacing the copper local loop with fiber optic cables also extending close to subscribers. The term Fiber to the Node refers to the installation of fiber optic cables to a switching facility in a neighborhood serving as many as 500 residences. Fiber to the Premises refers to the installation of fiber optic cables all the way to a pedestal serving one subscriber.

Coaxial Cable Pedestal Located on the Edge of a Residential Subscriber's Property

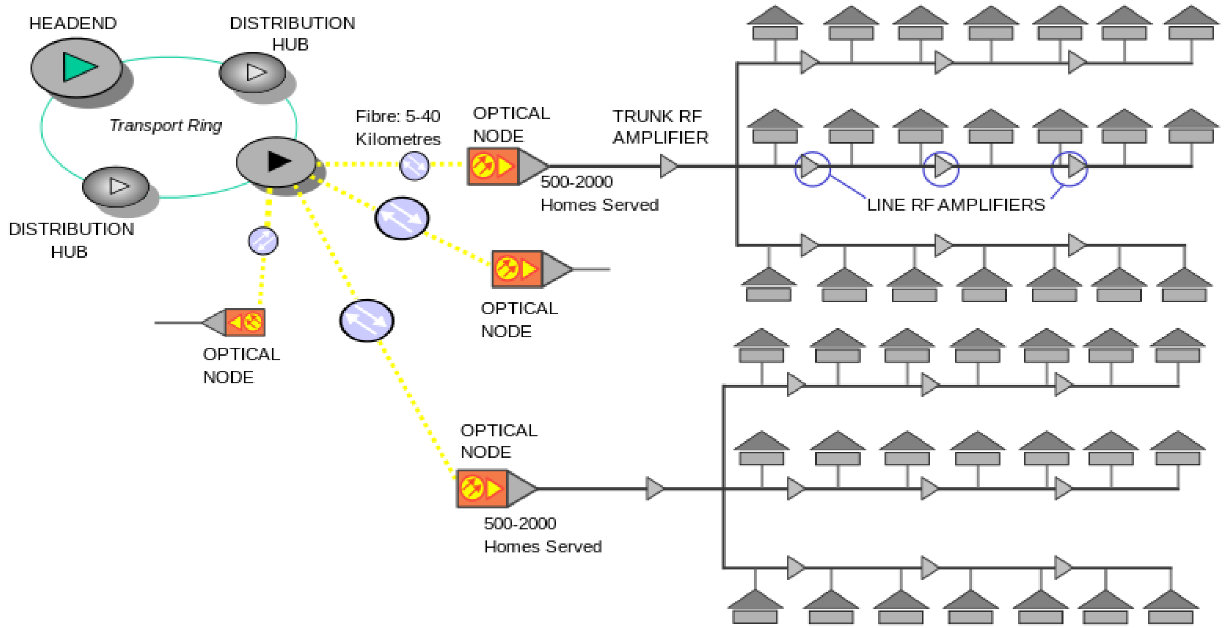
source: Dave Whitmore's Home Page; available at: http://davewhitmore.net/images/field.htm.

Fiber to the Pedestal Installation

Figure 1. The rear view of this fiber distribution hub shows the splice trays and an option for hardened drop cables.

source: OSP Magazine; available at: http://www.ospmag.com/issue/article/fiber-right.

Hybrid Fiber-Cable Distribution



source: Wikipedia; available at: http://en.wikipedia.org/wiki/File:HFC_Network_Diagram.svg.

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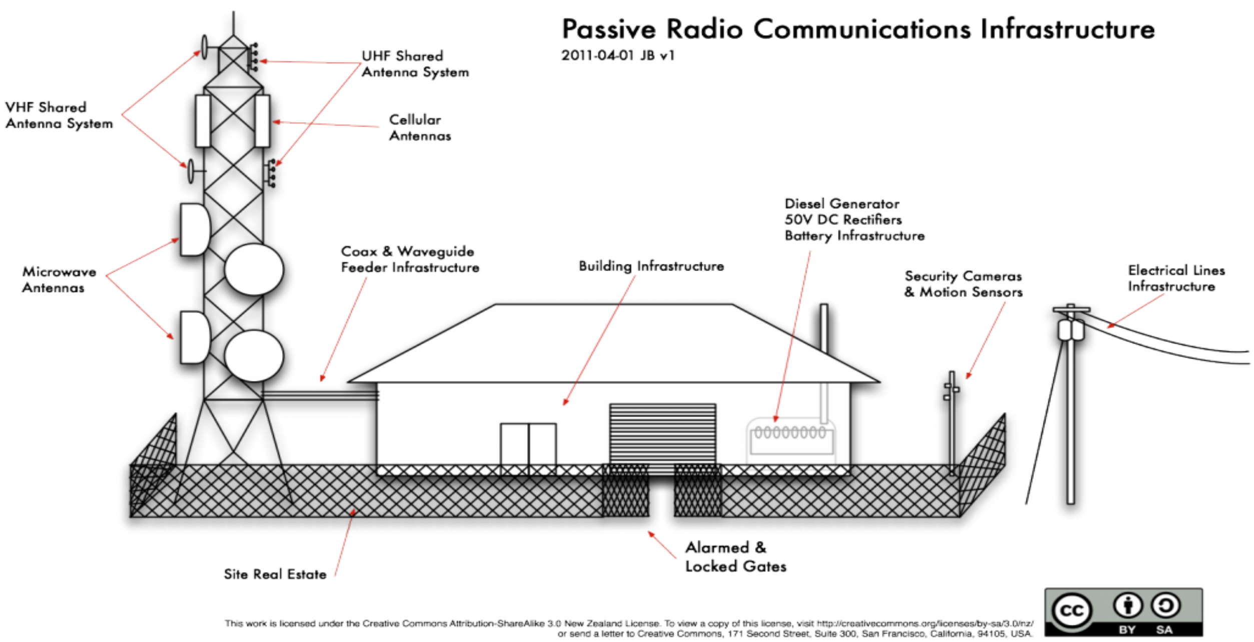
Infrastructure Sharing

Broadband service providers can share the cost of installing and maintaining infrastructure in ways that promote competition, operating efficiency and universal service. When multiple operators can spread the investment costs over a larger base of users, they can achieve scale economies represented by lower per unit costs of essential elements of service. Additionally consumers can benefit when infrastructure sharing helps expand the coverage area that carriers can afford to serve.

Infrastructure costs are comprised of capital expenditures in the physical plant needed to provide service, operating expenditures needed for ongoing service and the interest and other expenses operators incur when they borrow funds to invest in new infrastructure. Infrastructure costs also divide into passive and active elements. Operators can share passive elements without affecting their ability to differentiate service and market their offerings as superior.

Passive elements constitute the civil engineering and non-electronic elements of infrastructure including: physical sites, poles and ducts, power supplies, trenches, towers and masts, splitters, shelters, air conditioning equipment, diesel and other forms of backup power generators including batteries, and the premises easements and other authorizations to own or lease property. Because passive elements do not directly transmit content shared management of these resources does not impact coverage or capacity of a broadband network.



When operators share active elements they cooperate in the use and cost recovery of components such as spectrum, copper wire and fiber optic lines. Such sharing raises more difficult coordination and cost sharing issues and may also trigger regulatory matters such as who shall serve as the holder of any required license, how will that licensee represent the interests of all parties before the regulatory agency and how to ensure that a dominant carrier does not use sharing to handicap smaller competitors.

For more background on infrastructure sharing see:

Ashish Narayan, *Infrastructure Sharing: Need, Scope and Regulation*. powerpoint presentation at ITU Asia Pacific Centres of Excellence Training Course On Infrastructure Sharing, Aug. 31, 2010 Hotel Pullman, Bangkok, Thailand; available at: http://www.itu.int/ITU-D/asp/CMS/ASP-CoE/2010/InfraSharing/S1.pdf;

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available at: http://www.itu.int/wsis/c2/docs/2008-May-19/mdocs/C6-session3-Gupta.pdf;

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download.php?filename=2011_tel_Survey_Report_on_Infrastructure_Sharing_in_APEC_Region.pdf&id=1184.

Integrating Femtocell and Wi-Fi Coverage in Residences and Beyond

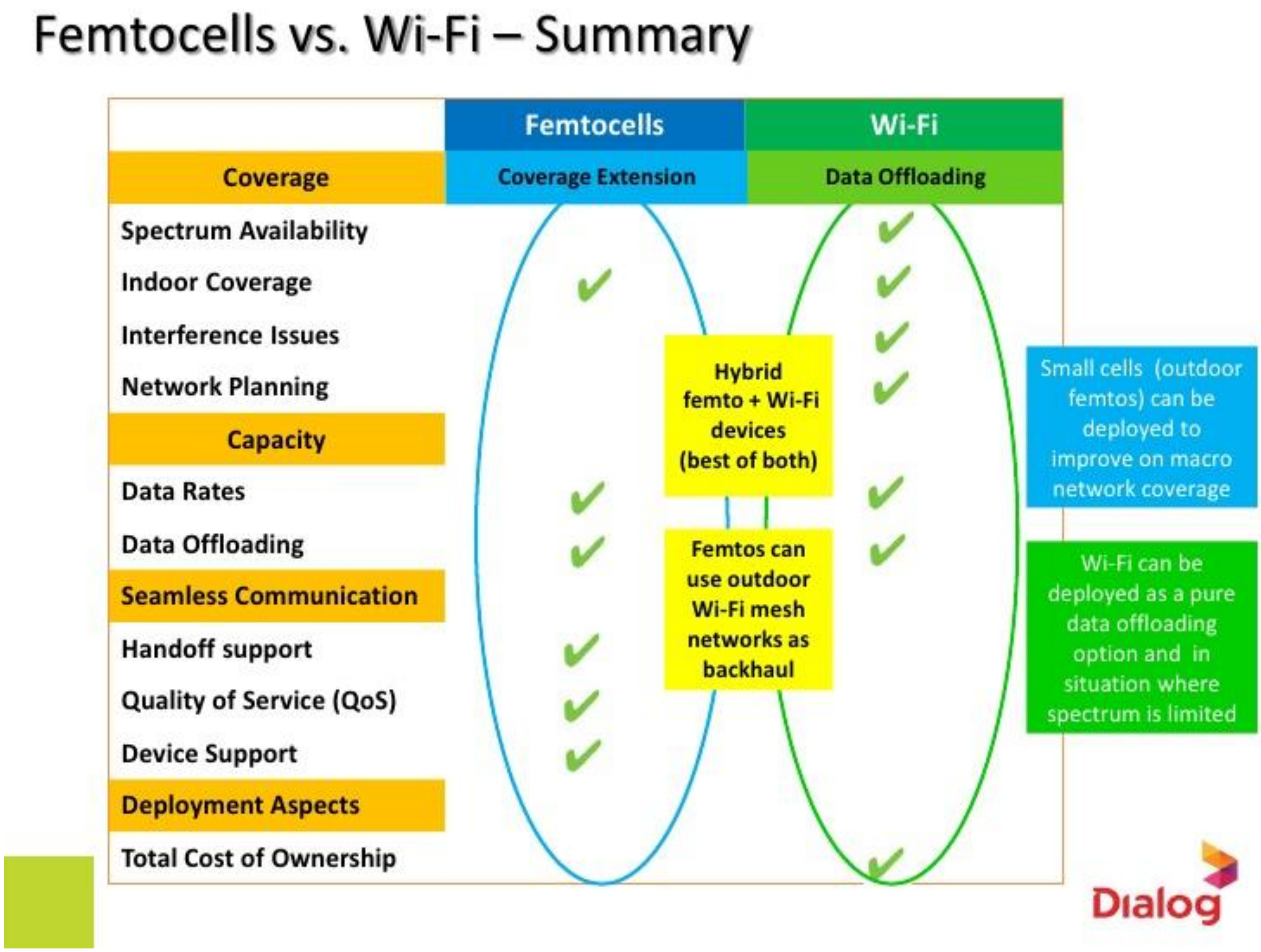
Currently some residential broadband subscribers have the option of using two separate wireless devices to extend the range and accessibility of their service. A Wi-Fi router provides access to more than one computer, tablet and smartphone by sharing a single broadband subscription available to any device equipped with a small receiver and transmitter operating on Wi-Fi frequencies, typically 2.4 GHz and 5 GHz. Wi-Fi routers assign addresses to each computing device to avoid data stream collisions. To avoid interference between computing devices, which might operate in close proximity to each other, these routers also assign different frequency channels to each device.

At residences wireless broadband subscribers also might install a small femtocell that operates as a low-powered base station to improve network accessibility. Mobile wireless broadband services operate on very high frequencies that partially bounce off walls and other obstructions instead of penetrating them. To improve in-building signal penetration some wireless carriers offer subscribers the option of installing a device that receives weak incoming wireless signals, amplifies them and retransmits them inside a building. Subscribers with mobile radio handsets communicate with the nearby femtocell instead of the closest available network tower that might have a location far from the residence.

Integrating the femtocell and Wi-Fi devices with a subscriber's wired broadband service has the potential to generate benefits to both carriers and their subscribers. Wireless carriers can install a specific type of femtocell designed to interconnect with their subscribers' wireline broadband service that might be offered by an affiliate of the wireless carrier, or by another carrier. By connecting the femtocell with a wired broadband connection, the wireless carriers can offload subscriber traffic that otherwise would travel through the femtocell and onto the wireless carrier's network. The wireless carrier can reduce its volume of traffic and the potential for network congestion by routing traffic originating and terminating at residences via an available wireline broadband connection instead of the wireless connection. Subscribers benefit by having a more reliable service capable of delivering high bandwidth intensive applications such as full motion video.

In the future manufacturers will combine the femotocell coverage extension function with the Wi-Fi ability to offload data from wireless to wireline networks and perhaps more importantly from one type of wireless network to another. This device also will provide the necessary modem function so that both wireless and wireline routing options are available depending on current network conditions.

Additionally wireless operators may plan on combining their 4G networks with small cell configurations using Wi-Fi frequencies. Rather than offload broadband traffic onto a wired carrier's network the wireless carrier can assign traffic to either its 4G network, or localized Wi-Fi small cells based on the nature of the traffic to be delivered and the potential for congestion. Carriers might install the small cell option in places where high demand and the potential for congestion is likely, such as shopping malls, stadiums, university campuses and public transportation like airports and train stations.



source: Pradeep De Almeida, How Wi-Fi and Femtocells Complement One Another To Optimize Coverage and Capacity (May, 2012); available at: http://www.slideshare.net/zahidtg/how-wifi-and-femtocells-complement-one-another-to-optimise-coverage-and-capacity.

For more information on femtocell-Wi-Fi integration see:

Cisco, *Architecture for Mobile Data Offload over Wi-Fi Access Networks* (2012); available at: http://www.cisco.com/en/US/solutions/collateral/ns341/ns524/ns673/white_paper_c11-701018.pdf;

4G Portal.com, Mobile data offloading: Femtocell vs. WiFi – tutorial (Nov. 27, 2012); available at: http://4g-portal.com/mobile-data-offloading-femtocell-vs-wifi-tutorial;

OECD, Directorate for Science, Technology and Industry, Committee for Information, Computer and Communications Policy, Working Party on Communication Infrastructures and Services Policy, *Fixed and Mobile Networks: Substitution, Complementarity and Convergence* (Oct. 8, 2012); available at: http://search.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=DSTI/ICCP/CISP(2011)11/FINAL&docLanguage=En;

Pr. Sami Tabbane, Wireless Broadband Network Planning & Carrier WiFi and 3G Data Offload (September 2012); available at: http://academy.itu.int/moodle/pluginfile.php/38891/mod_resource/content/1/Wireless_Broadband_Network_planning_Wifi_offload_v4_ST.pdf.

Internet of Things

Currently the Internet provides a medium for the transmission and processing of information created and used by humans. Computers, servers and other devices store, switch and transmit the information, but human involvement must occur in one or more instances. The Internet of Things refers to the prospect for the creation of data by devices, such as sensors, that do not involve humans in the collection, processing, storage and even interpretation of the information:

> [T]he predictable pathways of information are changing: the physical world itself is becoming a type of information system. In what's called the Internet of Things, sensors and actuators embedded in physical objects—from roadways to pacemakers—are linked through wired and wireless networks, often using the same Internet Protocol (IP) that connects the Internet. These networks churn out huge volumes of data that flow to computers for analysis. When objects can both sense the environment and communicate, they become tools for understanding complexity and responding to it swiftly. What's revolutionary in all this is that these physical information systems are now beginning to be deployed, and some of them even work largely without human intervention. [2]

The Internet of Things requires physical objects to have the ability to identify themselves and regularly transmit data measurements via the Internet. Tiny measurement devices, commonly referred to as sensors, can operate in a variety of hostile, mobile and other environments where ongoing human monitoring would be impossible or too expensive. For example, monitors can be installed under or on the skin of people so that medical data, such as heart rate, blood pressure and glucose levels, can be transmitted on an ongoing basis. So long at the reported data does not fall above or below a prescribed level the receiving computer would collect the data and do nothing more with it. However should the reported data exceed set parameters the computer could have programmed instructions to issue and alert triggering human intervention.

Device miniaturization, wider and cheaper Internet access and drastic drops in the cost of data storage make it possible for computer and network intelligence to become part of new networks serving households and businesses. Significant operating efficiency gains can occur, because regular monitoring can occur automatically and frequently without human intervention. For example, a utility company can measure power demand on an immediate, "real time" basis, rather than send meter readers to make monthly on-site visits to each subscriber. With immediate power demand information, utility management and programmed computers can use price changes to stimulate or retard demand and better avoid outages.

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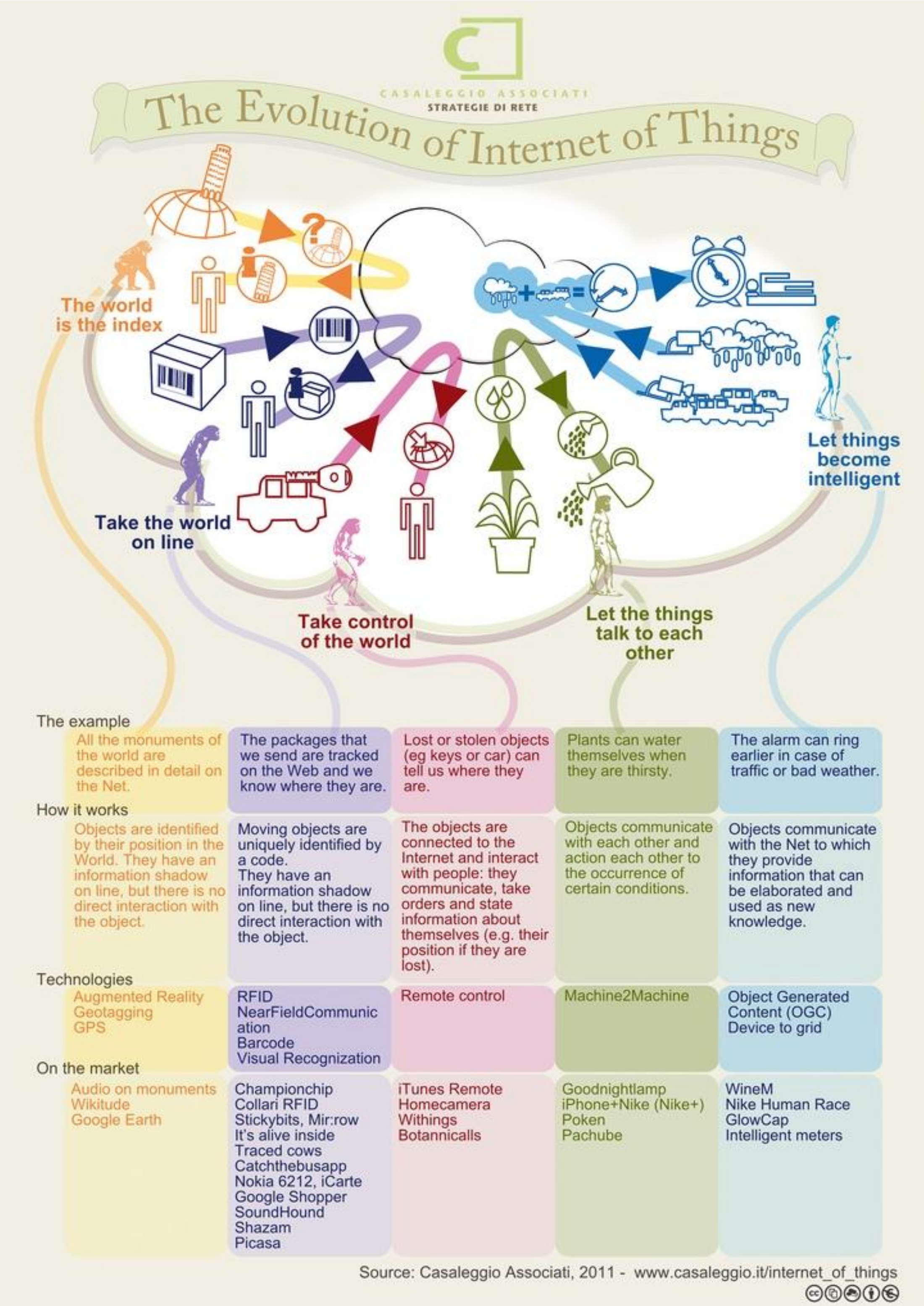
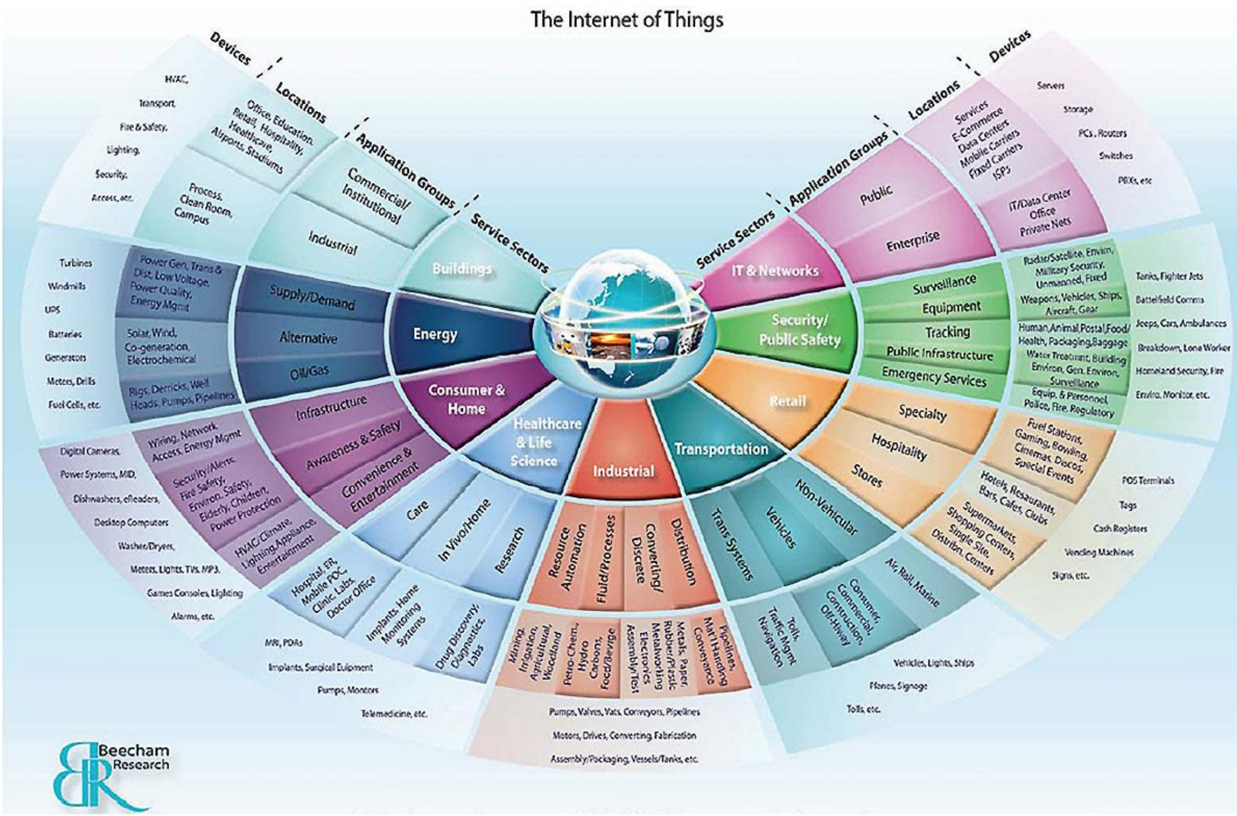
[2] Michael Chui, Markus Löffler, and Roger Roberts, McKinsey Quarterly (March, 2010); available at: http://www.mckinseyquarterly.com/The_Internet_of_Things_2538.


CASALEGGIO ASSOCIATI
STRATEGIE DI RETE
The Evolution of Internet of Things
The world is the index
Take the world on line
Take control of the world
Let the things talk to each other
Let things become intelligent
The example
All the monuments of the world are described in detail on the Net.
The packages that we send are tracked on the Web and we know where they are.
Lost or stolen objects (eg keys or car) can tell us where they are.
Plants can water themselves when they are thirsty.
The alarm can ring earlier in case of traffic or bad weather.
How it works
Objects are identified by their position in the World. They have an information shadow on line, but there is no direct interaction with the object.
Moving objects are uniquely identified by a code. They have an information shadow on line, but there is no direct interaction with the object.
The objects are connected to the Internet and interact with people: they communicate, take orders and state information about themselves (e.g. their position if they are lost).
Objects communicate with each other and action each other to the occurrence of certain conditions.
Objects communicate with the Net to which they provide information that can be elaborated and used as new knowledge.
Technologies
Augmented Reality
Geotagging
GPS
RFID
NearFieldCommunication
Barcode
Visual Recognization
Remote control
Machine2Machine
Object Generated Content (OGC)
Device to grid
On the market
Audio on monuments
Wikitude
Google Earth
Championchip
Collari RFID
Stickybits, Mir:row
It's alive inside
Traced cows
Catchthebusapp
Nokia 6212, iCarte
Google Shopper
SoundHound
Shazam
Picasa
iTunes Remote
Homecamera
Withings
Botannicalls
Goodnightlamp
iPhone+Nike (Nike+)
Poken
Pachube
WineM
Nike Human Race
GlowCap
Intelligent meters
Source: Casaleggio Associati, 2011 - www.casaleggio.it/internet_of_things



source: Beecham Research; available at: http://blogs.cisco.com/wp-content/uploads/beecham_research_internet_of_things.jpg.

For more information see:

Internet of Things Europe, Web site; available at: http://www.internet-of-things.eu/;

Dave Evans, *The Internet of Things How the Next Evolution of the Internet Is Changing Everything* (April, 2011); available at: http://www.cisco.com/web/about/ac79/docs/innov/IoT_IBSG_0411FINAL.pdf;

Keller Easterling, An Internet of Things, e-flux; available at: http://www.e-flux.com/journal/an-internet-of-things/;

Cisco, Internet of Things, available at: http://www.cisco.com/en/US/solutions/ns1168/internet_of_things.html;

International Telecommunication Union, ITU-T Technology Watch Report 4, *Ubiquitous Sensor Networks*, (Feb. 2008); available at:

http://www.itu.int/dms_pub/itu-t/oth/23/01/T23010000040002PDFE.pdf;

OECD, *Machine-to-Machine Communications: Connecting Billions of Devices* , OECD Digital Economy Papers**,** No. 192, OECD Publishing; available at: 10.1787/5k9gsh2gp043-en;

Intel, Postscapes, Tracking the Internet of Things, Infographic: Intel Internet of Things; available at: http://postscapes.com/infographic-intel-internet-of-things;

Joel Young, Simplifying the Internet of Things (Jan. 31, 2013); available at: http://www.youtube.com/watch?v=W_T0ZQlpoBg;

Web of Things Blog site; available at: http://www.webofthings.org/.

OECD , *Building Blocks for Smart Networks*, OECD Digital Economy Papers**,** No. 215, OECD Publishing; available at: 10.1787/5k4dkhvnzv35-en;

Yong-Woon Kim, A standardization initiative on Sensor Networks in JTC 1 SC 6 - including Visions for Ubiquitous Sensor Network (Aug. 4, 2008); available at: http://www.itu.int/dms_pub/itu-t/oth/15/05/T15050000010005PDFE.pdf;

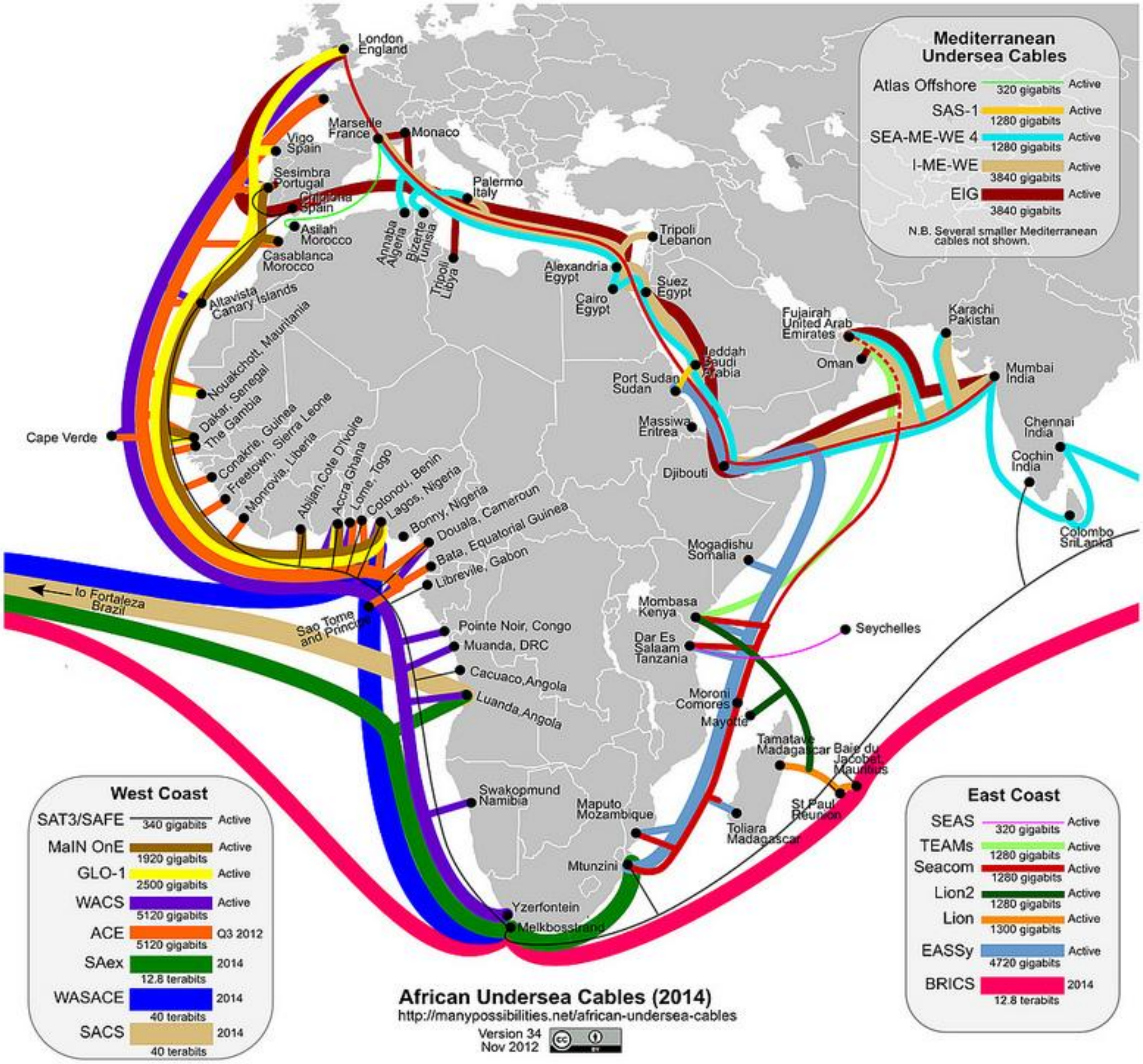
Google Glass, Worldwide web site; available at: http://www.google.com/glass/start/.

New African Submarine Cables

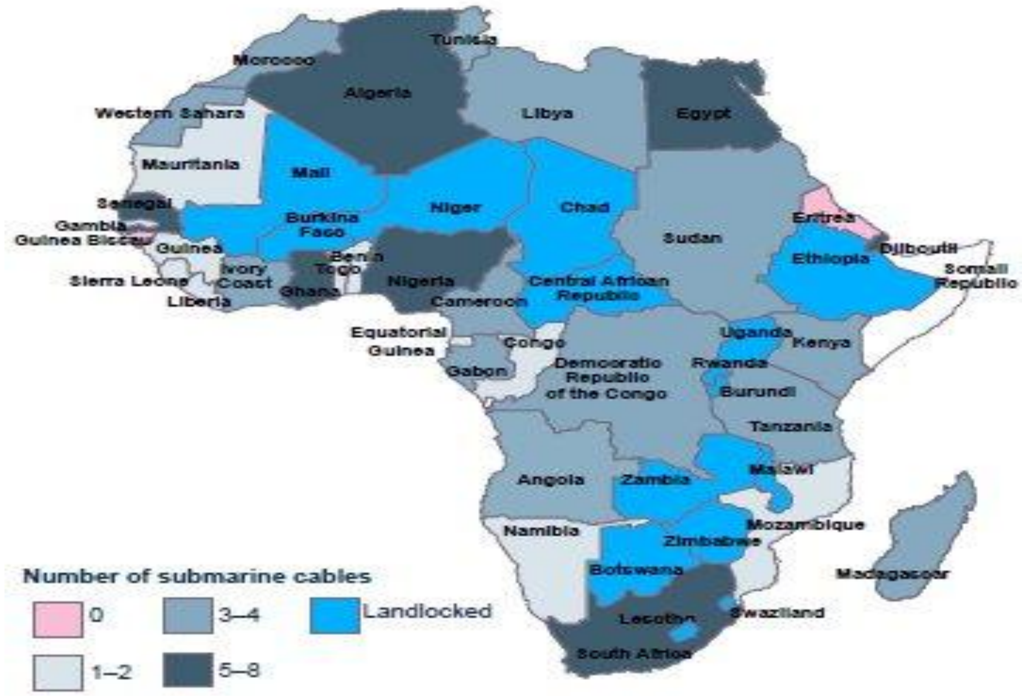
As never before, residents throughout the continent of Africa have access to high speed fiber optic cables including several submarine cables that link Africa with other transoceanic cables traversing the world. African submarine capacity divides between west and east coast systems. On the west coast the SAT-2 cable provided the first available bandwidth in 1993 followed by the SAT-3/SAFE cable in 2002. Between 2010 and 2012 four new systems began service: Glo-1 and Main One Main Street Technologies in 2010 and Africa Coast to Europe ("ACE") and the West Africa Cable System ("WACS") in 2012. WACS offers a 14,000 kilometer route from South Africa to Portugal and the United Kingdom with a total bit transmission speed of 5.12 Terabits per second. The ACE cable follows a serving 21 landing points in Africa.

On the east coast of Africa the East Africa Marine System delivered the first fiber optic submarine cable capacity in 2009. The Seacom cable, launched in 2009, provides connectivity between the east coast of Africa onward to Europe and India. The key markets served are: Tanzania, Kenya, Uganda, Mozambique, South Africa and Rwanda. The East Africa Submarine Cable System ("EASSy") started operations in July 2010, providing a 10,800 kilometer fiber optic pathway running from Sudan to South Africa. This $263 million project has a total capacity of 3.84 Terabits per second divided into lines currently offering up to 30 Gigabits per second transmission speed. There are nine landing stations in South Africa, Madagascar, Mozambique, Comoros Islands, Tanzania, Kenya, Somalia, Djibouti and Sudan.

Existing and Planned Submarine Cables in Africa



Number of Submarine Cables Available by African Nation



source: Analysys-Mason; available at: http://www.oafrica.com/uploads/analysys-mason-submarine-cables.jpg.

For background on African submarine cable projects see:

Michael Kende, *Terrestrial Capacity: From Cape Town to Cairo – Reality or Illusion* (Aug. 23, 2012); available at: http://www.internetsociety.org/sites/default/files/images/Analysys%20Mason%20Cross-Border%20data.pdf;

Mike Last, *EASSy: a status report* (2010); available at: http://ei-africa.eu/wp-content/plugins/alcyonis-event-agenda//files/EASSy_(the_East_African_Submarine_Cable_System)_-_Eastern_Africa_Future_Digital.pdf;

Hamilton Research, Africa Bandwidth Maps; available at: http://www.africabandwidthmaps.com/?page_id=958;

Aidan Baigrie, *The Role Submarine Cables can play in the Interconnection of Africa's Internet*, (Aug. 2012); available at: http://www.internetsociety.org/sites/default/files/images/AfPIF%20August%202012%20v3.0%20%28AB%2021%20Aug%2012%29.pdf;

Eric M. K. Osiakwan, *State of Fiber Infrastructure in Africa* (2012); available at: http://euroafrica-ict.org/wp-content/plugins/alcyonis-event-agenda//files/State_of_fiber_infrastructure_in_Africa.pdf.

Powering Remote Broadband Access

Access to broadband facilities in remote areas often requires consideration on how to install and maintain other necessary infrastructure such as a reliable source of electrical power. A major challenge to rural connectivity lies in the lack of a “last mile” infrastructure providing a link to a regional or national backbone network. Telecenters and broadband kiosks may not have a direct link to the power grid and therefore must have a sustainable, self-contained direct source. Power options include rechargeable batteries, solar power, diesel/gas generators, micro-hydroelectric dams and small windmills.

Solar-powered charging station at the Jokko Telecenter, Senegal.

Source: Joko Initiative Blog site (October 12, 2010); available at: http://jokkoinitiative.blogspot.com/2010/10/soon-to-be-implemented-in-south-senegal.html.

For background on rural power generation options see:

Dean L. Mulozi, *Rural Access: Options and Challenges for Connectivity and Energy in Zambia*, International Institute for Communication and Development, Zambia Association for Advancement of Information and Communication Technology (Jan. 2008); available at: http://www.iicd.org/files/Zambia-Rural-Access-Report.pdf;

Barbara Fillip and Dennis Foote, *Making the Connection: Scaling Telecenters for Development*, Chapter 6: Identifying Appropriate Technologies, 6.2. Technology Packages, Academy for Educational Development (March, 2007); available at: http://connection.aed.org/main.htm;

Rio Tapajós (Brazil) Telecenter Installation Project Web site; available at: http://endruralpoverty.org/what-we-do/projects/pastprojects/brazil-telecenter-project-;

SolarCubed and the Solar-Computer-Lab-in-a-Box, Blog entry at ICT4D Views from the Field (June 24, 2012); available at: http://ict4dviewsfromthefield.wordpress.com/2012/06/24/introducing-solarcubed-and-the-solar-computer-lab-in-a-box/;

PISCES Project Provides Solar Powered Wifi to Remote Islands, Blog entry at ICT4D Views from the Field (August 4, 2012); available at: http://ict4dviewsfromthefield.wordpress.com/2012/08/04/pisces-project-provides-solar-powered-wifi-to-remote-islands/.

Satellite Backhaul

Satellites provide broadband network access to and from local distribution facilities located in the most remote areas as well as locations where topography restricts connection to backbone networks and when emergency telecommunications is needed. The satellite option typically triggers high operating costs with comparatively slower transmission speeds and problems with latency, transmission delays due to the length of time it takes to transmit and receive signals to and from satellite operating as far as 22,300 miles from earth.

Despite their limitations satellites may provide the only viable means for users in the remote locations to access the Internet cloud. Best practices in satellite backhaul address how to build and maintain facilities in a timely and efficient manner, taking into consideration particular site requirements such as the need for a reliable power source where no installed grid access option exists.

Recent developments in satellite backhaul include the installation of smaller sized satellite dishes that operate in the 20-30 GigaHertz, Ka-band. These "[s]atellites can use more spot beams. Rather than broadcast the same signal across their whole footprint, the satellites can reuse the spectrum many times over because they have been fitted with a number of small spot beam antennas for specific geographic coverage. The same spectrum can be reused in every second spot beam. This greatly increases the overall system capacity and total throughput available." [3]

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[3] Interview with Richard Deasington, iDirect, on the changing face of satellite backhaul for small cells (Feb. 13, 2013); available at: http://www.thinksmallcell.com/Femtocell-

"The second major advance has been the change from using dedicated bandwidth to packet switched architecture.

- The older fixed capacity allocation method [Single Channel per Carrier] left bandwidth unused, wasting system capacity that could have been used elsewhere. Allocating bandwidth on demand means that statistical multiplexing gains can increase total system capacity by anything from 30 to 80%.

- Rather than pay for a fixed bandwidth link, regardless of how much of it is being used, satellite operators can be more creative in their tariff plans, and for example, they can charge on usage rather than on a fixed capacity basis.

- For small cells, where there are potentially thousands of sites to be connected, it doesn't make economic sense to use dedicated bandwidth, so solutions that can centrally manage bandwidth will be used." [4]

For background on satellite backhaul see:

Asia-Pacific Satellite Communications Council, Newsletter, Second Quarter 2012; available at: http://www.apscc.or.kr/upload/pdf/Q2%202012.pdf;

Comtech EF Data Corporation, *Challenges & Opportunities for 3G Backhaul over Satellite* (May 2011); available at: http://www.comtechefdata.com/files/articles_papers/WP-Challenges-Opportunities-for-3G-Backhaul-over-Satellite.pdf;

Julian Bright and Dimitris Mavrakis, *Satellite backhaul for rural small cells* (2012); available at: http://www.informatandm.com/wp-content/uploads/2012/04/iDirect-White-Paper_online.pdf.

Interview/interview-with-richard-deasington-idirect-on-the-changing-face-of-satellite-backhaul-for-small-cells.html.

[4] *Id*.

Types of 4G Wireless Service

The latest generation of wireless networking offers the promise of bit transmission speeds that rival what wired terrestrial systems can offer. So-called 4G networks represent the fourth major technological change in wireless networking with dedicated bandwidth for data services and transmission formats conducive to very fast broadband service. The preceding generations did not offer networks optimized for data services and accordingly offered significantly slower transmission speeds. 1G service offered analog voice services and no data. 2G services offered a digital transmission format, but no special accommodation for data services. In the third generation, wireless carriers retrofitted their voice networks to handle data services, but the bit transmission rate rarely exceeded 200-400 kilobits per second.

While the 4G networks currently in operations do not fully comply with the transmission speeds identified in international standards, these networks, providing Long Term Evolution ("LTE") regularly offer speeds between 5 and 12 megabits per second ("Mbps"). The International Telecommunication Union official standard for 4G, the International Mobile Telecommunications Advanced (IMT-Advanced) specification, establishes a peak transmission speed standard for 4G service at 100 Mbps for high mobility communication (such as from trains and cars) and 1 gigabit per second ("Gbps") for low mobility communication (such as pedestrians and stationary users).

The IMT-Advanced 4G specification establishes a number of operating standards including the use of Internet Protocol, packet switching instead of formats primarily suited for voice communications. Networks must efficiently use available bandwidth both in terms of supporting shared use of the same channel by multiple users and the ability to scale up the use of allocated bandwidth as demand grows. Carriers use Orthogonal Frequency-Division Multiple Access ("OFDMA") technology that divides available bandwidth into many channels and also multiplexes data streams into multiple pieces, each of which is modulated onto a separate carrier which are later combined.

Another spectrum efficiency requirement imposes a minimum rate of how many bits can be transmitted per channel and by each individual transmission cell. The standard also requires that all network operators can handle the traffic of other carriers thereby eliminating format incompatibility as exists between 3G networks that operate on the same spectrum, but use different transmission formats, e.g., Time Division Multiple Access versus Code Division Multiple Access. 4G carriers also have to provide subscribers with the ability to transmit and receive data that represents full motion video and high fidelity sound.

It appears that the LTE format for 4G service has become the consensus standard in light of the decision by many carriers to purchase and install 4G equipment. Previous a significant number of formats competed for adoption including: High Speed Packet Access, Wi-MAX, WCDMA, Edge and EV-DO.

For background on 4G wireless service, see:

Priya Ganapati, *Wired Explains: Everything You Need to Know About 4G Wireless* (June 4, 2010); available at: http://www.wired.com/gadgetlab/2010/06/wired-explains-4g/;

4G Trends web site, available at: http://www.4gtrends.com/;

infoDEV, *IC4D 2012: Maximizing Mobile* (2012); available at: http://www.infodev.org/en/Publication.1179.html;

ITU/BDT Arab Regional Workshop on "4G Wireless Systems," Tunis-Tunisia, 27-29 (January 2010); available at: http://www.itu.int/ITU-D/arb/COE/2010/4G/ListofDocs-Tn.doc;

Sungho Jo, LTE and Network Evolution (July, 2011); available at: http://www.itu.int/dms_pub/itu-t/oth/06/4D/T064D0000020072PDFE.pdf.

Ultra High Definition Television

The next generation of high definition television sets will have even more resolution than currently available. Video screen resolution is measured in terms of the number of columns and lines as well as the total number of pixels, the smallest unit of video display. The current best standard for high definition television combines 1920 vertical columns with 1080 horizontal lines. Multiplying the number of columns by lines identifies the total number of pixels displayed.

Ultra high definition television doubles or quadruples the number of columns and lines. So-called 4K Ultra High Definition contains 2160 lines of resolution and 8K 4320 lines. Ultra high definition video resolution will make it possible for television manufacturers to offer larger sets with screens exceeding 84 inches as measured diagonally.

Ultra High Definition video will likely generate even greater consumer demand for faster broadband transmission speeds to accommodate the increased amount of content delivered per video frame. Terrestrial broadcasters and cable operators can repurpose some bandwidth by eliminating analog transmissions. However, Internet Service Providers, as operators of a fully digital medium, will have no ability to repurpose bandwidth to accommodate rising demand.

For more information on ultra high definition television see:

James Rivington , *Ultra HD and 4K: Everything you need to know*, techradar AV (June 4, 2013); available at: http://www.techradar.com/us/news/home-cinema/high-definition/ultra-hd-everything-you-need-to-know-about-4k-tv-1048954;

Ty Pendlebury, *What is 4K? Next-generation resolution explained*, Cnet (Jan. 23, 2012); available at: http://reviews.cnet.com/8301-33199_7-57364224-221/what-is-4k-next-generation-resolution-explained/;

Ultra HDTV: What is Ultra High Definition?, Ultra HDTV magazine; available at: http://www.ultrahdtv.net/what-is-ultra-hdtv/.

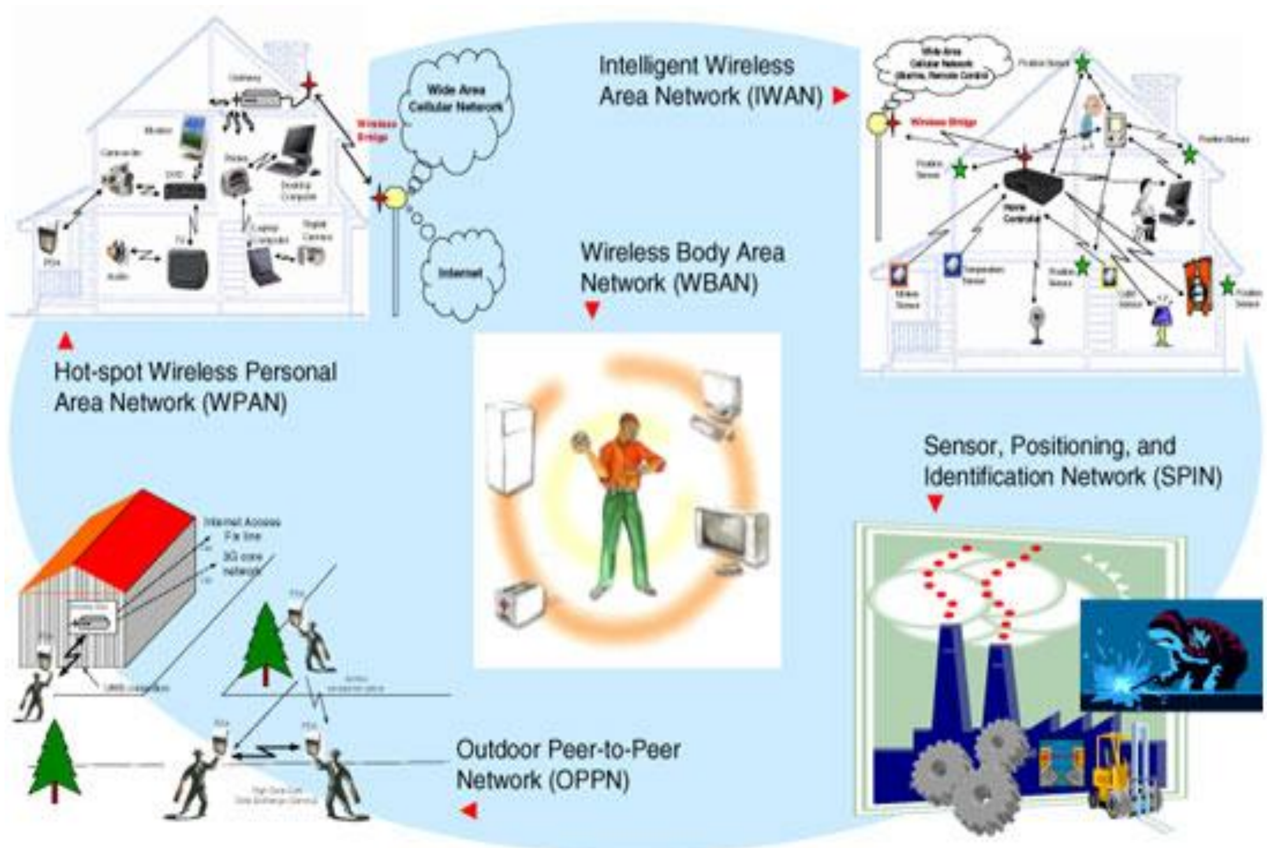
Ultra Wideband Networks

Next generation network options use even higher spectrum to satisfy the ever increasing demand for wireless broadband service. So called Ultra Wideband ("UWB") networks provide very high speed bit transmission using a wide range of extremely high frequencies, at or above the 2.4 GHz band currently used for Wi-Fi service. UWB transfers large amounts of data wirelessly over short distances, typically less than ten meters. Unlike other wireless systems, which are limited to relative narrow allocation of spectrum, UWB operates by transmitting signals over a very wide range of spectrum, but at very low power.

UWB networks can satisfy individual short broadband requirements and provide a wireless alternative to possibly inconvenient wire-based services. So-called Personal Area Networks will provide broadband connectivity like that currently served by Bluetooth applications that can link mobile phones, portable computers, cars, stereo headsets, and MP3 players with sources of content. The low power and short range of these technologies supports unlicensed use.

In light the proliferation of sensors, which typically need to transmit over very short distances, UWB technologies can power an Internet of Things. UWB can avoid causing interference with current narrowband and wideband radio services and between unlicensed users. It can operate in hostile environments and has been miniaturized so that it can be embedded in chip sets attached to other devices.

An Internet of Overlapping Networks



source: ERCIM News; available at: http://www.ercim.eu/publication/Ercim_News/enw64/hirt.html.

For more information on Ultra Wideband Networks see:

Radio Electronics.com, Ultra wide band (UWB) development and applications; available at: http://www.webcitation.org/66KYowUce;

Track IT Systems, UWB, available at: http://www.thetrackit.com/library/UWB%20Defin.pdf;

Asia Pacific Telecommunity, Ultra Wide Band (UWB), No. APT/AWG/REP-01(Rev.1) (September 2012); available at: http://www.apt.int/AWF-RECREP;

Philippe Tristant, Ultra Wide Band (UWB) and Short-Range Devices (SRD) technologies (2009); available at: http://www.itu.int/md/R09-SEM.WMO-C-0021/en;

Australian Communications Authority, *Ultra Wideband (UWB) A Background Brief* (May, 2003); available at: http://www.acma.gov.au/webwr/radcomm/frequency_planning/spps/0307spp.pdf;

New Zealand Ministry of Economic Development, Spectrum Allocations for Ultra Wide Band Communication Devices, A Discussion Paper (April 2008); available at: http://www.rsm.govt.nz/cms/pdf-library/policy-and-planning/radio-spectrum/spectrum-allocations-for-ultra-wide-band-communication-devices/ultra-wide-band-commnunication-devices-discussion-paper-232-kb-pdf.

White Spaces Explained

White spaces refer to radio spectrum allocated for a specific use, but available for other uses in many locations where such secondary uses will not cause interference to the primary, authorized users. Historically the International Telecommunication Union on an international, multilateral basis and individual nations on a domestic basis typically allocate spectrum for a single, specific use. This results in many instances where no primary spectrum user operates, but administrative rules prevent other uses. Put another way concerns about the potential for interference have motivated spectrum allocation decisions that result in inefficient use, because significant amounts of bandwidth remain unused even though many uses can occur without causing harmful interference.

For example, most nations have allocated a large amount of spectrum for radio and television stations, typically on an exclusive basis. Such exclusivity ensures that the broadcast signal encounters no interference, but there are many locations where spectrum use of broadcaster assigned frequencies have no potential to interfere with actual broadcast transmissions. White spaces refers to the geographic areas where there exists no potential for interference, because actual users are located at great distances away and in some instances there may be no actual users whatsoever.

The broadcast television band constitutes a likely candidate for identifying white spaces, because national regulatory authorities created a very large frequency band for this service and often substantial distances separate actual users of any specific broadcast channel. “White spaces exist primarily because analog television receivers were highly susceptible to interference, requiring the FCC to create frequency ‘guard bands’ between television channels in order to prevent interference. For example, in a given viewing market, if channel 9 is licensed, channel 8 and 10 will be vacant, as will channel 9 in any neighboring viewing market.” [5]

With the conversion from analog to digital television broadcasting in many locations the amount of white spaces increases significantly. Some nations have identified spectrum for reallocation to other services such as wireless broadband. In some instance nations auction the newly available spectrum and accrue a substantial monetary infusion into the national treasury, a so-called Digital Dividend. Even for nations reallocating some of the freed up spectrum, the expanded availability of white spaces has resulted in changes in policies allowing non-interfering uses.

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[5] Sascha D. Meinrath and Michael Calabrese, “White Space Devices” and the Myths of Harmful Interference, 11 LEGISLATION AND PUBLIC POLICY, 495, 497 (2008).

White Spaces Interference Avoidance

The opportunity to use white spaces for broadband access depends on the ability of secondary users to apply techniques that ensure the ability of primary users to continue operating without interference. For broadcast television white spaces this means that even unlicensed broadband applications must use sophisticated techniques that can sense other uses and change frequencies to avoid causing interference.

Technologies such as software-defined and cognitive radio offer such frequency agility. They have sensing capabilities that can identify frequencies where TV channels exist and can find and quickly move transmissions to open spectrum. This means that instead of simply tuning into a specific frequency, white spaces devices must have built in intelligence for detecting other spectrum users and quickly finding other frequencies on which to operate.

In addition to using receivers to sense whether a specific frequency has an existing user, white space devices can interrogate data bases that map and identify preexisting registered uses for specific locations. In light of inexpensive access to the very accurate Global Positioning Satellite service, white spaces transmitters can employ geo-location procedures to assess the interference potential before operating.

Additionally white spaces devices can operate at very low power to provide location specific broadband access in much the same way as Wi-Fi operates. With low power Wi-Fi devices can reduce interference even for other users in close proximity. Also Wi-Fi devices can change channels once interference is sensed. In addition to operating at low power and having the ability to change transmitting frequencies, white spaces devices have sensing capabilities that trigger a change in frequency to avoid causing interference in the first place.

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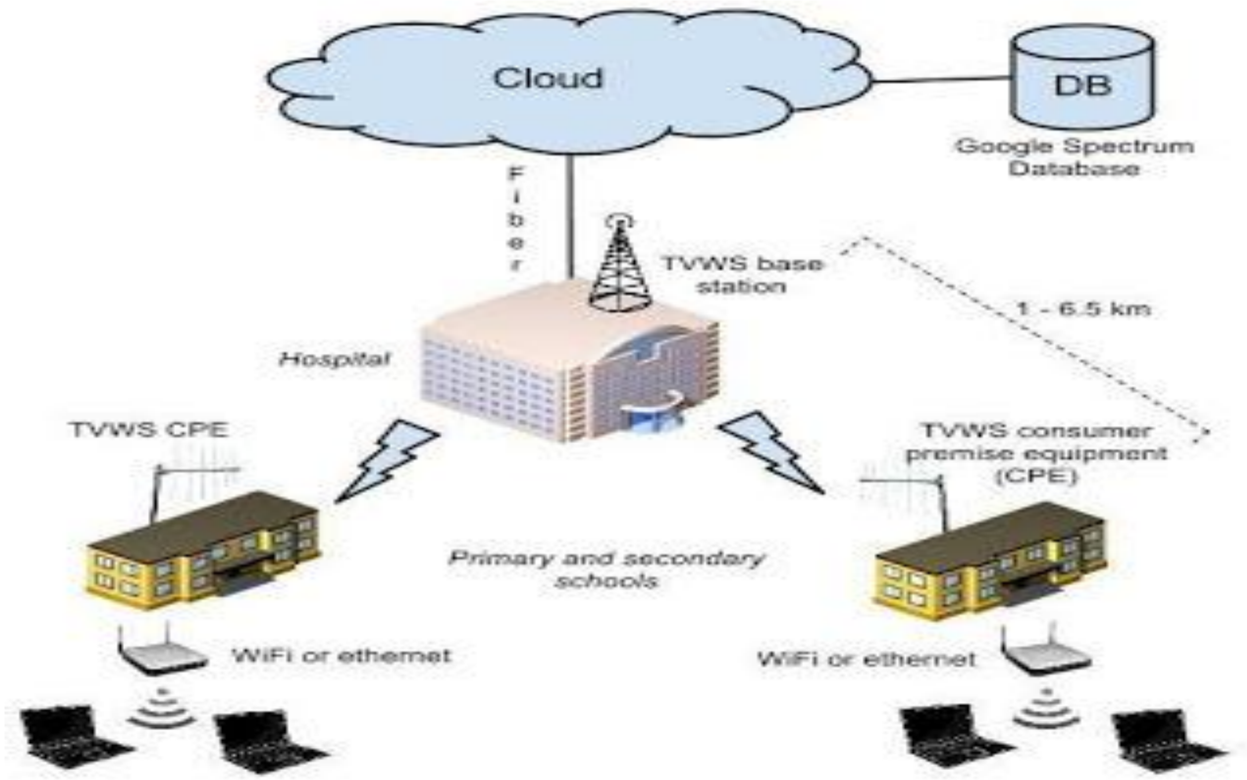
Michael Fitch, Maziar Nekovee, Santosh Kawade, Keith Briggs, and Richard MacKenzie, *Wireless Service Provision in TV White Space with Cognitive Radio Technology: A Telecom Operator's Perspective and Experience*, IEEE Communications Magazine, 64-73 (March 2011).

White Spaces Test and Demonstration Project



source: Google Africa Blog, Announcing a new TV White Spaces trial in South Africa (March 25, 2013); available at: http://google-africa.blogspot.co.uk/2013/03/announcing-new-tv-white-spaces-trial-in.html.

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ArsTechnica, Solar power, white spaces bring 16Mbps broadband to towns without electricity (March 26, 20130: available at: http://arstechnica.com/information-technology/2013/03/solar-power-and-white-spaces-bring-internet-to-towns-without-electricity/;

Tertiary Education and Research Network of South Africa, The Cape Town TV White Spaces Trial web site; available at: http://www.tenet.ac.za/about-us/the-cape-town-tv-white-spaces-trial.

Michael Calabrese, Some Spectrum Basics (May 3, 2012); available at: http://wirelessfuture.newamerica.net/sites/newamerica.net/files/profiles/attachments/Calabrese_ColumbiaACCESSconf_Slides_Spectrum101_050312.pdf;

United States Federal Communications Commission, White Space web site; available at: http://www.fcc.gov/topic/white-space;

Spectrum Bridge, TV White Spaces Powering Smart City Services - The First Database Driven TV White Spaces “Smart City;” available at: http://www.spectrumbridge.com/ProductsServices/WhiteSpacesSolutions/success-stories/wilmington.aspx.

Wireless Device Tethering

Tethering refers to the ability to link two devices so that they can share a function such as wireless access to the Internet. Cellphone users might want to use personal computers and tablets for accessing the Internet instead of their phones which may not have a sufficiently large screen or the capability of accessing the World Wide Web. Some personal computers and tablets can achieve direct wireless access using installed electronics or with the insertion of a dongle into an interface such as a Universal Service Bus ("USB") jack. Devices lacking direct access capability can tether to a cellphone for indirect access.

Currently many areas in the world have cellular radio access, but lack a local broadband access options such as Wi-Fi. For locations one can tether a personal computer or tablet to the cellphone thereby securing the Internet access available via the cellphone. Note that the cellphone must have software supporting tethering and the wireless carrier may impose a surcharge for this feature, or prohibit the option.

Example of a Dongle Providing Wireless Access to a Peronal Computer or Tablet

source: Pete's Tech Ramblings, The $50 wireless tethering solution (May 9, 2009); available at: http://petetek.blogspot.com/2009/05/50-wireless-tethering-solution.html.

Cellphone Tethering

source: Toolbox.com, Cell Phone Tethering: Secure or just another hole in the wall? (July 29, 2009); available at: http://it.toolbox.com/blogs/adventuresinsecurity/cell-phone-tethering-secure-or-just-another-hole-in-the-wall-33152.

Creating Your Own Mobile Wi-Fi Hotspot

In areas where Wi-Fi broadband access does not exist, subscribers to a broadband service can create a limited, short range alternative. So called mobile Wi-Fi hotspots use a portable wireless router to provide shared access to a broadband service such as 4G wireless data. This small, battery powered device offers a portable hotspot that taps into wireless data services, just like a smartphone does, and then wirelessly shares its data connection with other nearby Wi-Fi-enabled devices such as a personal computer or handset. Several users can share the single Wi-Fi connection and encryption techniques provide a password authentication process to prevent unauthorized access.

A Portable Mobile Wi-Fi Hotspot Router

source: The Cool Gadgets, MiFi 4510L: Novatel Wireless Mobile Hotspot – Introduced For Verizon Wireless Network; available at: http://thecoolgadgets.com/mifi-4510l-novatel-wireless-mobile-hotspot-introduced-for-verizon-wireless-network/.

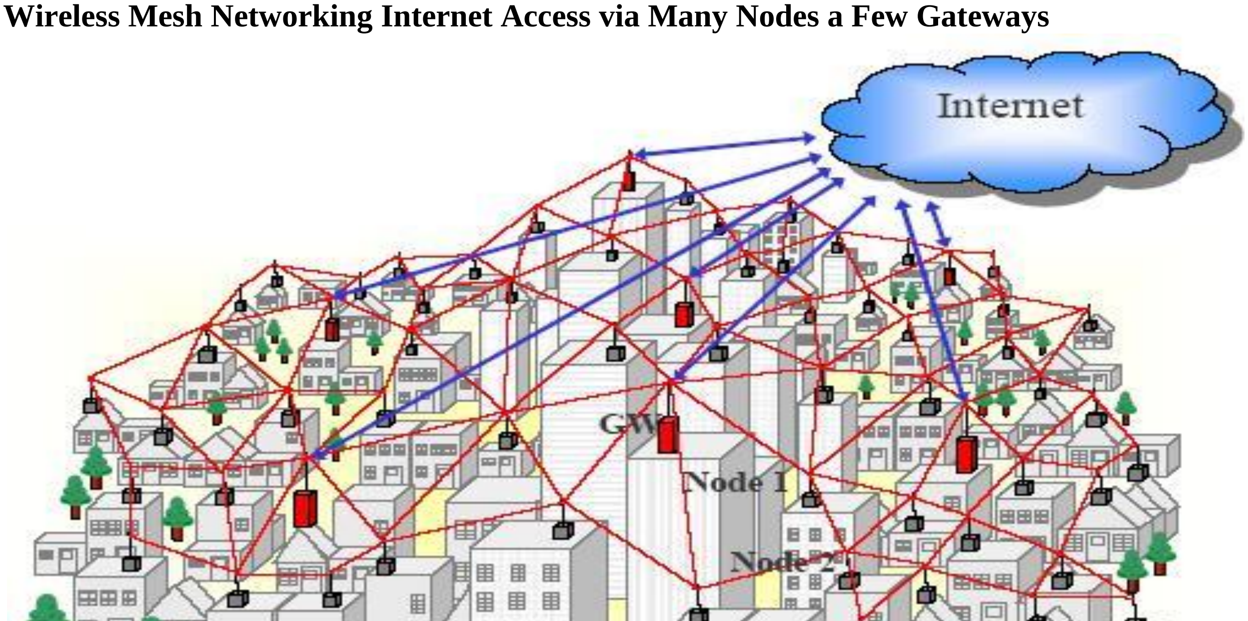
Wireless Mesh Networking

Wireless mesh networks provide broadband access through the coordination and interconnection of nodes that have can receive and retransmit traffic. In much the same way as the Internet provides a managed, "best efforts" routing of traffic, the software configured management of nodes achieves the same "dynamic routing" based on intelligent selection of which node can help move traffic to the final destination or closer to that destination.

Wireless mesh networking requires at least one broadband connection to the Internet, e.g., a cable modem or DSL link. Access to that links can be shared over many geographically separated users who can secure a link to the broadband connection via one or more intermediary nodes. The geographical range of the mesh network extends with increases in the number of installed nodes.

Wireless mesh networking can provide a low cost way to extend the reach of a broadband connection. However its open and shared networking characteristics does create security risks, particularly when nodes are installed in a variety of locations not under the control of a single manager. Nevertheless wireless mesh networks can offer a quickly installed and inexpensive way to share broadband access, particularly on an unlicensed and noncommercial basis.

Wireless Mesh Networking Internet Access via Many Nodes a Few Gateways



source: ***Wireless Networking in the Developing World, Mesh networking*****; available at:** **http://www.booki.cc/wireless-networking-in-the-developing-world/mesh-networking/.**

For more information on mesh networking see:

Ben DuPont, *Wireless Mesh Networks: An Introduction*; InformationWeek Analytics; available at: http://reports.informationweek.com/abstract/20/7396/Network-Systems-Management/fundamentals-wireless-mesh-networks.html;

Samir R. Das, *Wireless Mesh Networking*; available at: http://www.ieee.li/pdf/viewgraphs/wireless_mesh_networking.pdf;

Emergent by Design; 16+ Projects & Initiatives Building Ad-Hoc Wireless Mesh Networks (Feb. 11, 2011); available at: http://emergentbydesign.com/2011/02/11/16-projects-initiatives-building-ad-hoc-wireless-mesh-networks/;

David Johnson, Karel Matthee, Dare Sokoya, Lawrence Mboweni, Ajay Makan, and Henk Kotze, Wireless Africa, Meraka Institute, Building a Rural Wireless Mesh Network
A do-it-yourself guide to planning and building a Freifunk based mesh network (Oct. 30, 2007); available at: http://emergentbydesign.com/2011/02/11/16-projects-initiatives-building-ad-hoc-wireless-mesh-networks/;

Lee M.S. Bash, Christophe Jelger and Christian Tschudin, *A case study in designing an autonomic wireless mesh network* (2007); available at: http://cn.cs.unibas.ch/pub/doc/2007-adhoc.pdf;

Andreas J. Kassler, ICTP-ITU/BDT School on Sustainable Wireless ICT Solutions 2012
Introduction to Wireless Mesh Networks (2012); available at: http://wireless.ictp.it/wp-content/uploads/2012/02/school_Triestse_2012_Intro_v1.pdf.

ENDNOTES

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[1] For background on the history of Internet development *see* Barry M. Leiner, Vinton G. Cerf, David D. Clark, Robert E. Kahn, Leonard Kleinrock, Daniel C. Lynch, Jon Postel, Larry G. Roberts and Stephen Wolff, Internet Society, *A Brief History of the Internet* (2003); available at: http://www.isoc.org/internet/history/brief.shtml.

[2] "The World Wide Web (known as "WWW', "Web" or "W3") is the universe of network-accessible information, the embodiment of human knowledge.

The World Wide Web began as a networked information project at CERN, where Tim Berners-Lee, now Director of the World Wide Web Consortium [W3C], developed a vision of the project.

The Web has a body of software, and a set of protocols and conventions. Through the use hypertext and multimedia techniques, the web is easy for anyone to roam, browse, and contribute to." World Wide Web Consortium, *About The World Wide Web* available at: http://www.w3.org/WWW/.

[3] The Internet is a vast network of individual computers and computer networks that communicate with each other using the same communications language, Transmission Control Protocol/Internet Protocol (TCP/IP). The Internet consists of approximately more than 100 million computers around the world using TCP/IP protocols. Along with the development of TCP/IP, the open network architecture of the Internet has the following characteristics or parameters: 1. Each distinct network stands on its own with its own specific environment and user requirements, notwithstanding the use of TCP/IP to connect to other parts of the Internet. Communications are not directed in a unilateral fashion. Rather, communications are routed throughout the Internet on a best efforts basis in which some packets of information may go through one series of computer networks and other packets of information go through a different permutation or combination of computer networks, with all of these information packets eventually arriving at their intended destination. 2. Black boxes, for lack of a better term, connect the various networks; these boxes are called 'gateways' and 'routers.' The gateways and routers do not retain information but merely provide access and flow for the packets being transmitted. There is no global control of the Internet." Konrad L. Trope, *Voice Over Internet Protocol: The Revolution in America's Telecommunications Infrastructure*, 22 COMPUTER AND INTERNET LAW, No.12, 1,4 (Dec. 2005).

[4] *See* Communications Assistance for Law Enforcement Act and Broadband Access and Services, 19 F.C.C.R. 15676 n.181 (2004). *See also* Joshua L. Mindel & Douglas C. Sicker, *Leveraging the EU Regulatory Framework to Improve a Layered Policy Model for US Telecommunications Markets*, 30 TELECOMMUNICATIONS POLICY, 136, 137 (2006); Douglas C. Sicker & Lisa Blumensaadt, *Misunderstanding the Layered Model(s)*, 4 JOURNAL ON TELECOMMUNICATIONS AND HIGH TECHNOLOGY LAW, 299 (2006); David P. Reed, *Critiquing the Layered Regulatory Model*, 4 JOURNAL ON TELECOMMUNICATIONS AND

HIGH TECHNOLOGY LAW, 281 (2006); Lawrence B. Solum & Minn Chung, *The Layers Principle: Internet Architecture and the Law*, 79 NOTRE DAME LAW REV. 815 (2004); Richard S. Whitt, *A Horizontal Leap Forward: Formulating a New Communications Public Policy Framework Based on the Network Layers Model*, 56 FEDERAL COMMUNICATIONS LAW JOURNAL 587 (2004).

5 "The idea of a computer network intended to allow general communication between users of various computers has developed through a large number of stages. The melting pot of developments brought together the network of networks that we know as the Internet." Wikipedia, History of the Internet; available at: http://en.wikipedia.org/wiki/History_of_the_Internet.

6 The Internet cloud refers to the vast array of interconnected networks that make up the Internet and provide users with seamless connectivity to these networks and the content available via these networks. "The increasing functionality of the Internet is decreasing the role of the personal computer. This shift is being led by the growth of "cloud computing"--the ability to run applications and store data on a service provider's computers over the Internet, rather than on a person's desktop computer." William Jeremy Robison, *Free at What Cost?: Cloud Computing Privacy Under The Stored Communications Act*, 98 GEORGETOWN LAW JOURNAL 1195, 1199 (April, 2010).

7 *See* Government of Finland, Ministry of Transport and Communications, Press release, *Access to a minimum of 1 Mbit Internet connection available to everyone in Finland by July 2010* Oct. 16, 2009); available at: http://www.lvm.fi/web/en/pressreleases/view/920100.

8 For background on how peering developed see Scott Marcus, *Global Traffic Exchange among Internet Service Providers*, OECD Briefing (2001); available at: http://www.oecd.org/dataoecd/45/9/1894955.pdf; William B. Norton, *Interconnection Strategies for ISPs*, Document v.2.0; available at: http://pharos.equinix.com/pdf/whitepapers/ISPInterconnectionStrategies2.pdf; Joe Waz, Comcast Voices, *How Internet Peering Works*, available at: http://www.youtube.com/watch?v=sKBGDocS_Yg; William B Norton, *Peering Tutorial*, presented at the APRICOT 2012 Peering Forum, New Delhi, India (Jan 28, 2012); available at: http://www.apricot.net/apricot2012/__data/assets/pdf_file/0010/45586/peering-tutorial.pdf; Anna-Maria Kovacs, *Internet Peering and Transit* (April 4, 2012); available at: http://www.techpolicyinstitute.org/files/amkinternetpeeringandtransit.pdf

9 The first and last kilometer refers to the link, of any length, provided by a retail ISP to subscribers so they can download and receive content from the Internet cloud and also upload and content and instructions.

10 For a list of the global ISPs, see The Cooperative Association for Internet Data Analysis, Ranking of Autonomous Systems (AS); available at: http://as-rank.caida.org/; Russ Haynal's ISP

Page, Major Internet Backbone MAPs, available at: http://navigators.com/isp.html.

[11] See OECD, *Smart Sensor Networks: Technologies and Applications for Green Growth*, OECD Digital Economy Papers, No. 167, OECD Publishing (2009); available at: http://dx.doi.org/10.1787/5kml6x0m5vkh-en; The Internet of Things Council, World Wide Web Page, http://www.theinternetofthings.eu/; Eric Savitz, *How The Internet Of Things Will Change Almost Everything*, Forbes (Dec. 17, 2012); available at: http://www.forbes.com/sites/ciocentral/2012/12/17/how-the-internet-of-things-will-change-almost-everything/.

[12] For an assessment of what Next Generation Networks will offer and how they will operate see OECD, *Next Generation Access Networks and Market Structure*, OECD Digital Economy Papers, No. 183, OECD Publishing (2011); available at: http://dx.doi.org/10.1787/5kg9qgnr866g-en.

[13] "The amount of spectrum in the VHF and UHF bands that is above that nominally required to accommodate existing analogue programmes, and that might be thus potentially freed up in the switchover from analogue to digital television, is defined as the digital dividend." International Telecommunication Union, ITU News, *The Digital Dividend Opportunities and Challenges* (Jan.-Feb. 2010); available at: http://www.itu.int/net/itunews/issues/2010/01/27.aspx; See also, Government of Australia, Department of Broadband, *Communications and the Digital Economy, Digital Dividend*; available at: http://www.dbcde.gov.au/radio/radiofrequency_spectrum/digital_dividend; International Telecommunication Union, Telecommunications Development Sector, *Digital Dividend: Insights for Spectrum Decisions* (Aug. 2012); available at: http://www.itu.int/ITU-D/tech/digital_broadcasting/Reports/DigitalDividend.pdf.

[14] See The World Bank, infoDev, ICT Regulation Toolkit, Practice Note, *Refarming of Spectrum Resources*; available at: http://www.ictregulationtoolkit.org/en/PracticeNote.aspx?id=2320.

[15] "Television stations often operate on the same or adjacent channels. However, to avoid interference between each other, television stations are often operated in geographically separate areas. Further, there are areas of the country where, because of population density, not all television channels are utilized. This unused spectrum between TV stations -- called white spaces -- represents a valuable opportunity for our changing wireless mobile landscape. This block of spectrum is ripe for innovation and experimental use, holding rich potential for expanding broadband capacity and improving access for many users, and for developing technologies that can expand this type of spectrum access to other frequencies and services in order to greatly increase our ability to utilize spectrum." Government of the United States of America, Federal Communications Commission, White Space, http://www.fcc.gov/topic/white-space; Open Spectrum Alliance, Television White Spaces Spectrum in Africa Workshop, World Wide Web site; available at: http://www.openspectrum.org.za/schedule/; Government of the

United Kingdom, Ofcom, TV White Spaces; available at: http://stakeholders.ofcom.org.uk/consultations/whitespaces/; Dr Joe Butler, Technology Director for Radio Spectrum Policy, Ofcom, *TV White Space Devices ...and beyond!* (Oct. 2011); available at: http://www.oecd.org/sti/broadbandandtelecom/49435354.pdf.

[16] For background on unlicensed spectrum management issues and the problem of excessive and inefficient use, see Phil Weiser and Dale Hatfield, *Policing the Spectrum Commons*, 74 FORDHAM LAW REVIEW 663 (2005); available at: http://ir.lawnet.fordham.edu/cgi/viewcontent.cgi?article=4111&context=flr; Philip J. Weiser & Dale Hatfield, *Spectrum Policy Reform and the Next Frontier of Property Rights*, 15 GEORGE MASON LAW REVIEW, 549 (2008); Kevin Werbach, *Supercommons: Toward a Unified Theory of Wireless Communication*, 82 TEXAS LAW REVIEW 863 (2004); Thomas W. Hazlett, *Spectrum Tragedies*, 22 YALE JOURNAL ON REGULATION 242 (2005).

[17] Microwave refers to the extremely small size of the transmitted waveform.

[18] "Currently, agreements for the exchange of Internet traffic are unregulated and left solely to commercial negotiation between Internet backbone providers. Agreements for the exchange of traffic between operators are called 'peering agreements' and depending on the balance of traffic, it may be either free or paid. Other arrangements provide that one network will carry traffic without exchanging traffic on that network link. This will involve payment, and such service is called 'transit.'" Daniel L. Brenner and Winston Maxwell, *The Network Neutrality and the Netflix Dispute: Upcoming Challenges for Content Providers in Europe and the United States*, 23 INTELLECTUAL PROPERTY AND TECHNOLOGY LAW JOURNAL 3,5 (March 2011).

[19] For background on the Internet Exchange market and policy challenges, see Dennis Weller and Bill Woodcock, *Internet Traffic Exchange, Market Developments and Policy Challenges* OECD Digital Economy Papers, No. 207, OECD Publishing (2012); available at: http://dx.doi.org/10.1787/5k918gpt130q-en.

[20] For example, the Exede service available in the United States offers 12 Mbps downloads and 3 Mbps uploads for $50-100 USD monthly depending on the amount of capacity used (10-25 Gigabyte tiers). See http://www.exede.com/internet-packages-pricing.

[21] For example the distinction between services to fixed and mobile users has become blurred by the convergence of previously discrete and mutually exclusive services. See, e.g., OECD, *Fixed and Mobile Networks: Substitution, Complementarity and Convergence*, Digital Economy Papers, No. 206, OECD Publishing (2012); available at: http://dx.doi.org/10.1787/5k91d4jwzg7b-en.

[22] For background on rural broadband backbone networks, see Seán Ó Siochrú, *Rural Broadband Backbone: A case study of different approaches and potential*; available at: http://www.apc.org/en/system/files/APCProPoorKit_PolicyAndRegulation_CaseStudyRural_EN

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[23] "So, as we start seeing digital divides closing around Internet access and mobile phone ownership, a new broadband divide is growing. This is already – and will continuingly – require a strategic response which, if not led, must at the least be coordinated by government. As and where this happens, the development results will be impressive. Broadband uptake is associated at the macro level with growth in indicators such as employment and GDP, and at the micro level there are many new employment- and productivity-enhancing opportunities." Richard Heeks, *The ICT4D 2.0 Manifesto: Where Next for ICTs and International Development*, Development Informatics Group, Institute for Development Policy and Management, University of Manchester, OECD Development Informatics Working Paper Series No. 42, p.7 (2009), available at: http://www.oecd.org/ict/4d/43602651.pdf.

[24] Ghana Internet eXxchange Association, World Wide Web site; available at: http://www.gixa.org.gh/.

[25] See Edwin San Roman, "*Bringing Broadband Access to Rural Areas: A Step-By-Step Approach for Regulators, Policy Makers and Universal Access Program Administrators The Experience of the Dominican Republic*, paper presented at the 9th Global Symposium for Regulators (GSR); available at: http://www.itu.int/ITU-D/treg/Events/Seminars/GSR/GSR09/doc/GSR09_Backgound-paper_UAS-broadband-DR-web.pdf.

[26] "A negative NPV means that the project is not profitable. To get companies to invest the rate of return of a project has to be equal or greater than what can be achieved elsewhere. This happens when the NPV is equal to zero or, in other words, when the IRR equals the discount rate. Therefore, a subsidy that makes NPV equal to zero has to be offered to make the rural project attractive for current operators and potential new entrants." *Id* at 61.

[27] *Id*. at 63.