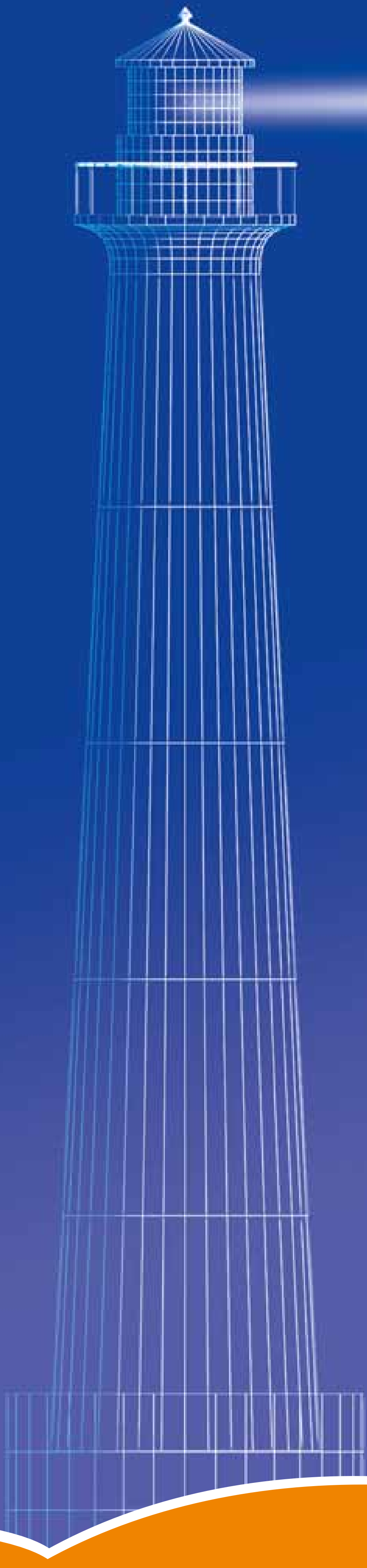
International Telecommunication Union



GSR 2005

DISCUSSION PAPER

BROADBAND PROVISIONING

Comments are welcome and should be sent by 5 December 2005 to GSR05@itu.int

International Telecommunication Union

GLOBAL SYMPOSIUM FOR REGULATORS

MEDINA CONFERENCE CENTRE
YASMINE HAMMAMET, TUNISIA

14-15 NOVEMBER 2005

Work-in-progress, for discussion purposes

Broadband provisioning for developing countries

Prepared by *MICHAEL BEST AND BJORN PEHRSON*

Comments are welcome and should be sent by 5 December 2005 to
http://www.gsr2005@itu.int

TABLE OF CONTENTS

Page

GSR Discussion Paper

Broadband provisioning for developing countries*

Introduction

The purpose of this paper is to facilitate decision-making by regulators, policy makers, and potential broadband providers. This paper identifies and analyzes the key promising technologies that can help promote to broadband access in developing countries, particularly in rural and underserved areas. The range of broadband systems is organized into three broad families of technologies: **broadband wireline networks,** including DSL, cable TV, powerline, Local Area Networks (LAN) over twisted pair copper cables and fibre solutions; **broadband wireless solutions**, including third generation mobile, wireless Local Area Networks and other fixed and mobile wireless access solutions; and **non-terrestrial options,** including VSATs and stratospheric solutions. The paper will analyze the benefits and challenges of all, the types of equipment, infrastructure and software that are needed to deploy each and their viability for rural and underserved areas of developing countries. The viability analysis is based on a series of factors including current levels of infrastructure deployment, power requirements, types of equipment and infrastructure investments required, capacity provided and how different terrains impact deployment. The paper concludes that there is not a significant environment on the planet today in which broadband internet does not make commercial, social, and institutional sense, given the political will to foster an enabling environment to drive demand for broadband by a full range of stakeholders.

1 What Do We Mean When We Say "Broadband"?

Like many terms used in today's fast moving technology sector, the term "broadband" is not well defined. The word was originally used in the network engineering community to signify transmissions over some medium carrying multiple channels simultaneously. This would be in contrast to "baseband" where a single channel was transmitted at anytime. Today, however, "broadband" is used much more frequently to indicate some form of high-speed internet access.

The decision of which networks provide sufficient capacity to be called "broadband" is a matter open to debate. Many attempts to associate broadband with a particular speed or set of services, but in reality the term "broadband" is like a moving target. Internet speeds are increasing constantly, and at each new advance, marketers eagerly emphasize just how blazingly fast the latest connection speeds are. The speed of a network is usually expressed in term of its underlying data rate and measured in bits per second (the bandwidth). What is not in debate is that today's dial-up Internet speeds, topping at around 56 Kbp/s, are *not* broadband connections. But beyond that it is a matter of taste. The United States Federal Communication Commission (FCC) has defined broadband as starting at 200 Kbp/s, the OECD at 256 Kbp/s, and the International Telecommunication Union defines broadband as a network whose combined capacity, both up and down, sums to 256 Kbp/s or above.

A good example of the broad range of definitions can be found within Sweden. The Swedish IT Commission (1994-2004) defined broadband as supporting a formidable 5 Mbit/s up and down; the Swedish government as at least 2 Mbit/s up and down while Sweden's incumbent operator, Telia, defines it as at least 0.5 Mbit/s both up and down. In Swedish metropolitan area networks (MANs), 10-100 Mbit/s, has become the standard.

---

* This discussion paper has been prepared by Michael Best and Bjorn Pehrson. The views are those of the authors and may not necessarily reflect the opinions of the ITU or its membership.

While the parameters of definition in the market space are wide, for the purposes of this paper the term broadband refers to data rates that correspond to the ITU definition as outlined above.

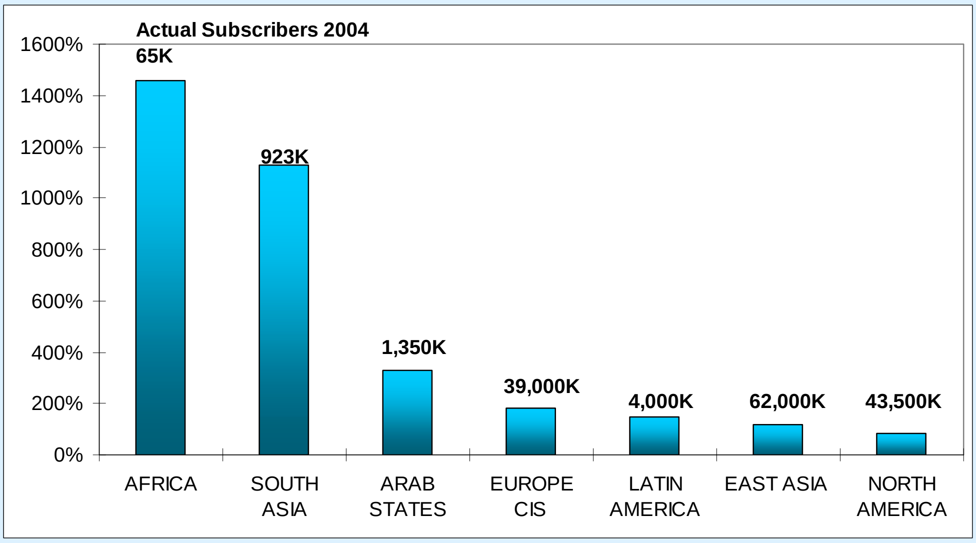
Beyond precise data rate thresholds, perhaps an even more useful way to define broadband – whether it is fixed or wireless - is in terms of what, at a minimum, can be accomplished with it. This certainly includes fast downloads when using the web. But it also should include CD quality streaming audio, fully interactive voice services such as VoIP, some level of interactive video chat services (if not full capability video conferencing), and reasonable quality streaming video services (if not full DVD quality video on demand). Note that realizing this wish list is not simply predicated on available bandwidth. Interactive applications such as VoIP also require small latency (delays), error rates, and jitter (whereupon data arrives out of order).

2 The State of Global Broadband Growth on Wireline Networks

The number of total global internet users continues to increase, reaching around 875 million at the end of 2004[1]. Broadband internet access technologies (e.g. DSL, cable modems, wireless LANs, fibre optics) are changing the quality as well as the purpose of access, and new wireless broadband technologies, such as wireless metropolitan area networks (e.g. WiMAX), offer great promise for countries lacking in physical communication infrastructure.

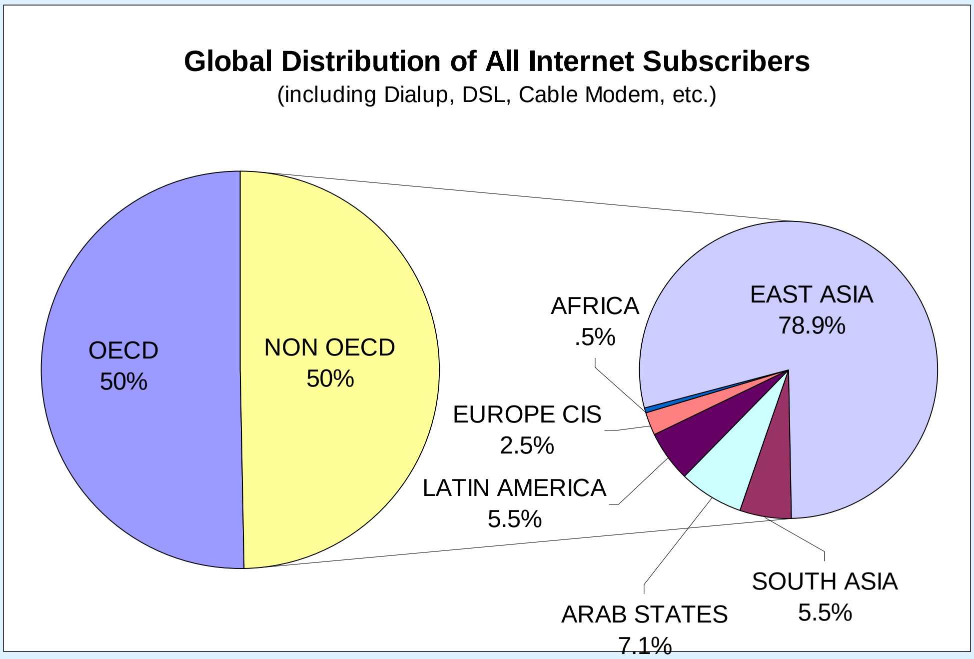
There are over 98 million DSL broadband subscribers in the world today, in addition to over 51 million cable broadband subscribers and a further 9.3 million who are using ‘other’ technologies (this includes technologies such as satellite broadband internet, Fiber-to-the-home internet access, Ethernet LANs, etc.) in the attempt to attain ‘always on’ internet access. This brings total fixed line broadband subscribers to nearly 159 million already at the end of the 2004. While the total number of these subscribers has undoubtedly been increasing around the world, it is notable that the fastest rates of broadband (and specifically, DSL) growth today is occurring in the developing countries of South Asia (notably India and Pakistan) and sub-Saharan Africa. (See Figure 1) Indeed, while there is a general perception that internet growth is limited to the wealthier OECD members, in fact internet subscribership is currently being driven at about equal rates between OECD and non-OECD countries (see Figure 2). About 50 per cent of all general internet subscribership in the world is now accounted for by non-OECD nations.

Figure 1: Rate of Broadband Growth By Region (2002-2004)



Source: ITU World Telecommunications Indicators Database

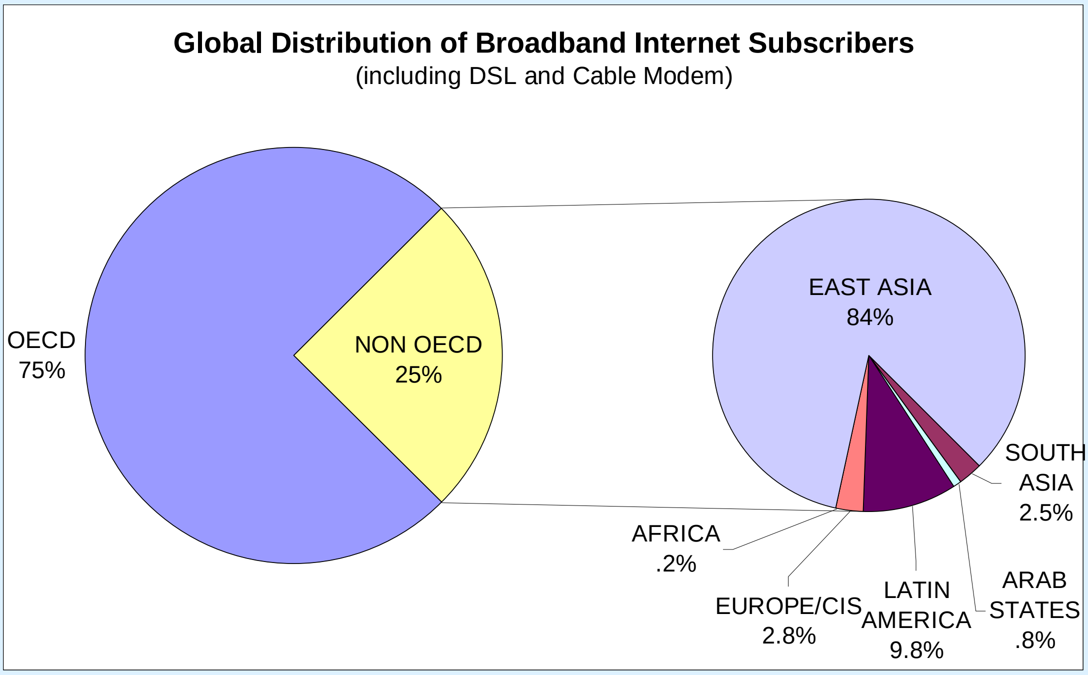
Figure 2: Global Distribution of Internet Subscribership (2004)



Source: ITU World Telecommunications Indicators Database

Non-OECD countries today account for a full 25 per cent of broadband subscribership (see Figure 3). While the growth rate from year to year of total non-OECD country broadband subscribers has been increasing steadily from 71 per cent in 2002-2003 to over 107 per cent between 2003-2004, overall *global* broadband rates of growth show evidence of even year-to-year growth, at around a consistent 49 per cent between 2003 and 2004. This does not mean, however, that there is any decrease in the absolute numbers of subscribers. Rather the fervor of quick and sudden broadband deployments over the past few years are now being tempered and stabilized. China is an exception to this rule, logging steady broadband year-to-year growth rates relative to Canada, Japan, Korea (Rep.) and the United States, who have the highest numbers of broadband subscribers.

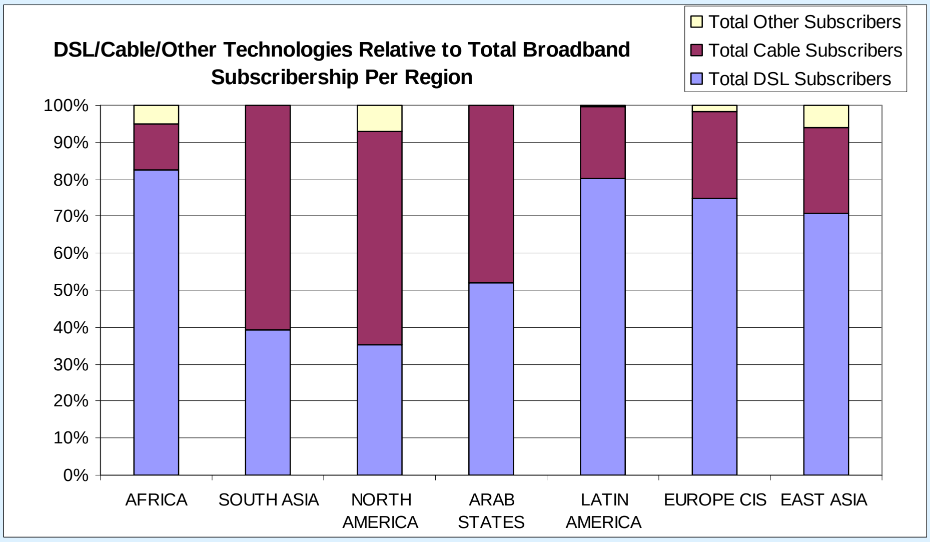
Figure 3: Global Distribution of Broadband Internet Subscribers (2004)



Source: ITU World Telecommunications Indicators Database

Globally, already in 2003 about 30 per cent of all internet use was on broadband. Of the total broadband subscriber base, 32 per cent are using cable modems for access, 62 per cent are using DSL, and 6 per cent are using another technology. Figure 4 below depicts the breakout of broadband access type by region. It is fair to assume that while there may be other ways (i.e., VSAT connection) of achieving 'broadband status', most are connected via DSL or cable modems, and the majority of the remainder—close to 60 per cent of internet subscribers-- is using dial-up. It is clear from the figure that DSL features most prominently in Latin America, Europe/CIS, Africa and East Asia, while South Asia and North America are more dominated by cable modem technology.

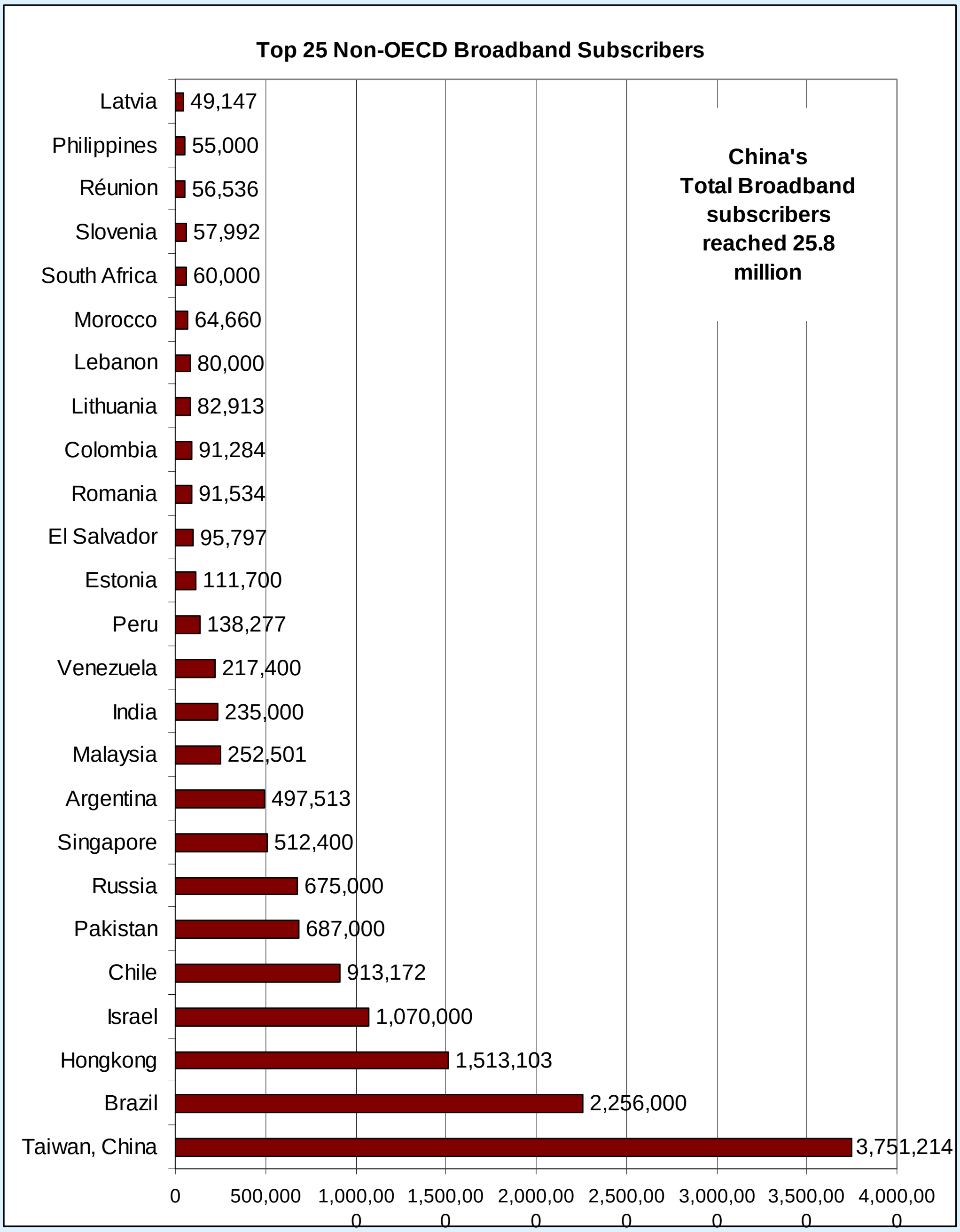
Figure 4: DSL/Cable/Other to Total Broadband Subscribers (by Region) 2003



Source: ITU World Telecommunications Indicators Database

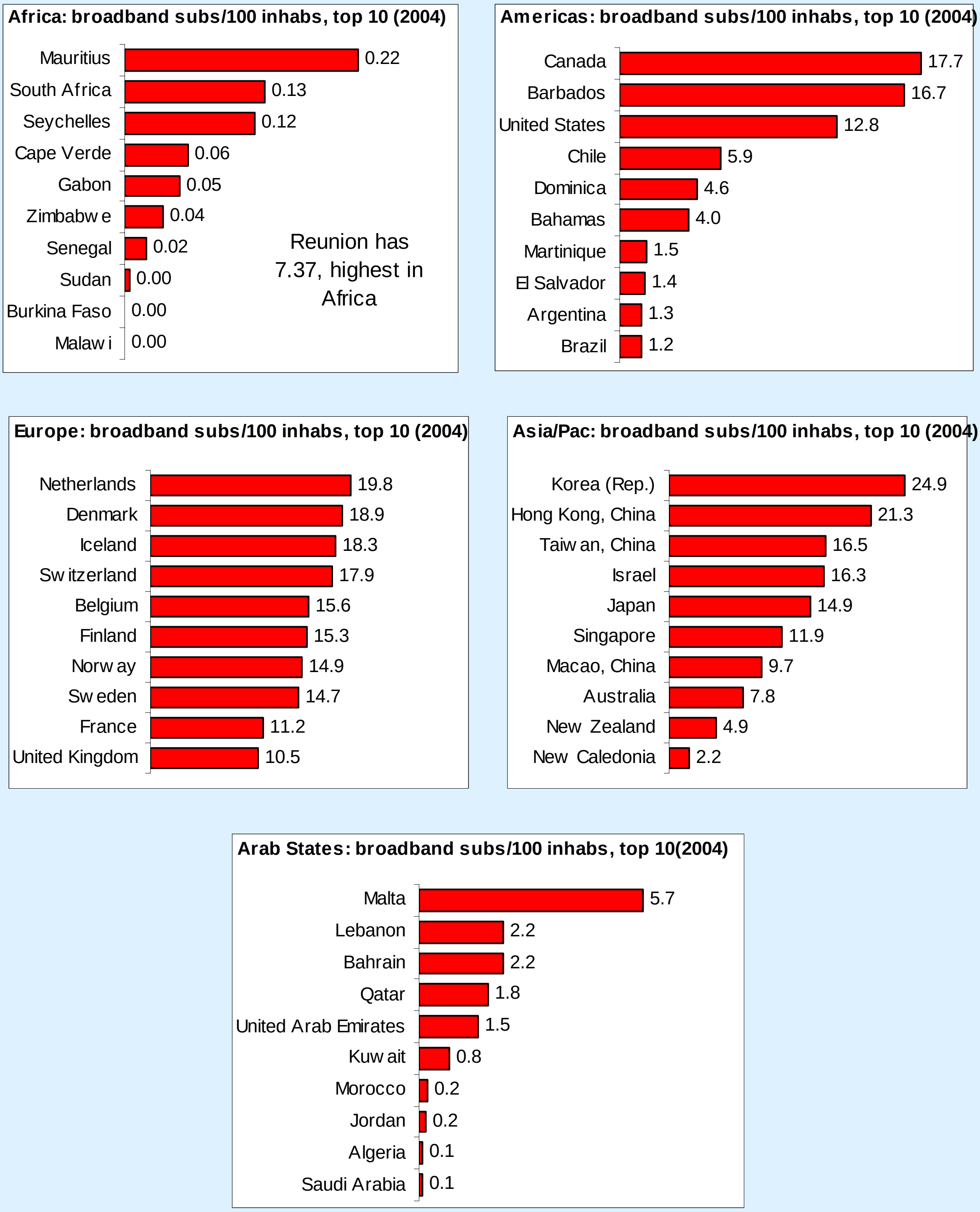
While the growth of DSL subscribers in non-OECD countries contributions was negligible until 2003, suddenly in 2004 non-OECD countries had a 22 per cent higher impact on total global DSL growth. This was mirrored by a corresponding 6 per cent decrease in the predominance of OECD countries as drivers of DSL take-up. This signals a clear recognition by telecommunication operators and investors that developing, non-OECD markets are valuable and hold potential, as they begin to build out new communications infrastructure in places it has not existed before. Figures 5a and 5b below offer a breakout of which countries have what kind of subscriber base.

Figure 5a: Top 25 Broadband Subscribers, Non OECD Countries (2004)



Source: ITU World Telecommunications Indicators Database

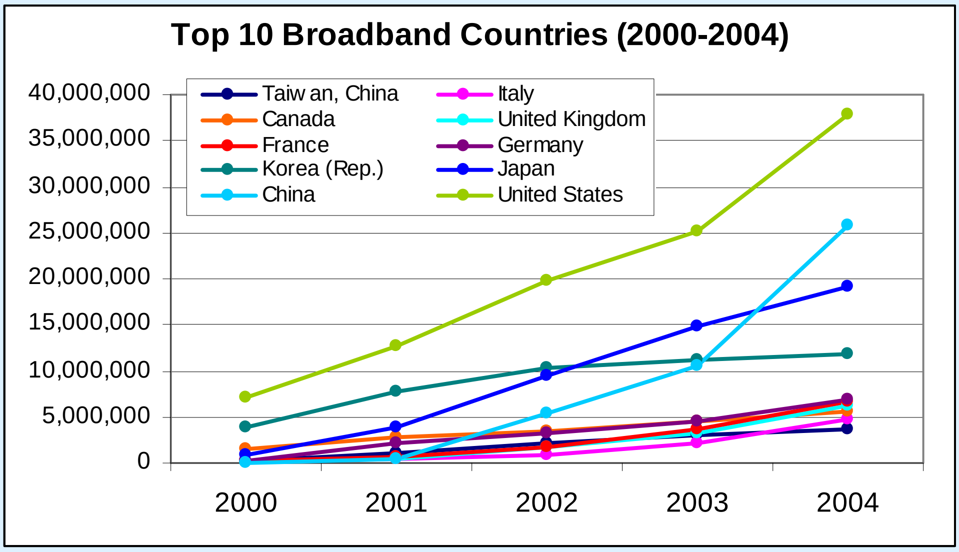
Figure 5b: Top 10 Broadband Countries by Region



Source: ITU World Telecommunications Indicators Database

Growth in terms of absolute fixed line broadband subscriber numbers is abundant. Figure 6 provides a snapshot of some of the most developed countries that have adopted and expanded their broadband subscriber bases successfully.

Figure 6: Top 10 Broadband Subscribers, World (2000-2004)



Source: ITU World Telecommunications Indicators Database

Considerable new broadband deployment activity in nations throughout the developing world, from the Arab States to Southeast Asia, warrants attention. For example, DSL broadband internet lines have been rolled out in Egypt from TE Data, and ISP Nile Online. In Chile, carrier Telsur has initiated an internet/broadband development project, which has seen a total investment of US$20 million in the last five years. Brazil has launched triple play services including broadband, as has the Indian operator MTNL. From Fiji to Oman, the telecommunications industry is evolving to expand in the direction of broadband infrastructure, and most of these are DSL based.

Some transition countries are moving faster than others, jumping straight ahead to providing wireless broadband connectivity; for example, Bulgaria has opened a tender for several decade-long nationwide point-to-multipoint wireless broadband licenses, and seven contenders expressed interest, according to the country's telecoms regulator CRC. Meanwhile, in Saudi Arabia, broadband wireless technology has been deployed to enhance data transfer rates in the kingdom's urban areas. Asian markets have been particularly active; and representatives from China, Japan and Korea (Rep.) have reached an agreement to jointly develop future 3G technologies. These developments have not been driven uniquely by governments and telecommunication operators; large-scale international manufacturers are also doing their part. Intel, for instance, has announced its plans for WiMAX, trials in Malaysia, Philippines and Thailand before the end of 2005, and in Indonesia and Vietnam before the end of 2006.

The challenge today is to extend the promising signs of broadband growth throughout the developing world, and in particular to rural and underserved areas. Technological solutions and innovations like VoIP and broadband applications are providing the means by which broadband connectivity can be used to leverage legacy networks where they exist and to deploy entirely new infrastructure in un-served areas. Some countries are already extending broadband connectivity nationwide. (See Box 1.)

Box 1: Broadband Wireless Nations

A small set of countries has announced plans to become the world's "first broadband wireless nation". Who will be the world's first broadband wireless country? Mauritius and TFYR Macedonia both are deploying fixed wireless broadband networks across the bulk of their countries using technologies that are tracking the emerging 802.16 WiMAX standards.

In Mauritius, the small African island nation of 1.2 million people, the wireless network is reported to already cover 60 percent of the island and 70 percent of the population. By the end of 2005 Mauritius intends coverage to reach a full 90 percent of the country.[2]

In TFYR Macedonia, a country of 2 million people, local network provider On.NET is deploying a broadband wireless network across the country using Motorola Canopy radios. This project is a unique partnership between the donor community, the Government of TFYR Macedonia, and the private sector. The Government of China has donated thousands of personal computers to be used in the nation’s primary and secondary schools. Complimenting that donation, USAID is providing broadband internet connectivity to 460 primary and secondary schools and 71 other sites through 2007. This substantial guaranteed countrywide customer base has created the business case for On.NET to make a significant investment in a pervasive countrywide wireless network.

On.NET is free to sell capacity to additional corporate or consumer subscribers throughout the country. Furthermore, in metropolitan areas they are deploying a mesh based (see Box 8) network providing pervasive hotspot connectivity in the country’s population centers.

In October 2005 the project partners announced an important milestone, that 95 percent of the country’s population is within reach of the broadband wireless signal.

3 The State of 3G Wireless Broadband Deployment3

IMT-2000 technologies, known popularly as 3G, are also starting to grow broadband subscribers. Two of the most popular 3G technologies are W-CDMA, the 3G migration path for GSM networks, and the family of CDMA2000 technologies, including CDMA 20001x and CDMA 1x EV-DO. These 3G technologies are discussed more fully below, in section 5.3 below. There were nearly 134 million IMT-2000 subscribers on 166 networks by year end 2004.

4 The poor pay more for less broadband

The ITU World Telecom Indicators database[4] shows that not only is broadband penetration higher in high-income countries, but that low-income countries pay more for less capacity. Not surprisingly, upper income countries have more broadband subscribers per 100 people than the lower or middle-income countries. Indeed, while the means are not significantly different between low and middle-income countries, with less than one broadband subscriber per 200 people, there is a statistically very strong difference between the case of upper income countries and all other countries.

Given the fewer broadband users per capita in low-income countries, how does the price and capacity of the service vary from country to country? The average fee paid by low-income countries for broadband service is US$291 per month compared to a mean for upper income countries of US$18 per month. While the poor pay more for their broadband service on average they also receive less bandwidth. The average high-speed downlink capacity for upper income countries is 3.8 Mbp/s compared to an average for low-income countries of 712 Kbp/s.

In summary, broadband penetration in low and middle-income countries trails significantly penetration in upper income countries. While penetration is very small in low-income countries broadband subscribers there pay considerably more money for inferior service. As is so often the case, the poor pay more.

5 Promoting Broadband in Developing Countries: A Technology Analysis

Each wave of technological developments offers new promise in the battle to bridge the digital divide. Most new technologies are cheaper to deploy than legacy copper networks, and, at the same time, can deliver a full range of ICT services, from voice to broadband applications and services. Many new technologies can also be deployed incrementally, even locally, rather than on the large scale of traditional telecommunications networks. Not only does this make deployment more affordable to traditional telecommunications operators and service providers, reducing investment strain, it opens the door to a whole new range of possible broadband providers who can drive demand for broadband services. The types of broadband providers enabled by new technological developments include regional or private network operators, small and micro entrepreneurs, as well as public institutions such as universities, schools, libraries, post offices, local government offices, health facilities, and non-governmental organizations active in developing countries. This paper will now identify and analyze the key promising new technologies that can help promote broadband access in developing countries, particularly in rural and underserved areas.

5.1 How are broadband networks designed?

To structure the discussion, two generic concepts describing two different dimensions of networks are useful, layered architecture and network topology. These are important because they help us understand the dynamics that determine incentives, viability and the potential for collaboration between entities that are tasked with the deployment of broadband. In order to help regulators make informed decisions in light of the array of technical options before them, the following sections break out the various aspects and layers of networks, providing definitions, technical specifications, as well as comparisons between DSL, CATV, broadband via powerline solutions, and fibre optical networks as part of a Wireline Broadband Roadmap. These sections also provide detailed explanations of the various link layers (point to point vs. point-to-multipoint access networks), system types, wireless broadband, as well as options for non-terrestrial wireless broadband networks where wireline solutions are not feasible or applicable.

5.1.1 Layered network architecture

The layered network architecture divides a network at any specific point into layers, each of them adding value to the physical medium of communication. A layered architecture based on open standards is useful for several purposes:

– *Technical:* to define physical and logical interfaces required to connect different subsystems.

– *Commercial:* to define the conditions under which a user or a provider of value added services can get access to services provided by a specific provider at a specific level.

– *Regulatory:* to identify the value chains and define the roles of actors providing services in different layers, to regulate where there should be competition and where it should be possible for any service provider to buy services to provide value added services at a higher level. Rights of way, spectrum licensing, access to essential resources and local loop unbundling, are all examples of such regulations at different levels.

The following layers are explained in greater detail:

5.1.1.1 Physical Layer

The physical layer identifies a medium, such as radio spectrum or wires of different sorts (i.e., copper or fibre), and specifies the mechanical and electrical interfaces that connect to the medium for communication purposes.

The most important media include:

Wireless spectrum: This is a scarce natural resource, which is why regulation is necessary to manage the resource. Existing regulations are often more restrictive than technically and economically motivated from a public good perspective, preventing new innovative actors from entering the market. This is clearly illustrated by reliance on license-free spectrum in the dynamic development of Wi-Fi, and is explored more fully in the GSR Discussion Paper on Broadband Spectrum Management.

Wire line infrastructure: This includes fibre, copper cables and coaxial cable, is largely unlimited in supply, and can be deployed and made available at a cost. In some countries, the provisioning of passive infrastructure is an independent business while in others it is an integrated part of vertically integrated operator(s). In many countries, regulations governing ownership of or access to wireline infrastructure may be more restrictive than necessary to promote broadband access. Access to the physical medium is essential for those that have special needs regarding the choice of transmission system or for those that want to compete at the link level and above, e.g. by introducing a new competitive transmission technology. Regulatory measures to promote access to both wireline and wireless broadband infrastructure are explored more fully in the GSR Discussion Paper, The Role of Regulators in Promoting Broadband.

5.1.1.2 Link Layer

Access to link level services is essential to service providers and organisations that need private networks which seek to build their own networks without having to operate their own transmission systems. The link layer adds procedures for digital data transmission over the physical medium, point-to-point or point-to-multipoint. The link layer includes medium access both to wireless spectrum and wire lines, error control, such as automatic repeat request when check sums do not match, forward error correction (FEC) based on the inclusion of redundant information coded in a way that transmission errors can be corrected directly rather than via retransmission requests, etc. Different link level technologies also have different properties that are important for users, such as capacity, performance, security, privacy, etc.

The properties of the discussed link level technologies are different and may be of different significance to operators, users and regulators wanting to strike a balance between producer and consumer interests. Links are implemented using transmission equipment, and the most important ones to be discussed here include the most commonly used Wide Area Network (WAN) technologies; technologies for data access over legacy networks such as digital subscriber lines (DSL) over the Public Switched Telephone Network (PSTN), cable modems over cable TV networks, broadband over power line (BPL) of the electrical power grid, and a range of both wired and wireless local and metropolitan area network (LAN/MAN) technologies, all of which use the Ethernet frame data format according to the IEEE 802.3 standard[5]. An Ethernet frame is the unit of data that is transmitted between network points on an Ethernet network. Examples of such wired networks include Ethernet with data rates from 10 Mbp/s to 100 Gbp/s (IEEE802.3) while examples of wireless link level equipment include: WiFi (IEEE 802.11) that has exploded over the last 5 years and WiMAX (802.16) which is expected to grow as a wireless backbone technology.

5.1.1.3 Network Layer

The network layer provides mechanisms for addressing and forwarding of data. This paper assumes that the Internet Protocol (IP) is used for this purpose. The network layer is implemented by network elements such as routers interfacing to different link level technologies, link level switches and multiplexers, etc, to connect network hosts (servers and terminals). This is the level at which all ISPs provide services.

5.1.1.4 Transport Layer

The transport layer provides end-to-end connections between user applications in network hosts. The central transport protocols include the connection oriented Transport Control Protocol (TCP) and the User Datagram Protocol (UDP).

5.1.1.5 Application Layer

In the application layer, the communication parts of a user application, such as email or file transfer, web access, database access, are implemented.

5.1.2 Network Topology

The network topology divides networks into functional parts, including access, backbone and service networks and traffic exchange points where different service providers exchange traffic. Each of these functional parts is built up by layers according to the previous section.

5.1.2.1 Access networks

Access networks include links between users and the service providers’ networks, whether they go the first or last mile or meter. First mile refers to where a user or local service-provider, or perhaps even an apartment building company[6] owns the access network and connects to service providers via their own upstream links. Last mile refers to where a service provider owns the access network and connects to the users downstream via its own links. Different link level technologies used in access networks have different properties with different sets of strengths and weaknesses that can be valued differently by regulators, users, operators and network owners. Depending on the geographical context, the access network could be a LAN or a MAN. As will be discussed in a later section, the technical solutions might be different depending on who owns the access network. In open regulatory environments, it could be owned by anyone, including a service provider, an organization, a municipality, or a user agent or a neutral agent, such as a real estate owner or independent operator.

The physical layer infrastructure available for access networks includes PSTN, cable networks, electrical power networks, radio spectrum, and increasingly fibre to the neighbourhood, office or home (FTTP, i.e. fibre to the premises). On the user premises, the connections to the residential or office gateway could use dedicated wiring, legacy copper telephone wiring, power line communication or wireless. The most common link level technology on user premises is a local area network (IEEE 802), wired Ethernet or wireless (Wi-Fi).

In an environment with more than one operator, local loop unbundling is an important first step towards an open market, however often limited by a dominant owner of the infrastructure competing with its own customers regarding service provision. A more developed market requires independent ownership of the infrastructure and mechanisms for service providers to obtain direct access to users without intermediary gatekeepers in the way.

5.1.2.2 Backbones

Backbones consist mainly of long haul links which ISPs can use to expand their service networks geographically, to get transit to the Internet and to connect to regional traffic exchange points. In some countries, an open backbone market has emerged due to the existence of parallel or complementary fibre infrastructures deployed by different owners, including telecom operators, power utility companies, railways, pipeline companies, municipalities, etc.

5.1.2.3 Service networks

A service network contains the servers of an Internet Service Provider offering services to users via access networks, transit to the next tier ISPs and peering with neighbouring ISPs in the same tier.

5.1.2.4 Traffic exchange points

Traffic exchange points are used by operators to exchange traffic via peering directly between their service networks rather than indirectly via transit through their upstream providers. An Internet exchange point (IXP) consist in its simplest form of a link layer switch over which ISPs peer to exchange IP-traffic. The service provided by an exchange point is to improve the network performance by keeping local traffic local and minimizing transit costs for the connected Internet Service Providers. This is particularly important in areas where the backbone consists mainly of satellite links with long delays, high bandwidth prices and the remote ends on different continents.

This is a particular problem in Africa. To compensate for the fact that Africa is comprised of a large number of VSAT “islands” on the shores of other internet backbone “continents”, one solution that has been identified is that IXPs be interconnected, even via satellite links if better alternatives are lacking. This would cut the number of satellite hops by making direct hops between IXPs rather than taking the transit route that would involve at least two hops, sometimes more, plus perhaps a few transcontinental and overseas passages depending on where the different transit links happen to terminate. The main drawback of distributing an IXP geographically by connecting local IXPs is the bundling of the switching function and the long haul link, which could lead to unfair competition in situations where link capacity is expensive.

In communities that only have VSATs available as gateways, it makes sense to have a local IXP keeping local traffic local before sending it upstream via the satellite channel. This is also valid for remote local communities that can take advantage of limited alternative fibre stretches, e.g. used for meter monitoring in pipelines (water, oil, gas) or power lines. IXPs thus start appearing in the local access networks, not only between service networks. The importance of IXPs is explored more fully in the joint ITU-IDRC Report *Via Africa: Creating local and regional IXPs to save money and bandwidth.*

5.2 Wire-line Broadband Roadmap

Internet access has in the early phases of Internet expansion been provided mainly by using legacy infrastructure deployed to provide other services, such as fixed telephony (PSTN) and cable TV (CATV). It has been provided by leveraging existing infrastructure, and in areas where such infrastructure has not existed, has been utilized via satellite (i.e., bi-directional VSATs). In some areas, communication over power lines (PLC) has been considered a viable alternative.

To an increasing extent today, where possible, dedicated broadband networks are being deployed. Such networks are typically based on Ethernet over fibre, in backbones, to the curb, block or neighbourhood, and to the home and/or office premises. They can interface to any other link level technology to take advantage of existing infrastructure.

At the same time, new technologies have been developed to be able to provide broadband services over the legacy networks, such as DSL over PSTN, HFC for cable TV networks and broadband over power line (BPL).

The different link level technologies involved are discussed and analyzed below to provide:

- A description of likely broadband upgrades based on existing infrastructure,
- The differences in quality of service and transmission rates of the various solutions;
- An indication of the kinds of infrastructure investments that are required to deploy each technology (as a proxy for cost); and
- A means of assessing the suitability to different socio-economic and geographical contexts.

5.2.1 Upgrades to PSTN

5.2.1.1 Dial-up and ISDN

Due to high teledensity in developed countries, PSTN has long served as a primary access network to the Internet, through dialup modems or leased telephone lines. Data communication via a dialup telephone connection requires an analogue modem at both ends of the telephone line. Traditional modems encode data in the same frequency band as the one carrying the voice call (up to 4 KHz). The user can either speak or send data. Data rates vary between 2.4 and 56 Kbp/s per connection depending on the quality of the analogue copper telephone line, whether or not the network operator's central office switch is digital, whether the switches are clock synchronized, and whether the switches are connected via modern media like fibre or microwave.

From an economic point of view, user modems are cheap and typically integrated in most new computers. Carrier class dialup servers required at the ISP end are quite expensive, while lower class equipment that can be used by rural entrepreneurs on a small scale is cheap (less than USD 500) and supported by open source software. From the user point of view, the usage includes the telephone call cost to the telecom operator while connected and the ISP fee, which may be flat or connection-time based.

Upgrade from PSTN to ISDN requires a digital network to the user premises, and thus investment in equipment both at the central office and at the user end. If already installed, ISDN is still an alternative for internet access in areas where more advanced services such as DSL, cable networks or fibre networks cannot be used. If ISDN is not already installed, DSL appears to be a better investment since it facilitates cheaper and higher quality broadband service. ISDN and some DSL systems are not designed to be used over the same infrastructure. Users that have upgraded from PSTN to ISDN may have to downgrade again, before upgrading to DSL.

Compared to dialup PSTN, ISDN is an improvement both from a bandwidth and reliability point of view. Operators offer ISDN services including two channels as a basic rate offering (BRI) and 24 or 30 channels (depending on basic PSTN type), as a primary rate offering (PRI). Available user equipment consists of simple routers interfacing to the ISDN modem including 2 or 24/30 channels and an Ethernet interface for a local area network on the customer premises. The equipment supports automatic opening of new channels as needed when the traffic increases, thereby providing from 64 to 1.5/2Mbp/s connections. It is also possible to connect different channels to different destinations. On the operator side, the ISP typically leases a primary rate connection (PRI) from the telecom operator. From the user point of view, the usage includes the call fee to the telecom operator for each channel while connected, and the ISP fee, which may be flat or connection-time based.

Even in the best of circumstances with 56/64 Kbp/s maximum bandwidth per connection at voice tariffs, dialup systems or ISDN systems are not able to offer competitive broadband services.

5.2.1.2 Digital Subscriber Line (DSL)

DSL includes a family of technologies providing a digital connection in an unused part of the frequency spectrum of the copper wire subscriber line in the telephone network (ITU-T G.933.2 and www.dslforum.org). The voice and data connections can thus be used independently of each other.
The DSL technology provides a significant enhancement of the installed PSTN base and protects the value of the copper network. According to the ITU World Telecommunication Indicators database, DSL is used to provide over 60 percent of worldwide home broadband connectivity.

The bandwidth that DSL systems can provide has been increasing and there are now systems installed that can provide 256 Kbp/s - 1.2 Mbp/s upstream and 512Kbp/s -28 Mbp/s downstream. The limits are set by the attenuation of signals at higher frequencies, which depends on the quality of the copper lines and their installation. The distance between the subscriber and the exchange usually has to be in the range 0,3-5 Km, depending on data rates.

To deploy DSL, equipment must be added at both ends of the subscriber line. At the user end, a DSL modem and a cheap passive splitter must be installed. The passive splitter plugs into the existing telephone socket and splits the incoming signal between the telephone and the DSL modem. On the other side of the modem, the user can connect a computer directly, or a LAN via a customer premises gateway for less than USD100. The DSL modem converts between the data format used in the local area network environment, mostly an Ethernet LAN (IEEE802.3), into a digital audio stream. On the operator side, before the subscriber line is connected to the telephone exchange, the DSL circuits are separated and terminated in a digital subscriber line access multiplexer (DSLAM), which aggregates the digital connections from different users and feed them into the ISP network.

ADSL

ADSL (Asymmetric Digital Subscriber Line) is the most widespread DSL-technology. The data channels use one frequency band for a low speed upstream channel (25 KHz to 138 KHz) and another for a high-speed downstream channel (139 KHz to 1.1 MHz).

Data transmission speeds vary mainly based on the distance between the subscriber and the central office. Some users cannot be reached by ADSL due to their distance from the central office. In Denmark in 2004, for example, about 5 per cent of households could not be reached by any ADSL services and only 70 per cent of the population could access a 2 Mbp/s connection. More recent ADSL standards, such as ADSL2 and ADSL2+ promise improved capacity and coverage.

VDSL

VDSL (*Very high-rate Digital Subscriber Line*) is similar to ADSL but optimized for shorter distances, 300-1500m. Existing systems offer capacities up to 52 Mbp/s by including more high frequency bandwidth in the copper cables and by deploying more efficient modulation. To extend the range, VDSL requires deployment of a fibre optical backbone network to the curb, block or neighbourhood (street cabinet), and a power supply for the street cabinet, which is not required by PSTN. This increases deployment costs significantly. It has also other limitations, including interference from ADSL and AM radio services. VDSL2, a standard under development, promises to achieve bit rates of up to 100 Mbp/s.

Uni-DSL

UDSL or UniDSL (One DSL for Universal Service), a new variant of DSL, integrating all earlier DSL variants, promises aggregated bit rates of up to 200 Mbp/s, including 100 Mbp/s symmetrical connections. While Uni-DSL gives operators the flexibility to offer a range of connections, the higher data rates cannot be offered on the existing PSTN infrastructure. Uni-DSL would require a fibre backbone infrastructure and would use only a part of the existing subscriber line closest to the user premises.

5.2.2 Upgrades to CATV networks

5.2.2.1 Broadband communication over cable TV networks

Cable TV (CATV) networks use coaxial cable, initially only for distribution of TV-channels in a tree-structured network created by using passive splitters, to reach all users in a point-to-multipoint topology. Broadband communication over cable TV networks is accomplished by transferring data full duplex via unused bandwidth in the cable, similar to what DSL does over PSTN. The standard is “Data over Cable Service Interface Specification” (DOCSIS)[7]. The basic data rates are 54 Mbp/s downstream and 3 Mbp/s upstream. An Internet service provider connects to the cable company central office (known as the head end by CATV operators) and uses the cable network to connect to users.

Similar to the DSL case, equipment has to be installed both at the head end and at the customer premises. On the operator side, at the head end, a cable modem termination system (CMTS) is installed that separates the digital communication channel from the CATV circuits, aggregates connections from different users and feeds them into the ISP network. On the user side, a splitter and a cable modem (CM) must be installed. The splitter divides the incoming signal between the TV set and the cable modem. On the other side of the modem, the user can connect a computer or a residential gateway via an Ethernet port and a USB telephone connecting to a Voice over IP service, if provided by the ISP.

From an economic point of view, broadband over cable is favourable in areas where there is already an existing cable network. The tree-structured point to multipoint technique has, however, several severe disadvantages compared to point-to-point solutions:

- For the regulator, it is less attractive since it has a lock-in effect by preventing local loop unbundling on the physical and link levels.
- For the operator, it is more complex to plan, manage and upgrade.
- For the user, the performance depends on traffic from other users due to sharing without traffic control of individual connections. Users in a neighbourhood (typically, 100 - 2000 homes) share the available bandwidth provided by a single coaxial cable line. Therefore, connection speed can vary between 10 Mbp/s and a few Kbp/s depending on the traffic from other users. While most networks share a fixed amount of bandwidth between users, cable networks generally spread over larger areas and require more attention to such performance issues. The broadcasting technique also raises concerns regarding security and privacy. To address these concerns, the DOCSIS standard includes encryption and other privacy features that are supported by most cable modems.

5.2.2.2 Hybrid Fibre Coaxial

Hybrid Fibre Coaxial (HFC) is a network integrating a conventional coaxial cable network, and fibre optic cables between the head end and the curb, block or neighbourhood interfaced by converters. An HFC network may carry a variety of signal types, including analogue TV, digital TV, telephone, and data. It increases the competitiveness of the cable operators industry in a similar way as the PON (Passive Optical Network) reinforces the wire line operator industry. PON is discussed in greater detail in section 5.2.4.2.

5.2.3 Broadband via Power line

Power line communication (PLC) systems that use the existing electrical power grid as a local loop for delivery of broadband services are sometimes referred to as Broadband via Power Line (BPL). The typical power grid comprises generators, high voltage lines (155-765 kV), substations, medium voltage lines (1-40kV), transformers and low voltage lines (up to 400 V). High voltage lines are unsuitable for BPL since there are too many electromagnetic disturbances (noise). The need for standards ensuring coexistence and interoperability between technologies, and compliance with Electro Magnetic Compatibility (EMC) regulation, is attended to by several organizations. IEEE has started work towards a “Standard for Broadband over Power Line Hardware (P1675)[8] intended to provide electric utilities with a comprehensive standard for installing the required hardware on distribution lines. The standard is targeted for completion in mid-2006. There are also working groups within the Special International Committee for Radio-Electric Disturbances (CISPR)10, the relevant directives of which include EN55022 (European) and CISPR22 (international).

In Europe, standards include the low power voltage 240-volt and frequencies from 30 kHz to 150 kHz. In North America, corresponding standards include the 120-volt grid and allow use of frequencies above 150 kHz as well. Power utility companies often use frequencies below 490 kHz for their own telemetry and equipment control purposes.

BPL uses medium voltage power distribution lines (Access BPL) and low voltage in-house wiring (In-house BPL).

Access BPL uses modems and couplers, which are inductive injectors wrapped around the power lines. Typically, a fibre optic network connection from an ISP is terminated in an opto-electric converter and connected to a BPL modem at the utility substation where the high-voltage lines are transformed to medium voltage distribution networks. The traffic is fed into and extracted from the distribution lines via couplers.

The Radio Frequency (RF) carrier supporting the communications signals can share the same line with the electrical signals as they operate at different frequencies. This is otherwise known as Frequency Division Multiplexing (FDM) of telecom and electrical power, with the BPL signal using frequencies between 2 MHz and 80 MHz.

Repeaters amplifying the signal and regenerating data have to be installed about every 300 meters from the station towards customer premises. Signals are terminated in a device just before the transformation to low voltage lines (110/220 V) used in-house.

In-House BPL facilitates home networking by enabling devices plugged into wall outlets in a building to communicate with each other over the existing wiring. One formal industrial standard that serves as an industry reference point is HomePlug (www.homeplug.org), offering specifications that operate in the frequency range 4.5 to 21 MHz; some in Europe operate from 10 to 30 MHz. In-House BPL and Access BPL are not dependent on each other, which means that one may be used together with other technologies in exclusion of the other.

Examples of Access BPL systems manufacturers include:

- **Ilevo** [www.ilevo.com] offers products providing 200 Mbit/s and 45 Mbit/s. Each power outlet is an access point to the power line network. The Ilevo systems include a head end connecting the power grid to an upstream ISP via any standard link level technology, different types of repeaters and a modem at the customer premises. The frequency band used is 1-30 MHz.
- **Amperion** [www.amperion.com] offers products that deliver Internet connectivity via a wireless link called PowerWi-Fi (IEEE802.11b) to an Ethernet port, instead of via the in-house wiring. These systems operate over 3-35 kV MV lines, and provide up to 24 Mbp/s of delivered throughput per injection point depending on line quality and equipment spacing.

5.2.4 Fibre networks

The paper thus far has discussed ways to extend networks primarily dedicated to other services to provide broadband internet access. This section takes the opposite perspective: how to take advantage of fibre technology to deploy broadband networks offering data as well as voice and video/TV services? In addition to a technical overview, this section will discuss strategies for deployment of fibre in developing countries particularly in rural and underserved areas where penetration of wired telephone networks is low, and in many cases decreasing due to the introduction of cellular wireless telephone networks. The wireless networks in many developing countries are based on microwave backbones which provide little support for broadband applications. Many, if not most rural and underserved areas thus lack a broadband communication infrastructure as well as other types of infrastructure, such as power, water and sanitation, and even basic transport. Nevertheless, these regions also have users that demand broadband services.

The lack of legacy infrastructure can clearly be turned into strength in the form of leapfrogging by coordinating fibre deployment with other infrastructure programmes, especially extensions of the power grid (as power and ICTs mutually boost each other's market), as well as along railways, pipelines and roads. Many developing countries have in recent years developed such strengths, including political awareness manifested in national ICT policies and National Information and

Communication Infrastructure (NICI) plans. The most striking examples include Laos, Rwanda and Tanzania, but many other countries are developing similar strengths. The availability of infrastructure creates new opportunities, where the regulatory environment allows those who recognize these opportunities to act.

5.2.4.1 Physical layer

An optical fibre is a hair-thin thread of glass that transports light waves with very low diminution over long distances. Fibre is deployed in cables. Standard cables contain 24, 40 or 96 fibres. Cables can be deployed under ground in conduits, under water as submarine cables or hanging in poles or pylons. The cost of deploying fibre is mainly associated with the extent of the civil engineering work involved. The marginal cost of adding more fibre cores in a cable is generally very low compared to the costs associated with deploying other infrastructure.

Power utility companies deploy fibre, primarily for supervision, control and data acquisition (SCADA) of the power grid, but are increasingly adding more fibre at a very low marginal cost to lease to others. These companies normally use a special ground wire with a fibre cable in the core (optical power ground wire, OPGW) in green field installations or wrap fibre around the transmission lines in brown field installations (known as SkyWrap). Thus, every power grid substation, including in rural and underserved areas, becomes a point of presence for access to fibre.

Signalling over optical fibre is accomplished by lasers as transmitters and photo diodes as receivers. Standard data rates are 1, 2.5 10 and 40 Gbps in each stream. A 100 Gbps prototype was presented at the 2005 European Conference on Optical Communication (ECOC). Wavelength Division Multiplexing makes it possible to have up to 96 parallel data streams in one single fibre. The maximum total capacity in one single fibre is currently thus in the 1-10 Tbps range.

Optical networks

When discussing optical fibre, the physical layer consists of two sub-layers, the passive fibre itself, without any signals, and an active purely optical network. In the passive fibre network, passive optical splitters can be installed creating a tree structure infrastructure, similar to what is done with coaxial cable in cable networks. This infrastructure is called a passive optical network (PON) and is used to implement point-to-multipoint links, such as Ethernet over PON (EPON), discussed in the link layer section below. Active optical networks focus on the optical signals, rather than the passive fiber itself, implementing wave-length division multiplexing and optical switching.

A passive optical network (PON) is a tree-structured physical point-to-multipoint infrastructure. PONs are created by introducing passive optical splitters on fibre cables. The design is similar to CATV networks in that they are designed for shared use, providing broadcast to end-users. Passive means that the transmission of signals from the central office to the customer premise equipment does not require power. Instead, PONS use light waves for data transfer. The use of such trees to establish links (PON) is discussed in the link layer section below.

Active optical networks are point-to-point infrastructures and include active (powered) optical components that provide routing, grooming and restoration of signals at the wavelength level, as well as wavelength-based services, by using wavelength division multiplexing.[11] This means creating a purely optical network infrastructure, before involving the electrical or digital domains on the link level.

Not all fibre networks are designed using an optical network sublayer in the physical layer. The main arguments for introducing an optical sublayer on top of the passive fibre, before adding the digital communication link, are:

Better utilization of the installed optical fibre base, including the possibility to resell capacity on a wavelength basis rather than an entire fibre. This argument mainly concerns the already installed fibre base since the marginal cost of adding more fibre cores when deploying a new cable is mostly very low.

– Better network restoration capability after network failures since optical networks can perform protection switching faster and more economically;

– Reduced cost of the entire communication system since the distributed wavelength routing scheme decreases the cost for cross-connects and only wavelengths that inject or tap traffic at a node need an electrical network element at that node.

5.2.4.2 Link layer

The dominant wire line link level technology in fibre ***access networks*** is Ethernet (IEEE802.3). The 10/100 Mbp/s Ethernet is standard in all new computers, including laptops; 1 Gbp/s Ethernet is a standard interface in most networking components used in access networks.

Regarding ***backbones***, 10 Gbp/s Ethernet have been in operation for quite some time in high end network components, a few 40 Gbp/s backbones are in operation, and soon 100 Gbp/s backbones will be deployed. In the backbone, the IEC Synchronous Digital Hierarchy and ANSI Synchronous Optical Network standards (SDH/SONET)[12] still dominate due to more robust and reliable carrier-class equipment being available. The considerably cheaper and less complex Ethernet technology is however making its way into the backbone, reducing both CAPEX and OPEX expenditures. Moreover, ***Internet Exchange Points*** are now Ethernet-based and the 30 year old Ethernet technology is thus expanding to all parts of the network topology.

Point-to-point access networks

Point-to-point access networks establish independent links between user premises and service networks. They offer maximum flexibility to all stakeholders, regardless of who owns and operates the involved links. The operator-neutral model developed by the housing industry, municipalities, service providers and systems manufacturers in Sweden is neutral in the sense that the passive access network infrastructure is often owned by housing companies, condominiums or tenant organisations and in some cases also by municipalities.

Access networks are connected to a shared access network backbone to which any service provider can connect their service network gateway and offer services. The access network backbone is designed so that individual users in a housing area can select service providers independently of each other. Low-cost standard Ethernet multiplexers or switches are used to aggregate links from user premises to the access network gateway while preserving the provider selection.

The operator-neutral model suits rural and underserved areas well since there are few traditional operators that are likely to see a profitable business there. Given an adequate regulatory environment and appropriate technologies, local entrepreneurs that know the local market opportunities can provide local services and connect users to a point of presence of the larger service providers.

Point-to-multipoint access networks

IEEE 802.3ah Ethernet in the First Mile standard and the ITU-T G.984 GPON standard have made Ethernet the preferred protocol also among the traditional vertically integrated telecom operators.

PON, as mentioned earlier, is a point-to-multipoint technology similar to cable networks, but fibre-based. By introducing passive optical splitters and couplers, a tree structure is created from an optical line terminator at the operator central office to optical network terminals (ONT) at a number of customer premises. Downstream data is broadcasted to the terminals, each of them looking for a matching address at the protocol transmission unit header. Upstream traffic is coordinated using a

Time Division, Multiple Access (TDMA) protocol, in which dedicated transmission time slots are granted to each terminal.

The main fibre can operate at 155 Mps, 622 Mbp/s (Broadband PON or BPON managing up to 16 ONTs) and 1.25 Gbp/s or 2.5 Gbp/s (Gigabit PON or GPON managing up to 32 ONTs). Bandwidth allocated to each customer from this aggregate bandwidth can be static or dynamically assigned in order to support voice, data and video applications. The terminal can provide all the appropriate interfaces. A single fibre, meanwhile, can service 16, 32, or more buildings through the use of passive devices to split the optical signal and PON protocols to control the sending and transmission of signals across the shared access facility. From an economic point of view, PON saves the cost for fibre and equipment at the central office/head end, compared to using point-to-point connections.

Any savings should, however, be weighed against the weaknesses vis-a-vis point-to-multipoint technologies, as discussed for broadband in cable networks. For a regulator pushing an open regulatory regime, the lock-in effect of PON is less attractive since the topology of the physical medium makes it impossible to separate users and thus prevents local loop unbundling on the physical and link levels. There is no unique path between the central office and a single user due to the fact that passive splitters are used to build the physical infrastructure, like in a cable network. Active optical networks, on the other hand, use switches, so that end users can be separated.

For the operator, it is more complex to plan, manage and upgrade than point-to-point links. For the user, the performance depends on traffic from other users due to sharing unless traffic control of individual connections is introduced. The broadcasting technique also requires concerns regarding security and privacy to be addressed. Policy makers and regulators seeking to promote green field fibre backbone deployment will wish to weigh carefully the costs and benefits of these two fibre options to best meet the ICT development goals of their country.

5.2.4.3 Cases from development countries

Fibre deployment is taking off in developing countries and has in several cases already occurred. . The technologies exist and are not that expensive. In many of the developing countries deploying fibre, universities are at the forefront, establishing National Research and Education Networks (NRENs). Bangladesh, India and Pakistan all have national fibre backbones:

- The Pakistan Education and Research Network (PERN) connect all public universities in Pakistan.
- Laos has a national fibre infrastructure reaching all province and district capitals. There is an Internet Exchange Point (IXP) to which all ISPs, except the incumbent, are connected. The universities are in the process of setting up an NREN and participate in a European Union (EU) funded regional academic backbone programme TEIN2, connecting NRENs in the ASEAN countries participating in the ASEM (Asia-Europe Meeting) programme. For 1-2 million USD, Laos could have a national link level backbone consisting of four Gbp/s Ethernets, with points of presence in each province capital, using one fibre pair in one of the nationally deployed cables.
- A Kenyan network provider, in an order reported to cost USD 50 million, has commissioned the supply of an optical fibre network with a length of 1,140 kilometres by the end of 2006. The optical fibre technology supplied is to provide mobile operators, ISPs and fixed-line operators with a core network that extends from the Kenyan coastal city of Mombassa in the southeast to the country's borders with its western neighbours.
- In Rwanda, Terracom is in the process of deploying EPON to all schools and other priority groups. Rwanda has an IXP with all ISPs connected. The academic institutions are in the process of organizing an NREN.

- Both Tanzania and Mozambique have a mix of multiple fibre owners. Both have IXPs and are in the process of establishing NRENs.
- Malawi and Zambia rely on power utilities for fibre deployment. Both are in the process of deploying IXPs and the universities are in the process of setting up NRENs in both countries.
- Bolivia has a national fibre backbone, an IXP and an expanding NREN.

Box 2: Radio transmission primer

All wireless networks communicate via electromagnetic energy. Such energy is, to a first order, described by a single figure of merit: its wavelength or frequency. Since electromagnetic energy traces a sine wave, the frequency specifies the number of humps (or troughs) per second of time and this unit is called the Hertz (or just Hz).

Radio waves between 30 MHz (million Hz) and 20 GHz (thousand million Hz) are usually used for data. Lower frequencies are used mostly for broadcast services such as FM and AM broadcast radio (though in some cases these are also used for data). Energy much above 20 GHz is not very suitable for data over long distances as it is easily absorbed by particulated water vapor in the atmosphere. Note that visible light is electromagnetic radiation in the Terahertz range.

Indeed, the frequency of electromagnetic energy does a lot to delineate its propagation properties. Relatively low frequency energy, such as that used for AM radio broadcast, travel as ground waves literally hugging the earth's surface. This allows the radio waves to travel past the horizon dramatically extending its distance. Furthermore, such long waves are not easily absorbed or reflected by objects such as trees, buildings, and the like. Relatively low frequency energy also can be bounced (or duck back and forth) off of the ionosphere, which again can dramatically extend the distance travelled (Figure 7).

Due to their ability to hug the earth, bounce off of the atmosphere, and/or avoid or penetrate obstructing objects, low frequency radio communications can travel long distances with significant reliability and clarity. Furthermore, the engineering of transmitters and receivers at lower frequencies is easier and requires less sophistication resulting in cheaper appliances.

In contrast higher frequencies, in the microwave spectrums, generally require line of site (LOS) and cannot travel much past their horizon. The direct LOS requirement can be mitigated, as seen in some emerging 802.16 technologies, through sophisticated multi-path approaches. In this case the signal reaches the receiver not necessarily in a straight line from the transmitter but instead reflects off one or more bodies creating multiple paths from the sender to the receiver.

Given these propagation properties, and the significant complications that arise from multi-path fading, it would seem that the lower the frequency the easier and better! But when we are thinking about broadband digital data transmission there is one major advantage to higher frequencies – the higher the frequency the more data that can be transmitted. In fact, typically 1 – 4 bits per second of data can be encoded for each cycle-per-sec of the radio wave. Note that this is related to but not equal to the data rate delivered to a user since many of these bits are put to other purposes. Indeed many bits must go to the basics of signalling, error detection and correction, and so forth.

These propagation properties are the physical laws that proscribe the capabilities of wireless networks. Broadband wireless networks are all situated in the microwave spectrum in order to take advantage of much higher signalling rates. However, they all must do battle with the relative difficulties in signal loss and fading.

Figure 7: Low frequencies can either bounce off the atmosphere or hug the earth, travelling past the horizon. Both features extend the range of low frequency transmission

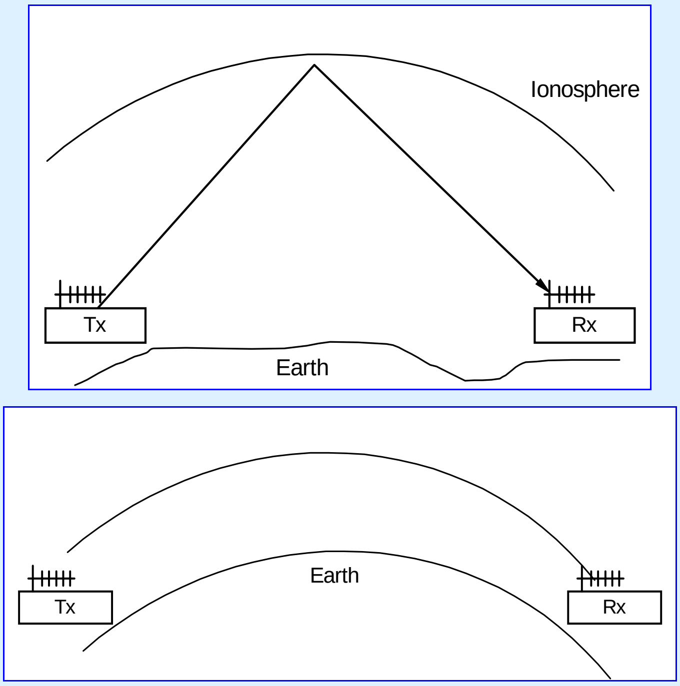
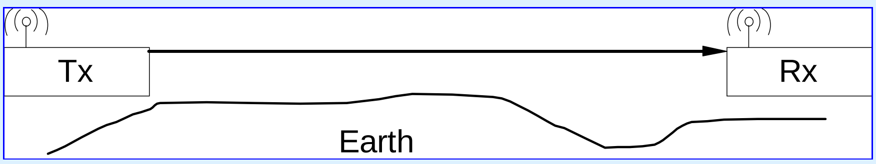


Figure 8: High frequencies require line of site (LOS)

High frequencies require line of site (LOS) between the transmitter and receiver and can be obstructed by foliage, buildings, and the like. Some more complicated systems mitigate somewhat this LOS requirement by allowing the transmitted signal to arrive via multiple paths that have reflected off of surrounding elements.



5.3 Broadband Wireless Access (BWA) Networks

A range of terrestrial wireless solutions are on offer or on the horizon. The development of BWA solutions has been marked both by significant technological progress, as well as substantial industry dropout, as some players forge ahead and others are left behind. BWA solutions can be divided into four primary sub-categories, two of which (GSM and CDMA) are also often labelled as third generation (3G) or IMT-2000 cellular systems. The other two major families, WiMAX and 802.20, are growing in use and maturity in parallel with the development of their standards. While the 3G systems have evolved out of the mobile telephony sector and focused on mobility the other two technologies have emerged from the data networking sectors and often offer fixed wireless solutions (though they too are moving towards mobility).

Box 3: Decoding the 2G cellular acronyms

Second generation (2G) cellular phone systems have seen extraordinary increased levels of penetration worldwide and indeed the number of 2G mobile subscribers surpassed the number of fixed line subscribers from 2002. 2G mobile systems have been implemented using four different classes of technologies each of which is known by it acronym:

Global System for Mobile Communications (GSM). This is the predominant technology worldwide and the predominant system in Europe. It is also used in many nations in Africa, Asia, the Middle East and some countries in the Americas.

Time Division Multiple Access (TDMA). While this term refers to a radio modulation scheme that can be generally applied it also refers specifically to the IS-95B cellular standard, and is the leading technology in the Americas.

Code Division Multiple Access (CDMA). While this term refers to a radio modulation scheme that can be generally applied it also refers specifically to the IS-136 standard. The largest number of CDMA subscribers are in the Americas, followed by the Asia-Pacific region. CDMA has enjoyed less take up in Europe, the Arab States and Africa.

Personal Digital Cellular (PDC). This system is deployed only in Japan.

Source: ITU

5.3.1 GSM

Second generation (2G) GSM networks were initially implemented in Europe and then Asia and have since been installed across much of the world. Original GSM systems support only very limited data capacity (well below that required to be labelled broadband). The next step for GSM-based data services has been 2.5G general packet radio services (GPRS) and the enhanced data GSM environment (EDGE). GPRS offers maximum speeds of 171.2 Kbp/s while EDGE can triple those rates. A typical cell radius for these 2.5G networks is 500-1000 meters, meaning that to achieve complete coverage, every point in the coverage area can be no more than 1Km away from an antenna. GPRS and EDGE technologies allow mobility at vehicular speeds and handle seamless handoff between cells.

The upgrade costs from 2G to 2.5G networks can be extensive since they generally require both soft and hardware upgrades at the base station and may also require upgrades to the backhaul network and increased connectivity at the core network. In addition, in many settings, high costs for spectrum licensing (in the 2GHz band) add to the upgrade costs. Subscriber appliances (e.g. phone handsets) also require upgrades to support 2.5G and handset replacement cycles have often been a central component to system adoption. While estimating the cost is difficult, common implementations have experienced costs per base station above $100,000 or, said another way, upgrade costs per subscriber on the order of $50 or more in low-population density areas.

Third generation W-CMDA systems are an incremental upgrade from GSM's 2.5G networks. These networks, sometimes called UMTS, have seen initial deployments in Europe and Japan. Standard W-CDMA systems can support up to 2 Mbp/s while an enhanced version, called HSDPA, allows downlink rates up to 14 Mbp/s by using a higher modulation rates and other advanced techniques. Given 2.5G base stations and available backhaul networks and spectrum the upgrade from 2.5 to 3G systems can be done incrementally and with relative ease. For instance, 3G services can be offered on a cell-by-cell basis and only in those areas with sufficient subscriber demand. In practice, however, 3G upgrades are done across an entire region in order to provide consistency in service levels for mobile customers and to allow broad marketing and sales plans.

Table 1: Comparative prices for mobile data services
Price per Mbit/s, for selected operators in selected countries, June 2004, in USD, at different monthly usage thresholds, compared with NTT DoCoMo's unlimited usage monthly price

Operator (country)	Technology	1 Mbit/s	10 Mbit/s	100 Mbit/s	1 Gbit/s
Orange (France)	GPRS	1.46	1.22	1.22	1.22
T-Mobile (Germany)	GPRS	10.68	2.62	2.09	0.23
TIM (Italy)	GPRS	1.82	1.82	1.82	1.82
Telefonica (Spain)	GPRS	7.29	7.29	1.46	1.46
Vodafone (UK)	GPRS	13.71	3.86	2.15	2.15
NTT DoCoMo (Japan) (package)	W-CDMA	9.14	3.92	1.35	0.07
NTT DoCoMo (flat-rate)	W-CDMA	35.00	3.50	0.35	0.04

Source: 3G Mobile, ITU Research

Box 4: TD-SCDMA – A Chinese Standard

TD-SCDMA is a 3G standard created by the Chinese Academy of Telecommunications Technology working with equipment vendors such as Siemens. Similar to the WiBRO initiative described below, TD-SCDMA is interesting in the way that the public sector has collaborated with private interests to create a local network standard. In fact, the Chinese have explicitly positioned TD-SCDMA as a way for the country to avoid dependence on "Western technologies". And with China having more mobile subscribers than any other nation in the world, the country has a sufficient market size to support its own standard.

The TD-SCDMA standard (Time Division Synchronous Code Division Multiple Access) is an evolution from the GSM standard in the same way of W-CDMA. Field tests have shown the system to work at vehicular speeds and at a 21 Km distance from the base station. Data rates are published as ranging from 1.2 Kpb/s to 2 Mbp/s.

The fact that the published data rates are so broad is more than a curiosity as technical trials have shown a disappointing delivered capacity. The government has called on an "intensive industry-wide effort" to deliver on the technology and to make it competitive.

5.3.2 CDMA

The second major 2G cellular technologies fall into the CDMA IS-95 family. These systems developed by Qualcomm and used primarily in the United States, do not use the time division multiplexing (TDMA) modulation approach of 2G GSM but, instead, carry multiple transmissions simultaneously by filling the channel with packets encoded for their specific destination device. Note that these CDMA approaches are not compatible with the W-CDMA approach described above; their similar names may be misleading.

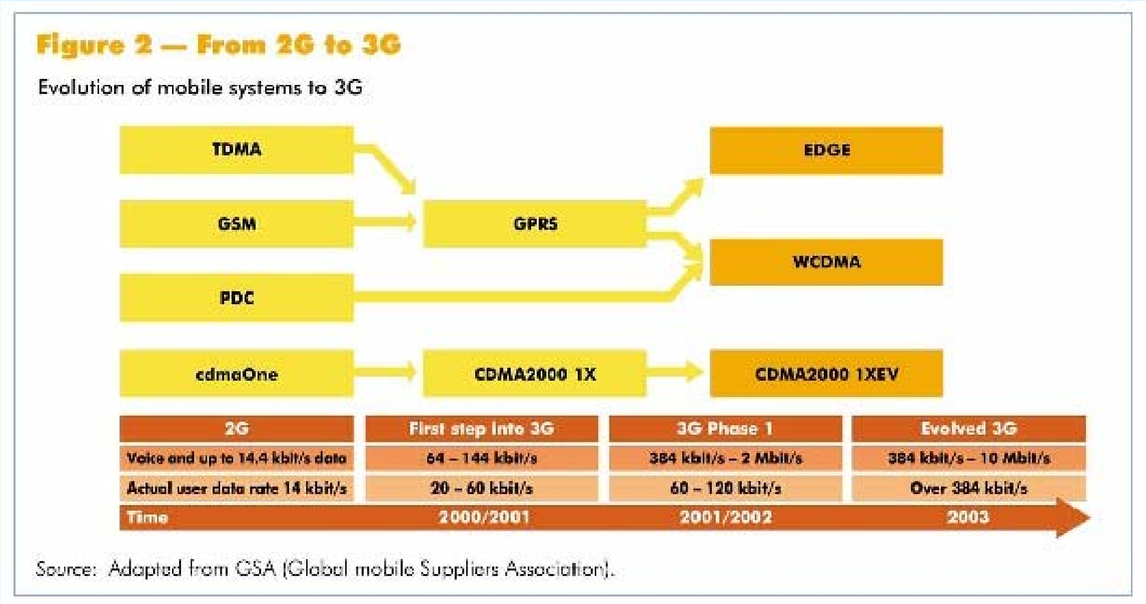
There is a family of 3G upgrades for CDMA networks that are called CDMA2000. This includes the CDMA2000 1x systems which support data rates up to 307 Kbp/s. The CDMA Development Group (CDG) reports their CDMA2000 subscriber numbers as 3G users. This is somewhat clarified by the idea of some operators and equipment manufacturers that the real equivalent to 3G is in fact CDMA2000 1xEV (for Evolution), which is a higher-speed version of 1x. Within this set of technologies are CDMA2000 1xEV-DO (data only) and 1xEV-DV (data/voice). Recent versions of EV-DO and EV-DV support 3.1 Mbp/s downstream and 1.8 Mbp/s upstream theoretical data rates. Real-world rates are about half that speed.

The upgrade paths from a 2G CDMA IS-95 networks to a 3G CDMA2000 network are perhaps like that experienced from GSM to GPRS/EDGE. Certainly they can require similar attention to handset, backhaul, and core network enhancements. However, some industry experts (and many CDMA advocates) have argued that the upgrade requirements on base stations migrating from

CDMA IS-95 to CDMA2000 is easer and cheaper than that required to move from GSM to GPRS/EDGE or W-CDMA.

The performance and market adoption of 3G networks (CDMA2000 and W-CDMA both) has, to date, been disappointing. This has been due in part to the high price associated with network upgrades, the extraordinary rates paid for 3G spectrum in some areas (mostly Europe), and the lack of suitable applications to motivate subscriber adoption and handset upgrades. But the vision is compelling: ubiquitous internet access enjoyed while moving at vehicular speeds with broadband (DSL or cable modem comparable) bandwidths and latencies.

Figure 9



Box 5: Wi-Fi beyond hotspots

The explosive growth of Wi-Fi hotspots that provide wireless local connections in business complexes, homes, and public spaces such as coffee shops and airport lounges has made Wi-Fi a household word. The IEEE 802.11 family of standards was designed by the data networking community for just these contexts: indoor, short range (one hundred meters per access point), nomadic (can support walking speeds), but with weak handoff between access points. But the vision of Wi-Fi networks simply as a replacement technology to the physical cables in the home or office LAN now seems wildly constrained.

The amazing growth of Wi-Fi has driven economies of scale such that the price for access points and end-user systems can be as low as $50 or even less. And this attractive pricing, along with the spectrum license-exemptions that many countries offer to the frequencies used by Wi-Fi radios, has led researchers to explore ways that Wi-Fi chipsets can be used in other networking environments, especially those designed to be served by the WiMAX family of systems described below (as well as mesh networking environments, see Box 8).

A number of university research projects (and probably others) have been exploring modifications to 802.11 systems that would make them better suited to long distance point-to-point backhaul networking. This includes work at the Indian Institutes of Technology campuses in Kanpur and Chennai as well as the University of California, Berkeley in the United States. These projects have attempted long-range (10s of kilometers) point-to-point backhaul hops using 802.11 systems. The principle problem with the 802.11 standard within these contexts lies with the way multiple radios on the network contend for transmission capacity (in technical jargon, the MAC layer uses a Carrier Sense Multiple Access (CSMA) protocol which, while being well suited for local area networks is ill suited for wide-area networks). Research projects have developed new Wi-Fi protocols better suited for long-distance point-to-point networking. What may be emerging is a “rural network” extension to the 802.11 family that could be in direct competition with WiMAX.

More likely, however, is that Wi-Fi networks will compliment WiMAX (and related networks). Wi-Fi hotspots can provide nomadic broadband for the last 100s of meters with WiMAX or other networks backhauling from there to the core head end.

5.3.3 WiMAX

A range of technologies fall under the WiMAX moniker including those that comport to the emerging set of IEEE 802.16 standards. WiMAX systems promise to be very high capacity (up to 134.4 Mbp/s in a 28 MHz channel), travel long distances (50 Km or more), not require line of site, work at vehicular speeds (under the 802.16e extension), enjoy high spectral efficiency (by using OFDM, described below, under the 802.16a/d extension), and be inexpensive (with base stations in the $10,000 range). It sounds like a broadband wireless dream-come-true but for the fact that not all of these extensions have worked yet in the real world and all of these desirable qualities cannot be enjoyed at the same time under the same network (e.g. there is not at present a cheap, efficient, high-capacity system that works at vehicular speeds).

Nonetheless, WiMAX systems show great promise for the provision of broadband internet services especially in remote areas and especially when fully ubiquitous access and vehicular speeds with seamless handoff is not a high priority.

Box 6: 802.16 extensions in the works

802.16a	Works in 2-11 GHz range and supports mesh deployments.
802.16b	Increases the amount of spectrum that can be used in 5 and 6 GHz range. Provides Quality of Service guarantees.
802.16c	Works in a higher frequency range of 10 to 66 GHz.
802.16d	Improvements to 802.16a; this standard supplants 802.16 and 802.16a.
802.16e	Supports mobile devises.

While the 802.16 standard, and its extensions, were still being finalized at the time of publication, a number of vendors have been offering technologies that are designed for the WiMAX metropolitan point-to-point or point-to-multipoint broadband market. Some of these technologies have plans to comport with the 802.16 standard as soon as it is stable. One example of these technologies is the Canopy system from Motorola. Canopy can travel 50 km in a single hop providing 10 Mbp/s shared bandwidth. Outdoor access points can list for $1,000 with customer premises equipment costing $500.

Samsung and LG Electronics of Korea (Rep.) have developed a WiMAX styled technology called WiBro (for wireless broadband). The technology is designed for 2.3GHz and offers 512 – 1024 Kbp/s per user and allows users to travel at near vehicular speeds (around 60 km/h). The system has emerged with assistance from the government of Korea (Rep.) which was eager to see a locally produced technology.

Korea (Rep.) had encouraged WiBro to be used as the basis for the 802.16e mobile WiMAX standard. Other important stakeholders were not supportive of WiBro as a standard setting technology along technical grounds, especially as it relates to the frequency of use. The 802.16e standardization process would have, of course, been weakened if two competing technologies were to emerge. However, at this point, companies from both sides of the argument have agreed to converge on a shared single standard.

The European Telecommunications Standards Institute (ETSI) has also developed broadband metropolitan area network standards under the name HiperMAN. Like WiBro and other related technologies, these systems allow for long-distances (10s of kilometers) and high bandwidth (up to 280 Mbp/s per base station).

The WiMAX Forum has been working with the HiperMAN, WiBro, and IEEE 802.16 standards to try to ensure interoperability amongst these various systems.

5.3.4 802.20 – the newest standard on the block

While WiMAX started as a fixed wireless technology and has since been evolving towards support of mobility (under the .16e extension), the IEEE 802.20 standard originated explicitly as a mobile broadband technology. The fact that its original design requirements included mobility should prove beneficial to the standard (as opposed to trying to add support for mobility onto an existing fixed wireless standard). However, one significant advantage of the 802.16 family of systems is a first-mover advantage and at present stronger industry support from major players.

Through its recent acquisition of Flarion Technologies and their Flash-OFDM technology, Qualcomm, has just demonstrated its support of the emerging 802.20 standard by its. This system plans to comport to the 802.20 standard as it is finalized.

Orthogonal frequency-division multiplexing (OFDM) is emerging as a leading technology for providing very high bandwidth wireless connectivity. As the speed of wireless services increase so does the requirement for more and more radio spectrum. And this spectrum can be hard to acquire and expensive. Thus spectral efficiency, the number of bits that can be encoded into a single radio cycle becomes more and more important. OFDM based technologies, including WiMAX, enjoy spectral efficiencies of around 4 bps/Hz as compared to 802.11d, for instance, which is under 2 bps/Hz.

OFDM works by segmenting available spectrum by frequency and carrying a portion of user data on each of these frequencies. Each of these frequencies is unique and non-overlapping, and thus orthogonal one to the next. This ensures that there is no interference between the various tones. This technique, along with other sophisticated improvements in digital signal processing, has produced an efficient and speedy network technology.

Flash-OFDM can deliver to users capacity of around 1 Mbp/s downstream and .5 Mbp/s upstream while motionless, though while moving at vehicular speeds available bandwidth is diminished. One significant strength of the Flash-OFDM system is its spectral efficiency at about 4 bps per Hz (similar efficiency is planned for the 802.16a OFDM extension). When spectrum is scarce and/or expensive, this is a great advantage. In some rural and underserved areas where the microwave radio bands are relatively underutilized, this advantage need not be so compelling.

Another early system that intended to track the emerging 802.20 standard, iBurst, is based on radio technologies (and in particular smart antenna designs) by the United States based ArrayComm. Early deployments of this mobile broadband system have gone up in Australia and South Africa.[13]

Box 7: The evolution of a "Southern" solution

Broadband corDECT is an important incremental improvement on the corDECT system designed at the Indian Institution of Technology, Madras. The initial DECT system, based on the European standard originally developed for cordless telephones provided LOS connectivity at a maximum of 70 Kbp/s. One significant strength of this system is its relative low cost.

While the benefits of non line-of-sight systems are palpable, there is no immediately available technique to develop a NLOS DECT based system. This is because of the power restrictions placed upon the spectrum used by DECT radios. Broadband corDECT is able to turn this "bug" into a feature by taking advantage of the line-of-sight requirement to enhance capacity. Through spatial reuse of spectrum, enhanced modulation levels, and the use of radio wave polarization techniques, Broadband corDECT delivers 256 and ultimately as much as 512 Kbp/s dedicated bandwidth to each user. Costs are considered affordable at around $150 per subscriber including base station and customer equipment costs.

Source: Midas Communications

Box 8: Mesh networks

A mesh network is an interconnection of communication nodes that are capable of passing messages directly between each other in the absence of a dedicated intermediary. The communication nodes used in a mesh network can be of any type from handheld sensors to web-browsing desktop computers to Wi-Fi routers. The difference between this direct form of communication between clients (also known as multipoint-to-multipoint or peer-to-peer) and traditional networking is that in a traditional network, a dedicated router would be required to pass all messages from one client to another. Mesh networks still frequently make use of dedicated routers, but enjoy the freedom to not rely solely on such infrastructure. The arrangement (topology) of client communication devices (nodes) is also very flexible. The important part is that each node is capable of talking directly to its neighbors within range, whether client (computers, sensors, kiosks) or infrastructure (routers, access points, gateways).

There are a number of reasons that a mesh network might be chosen over a traditional one, and these include scalability, extensibility, resiliency, and consideration of the physical infrastructure. Scalability stems from the flexibility of a mesh network for choosing the path of a message being passed. When an additional node is added to a traditional network, it has to be able to communicate with a dedicated router, which necessarily either increases the load on an existing router or requires a new router to be put into place. On a mesh network, however, the additional node not only consumes routing capacity but also adds its own capacity to the network. This means that the routing capacity and aggregate throughput within the network grows as the network grows rather than starting at some limit and decreasing, which is what happens in a traditional network.

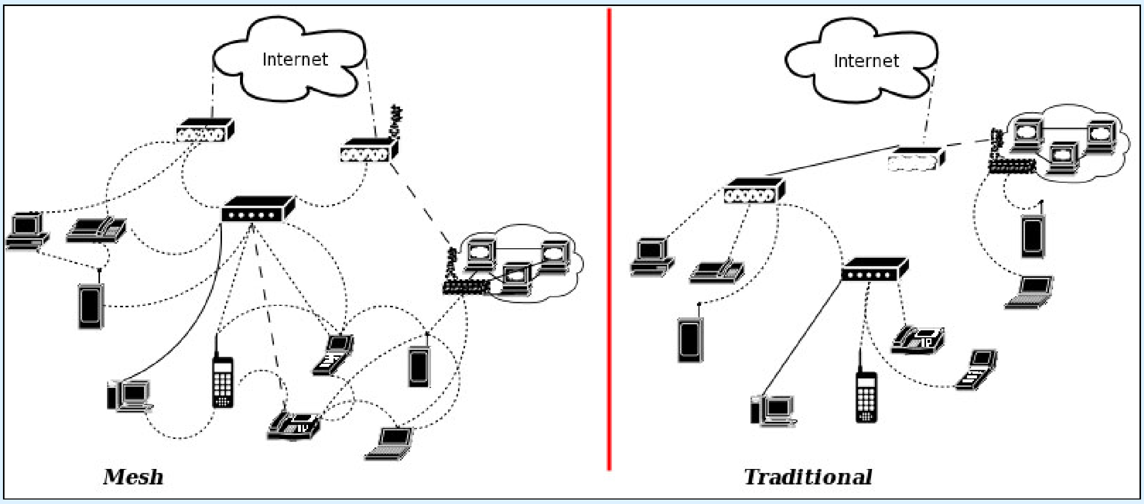
Extensibility is a very important advantage of mesh networks, particularly when referring to wireless mesh networks. Extensibility stems from the fact that any node can have its message hop from one point to another via a peer node. While in a traditional (point-to-multipoint) wireless network being out of range of a dedicated access point would mean loss of connectivity, in a mesh network connectivity can be maintained so long as there is another client node within range which can be used to eventually reach the access point or destination. There is no fundamental limit to the number of hops a message can make before reaching its destination, but implementation details mean that as the network extends farther and farther outward, it will eventually be beneficial to add a new dedicated access point.

Another advantage to mesh networks is in its tolerance of failures. Typically, in a mesh network there will be more than one path available for data to take, in comparison to a traditional network which only offers a single path. If, in a traditional network, a router suffers a failure, the nodes connected to it lose all connectivity. Another benefit of the multipath character of mesh networks is that the network diameter, or minimum number of hops separating any two communicating nodes, can be smaller than in a traditional network. This can result in reduced latency on the network.

There are drawbacks to mesh networking. First and foremost is that each communicating nodes needs to be willing and able to route traffic. This activity requires computational and electric power and thus could slow down the appliance or unduly drain its battery. In addition, mesh networks requires additional preparation and/or setup of each client and may be harder to maintain than a more centralized traditional network.

One area where mesh networking could make significant inroads is rural access. A mesh network provider based in a metropolitan area could offer services in remote areas by "piggybacking" connectivity over a series of subscribers in the direction of the end-user. Data traffic on the outer edge of the network in a remote village would only need a wireless connection strong enough to reach the next, closer subscriber to the metropolitan area. This second subscriber would then pass the traffic to another, closer subscriber and the process would continue until the traffic reached the backbone Internet connection. By using all subscribers as transit points, the mesh network can quickly reach distant areas with relative ease.[14]

Figure 10: A mesh network topology versus a traditional networ



5.3.5 Integrating Heterogeneous BWA Networks

What this roadmap makes clear is that there are a number of complementary and often-competing standards, standard setting institutions, proprietary offerings, and vendors. While considerable effort is being put to interoperability and merging of these various systems, it still is likely that many settings will have installed a heterogeneous collection of wireless networks. (Moreover, the functionality of many of these systems is converging, see Box 9).

Ongoing research work has been studying ways to integrate across these various network technologies. For instance, the Third Generation Partnership Project (3GPP) has been studying systems to inter-network 3G systems with WiMAX or Wi-Fi networks. Issues have included hand-off; authentication, authorization and accounting (AAA); and other considerations.

Box 9: Convergence of WLAN and 3G

There is, to date, not a single optimal broadband technology. Each major family of technologies enjoys some strengths and is hampered by some weaknesses. Below are some preliminary decision matrices that can help develop strategic choices among the technology types. Notwithstanding these technology differences, there is a period of significant convergence among the various offerings towards a similar set of design characteristics for the ideal broadband wireless network, which include:

– High bit-rates in an all-IP environment including IPv6 support
– End-to-end QoS
– Multimedia support
– Mobility at automobile and train speeds
– Seamless session management
– Security, security, security
– Support for flexible and dynamic spectrum and interference management (including software defined radios)
– Advanced authentication, authorization, and accounting protocols.

These goals are more than a pipe-dream. The fixed wireless and 3G families of networks are converging on each other, and beginning to converge on this network design wish list.

Figure 11: Convergence of WLAN and 3G technologies towards each other

Current WLAN Strengths

- Relatively inexpensive
- Data ready and high-bit rates (e.g. mobile WiMAX 802.16e?)
- QoS (e.g. WiFi 802.11e)

VoIP

Emerging WLAN Strengths

- Mobility

Current 2G strengths

- Ubiquitous
- Mobility
- QoS guarantees

High data rates
(e.g. W-CDMA)

Emerging 3G Strengths

- Multimedia support

As the capabilities and purposes of fixed wireless and 3G wireless networks converge, and approach the performance of wireline networks, perhaps it will become easier to make a strategic choice between these families of technologies.

5.4.6 Civil Engineering Costs for Broadband Wireless

According to Moore's law, an amazing pattern of exponential growth in the performance and affordability of computer technology will occur. Regrettably, Moore's law has yet to apply to the performance or cost of steel, cement, or labor. The result is that the "civil engineering" costs for outdoor radio networks, those associated with radio towers, cement foundations, and related requirements, are beginning to outdistance the cost of the solid state radio equipment.

Let’s consider the cost for radio masts or towers. Such facilities are required for fixed wireless and 3G radio networks in order to position signals above foliage and buildings that might obstruct them, extend the horizon, or meet other transmission requirements. In most major cities the skyline is littered with these towers. They range from masts on the order of a meter in height that are positioned on the roof of a customer’s premises, to 10 meter cellular network towers, to 100 meter (and higher) towers populated with high capacity point-to-point microwave antennas and, perhaps, broadcast TV or radio facilities.

The cost and effort required in constructing a radio tower can be influenced by a number of factors including local weather conditions (i.e. are there high winds or will there be icing) and the intended loading of the tower (i.e. one small antenna or many large ones). Towers are designed with these factors in mind and a choice is made between three principal support strategies: free-standing, bracketed against an existing structure, or supported with guy wires.

However, by far the most important factor in determining the cost and complexity of a tower design is its height. The height requirement dictates to a large degree the type of tower needed, the foundation strength, the requirements for guy wires, and so forth.

An additional cost associated with a tower that is especially critical in many parts of the world is the expenses associated with grounding. In areas that experience seasonal electric storms, tall radio towers are likely to attract lightening strikes. And such an event can spell the death of an antenna and the radio electronics. In order to protect the equipment, lightning attractors can be affixed at the top of the tower. The principal of a lightening attractor is simple: it should be higher than the equipment being protected and it should offer less resistance to the flow of electricity than “competing” local options (such as the radio equipment). Fixing an attractor above the radio and antenna is easy enough. But ensuring low electrical resistance requires careful attention to grounding. Especially in rural and underserved areas, where for instance a relay base station may be positioned, industrial grounds are not available and it is necessary to dig an earth pit which serves to ground the arrestor. This activity can add substantial expense.

The authors’ study of five different radio tower vendors shows that three critical expenses – the cost of the tower itself, installation labor costs, and the cost for grounding – all follow strict linear associations with the tower height.

Figure 12 shows empirical data for the tower and labor costs in the United States and Ghana and grounding costs in the United States. A simple regression performed on these data points shows the linear cost models which are depicted visually below. Our results can be summarized this way:

- In Ghana a 3 meter tower with installation and grounding costs just under USD220 and an additional USD 270 for each additional meter.
- In the United States a 3 meter tower with installation and grounding costs nearly USD 1,360 and almost an additional USD770 for each additional meter.

Of course these models are just that, estimates that help to clarify and guide our thinking. As a point of comparison, for instance, Motorola Canopy outdoor access points can list for approximately $1,000 while their subscriber modules can be under $500. Clearly any cost analysis of wireless broadband equipment should consider such civil engineering costs, since they are quick to dominate costs for radio equipment.

Figure 12: Empirical data points for tower, installation, and grounding costs

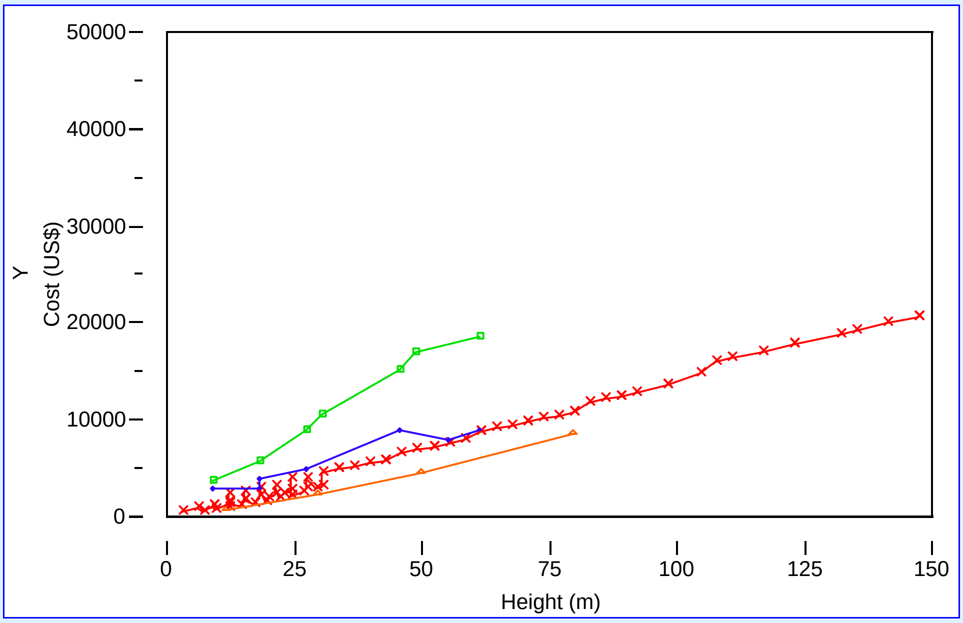
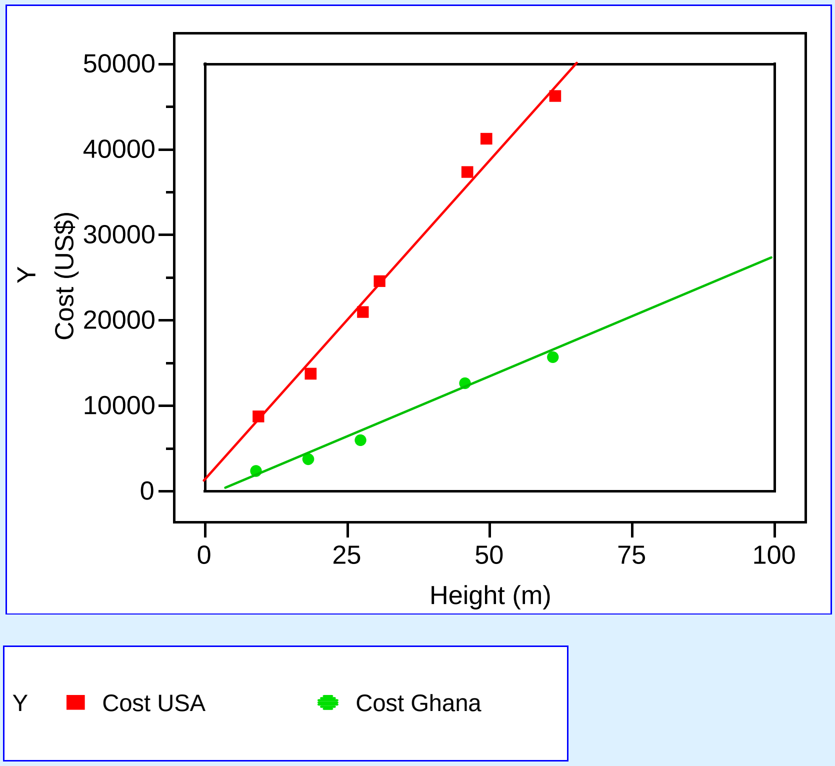


Figure 13: Linear model of tower, installation, and grounding costs in the USA and Ghana



A simple radio pole, perhaps just a few meters high (left); a free-standing radio tower used for a cellular phone network, perhaps 10 meters high (center); a guyed radio tower holding various antenna, perhaps 100 meters high (right).

5.4 Non-terrestrial wireless broadband

From a broadband internet access point of view, non-terrestrial systems are generally regarded as a complement in areas where there are no terrestrial networks. This is mainly due to high cost, limited bandwidth and longer delays. Still, the number of subscribers for internet access services provided by satellite operators is increasing. Besides TV distribution services and telephone connections, the capacity is primarily used to connect Internet service providers (ISPs) to the internet backbone, rather than connecting individual users to an ISP, although the latter is also an increasing market in rural and underserved areas.

Whether broadband internet access via satellite is the right choice in cases where there are alternatives depends on the cost/performance of the alternatives. The cost per megabyte via satellite is decreasing, albeit slowly. While the cost of operating the large low earth orbit constellations limits their margins, regional geostationary systems should be able to reduce their costs significantly. Prices in the order of US$ 0.10 per megabyte have been predicted.

The open standard for digital video broadcasting with return channel via satellite (DVB-RCS) is increasing its market share and is expected to benefit both users and industry through lower costs, customer choice and equipment interoperability. The market is, however, still dominated by a few proprietary vendor solutions.

A satellite terminal consist of two parts, an outdoor unit consisting of a transceiver and an antenna that is placed in direct line of sight to the satellite and an indoor unit interfacing the transceiver with the end user's communications device, such as a computer or a local area network. The aperture of antennas required decreases at higher frequencies due to the reduction in parabolic antenna beam width at higher frequencies. Due to this, terminals operating at higher frequencies are called Very Small Aperture Terminals (VSAT).

The frequency allocation relevant to the system types is being discussed in this section. Most satellite systems for television broadcast and broadband data communication in operation today use portions of the C and Ku-bands. In the C-band antennas are typically 2-4 metres while in the Ku band they can go below 1 metre, which also makes it easier to direct the antenna.

The lower frequency parts of the spectrum that the C and Ku band represent cannot accommodate the data rates and traffic volumes demanded. This has forced commercial satellite system operators to consider the Ka and V-band as well. These higher frequencies offer, however, additional challenges due to blocking of signals by rain, fading and signal scattering.

5.4.1 Stratospheric platforms

Stratospheric platforms operate within the stratosphere under aerodynamic conditions. High and low altitude platform stations (HAPS or LAPS) offer the coverage benefits of satellites at costs close to fixed infrastructure:[15]

HAP: High Altitude Platform, typically an airship soaring in the stratosphere at an altitude about 20km, well above normal aircrafts and below orbiting satellites. There are no commercial services yet but active research and development efforts [www.capanina.com]

LAP: Low Altitude Platform, typically an airship kept stationary at about 3 km. Commercial services are available, especially targeting temporary needs, like emergency response situations, sports activities, etc [www.worldskycat.com/markets/skycom.html]

The key market for LAPS and HAPS will likely be rural and developing areas that are underserved by traditional infrastructure. However, they could also play a key role for newer wireless technologies such as WiMAX. Since LAPS and HAPS are underlying platforms for delivering a range of wireless connectivity, their radio equipment could make use of the most current technologies to provide fast connectivity within line of sight. Since the line of sight requirement could be met for many applications, the frequencies and corresponding transmission speeds could be much higher.[16]

5.4.2 Network topologies

Independently of the system type, non-terrestrial wireless broadband network topologies fall in the following categories:

– **Bent pipe star** topology, characterized by having a large gateway earth station transmitting one or more high data rate forward link broadcasts to a large number of small user terminals. These broadcasts contain address information which allows each user terminal to select those transmissions intended for it. In the return direction, the remote user terminals transmit in bursts at low to medium data rates to the gateway.

– **Bent pipe point-to-point** topology having a dedicated duplex connection set up between a large gateway earth station and a single user terminal.

– **On Board Processor (OBP) Switching** Topology, in which the satellite rather than the gateway is the central node in a star network. The satellite is connected to the gateway by one or more high data rate trunks. The on board processor de-multiplexes the uplink trunk into several downlinks for different geographical areas, usually determined by the footprint pattern. The forward downlinks contain messages for large numbers of user terminals and the destination is identified by message headers. In the return channel, the uplink transmissions from user terminals in one or more cells are multiplexed onto a downlink trunk to the gateway.

The benefits of the “bent pipe” versus OBP are under discussion. In the bent-pipe system, the received signal is retransmitted without processing. While this scheme is less complex and has performed well in the first phase of Internet development via satellite, OBP promises better bandwidth efficiency and true mesh connectivity. OBP trials are being conducted by a number of companies.[17]

6 A Decision Framework for Broadband

Facilities based competition is a desirable element for any nation's broadband market but is a situation that simply may not exist in all parts of all countries. For instance, some high-income metropolitan areas may have multiple wireline broadband providers (the cable provider competing with the DSL operator) along with multiple mobile operators each competing to provide the most cutting-edge data solutions and, finally, local entrepreneurs or even municipalities offering wireless hotspot solutions. But in some low-income areas, and especially rural and sparsely populated areas, this level of competition may not be commercially viable. Initially, policy makers and regulators may succeed in coaxing only one broadband provider to enter rural and sparsely populated markets, while leaving the door open for other entrants once demand for broadband services has been established. In these environments, therefore, strategic choices may have to be made between various network families. In other words, some contexts may commercially support facilities based competition (or, said another way, "complimentary" networks) while other regions may face a choice of one network over the others.

There are currently three dominate technology families for the deployment of broadband Internet connectivity: **broadband wireline networks, (e.g.** DSL, cable TV and fibre solutions), **broadband wireless access (**e.g., third generation mobile and WiMAX), and **non-terrestrial wireless options,** (e.g. VSAT). Each of these solutions is in play today and each have contexts in which they are the most appropriate. In this section we will consider these contexts - the geographic, economic, demographic, and public policy environments – and how they determine the viability of each family of network solutions. **Our conclusion is that there is not a significant environment on the planet today in which broadband Internet does not make commercial, social, and institutional sense**.

These families of technologies under discussion in this report mostly describe the *edge network*, that is, the "last mile" component of the network that connects the base station or central office (or similar) to subscriber premises. The *backhaul network* is the facility that connects the various base stations together. And finally, this traffic is aggregated by the backhaul network and passed on to the Internet "cloud" which we will refer to as the *core network*. This paper has focused mostly on edge networks because, in particular, they are the most expensive and difficult to deploy. However, as stressed in Section 5.2.4 on broadband wireline networks, the availability of core network facilities, and in particular, fibre networks, is vital to promoting broadband deployment.

The next session explains the four main environments for the deployment of edge networks: converged, complementary, competing and exclusive in an effort to facilitate decision making by policy makers and regulators. Different policy and regulatory choices may apply to each environment, and new regulatory frameworks may have to be developed as broadband markets evolve and mature. While the goal of this publication is to identify regulatory practices and procedures to encourage initial broadband deployment, regulators and policy makers will also wish to look toward a future of more widespread broadband access.

6.1 Converged Environments

Converged environments are sprouting up (or currently under test) in areas densely populated with high-value and mobile/portable subscribers such as in metropolitan areas in North America. In a converged environment fixed wireline networks compete or compliment BWA networks. And BWA networks are being integrated such that using single converged appliances (phone handsets, PDA's, laptops) users can move seamlessly between 2.5G or 3G networks and WiFi or WiMAX networks. As these converged environments develop, two approaches to the integration of the wireless networks are being explored. Tightly coupled integration is implemented at a relatively low level within the network. Here, for instance, the WiMAX network will appear to the 3G facility as just another cellular-access network. Thus seamless handoff between cellular and WiMAX networks can be expected. In comparison, another approach, loose coupling, implements integration at the Internet protocol layer. This form of integration will still support some limited handoff between networks. Finally, and more immediately, hybrid appliances can support a limited form of network convergence, for instance today's Wi-Fi and 2.5G enabled handsets.

Converged environments are the most capital and technology intensive requiring significant vertical integration amongst network operators. They also place significant cost burdens on each user since converged handsets and appliances are only now becoming available on the market and are expensive.

6.2 Complimentary Environments

Converged environments are just now emerging and in today's reality, in most areas with multiple broadband networks the networks either compete or compliment each other (or both). In a complimentary environment broadband network providers provision service to specific niche markets. The networks are often broadly pervasive but not wholly ubiquitous. For instance one of the authors subscribes to three different broadband network services provided by three separate operators: a cable based home broadband network; a hotspot WLAN facility available at coffee shop chains, airport terminals, and so forth; and a 2.5G EDGE network provided by a major cell phone operator. None of these networks are integrated as in a converged environment. But they all respond to specific needs of the author: when working at home, when enjoying a cup of coffee or waiting to board an airplane, and when requiring short but immediate connectivity for instance to quickly check email when travelling.

6.3 Competing Environments

In many areas where the number of high-value subscribers per unit area is substantial, but perhaps the organizational and capital environment has not yet been able to support much in the way of converged facilities, multiple broadband networks will be deployed in competition. Indeed this is the case for most metropolitan areas in North America, parts of Asia and Latin America, and Europe.

The example environment of one of the authors described above, with three complimentary broadband networks, also includes a number of competing network facilities. The local dominant cable provider offers home broadband service. Competing with this service is a DSL broadband service provided by the local exchange carrier. Similarly, multiple WLAN hotspot services compete, though not often at the identical physical location.

Indeed, we expect that in those areas which enjoy a large number and high density of high-value broadband users there will exist simultaneously instances of converged, complimenting, and competing broadband networks.

6.4 Exclusive Environments

In marked contrast, much of the developed world has no broadband provider at all. While regulators seek to promote competitive broadband provision, a more likely scenario, at least in the short term, is broadband provision in an "exclusive" environment. It is not that regulators seek to create single provider markets. The problem is they may only succeed, at least in the near future, in attracting one broadband provider. Rural areas that are sparsely populated, low-income areas, and places with challenging physical environments are all candidates for such exclusive broadband providers. It is these environments that are the most important and the most compelling for bridging the digital divide. Since only a single broadband network is likely to be able to be commercially viable, at least initially, picking the technology family, and getting the institutional and policy environments right to support the network, is critical. These contexts will include much of rural and semi-urban areas in low-income countries as well as extremely rural and remote areas the world over.

How can we best conceptualize and support broadband internet in these exclusive environments, especially in those green field cases that currently have no available access?

We wish to consider our three technological families, first the two “extreme” cases of fixed wireline solutions and non-terrestrial wireless, and then the “middle” case of fixed and mobile terrestrial wireless networks.

6.4.1 Wireline Broadband for Exclusive Environments

For conditions which include a large density of stationary users, and sufficient access to capital, public policy support, and organizational integration, wireline broadband solutions will make good sense. Indeed, fixed wire networks are the cheapest per bit, where the goal is to traffic a very large numbers of bits. Researchers have argued that fixed wireline solutions are the most cost effective, compared to available wireless solutions, in environments with more than 40 broadband subscribers per square km.

The choice between the three primary wireline edge technologies (DSL, cable, and fibre) will probably be driven mostly by what the extant networks are made up of. If there is a high-quality copper network already in place then that might suggest broadband DSL service. Similarly, if cable TV is in heavy use then coaxial and fibre networks might be able to support broadband data.

However, it is important to note that our exclusive environments are usually areas that do not include a large density of high-value users nor the necessary capital to support the financially intensive requirements of broadband wired networks. In other words, we expect few if any exclusive environments that would be best served by a fixed wireline broadband network.

6.4.2 Atmospheric Wireless Broadband for Exclusive Environments

VSATs are the clear solution for extremely remote areas and areas with extreme geographic conditions (e.g. severely mountainous). Today every part of the planet is touched by multiple satellite signals providing, for a price, broadband internet services. But, in general, it is this service price which reserves satellite connectivity only for the most remote and difficult settings. It is not uncommon to be confronted with a monthly fee of thousands of dollars for broadband satellite service.

Although this section focuses on various edge network solutions, one possible approach to the use of VSATs, which leverage economies of scale and create opportunities for sharing the expense, is to utilize VSAT technologies as the backhaul network. A local BWA network can then share this connectivity with multiple local subscribers.

6.4.3 WiMAX and Related Networks for Exclusive Environments

It is likely that the majority of exclusive environments, especially in rural and semi-urban areas in low- and middle-income countries, will receive broadband internet via some form of terrestrial wireless technologies. First this section considers the case for WiMAX and related networks in these contexts, trying to understand the business and policy environment that supports these systems, before contrasting these networks with their mobile 3G counterparts.

WiMAX, WiFI, 802.20 and related networks are an attractive solution in many environments, especially if the anticipated number of subscribers per square kilometer is 5 or lower. And because such wireless deployments can be driven bottom-up and can potentialy be deployed quite incrementally these systems can work in environments with relatively weak institutional support and small capital markets. A variety of point-to-multipoint wireless technologies exist that can provide broadband fixed wireless service and some of these technologies have been overviewed in the technology roadmap earlier.

Exclusive BWA networks can be visualized as a series of circles connected by sticks. The circles represent areas of coverage by a point-to-multipoint radio transceiver, representing the edge network. The sticks represent the backhaul network that ultimately aggregates the traffic at a head end and passes it on to a higher tier ISP, the core network. The “circle” of edge connectivity can have a radius that is only 100s of meters by using popular Wi-Fi systems, and the backhaul network can have “sticks” that extend for many 10s of kilometers using WiMAX related technologies. Likewise, the circles could have a radius of 10 or 20 kilometers using significant WiMAX base stations and omni-directional antenna facilities. And they, in turn, can be backhauled with long-distance point-to-point microwave networks or fibre, where it exists.

In an exclusive environment with a very small number of anticipated subscribers per unit area the fixed-wireless approaches of WiMAX and related networks promises to be the most cost effective approach. One reason is that it does not anticipate a ubiquitous signal but instead allows for a focused deployment of signals that connect only those specific areas requiring service. This is a benefit in sparse and low-demand areas but it is a liability where a network that is more universally available across a region is required. Furthermore, as shown in Figure 15 most WiMAX technologies do not support vehicular-speeds (though newer 802.20 and WiMAX technologies are emerging that do handle mobility) nor do they usually support seamless handoff between cells.

As noted above, however, while there are distinctions in mobility, cost, ubiquity, and even capacity between WiMAX, 802.20, and the 3G family of networks, in fact they are rapidly converging on a fairly similar feature set. For instance mesh Wi-Fi and WiMAX systems are available that can provide nearly seamless and ubiquitous coverage (see Box 8 on mesh networks). Similarly WiMAX standards (and 802.20) that support vehicular motion are in the works (see Box 9 on 3G and fixed wireless convergence).

6.4.4 3G for Exclusive Environments

Mobility and ubiquity are key elements to today’s 3G deployments. These may not be of critical singular interest in exclusive environments At first glance, in underserved and remote environments a ubiquitous and mobile broadband connection with seamless handoff at vehicular speeds may be asking for more than the market needs or can bear. Indeed there are many examples of deployed 2G networks that are used mostly as a fixed-mobile voice network. The Grameen Phone network is well known for providing rural voice services in Bangladesh via village “phone ladies”. Providing support for vehicular travel and seamless handoff to these “phone ladies” is, according to the project’s principal, a case of an engineering solution in search of a problem. And if vehicular mobility is generally not needed for voice traffic it probably is even less required for broadband data.

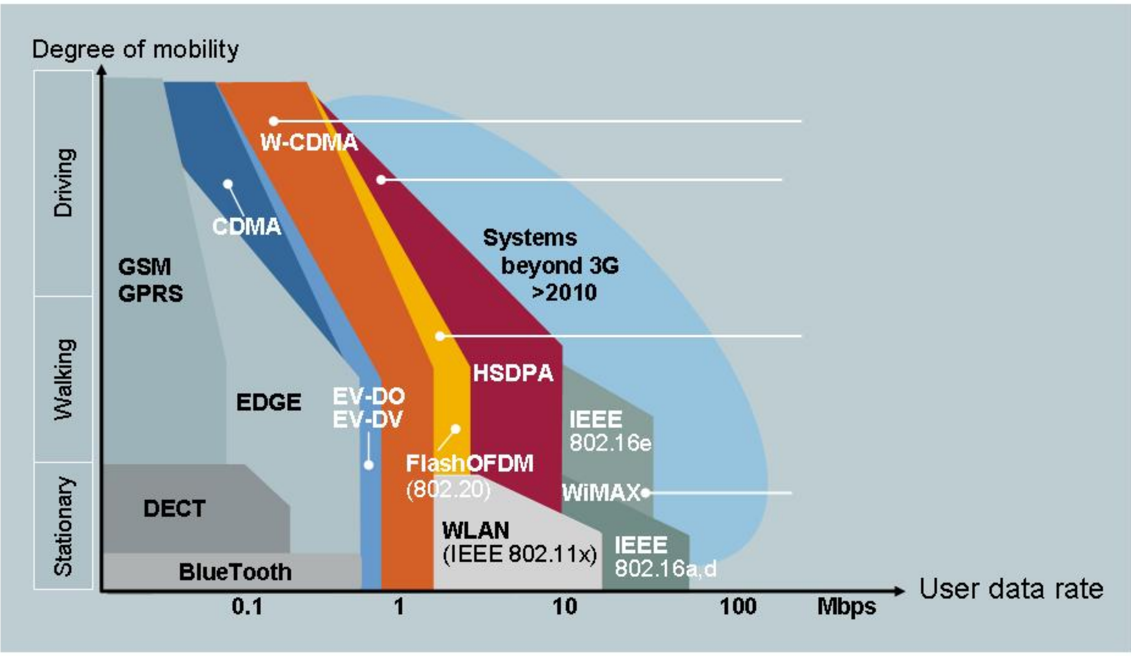
But perhaps there are sufficient markets for ubiquitous and mobile 3G in exclusive environments, including relatively remote and sparsely populated areas. After all, mobile 2G networks enjoy very high levels of world penetration even in some of the most remote and low-income areas in the world.

Moreover, much of the world currently is within the reach of an existing mobile phone network. These networks are mostly 2G (GSM or CMDA) both of which enjoy clear upgrade paths to 2.5 and ultimately 3G systems as summarized earlier in the technology roadmap. Thus, one very viable approach to broadband coverage even in remote exclusive areas is to leverage existing 2G networks (or even building new green field mobile networks) upgraded to 2.5G or 3G support. This may well depend on industry response and the regulatory environment.

While in terms of the consumer experience, both 3G and fixed broadband wireless approaches are converging (as fixed wireless gains mobility and ubiquity and 3G increases capacity), the two technologies come from very different communities. Fixed wireless technologies come from the data networking and computer science crowd and 3G from the telecommunications community. As such, institutionally they generally are structured differently. 3G networks are usually deployed through top-down planning via a vertically integrated large operator who has access to substantial investment capital. The deployments are generally over large regions and announced at a single moment. In other words, while many 2.5G to 3G systems allow incremental deployment (one base station at a time) for marketing and customer adoption purposes this is not usually what is done. Instead a large region with many base stations are upgraded all at once. So in practice, 3G installations have appealed more to large companies with significant start-up capital while fixed wireless networks have appealed more to community driven efforts employing a much more incremental approach.

There are many tradeoffs between the various types of BWA networks that can be deployed within an exclusive environment. In some cases robust 2G networks upgrading to 3G technologies will be the most promising solution. In other similar areas, the 2G base station infrastructure might be suitable for deploying WiMAX (or even 802.20) access points. Alternatively, in some green field settings it may be desirable to abandon the mobile phone market and develop a pin-point fixed wireless solution with connectivity surgically placed just where it is needed. In other green field environments it may be most appropriate to leap-frog straight to a 3G mobile network ready to provide mobile voice and stationary broadband data to an entire region.

Figure 14: Degree of mobility versus user data rate for popular BWA systems



Source: Siemens

7 Power requirements for broadband

An important requirement for pervasive broadband connectivity is reliable and relatively high-quality electric power sources. High-capacity wireless networks, and the multi-media enabled appliances that broadband applications call for, can accelerate the electric power requirements. So any consideration in deploying of broadband networks needs to also consider the availability of power solutions including, but not limited to, grid power.

Today's modern desktop personal computers have a few major sources of power consumption:

– The central processor (now often consuming 80 W)

– The screen (a CRT can consume up to 100 W)

– The hard drive (which can consume 100 W when spinning)

– RAM memory, graphics cards and other on-board devices (can consume up to 40 W)

Low-power consuming versions of these technologies do exist today (for instance as used in laptops). Their main sources of power consumption can be:

– The central processor (consuming as much as 40 W in full operation)

– The screen (an LCD can consume 50 W)

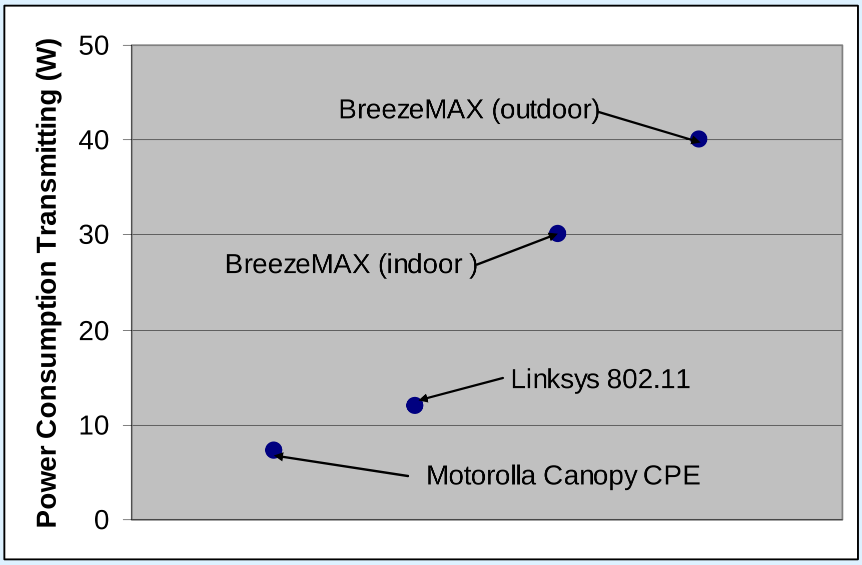
But more power efficient laptops can be engineered to require below 40 watts or less in normal operation. These figures give us points of comparison.

Figure 15 shows the power consumption for a set of popular WLAN radio technologies. BreezeMAX WiMAX technologies can require from 30 to 40 watts when in operation. A subscriber unit for Motorola Canopy consumes under 10W while an indoor wireless router from Links consumes just over 10W on average.

What these figures suggest is that a standard broadband-enabled PC can consume a fairly considerable power load and even low-power consuming laptops require a fair amount. Futhermore, the power load of a PC is nonlinear (it fluxates over time unlike a lightbulb for example) and a PC requires quite high quality power (again unlike a lightbulb). This puts further requirements on the source of the power.

Are there power solutions for broadband in areas that do not have reliable grid electricity? Even harder, is there a way to support mobile broadband without overly restricting the performance and capabilities of internet appliances (e.g. not supporting full screen real-estate)? Major solutions for off-grid powering of ICT systems includes solar PV cells, small wind systems, micro-hydro power technologies, and generator sets (diesel, gas, or other bio-fuels). Each of these solutions has its benefits as well as drawbacks. Below are two case studies which illustrate innovative applications of off-grid power for ICT's.

Figure 15: Power consumption of some wireless radio products



7.1 Two Off-Grid Power Case Studies

7.1.1 Tanzania - Kasulu Teachers Training College

At the Kasulu Teachers Training College (KTTC) in Tanzania, the agrarian "First Wave" and the information technology driven "Third Wave" mingle with each other to create a broadband service that is changing the lives of some of the most impoverished people in Africa. An Internet centre at the KTTC is equipping the next generation of teachers in Tanzania with the tools of an information society despite the fact that Kasulu has no electricity supply and its 15 phone lines have no data capabilities. What is unique about the project is that it is run by an unusual source of power – cow's manure.[18]

Kasulu has a population of 33,668 people[19] and is located in the northwest of Tanzania. Being close to the Burundi border, the region has seen a huge influx of refugees fleeing Burundi, escaping the civil war. In 2000, the Global Catalyst Foundation (GCF) in collaboration with the United Nations High Commissioner for Refugees (UNHCR) and Schools Online decided to explore the feasibility of setting up a Kasulu Internet Project[20] designed to promote cooperation and understanding between refugee Burundians and their neighboring Tanzanians in the Kasulu area. Another objective was to promote economic development and entrepreneurship in these impoverished regions.

GCF is a private foundation established by Kamran Elahian, a successful IT entrepreneur and founder of Global Catalyst Partners, a Silicon Valley venture capital firm. The organization's mission is "empowering people through technology" and it supports projects that "improve education, alleviate poverty, promote social tolerance and celebrate diversity," across the world.[21] Schools Online, another non-profit started by Elahian, has the goal of helping students use the Internet for learning and cross-cultural dialogue. Since 1996, the organization has assisted over 5,700 under-served schools in the United States and over 400 schools in 35 other countries with the equipment and support necessary to get online.[22]

Figure 16: UNHCR refugee camps in Tanzania. Source: Food and Agriculture Organisation

Under the Kasulu Internet Project, GCF, Schools Online and the UNHCR have collaborated in establishing three Internet centers – one located in a nearby UNHCR administered refugee camp called Meatball, the second at the Kasulu Folk Development College and the third at the Kasulu Teacher Training College.

GCF contributed USD120,000 in operational funds for the three centers for three years, and is responsible for the overall management of the project. The local communities have contributed their labor to build computer labs, UNHCR provides logistical and administrative support, and Schools Online provides the hardware and software infrastructure and the funds necessary for professional development and capacity building.[23]

At the KTTC facility, the 800 students enrolled in the teacher-training programme are the main computer-lab users. The labs are open to community members from 7pm–10pm during the week and also open on Saturdays and Sundays on a fee-for-use basis costing approximately USD1 per hour (1,000 Tanzanian Shillings). Members of the local NGO and UNHCR communities are frequent users of this heavily resourced laboratory during these opening hours.

Figure 17: KTTC computer laboratory

Source: Michael L. Best

The teachers and students study for the International Computer Driver's License (ICDL) and CISCO Academy courses. The ICDL has seven skill levels – word processing, file management, Internet etc. The CISCO Academy has seven students who pay approximately USD200 for a six-month course. About 10 students from town are also studying elements from the ICDL curriculum, paying approximately USD200 per course. Another 30 students from the KTTC also attend these classes but pay lower fees. Revenues from these training programs help KTTC pay for the cost of Internet access, maintenance and ongoing operations.

Currently the KTTC students who are enrolled in computer classes do so out of interest. But the Tanzanian Ministry of Education is planning to make IT training compulsory for teacher training and this is expected to put a large demand on facilities since all KTTC students will be requiring instruction.

The school is connected to the Internet through a VSAT service provided by I-way. The I-way connection offers 128 Kbp/s downlink and 30–40 Kbp/s uplink speeds and the Global Catalyst Foundation pays USD500 per month for the connection. The Internet is reasonably reliable though it does fail on occasion.

As mentioned above, the GCF chose to turn to an unusual source of power – cow's manure – to power the KTTC computer lab. The droppings of twelve cows are collected and fed into a 50-cubic-metre biogas plant that generates methane. This methane is then mixed with diesel in a 70:30 ratio and fed into a power generator producing 10 Kilowatts of power and running 15–16 PIII computers for eight hours daily. Six shared UPS systems provide a 30-minute power backup.

Nothing goes to waste in this system. After the methane is extracted, the remaining sludge is removed from the biogas plant to provide fertilizer for crops the college raises to feed its staff and students.

The biogas digester, the dairy cattle, cowshed and the 10-kilowatt generator cost approximately USD18,120. The biogas system was built in late 2001 and the computers arrived at the Kasulu Teacher Training College in early 2002.

Apart from powering computers, the college also wants to use methane for cooking. Currently, the college consumes several tons of timber every year to cook food for its students. Replacing timber with methane would be more eco-friendly and the cooks would also be spared the harmful effects of wood smoke. To do this, the college plans to increase the capacity of the biogas plant from 50 cubic meters to 200 cubic meters. To provide manure for the increased capacity, the college will have to maintain 40–50 cows. The additional methane generated would fuel a 30 Kilowatt generator and allow for a 100 percent methane powered system.

Figure 18: The biogas digester (top left), methane/diesel generator (bottom left), and cow corral (right)

Source: Michael L. Best

The Swedish International Development Agency (SIDA) is considering funding the expansion and would like to replicate the biogas system at the 30 Teacher Training Schools in Tanzania and perhaps scale to 3,000 secondary schools. The organization is also funding a micro-hydro power project in Kasulu where, along with a power micro-grid, fiber-optic cables will also be strung. The fiber-optic cables will be connected to the Internet via VSATs and used for networking NGO's, schools and clinics.

7.1.2 Tanzania - Mtabila Refugee Camp

Over 50,000 Burundian refugees stay at the Mtabila camp. Conditions at the camp are bleak, with very little work to occupy the refugees. The refugees live often in simple houses and mostly survive on food provided by the World Food Programme (WFP). Most of the adults at the camp are women.[24] The refugee camp also has a significant adolescent population that faces an uncertain future.

With no phone access, the ten computers at the Mtabila Internet Centre have the potential to serve as the refugees' main connection to the outside world. When the centre is open to the general population there is often a long wait for Internet access. Daily around 30 refugees use the centre to send email at a charge of approximately USD20 cents per session.[25] The Internet has reduced the refugees' sense of isolation and enables them to communicate with the outside world at a cost that is cheaper than the postal service. News and information downloaded from the web also help the refugees stay abreast of happenings in the outside world. The refugees access web sites, including those in Kirundi and Kiswahili languages.

For the refugees at the Mtabila camp, the Internet Centre is equipping them with skills that will be useful in the reconstruction of Burundi. The Kasulu Online[26] web site reports that around 2000 refugees have been educated in further or higher education and are the ones directly benefited by Internet access. Other refugees benefit through intermediated access that keeps them abreast of news of current events and helps them establish contact with friends and relatives who have email.

Figure 19: Mtabila camp VSAT and PV systems (top)

Mtabila camp VSAT and PV systems (top), refugees waiting outside of the computer lab (bottom left), and inside the computer lab (bottom right)

Source: Michael L. Best

Ten teachers, selected by the refugee community, are being put through training for the International Computer Driving License (ICDL). These same teachers also supervise the centre. The big surprise for these teachers, as well as camp administrators, has been the demand for email. Many of the refugees have friends and family scattered throughout Africa, Europe and North America and email is an affordable way of keeping in touch with their community.[27]

Broadband internet is provided via a VSAT terminal. And the power for the computers and Internet at the refugee camp is generated using photovoltaic cells. The solar setup cost approximately USD37,152 and consists of 48 solar panels of 75 watts each. Solar power was chosen over biogas because this eliminates dependence on fuel supplies and spare parts that a generator-powered system would entail.

Setting up the centers was a trying task due to poor telephone lines that barely supported email, delays in importing essential equipment, and the challenge of liaising between the various governmental, international and non-governmental agencies involved in the project. Despite these challenges, the project is beginning to deliver the intended benefits. Here is an excerpt from an email sent from a refugee at the Mtabila camp: "I'm not able to tell you how happy we are to get connection to the Internet! Before I was connected to the Internet I felt lost. But now that I am connected, I feel saved. The world will not forget us now, because we, the refugees, can speak to the outside." [28]

8 Conclusion

Taking advantage of the opportunity

Broadband Internet means connectivity at speeds that support interactive audio, full motion video, interactive video chat, speedy web searching, and many other valuable applications. While some parts of the world have seen explosive growth in broadband penetration most of the world have low levels of broadband diffusion, and what broadband is present is expensive and relatively low capacity. In an encouraging trend, however, many of these same areas in developing countries are enjoying some of the highest growth rates for broadband service and are clearly important areas for future market expansion.

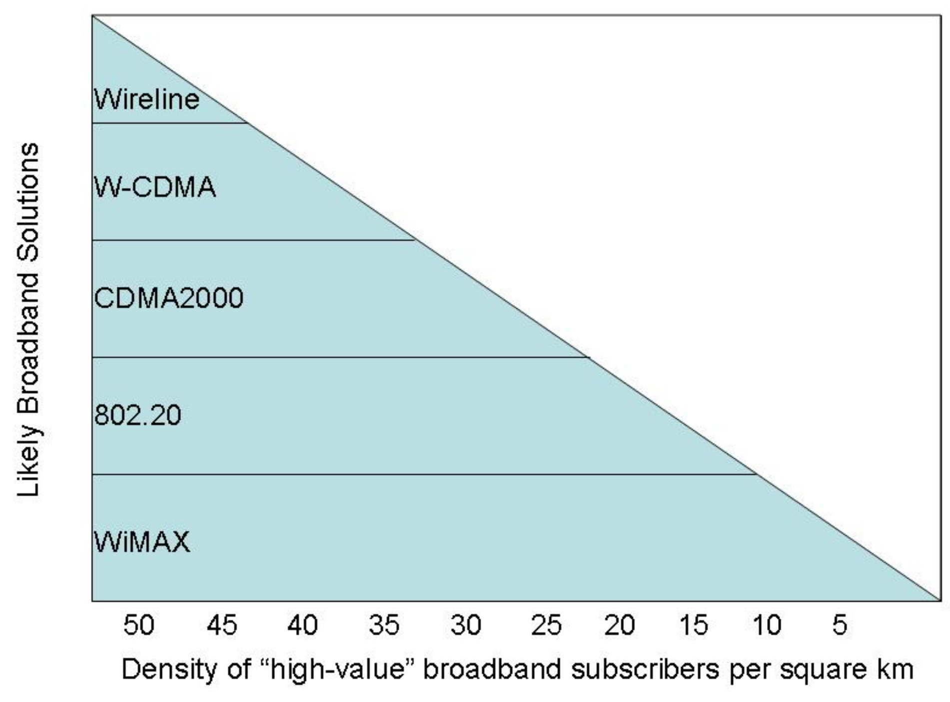
This paper has overviewed three important families of technologies that are instrumental in providing the edge network in a broadband system: broadband wireline services, broadband wireless access, and non-terrerstrial broadband wireless systems. All three of these families of systems have appropriate contexts in which they provide the best solution. In some contexts, such as areas which are densely populated with high-value subscribers, a collection of these systems will converge, compete, or complement each other. In other settings -- those with only limited numbers of potential broadband subscribers -- single network systems are likely to be an exclusive solution and sit in isolation. In cases where the density of potential subscribers is lowest, various wireless broadband solutions are likely to be the most cost effective.

These sets of technologies can be placed on a continuum of the density of high-value subscribers. With densities of 40 people per square kilometre and above wireline solutions are likely to be cost effective. As density declines to just a few people per square kilometre fixed wireless solutions, such as WiMAX, are more likely to be best suited.

Broadband deployment does not depend solely on technological choices. Capacity building to develop local human resources is vital. Education and training, including practical showcases and pilots involving all stakeholders on neutral ground is equally important in the quest to promote broadband access.

Governments can further organize open regional, national and local forums dedicated to identifying and meeting the broadband needs that include all key stakeholders. These stakeholders will include users (both current and potential); national and local development programs on healthcare, education and e-government; other public service institutions such as universities, libraries and local and national government offices; local entrepreneurs, traditional telecom operators, system manufacturers and owners of fibre infrastructure from other sectors, such as transport and utility companies. Together such stakeholder forums can strive to meet their broadband requirements and achieve the UN Millennium Development goals. Once broadband needs are identified, they can be met through the development of open market-based networks, fostered through effective regulatory practices. In conclusion, broadband deployment in rural areas of developing countries is likely to be fuelled both by civil society, including a range of public service actors, and the private sector, including local entrepreneurs building sustainable businesses.

Figure 20: Likely broadband solutions against the expected number of broadband subscribers per sq km



What is needed are regulatory frameworks designed to lower business risks and open markets to a full range of potential broadband providers. These key issues are addressed in the GSR Discussion Paper on the Role of Regulators in Promoting Broadband.

[1] It is important to note that all ITU data pertaining to Total Internet subscribers in 2003-2004 may appear slightly conservative, attributable mainly to slightly lower response (6% decrease) rates on the Annual ITU Telecommunications Indicators Survey compared to previous years, as well as to the fact that some countries have not yet reported their data for 2004.
[2] This is being done using wireless technologies developed by Texas based Navini Networks.
[3] It is important to note that data pertaining to the uptake of 3G services has not been historically collected by the ITU. This year 2005-6 constitutes the first year that the ITU will be collecting 3G specific data for inclusion in its World

Telecommunications Indicators database. Therefore, for the purposes of this paper, we rely on industry (association, news) sources

[4] Figure 8 is based on 2003 data.

[5] See http://standards.ieee.org/getieee802/portfolio.html for more information about the IEEE802 standard.

[6] In Sweden, apartment house companies own their own fibre networks to serve the tenants in their buildings. These networks connect to a point of presence of all operators at a metropolitan area hub. In a departure from the fibre *to* the home model, they outsource the link level of their fibre *from* the home networks to service-providers serving their tenants.

[7] See http://www.cablemodem.com/specifications/ for more information about DOCSIS.

[8] See http://grouper.ieee.org/groups/bop/ for further information about P1675 from the IEEE).

[9] See www.iec.ch/tctools/dashbd-e.htm for further information about the working groups with the CISPR.

[11] For further information about this process, please see http://www.iec.org/online/tutorials/acrobat/opt_net.pdf.

[12] See http://www.iec.org/online/tutorials/sdh/ for more information about SONET.

[13] Commercial acceptance has been disappointing on these systems and it is thought that ArrayComm intends to abandon this technology in order to focus on WiMAX based systems.

[14] ITU Internet Reports: The Portable Internet available via the Internet at http://www.itu.int/publications/bookshop

[15] ITU Internet Reports: The Portable Internet available via the Internet at http://www.itu.int/publications/bookshop

[16] Portable Internet.

[17]These include Astrolink, SpaceWay and EuroSkyWay.

[18] "Cow pats fuel computers" BBC Online. See http://news.bbc.co.uk/2/hi/technology/2957488.stm

[19] See http://www.tanzania.go.tz/census/districts/kasulu.htm

[20] See www.kasuluonline.or.tz

[21] See http://www.global-catalyst.org/pages/who_we_are.htm

[22] See http://www.schoolsonline.org/whoweare/index.htm

[23] See http://www.schoolsonline.org/whatwedo/update_sep_2002.htm

[24] "Rape at the end of the world." See http://www.unfpa.org/focus/tanzania/rape.htm

[25] "Cow pats fuel computers" BBC Online. See http://news.bbc.co.uk/2/hi/technology/2957488.stm

[26] See www.kasuluonline.or.tz

[27] "Tanzanian refugee camp gets wired for Internet" See http://www.hrea.org/lists/huridocs-tech/markup/msg00933.html

[28] "Start. Succeed (or Not). Repeat." *Los Angeles Times*. See http://www.latimes.com/la- tm-sventrepreneur10mar09,0,7991984.story

Printed in Switzerland
Geneva, 2005